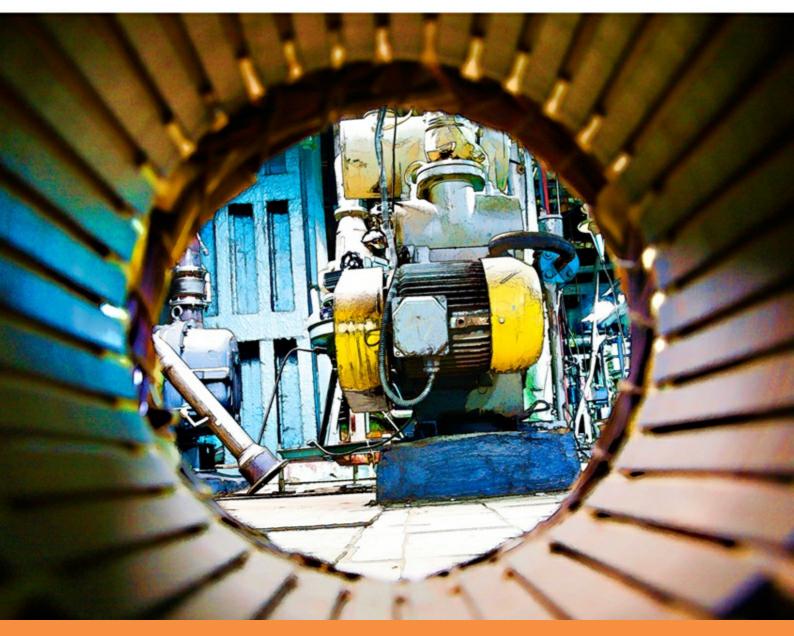
# Applied Thermodynamics: Software Solutions

Part-II

Dr. M. Thirumaleshwar



**bookboon.com** The eBook company Dr. M. Thirumaleshwar

## Applied Thermodynamics: Software Solutions

Part-II (Cycles for Gas turbines and Jet propulsion,

Vapor power cycles)

 Applied Thermodynamics: Software Solutions: Part-II (Cycles for Gas turbines and Jet propulsion, Vapor power cycles) 1<sup>st</sup> edition © 2014 Dr. M. Thirumaleshwar & <u>bookboon.com</u> ISBN 978-87-403-0747-4

### Contents

	Dedication	Part I	
	Preface	Part I	
	About the Author	Part I	
	About the Software used	Part I	
	To the Student	Part I	
	How to use this Book?	Part I	
1	Gas Power Cycles	Part I	
1.1	Definitions, Statements and Formulas used[1-6]:	Part I	
1.2	Problems on Otto cycle (or, constant volume cycle):	Part I	
1.3	Problems on Diesel cycle (or, constant pressure cycle):	Part I	
1.4	Problems on Dual cycle (or, limited pressure cycle):	Part I	
1.5	Problems on Stirling cycle:	Part I	
1.6	References:	Part I	



### **CLIVER WYMAN**



Oliver Wyman is a leading global management consulting firm that combines deep industry knowledge with specialized expertise in strategy, operations, risk usep industry knows by events because expensions and by operations, take management, organizational transformation, and leadership development. With offices in 50+ cities across 25 countries, Oliver Wyman works with the CEOs and executive teams of Global 1000 companies. OUR WORLD An equal opportunity employer.

### **GET THERE FASTER**

Some people know precisely where they want to go. Others seek the adventure of discovering uncharted territory. Whatever you want your professional journey to be, you'll find what you're looking for at Oliver Wyman.

Discover the world of Oliver Wyman at oliverwyman.com/careers





Download free eBooks at bookboon.com

© 2010 EYGM Limited. All Righ

### Contents

2	Cycles for Gas Turbines and Jet propulsion	8	
2.1	Definitions, Statements and Formulas used [1-7]:	8	
2.2	Problems solved with Mathcad:	20	
2.3	Problems solved with EES:	54	
2.4	Problems solved with TEST:	113	
2.5	References:	159	
3	Vapour Power Cycles	160	
3.1	Definitions, Statements and Formulas used[1-7]:	160	
3.2	Problems solved with Mathcad:	169	
3.3	Problems solved with EES	205	
3.4	Problems solved with TEST:	289	
3.5	References:	317	
4	Refrigeration cycles.	Part III	
4.1	Definitions, Statements and Formulas used	Part III	
4.2	Problems solved with Mathcad, EES and TEST	Part III	
4.3	References	Part III	

# Day one and you're ready

Day one. It's the moment you've been waiting for. When you prove your worth, meet new challenges, and go looking for the next one. It's when your dreams take shape. And your expectations can be exceeded. From the day you join us, we're committed to helping you achieve your potential. So, whether your career lies in assurance, tax, transaction, advisory or core business services, shouldn't your day one be at Ernst & Young?

What's next for your future? ey.com/careers

ERNST & YOUNG Quality In Everything We Do



5

5	Air compressors	Part III
5.1	Definitions, Statements and Formulas used	Part III
5.2	Problems solved with Mathcad, EES and TEST	Part III
5.3	References	Part III
6	Thermodynamic relations	Part III
6.1	Definitions, Statements and Formulas used	Part III
6.2	Problems solved with Mathcad, EES and TEST	Part III
6.3	References	Part III
7	Psychrometrics	Part IV
7.1	Definitions, Statements and Formulas used	Part IV
7.2	Problems solved with Mathcad, EES and TEST	Part IV
7.3	References	Part IV



6

Download free eBooks at bookboon.com

Click on the ad to read more

8	Reactive systems	Part IV
8.1	Definitions, Statements and Formulas used	Part IV
8.2	Problems solved with Mathcad, EES and TEST Pa	
8.3	References	Part IV
9	Compressible fluid flow	Part V
9.1	Definitions, Statements and Formulas used	Part V
9.2	Problems solved with Mathcad, EES and TEST	Part V
9.3	References	Part V



Hellmann's is one of Unilever's oldest brands having been popular for over 100 years. If you too share a passion for discovery and innovation we will give you the tools and opportunities to provide you with a challenging career. Are you a great scientist who would like to be at the forefront of scientific innovations and developments? Then you will enjoy a career within Unilever Research & Development. For challenging job opportunities, please visit www.unilever.com/rdjobs.

lue Bar



ALMO JERRY

Dove



# 2 Cycles for Gas Turbines and Jet propulsion

### Learning objectives:

- 1. In this chapter, 'Gas Turbine cycles' are analyzed with 'air standard assumptions'.
- 2. Brayton cycle is the air standard cycle for Gas Turbines. Ideal Brayton cycle consists of two isentropics and two constant pressure processes.
- 3. Modifications to the Ideal cycle to increase the thermal efficiency are also studied; these include adding a regenerator and resorting to multistage compression in the compressor and multistage expansion in the turbine.
- 4. Jet propulsion cycle used for aircraft propulsion is also analysed.
- 5. Several Functions/ Procedures are written in Mathcad and EES to determine net work, thermal efficiency etc of the Ideal and actual Brayton cycles.
- 6. Large number of problems from University question papers and standard Text books are solved with Mathcad, EES and TEST.

### 2.1 Definitions, Statements and Formulas used [1-7]:

### 2.1.1 Air standard assumptions:

Since the actual Gas power cycles are rather complex, we make following assumptions to simplify the analysis:

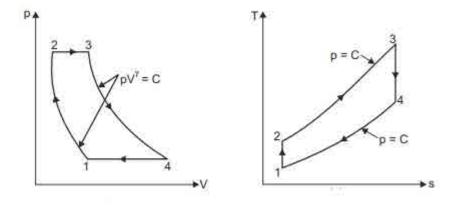
- i. Working fluid is air circulating continuously in a closed loop, with air behaving as an Ideal gas
- ii. All processes making up the cycle ate internally reversible
- iii. The combustion process is replaced by a heat addition process from an external source
- iv. The exhaust process is replaced by a heat rejection process that restores the working fluid to its initial state
- v. In 'cold air standard assumption', specific heat of air is assumed to be constant at cp = 1.005 kJ/kg.K and ratio of sp. heats as  $\gamma = 1.4$

#### 2.1.2 Ideal, simple Brayton cycle:

P-v and T-s diagrams are shown below:

Here, we have:

- 1-2: isentropic compression in compressor
- 2-3: external heat addition in heater (combustion chamber)
- 3-4: isentropic expansion in turbine
- 4-1: heat rejection in a cooler



Various quantities for the ideal Brayton cycle are calculated as follows:

### Air standard efficiency:

$$\eta_{\text{th}} = 1 - \left(\frac{1}{r_p}\right)^{\frac{\gamma-1}{\gamma}}$$

Compressor work:

$$W_{comp} = cp \cdot T1 \cdot \begin{pmatrix} \frac{\gamma - 1}{\gamma} \\ r_p & -1 \end{pmatrix} \qquad kJ/kg$$

Turbine work:

$$W_{turb} = cp \cdot T3 \cdot \left[ 1 - \left(\frac{1}{r_p}\right)^{\frac{\gamma}{1}} \right] \qquad kJ/kg$$

### Net work:

$$W_{net} = W_{turb} - W_{comp}$$
 kJ/kg

From Theory, optimum 
$$r_p$$
 for max. work is:  $r_p = \left(\frac{T3}{T1}\right)^{\frac{\gamma}{2\cdot(\gamma-1)}}$ 

Back Work ratio:

$$BWRatio = \frac{W_{comp}}{W_{turb}}$$

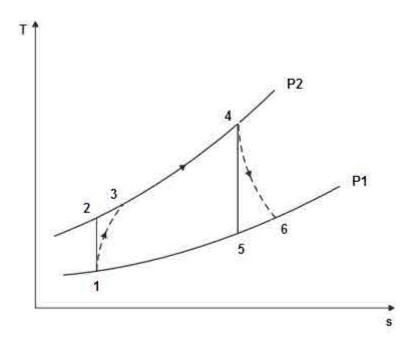
Heat supplied:

$$Q_{in} = cp \cdot (T3 - T2)$$
 kJ/kg

Thermal efficiency:

$$\eta_{\text{th}} = \frac{W_{\text{net}}}{Q_{\text{in}}}$$

### 2.1.3 Actual, simple Brayton cycle:



### Actual, Simple open cycle...Compr. work, Turbine work, Back Work Ratio:

$$W_{comp} = cp \cdot \frac{T1 \cdot \left(\frac{\gamma - 1}{\gamma} - 1\right)}{\eta_{comp}} \qquad kJ/kg$$

$$W_{turb} = cp \cdot \left[ T3 \cdot \left( 1 - \frac{1}{\frac{\gamma - 1}{r_p}} \right) \cdot \eta_{turb} \right] \quad kJ/kg$$

BWRatio = 
$$\frac{W_{comp}}{W_{turb}}$$

Net work:

Heat supplied:

$$Q_{in} = cp \left[ T_3 - \left[ T_1 + \frac{T_1 \cdot \left( \frac{\gamma - 1}{r_p} - 1 \right)}{\eta_{comp}} \right] \right] \quad kJ/kg$$

### Thermal efficiency of Actual Simple Open Cycle Gas Turbine :

$$Brayton\_actual\_EFF = \frac{W_{net}}{Q_{in}}$$

### Efficiency of Ideal Open Cycle Gas Turbine with Ideal Regeneration:.

.. Depends on pressure ratio and the cycle max to min temp. ratio

$$Brayton\_IdealRegen\_EFF = 1 - \left(\frac{T1}{T3}\right) \cdot r_{p}^{\frac{\gamma-1}{\gamma}}$$

### Efficiency of Ideal Open Cycle Gas Turbine with Ideal Regeneration:

In terms of temp. ratio, t=T1/T3, re-writing the above eqn, we have:

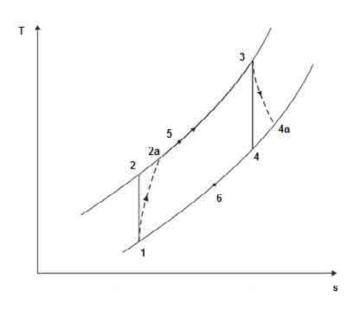
Brayton\_IdealRegen\_EFF = 1 - (t) 
$$r_p^{\gamma}$$

\_\_\_\_\_

### 2.1.4 Actual Open Brayton Cycle with Regeneration:

Here  $\epsilon$  is the effcy of regenerator, defined as:

$$\varepsilon = \frac{T5 - T2a}{T4a - T2a}$$



**Turbine Work:** 

$$W_{turb} = cp \cdot \left[ T3 \cdot \left( 1 - \frac{1}{\frac{\gamma - 1}{r_p}} \right) \cdot \eta_{turb} \right] \qquad kJ/kg$$

Compressor Work:

$$W_{comp} = cp \cdot \frac{T1 \cdot \left(\frac{\gamma - 1}{r_p} - 1\right)}{\eta_{comp}} \qquad kJ/kg$$

### Net Work:

Back Work Ratio:

$$BWRatio = \frac{W_{comp}}{W_{turb}}$$

Temp at exit of compressor:

$$T2a = T1 + \frac{T1 \cdot \left(\frac{\gamma - 1}{r_p} - 1\right)}{\eta_{comp}} \qquad K$$

Temp at exit of turbine:

$$T4a = T3 - T3 \cdot \left(1 - \frac{1}{\frac{\gamma - 1}{r_p}}\right) \cdot \eta_{turb} \qquad K$$



Discover the truth at www.deloitte.ca/careers



Click on the ad to read more

13

\_\_\_\_\_

Regen. effectiveness, z:

$$\varepsilon = \frac{T5 - T2a}{T_{4a} - T2a}$$

Therefore, temp at exit of high pressure stream in regenerator, T5 (K):

T5 = T2a + ε·(T4a - T2a) K

Heat supplied:

$$Q_{in} = cp \cdot (T3 - T5) kJ/kg$$

Thermal efficiency:

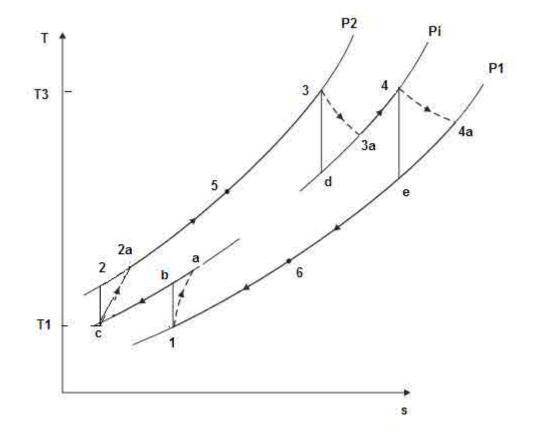
 $Brayton\_actual\_regen\_EFF = \frac{W_{net}}{Q_{in}}$ 

2.1.5 Actual open cycle...with reheating, inter-cooling and regeneration:

Given overall pr. ratio, rp:

Therefore, pressure ratio per stage =  $rp^{0.5}$ 

\_\_\_\_\_



14 Download free eBooks at bookboon.com

### Total Compressor work input, for two stages:

$$WK_{comp} = cp \cdot \frac{T1 \cdot \begin{pmatrix} 0.5 \cdot \frac{\gamma - 1}{\gamma} \\ r_p & -1 \end{pmatrix} \cdot 2}{\eta_{comp}}$$
 kJ/kg

### Total Turbine work output, for 2 stages:

WK<sub>turb</sub> = c<sub>p</sub> 
$$\cdot \left[ T3 \cdot \left( 1 - \frac{1}{0.5 \cdot \frac{\gamma - 1}{\gamma}} \right) \cdot \eta_{turb} \right] \cdot 2$$
 kJ/kg

Net Work output:

Back Work Ratio:

$$BWRATIO = \frac{WK_{comp}}{WK_{turb}}$$

Work Ratio:

WRATIO = 
$$\frac{WK_{turb} - WK_{comp}}{WK_{turb}}$$

Temp. T2a:

$$T2a = \frac{T1 \cdot \begin{pmatrix} 0.5 \cdot \frac{\gamma - 1}{\gamma} \\ r_p & -1 \end{pmatrix}}{\eta_{comp}} + T1 \qquad K$$

Temp. T4a:

$$T4a = T3 - \begin{bmatrix} T3 \cdot \left(1 - \frac{1}{0.5 \cdot \frac{\gamma - 1}{\gamma}}\right) \cdot \eta_{turb} \end{bmatrix} K$$

### T5, temp at exit of high pressure stream in regenerator:

$$\varepsilon = \frac{T5 - T2a}{T4a - T2a} \qquad \dots regen. effcy.$$

Then:

T5 = T2a + e·(T4a - T2a) K

### Heat supplied:

 $Q1 = cp \cdot (T3 - T5) + cp \cdot (T3 - T4a) kJ/kg$ 

### Thermal efficiency:

 $EFFCY = \frac{WK_{turb} - WK_{comp}}{Q1}$ 

2.1.6 Ideal Jet Propulsion cycle [1]:

Here, the ambient air is first compressed slightly in a diffuser, and then compressed in a compressor. The turbine produces just enough power to run the compressor and auxiliaries. High pressure, high temp exit from the turbine is further expanded in a nozzle to the ambient pressure. High velocity exit from the nozzle provides the thrust to propel the aircraft.



as the fifth Best Workplace in Canada, for companies with more than 1,000 employees. We are also very proud to be recognized as one of Canada's top 25 Best Workplaces for Women and as one of Canada's Top Campus Employers.



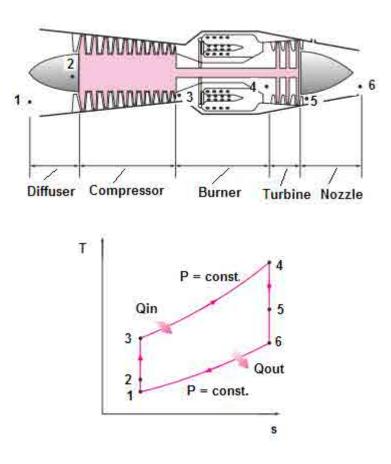


Audit • Tax • Advisory www.GrantThornton.ca/Careers



© Grant Thornton LLP. A Canadian Member of Grant Thornton International Ltd





### Schematic diagram of the turbo-jet and the T-s diagram are shown below:

In the above, we have:

- 1-2: Isentropic compression in diffuser
- 2-3: Isentropic compression in compressor
- 3-4: constant pressure heat addition in burner
- 4-5: Isentropic expansion in turbine
- 5-6: Isentropic expansion in nozzle
- 6-1: Constant pressure heat rejection

Generally, the ambient conditions (at the cruising height of aircraft), P1, T1 are known. Also, the compressor pressure ratio, rp (= P3/P2), and the temp at turbine inlet, T4 are given. The cruising velocity of aircraft, V1 is also known. For ideal jet propulsion cycle, turbine exit temp T5, nozzle exit temp T6, nozzle exit velocity V6, heat supplied, thrust produced, propulsive power and the propulsive efficiency are calculated as follows:

### Process 1-2: Isentropic pressure rise in diffuser:

From an energy balance:

$$h2 + \frac{V2^2}{2} = h1 + \frac{V1^2}{2}$$

V2 is nearly equal to zero.

Therefore:

$$(h2 - h1) - \frac{V1^{2}}{2} = 0$$
  
i.e.  $cp \cdot (T2 - T1) - \frac{V1^{2}}{2} = 0$   
i.e.  $T2 = T1 + \frac{V1^{2}}{2 \cdot cp}$  K....Ans.  
 $\underline{\gamma}$ 

And: 
$$P2 = P1 \cdot \left(\frac{T2}{T1}\right)^{\gamma-1}$$
 kPa...when P1 is in kPa

### Process 2-3: Isentropic compression in compressor:

P3 = rp·P2 kPa...Ans.  
T3 = T2·rp 
$$\gamma$$
 K...Ans.

### Process 4-5: Isentropic expansion in turbine:

Then: h3 - h2 = h4 - h5

i.e. 
$$cp \cdot (T3 - T2) = cp \cdot (T4 - T5)$$

i.e. T5 = T4 - T3 + T2 K...Ans.

And: 
$$P5 = P4 \cdot \left(\frac{T5}{T4}\right)^{\frac{\gamma}{\gamma-1}}$$
 kPa....Ans.

### Process 5-6: Isentropic expansion in nozzle:

$$T6 = T5 \cdot \left(\frac{P6}{P5}\right)^{\gamma} \quad K...Ans.$$

From an energy balance:

$$h6 + \frac{V6^2}{2} = h5 + \frac{V5^2}{2}$$

But, V5 is almost zero. Therefore:

$$cp \cdot (T6 - T5) + \frac{V6^2}{2} = 0$$

i.e.  $V6 = \sqrt{2 \cdot cp \cdot (T5 - T6)}$  m/s ....Ans.

### Net Thrust:

 $F = m \cdot (V6 - V1)$  N ...where m = air flow rate in kg/s.

### Propulsive power:

$$W_p = F \cdot V1 = m \cdot (V6 - V1) \cdot V1$$
 kW..Ans.



Low-speed Engines Medium-speed Engines Turbochargers Propellers Propulsion Packages PrimeServ

The design of eco-friendly marine power and propulsion solutions is crucial for MAN Diesel & Turbo. Power competencies are offered with the world's largest engine programme – having outputs spanning from 450 to 87,220 kW per engine. Get up front! Find out more at www.mandieselturbo.com

Engineering the Future – since 1758. **MAN Diesel & Turbo** 





### Heat supplied:

 $Q_{in} = m \cdot (h4 - h3) = m \cdot cp \cdot (T4 - T3)$  kW....Ans.

Propulsive efficiency:

$$\eta_{\mathbf{P}} = \frac{W_{\mathbf{P}}}{Q_{in}}$$

K.E. at exit:

 $KE_{exit} = m \cdot \frac{V6^2}{2}$  kW....Ans.

Heat rejected:

 $Q_{exit} = m \cdot (h6 - h1)$  kW...Ans.

Check:  $Q_{in} = W_P + KE_{exit} + Q_{exit}$ 

**Note:** In an actual Jet propulsion cycle, isentropic efficiencies of diffuser, compressor and turbine will have to be considered. Also, combustion efficiency in the burner section and the velocity coefficient of the nozzle will have to be taken in to account.

\_\_\_\_\_

### 2.2 Problems solved with Mathcad:

**Prob.2.1.** Write Mathcad Functions for Thermal efficiency, compressor work, Turbine work, Net work and Work ratio of an Ideal, Simple Gas Turbine cycle (i.e. Ideal Brayton Cycle):

### **Mathcad Functions:**

Thermal efficiency:

$$\gamma := 1.4$$

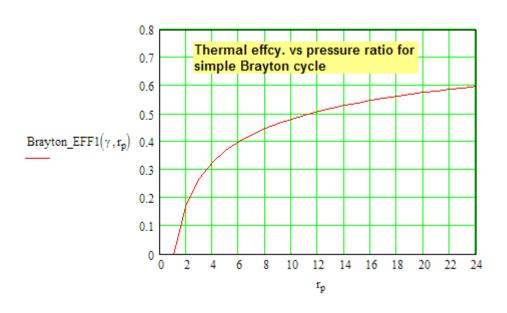
Brayton\_EFF1(
$$\gamma$$
,  $r_p$ ) := 1 -  $\left(\frac{1}{r_p}\right)^{\gamma}$ 

Ex:  $\mathbf{r}_p := 4$  Brayton\_EFF1( $\gamma, \mathbf{r}_p$ ) = 0.327

### Plot of effcy. vs pressure ratio, rp:

$$r_p := 1, 2... 25$$
 ....define a range variable

$$\gamma := 1.4$$



Compressor work:

$$W_{comp}(cp, T1, r_p, \gamma) := cp \cdot T1 \cdot \begin{pmatrix} \frac{\gamma - 1}{\gamma} \\ r_p & -1 \end{pmatrix}$$
 kJ/kg

 $W_{comp}(cp, T1, r_p, \gamma) = 146.527 kJ/kg$ 

Turbine work:

$$W_{turb}(cp, T3, r_p, \gamma) := cp \cdot T3 \cdot \left[1 - \left(\frac{1}{r_p}\right)^{\gamma}\right] \quad kJ/kg$$

Ex: cp := 1.005 kJ/kg.K T3 := 1500 K  $r_p$  := 4  $\gamma$  := 1.4

 $W_{turb}(cp, T3, r_p, \gamma) = 493.028$  kJ/kg

### Net work:

$$W_{net}(cp, T1, T3, r_p, \gamma) \coloneqq W_{turb}(cp, T3, r_p, \gamma) - W_{comp}(cp, T1, r_p, \gamma) \quad kJ/kg$$

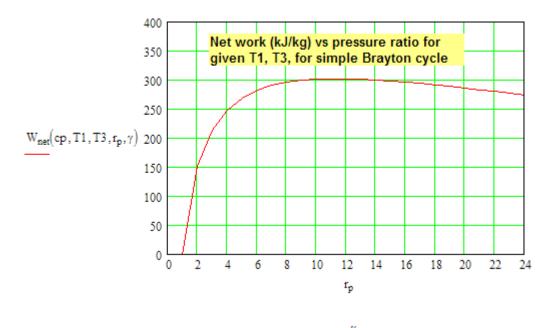
Ex: cp := 1.005 kJ/kg.K T3 := 1500 K T1 := 300 K  $r_p := 4 \gamma := 1.4$ 

 $W_{net}(ep, T1, T3, r_p, \gamma) = 346.5$  kJ/kg

### Plot W<sub>net</sub> vs r<sub>p</sub> for given T1, T3:

T1 := 300 K T3 := 1200 K

rp := 1,2..24 ....define a range variable



From Theory, optimum  $r_p$  for max. work is:  $r_p = \left(\frac{T3}{T1}\right)^{\frac{\gamma}{2\cdot(\gamma-1)}}$ 

Now: T1 := 300 K T3 := 1200 K And,  $\left(\frac{T3}{T1}\right)^{\frac{\gamma}{2\cdot(\gamma-1)}} = 11.314$ 

i.e. optimum pressure ratio for max. work =  $r_p = 11.314$ .

This is verified from the above graph.

Back Work ratio:

 $BWRatio(cp, T1, T3, r_p, \gamma) := \frac{W_{comp}(cp, T1, r_p, \gamma)}{W_{turb}(cp, T3, r_p, \gamma)}$ 

Ex: cp := 1.005 kJ/kg.K T3 := 1200 K T1 := 300 K  $r_p := 4$   $\gamma := 1.4$ 

BWRatio $(cp, T1, T3, r_p, \gamma) = 0.371$ 

## **X KBS** Group

# CAREERKICKSTART

### An app to keep you in the know

Whether you're a graduate, school leaver or student, it's a difficult time to start your career. So here at RBS, we're providing a helping hand with our new Facebook app. Bringing together the most relevant and useful careers information, we've created a one-stop shop designed to help you get on the career ladder – whatever your level of education, degree subject or work experience.

And it's not just finance-focused either. That's because it's not about us. It's about you. So download the app and you'll get everything you need to know to kickstart your career.

So what are you waiting for?

Click here to get started.

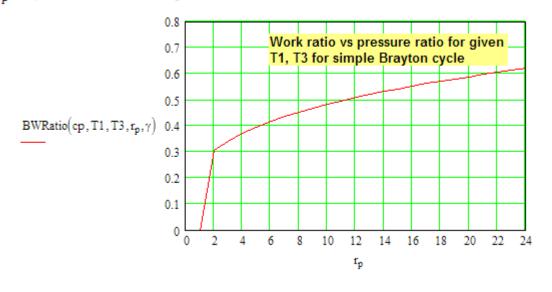


23

### Plot Back Work ratio vs rp:

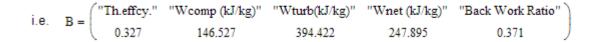
T3 := 1200 K T1 := 300 K

rp := 1,2..24 ....define a range variable



### Single program for Ideal, simple Brayton cycle:

Let:  $B := Brayton_cycle_simple(cp, T1, T3, r_p, \gamma)$ 



Thus, for given T1, T3, cp,  $\gamma$ , and  $r_{p}$ , Thermal effcy etc are calculated in one step, very conveniently.

\_\_\_\_\_\_

**Prob.2.2.** In a gas turbine plant, working on a simple Brayton cycle, air at the inlet to the compressor is at 1 bar, 30 C. Pressure ratio is 6. Max. temp is 900 C. Find the thermal efficiency, net work and back work ratio.

### Mathcad Solution:

```
Apply the above written Mathcad program:
```

Data:

T1 := 30 + 273 K T3 := 900 + 273 K cp := 1.005 kJ/kg.K  $r_p$  := 6  $\gamma$  := 1.4

Applying the Mathcad Function:

 $B := Brayton_cycle_simple(cp, T1, T3, r_p, \gamma)$ 

i.e.  $B = \begin{pmatrix} "Th.effcy." & "Wcomp (kJ/kg)" & "Wturb(kJ/kg)" & "Wnet (kJ/kg)" & "Back Work Ratio" \\ 0.401 & 203.571 & 472.328 & 268.756 & 0.431 \end{pmatrix}$ 

Thus:

Th. effcy. = 0.401 = 40.1%...Ans.

Compressor work = Wcomp = 203.571 kJ/kg ... Ans.

Turbine work = Wturb = 472.328 kJ/kg ... Ans.

Net work = Wnet = 268.756 kJ/kg .... Ans.

Back Work Ratio = 0.431 .... Ans.

**Prob.2.3.** Write Mathcad Functions for thermal efficiency etc of an actual, simple Brayton cycle i.e. taking in to account the isentropic efficiencies of compressor and turbine.

### **Mathcad Functions:**

Compressor Work (kJ/kg):

$$W_{comp}(T1, r_{p}, \gamma, cp, \eta_{comp}) := c_{p} \cdot \frac{T1 \cdot \left(\frac{\gamma - 1}{r_{p}} - 1\right)}{\eta_{comp}}$$

Applied Thermodynamics: Software Solutions: Part-II

### Turbine Work (kJ/kg):

$$W_{turb}(T3, r_{p}, \gamma, cp, \eta_{turb}) := c_{p} \cdot \left[T3 \cdot \left(1 - \frac{1}{\frac{\gamma - 1}{r_{p}}}\right) \cdot \eta_{turb}\right]$$

### Net Work (kJ/kg):

 $W_{net}(T1, T3, r_p, \gamma, cp, \eta_{comp}, \eta_{turb}) := W_{turb}(T3, r_p, \gamma, cp, \eta_{turb}) - W_{comp}(T1, r_p, \gamma, cp, \eta_{comp})$ 

### **Back Work Ratio:**

$$BWRatio(T1, T3, r_{p}, \gamma, cp, \eta_{comp}, \eta_{turb}) := \frac{W_{comp}(T1, r_{p}, \gamma, cp, \eta_{comp})}{W_{turb}(T3, r_{p}, \gamma, cp, \eta_{turb})}$$

Heat supplied (kJ/kg):

$$Q_{in}(T1, T3, r_p, \gamma, cp, \eta_{comp}) := cp \left[ T3 - \left[ T1 + \frac{T1 \cdot \left( \frac{\gamma - 1}{r_p} \right)}{\eta_{comp}} \right] \right]$$

### Be BRAVE enough to reach for the sky

Oracle's business is information - how to manage it, use it, share it, protect it. Oracle is the name behind most of today's most innovative and successful organisations.

Oracle continuously offers international opportunities to top-level graduates, mainly in our Sales, Consulting and Support teams.

If you want to join a company that will invest in your future, Oracle is the company for you to drive your career!

### https://campus.oracle.com



### **ORACLE IS THE INFORMATION COMPANY**



26

### Efficiency of Actual Simple Open Cycle Gas Turbine:

Brayton\_actual\_EFF(
$$r_p, \gamma, cp, T1, T3, \eta_{comp}, \eta_{turb}$$
) := 
$$\frac{W_{net}(T1, T3, r_p, \gamma, cp, \eta_{comp}, \eta_{turb})}{Q_{in}(T1, T3, r_p, \gamma, cp, \eta_{comp})}$$

### Single program for actual, simple Bryton cycle:

```
\begin{split} Brayton\_cycle\_actual(T1,T3,r_{p},\gamma,cp,\eta_{comp},\eta_{tutb}) &\coloneqq & Effcy \leftarrow Brayton\_actual\_EFF(r_{p},\gamma,cp,T1,T3,\eta_{comp},\eta_{tutb}) \\ & W_{comp} \leftarrow W_{comp}(T1,r_{p},\gamma,cp,\eta_{comp}) \\ & W_{tutb} \leftarrow W_{tutb}(T3,r_{p},\gamma,cp,\eta_{comp}) \\ & W_{net} \leftarrow W_{net}(T1,T3,r_{p},\gamma,cp,\eta_{comp},\eta_{tutb}) \\ & W_{out} \leftarrow Q_{in}(T1,T3,r_{p},\gamma,cp,\eta_{comp},\eta_{tutb}) \\ & BWRatio \leftarrow BWRatio(T1,T3,r_{p},\gamma,cp,\eta_{comp},\eta_{tutb}) \\ & A \leftarrow \begin{pmatrix} "Effcy' & W_{comp} & W_{botb} & W_{net} & Q_{iupp} & BWRatio \\ & Effcy' & W_{comp} & W_{botb} & W_{net} & Q_{iupp} & BWRatio \end{pmatrix} \end{split}
```

**Prob.2.4.** In a gas turbine plant, working on a simple Brayton cycle, air at the inlet to the compressor is at 1 bar, 30 C. Pressure ratio is 6. Max. temp is 900 C. Isentropic efficiencies of the compressor and turbine are 0.8 each. Find the thermal efficiency, net work and work ratio.

### Mathcad Solution:

Data:

 $\gamma := 1.4$   $c_p := 1.005$   $\gamma := 1.4$  T1 := 303 K T3 := 1173 K  $r_p := 6$  $\eta_{comp} := 0.8$   $\eta_{turb} := 0.8$ 

### Then, we have, using the Mathcad Function written above:

```
BB := Brayton\_cycle\_actual(T1, T3, r_p, \gamma, cp, \eta_{comp}, \eta_{turb}) i.e.
```

BB =	"Effey"	"Wcomp (kJ/kg)"	"Wturb (kJ/kg)"	"Wnet (kJ/kg)"	"Qsupp (kJ/kg)"	"Back WRatio"	١
	0.199	254.464	377.862	123.398	619.886	0.673	J

### Thus:

Th. effcy. = 0.199 = 19.9 %...Ans.

Compressor work = Wcomp = 254.464 kJ/kg ... Ans.

Turbine work = Wturb = 377.862 kJ/kg ... Ans.

Net work = Wnet = 123.398 kJ/kg .... Ans.

Heat supplied = Qsupp = 619.886 kJ/kg ... Ans.

Back Work Ratio = 0.673 .... Ans.

\_\_\_\_\_

Prob.2.5 Write a Mathcad Function for Thermal efficiency of an Ideal Brayton cycle with ideal regenerator.

Efficiency of Ideal Open Cycle Gas Turbine with Ideal Regeneration:.

Depends on pressure ratio and the cycle max to min temp. ratio:

Brayton\_IdealRegen\_EFF(
$$\gamma$$
, r<sub>p</sub>, T1, T3) := 1 -  $\left(\frac{T1}{T3}\right)$  · r<sub>p</sub>  $\frac{\gamma - 1}{\gamma}$ 

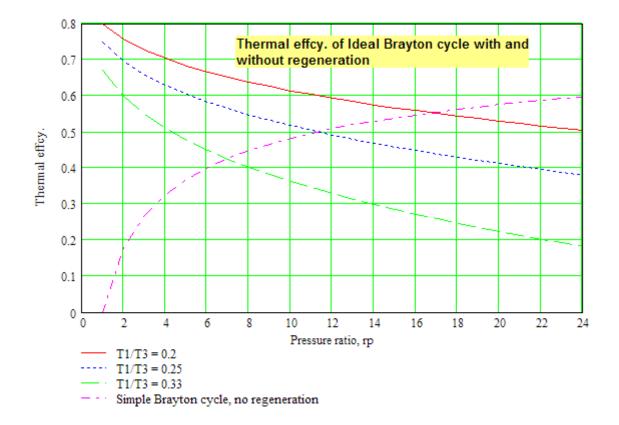
In terms of temp. ratio, t = T1/T3, re-writing the above eqn, we have:

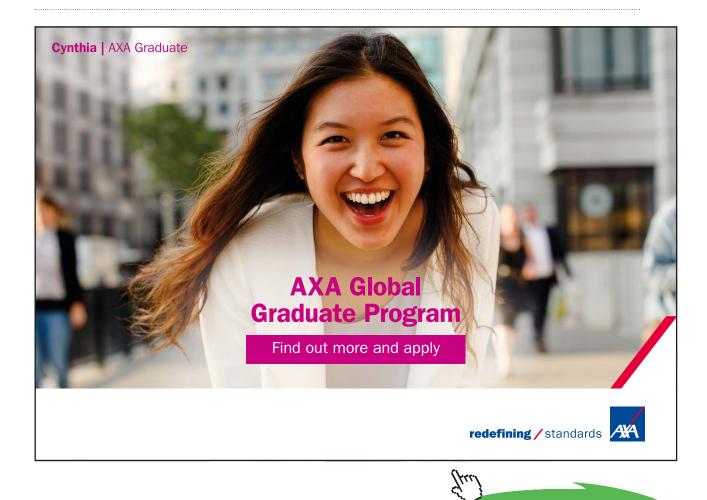
$$\label{eq:Brayton_IdealRegen_EFF} \begin{split} & \frac{\gamma - 1}{\gamma} \\ & \text{Brayton_IdealRegen_EFF}\big(\gamma, t, r_p\big) \coloneqq 1 - (t) \cdot r_p^{-\gamma} \end{split}$$

Plot the Efficiency vs pressure ratio, for different temp ratios:

 $\gamma := 1.4$ 

rp := 1,2..24 ....define a range variable





Click on the ad to read more

29

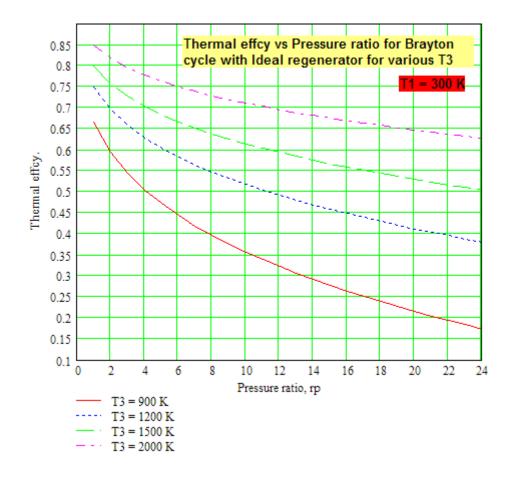
### Also, plot thermal effcy vs pressure ratio for T3 = 900, 1200, 1500 and 2000 K, with T1 = 300 K:

### We have:

T1 := 300 K γ := 1.4

 $Brayton\_IdealRegen\_EFF(\gamma, r_p, T1, T3) := 1 - \left(\frac{T1}{T3}\right) \cdot r_p^{-\frac{\gamma-1}{\gamma}}$ 

rp := 1,2..24 ....define a range variable



**Prob.2.6** Write Mathcad Functions for Thermal efficiency etc of an **ideal Brayton cycle with regenerator** of efficiency =  $\varepsilon$ 

### Mathcad Solution:

Let the pressure ratio be 10, and regenerator efficiency = 80%. Also, T1 = 300 K, T3 = 1400 K, cp = 1.005 kJ/kg.K,  $\gamma = 1.4$ .

We shall write Functions for all calculated quantities:

Data:

 $r_p := 10$   $\gamma := 1.4$  cp := 1.005 kJ/kg.K

T1 := 300 K T3 := 1400 K ε := 0.8 ....regen. effectiveness

We have for Regen. effectiveness:  $\epsilon = \frac{T5 - T2}{T4 - T2}$ 

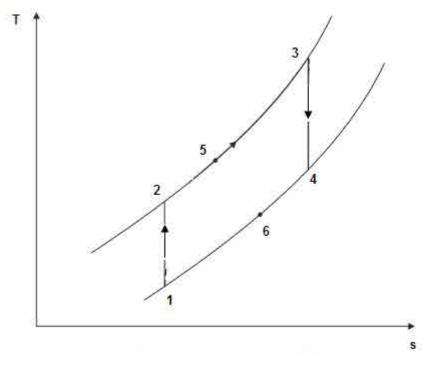


Fig.Prob.2.6

Temp at exit of compressor:

$$T2(r_p, \gamma, T1) := T1 \cdot r_p^{\gamma} K.$$

Temp at exit of turbine:

$$T4(r_p, \gamma, T3) := \frac{T3}{\frac{\gamma-1}{r_p}}$$
 K

### Temp at exit of high pressure stream in regenerator:

$$T5(r_p,\gamma,\epsilon,T1,T3) := T2(r_p,\gamma,T1) + \epsilon \cdot (T4(r_p,\gamma,T3) - T2(r_p,\gamma,T1))$$
 K

### Heat supplied:

$$Q_{s}\!\left(cp,r_{p},\gamma,\epsilon,T1,T3\right) \coloneqq cp \cdot \left(T3 - T5\!\left(r_{p},\gamma,\epsilon,T1,T3\right)\right) \hspace{1.5cm} kJ/kg$$

### Compressor Work:

 $W_{comp}(cp, r_p, \gamma, T1) := cp \cdot (T2(r_p, \gamma, T1) - T1) kJ/kg$ 

### **Turbine Work:**

 $W_{turb}(cp, r_p, \gamma, T3) := cp \cdot (T3 - T4(r_p, \gamma, T3)) kJ/kg$ 



### **Masters in Management**

Designed for high-achieving graduates across all disciplines, London Business School's Masters in Management provides specific and tangible foundations for a successful career in business.

This 12-month, full-time programme is a business qualification with impact. In 2010, our MiM employment rate was 95% within 3 months of graduation\*; the majority of graduates choosing to work in consulting or financial services.



As well as a renowned qualification from a world-class business school, you also gain access to the School's network of more than 34,000 global alumni – a community that offers support and opportunities throughout your career.

For more information visit **www.london.edu/mm**, email **mim@london.edu** or give us a call on **+44 (0)20 7000 7573**.

\* Figures taken from London Business School's Masters in Management 2010 employment report



### Net Work:

$$W_{net}(cp, r_p, \gamma, T1, T3) := W_{turb}(cp, r_p, \gamma, T3) - W_{comp}(cp, r_p, \gamma, T1) kJ/kg$$

### Thermal efficiency:

$$\eta_{\text{th}}(cp, r_p, \gamma, \varepsilon, T1, T3) := \frac{W_{\text{net}}(cp, r_p, \gamma, T1, T3)}{Q_{\text{s}}(cp, r_p, \gamma, \varepsilon, T1, T3)}$$

i.e.  $\eta_{th}(cp, r_p, \gamma, \epsilon, T1, T3) = 0.562 = 56.2 \%$  ... Ans.

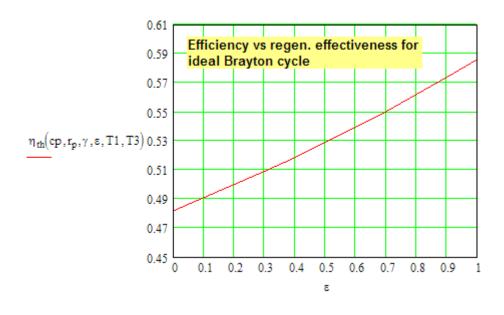
## (b) Plot Thermal efficiency of the cycle vs regenerator effectiveness, other conditions remaining the same:

Since efficiency is written as a function of other, involved variables, it is very easy to plot efficiency against any of the other variables.

$$r_p := 10 \quad \gamma := 1.4 \qquad cp := 1.005 \text{ kJ/kg.K}$$

T1 := 300 K T3 := 1400 K

 $\epsilon := 0, 0.1..1$  ....define a range variable

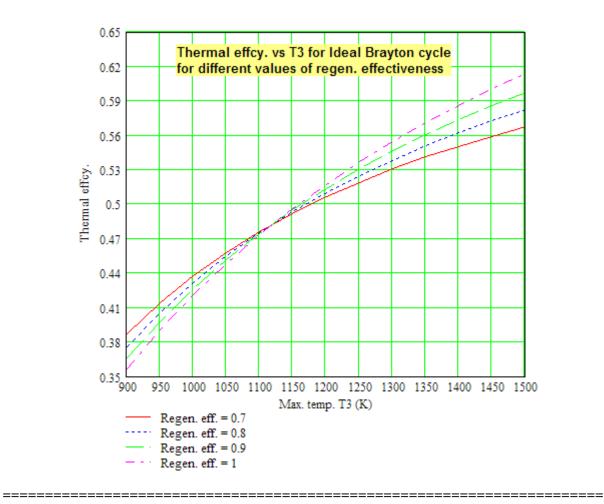


### If we need to plot efficiency vs T3:

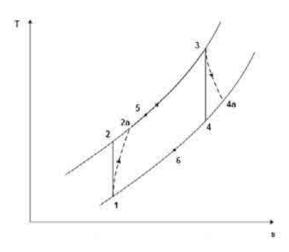
 $r_p := 10 \quad \gamma := 1.4 \qquad cp := 1.005 \quad kJ/kg.K$ 

T1 := 300 K

T3 := 900,950.. 1500 ....define a range variable



**Prob.2.7** Write a Mathcad Function for Thermal efficiency of an **actual Brayton cycle with regenerator**. i.e. *including* the efficiencies of compressor ( $\eta_{comp}$ ), turbine ( $\eta t_{urb}$ ) and the regenerator ( $\epsilon$ ):





### **Mathcad Functions:**

Turbine Work:

$$W_{turb}(\mathbf{r}_{p}, \gamma, cp, T3, \eta_{turb}) := cp \cdot \left[T3 \cdot \left(1 - \frac{1}{\frac{\gamma - 1}{r_{p}}}\right) \cdot \eta_{turb}\right] \qquad kJ/kg$$

**Compressor Work:** 

$$W_{comp}(r_{p}, \gamma, cp, T1, \eta_{comp}) := cp \cdot \frac{T1 \cdot \left(\frac{\gamma - 1}{r_{p}} - 1\right)}{\eta_{comp}} \qquad kJ/kg$$

### Net Work:

 $\mathbf{W}_{net}(\mathbf{r}_{p},\boldsymbol{\gamma},cp,T1,T3,\boldsymbol{\eta}_{comp},\boldsymbol{\eta}_{turb}) \coloneqq \mathbf{W}_{turb}(\mathbf{r}_{p},\boldsymbol{\gamma},cp,T3,\boldsymbol{\eta}_{turb}) - \mathbf{W}_{comp}(\mathbf{r}_{p},\boldsymbol{\gamma},cp,T1,\boldsymbol{\eta}_{comp}) \quad kJ/kg$ 

### Back Work Ratio:

$$BWRatio(r_{p,\gamma}, cp, T1, T3, \eta_{comp}, \eta_{turb}) \coloneqq \frac{W_{comp}(r_{p,\gamma}, cp, T1, \eta_{comp})}{W_{turb}(r_{p,\gamma}, cp, T3, \eta_{turb})}$$

### Temp at exit of compressor:

$$T2a(r_{p},\gamma,T1,\eta_{comp}) := T1 + \frac{T1 \cdot \begin{pmatrix} \frac{\gamma-1}{r_{p}} \\ r_{p} \end{pmatrix}}{\eta_{comp}}$$
 K

### Temp at exit of turbine:

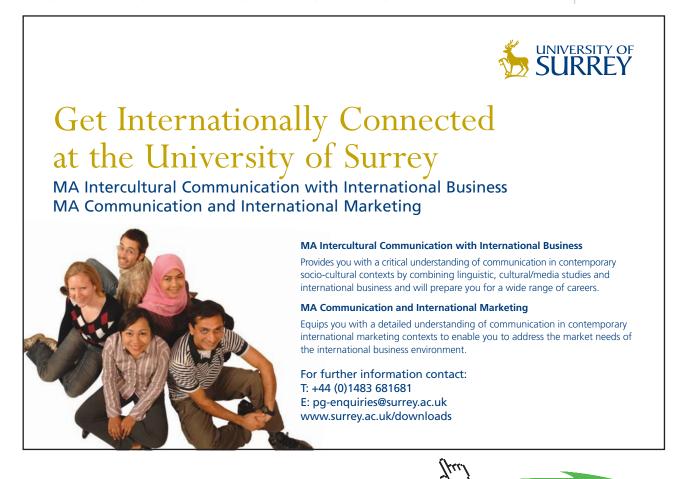
$$T4a(r_{p}, \gamma, T3, \eta_{turb}) := T3 - T3 \cdot \left(1 - \frac{1}{\frac{\gamma - 1}{r_{p}}}\right) \cdot \eta_{turb} \qquad K$$

### Regen. effectiveness, z:

$$\varepsilon = \frac{T5 - T2a}{T_{4a} - T2a}$$

### Therefore, temp at exit of high pressure stream in regenerator:

 $T5(r_{p},\gamma,T1,T3,\eta_{comp},\eta_{turb},\epsilon) := T2a(r_{p},\gamma,T1,\eta_{comp}) + \epsilon \cdot \left(T4a(r_{p},\gamma,T3,\eta_{turb}) - T2a(r_{p},\gamma,T1,\eta_{comp})\right) \\ K = \frac{1}{2} \left(r_{p},\gamma,T1,T3,\eta_{comp},\eta_{turb},\epsilon\right) = \frac{1}{2} \left(r_{p},\gamma,T1,\eta_{comp},\eta_{turb},\epsilon\right) + \frac{1}{2} \left(r_{p},\gamma,T3,\eta_{turb},\eta_{turb},\eta_{turb},\epsilon\right) + \frac{1}{2} \left(r_{p},\gamma,T3,\eta_{turb},\eta_{tu$ 



36

Click on the ad to read more

#### Heat supplied:

$$Q_{in}(r_p, \gamma, cp, T1, T3, \eta_{comp}, \eta_{turb}, \epsilon) := cp \cdot (T3 - T5(r_p, \gamma, T1, T3, \eta_{comp}, \eta_{turb}, \epsilon)) \quad kJ/kg$$

#### Thermal efficiency:

$$Brayton\_actual\_regen\_EFF(r_p, \gamma, cp, T1, T3, \eta_{comp}, \eta_{turb}, \epsilon) := \frac{W_{net}(r_p, \gamma, cp, T1, T3, \eta_{comp}, \eta_{turb})}{Q_{in}(r_p, \gamma, cp, T1, T3, \eta_{comp}, \eta_{turb}, \epsilon)}$$

#### Single program for actual, Brayton cycle with Regenerator:

```
\begin{split} Brayton\_actual\_regen(T1,T3,r_p,\gamma,cp,\eta_{comp},\eta_{turb},s) \simeq & [ Effect \leftarrow Brayton\_actual\_regen\_EFF(r_p,\gamma,cp,T1,T3,\eta_{comp},\eta_{turb},s) \\ & W_{comp} \leftarrow W_{comp}(r_p,\gamma,cp,T1,\eta_{comp}) \\ & W_{turb} \leftarrow W_{turb}(r_p,\gamma,cp,T1,\eta_{comp}) \\ & W_{net} \leftarrow W_{net}(r_p,\gamma,cp,T1,T3,\eta_{comp},\eta_{turb}) \\ & W_{set} \leftarrow W_{net}(r_p,\gamma,cp,T1,T3,\eta_{comp},\eta_{turb}) \\ & Q_{supp} \leftarrow Q_{in}(r_p,\gamma,cp,T1,T3,\eta_{comp},\eta_{turb},s) \\ & BWRatio \leftarrow BWRatio(r_p,\gamma,cp,T1,T3,\eta_{comp},\eta_{turb}) \\ & A \leftarrow \begin{pmatrix} "Effect" & W_{comp} & W_{turb} & W_{net} & Q_{supp} & BWRatio \\ & Bfect & W_{comp} & W_{turb} & W_{net} & Q_{supp} & BWRatio \end{pmatrix} \end{split}
```

Ex:

 $\gamma := 1.4$  c<sub>p</sub> := 1.005 kJ/kg.K T1 := 303 K T3 := 1173 K r<sub>p</sub> := 6

 $\eta_{comp} := 0.8$   $\eta_{turb} := 0.8$   $\epsilon := 0.75$  ....effcy of regenerator

#### Applying the above Mathcad Function, we get:

BB := Brayton\_actual\_regen $(T1, T3, r_p, \gamma, cp, \eta_{comp}, \eta_{turb}, \epsilon)$ 

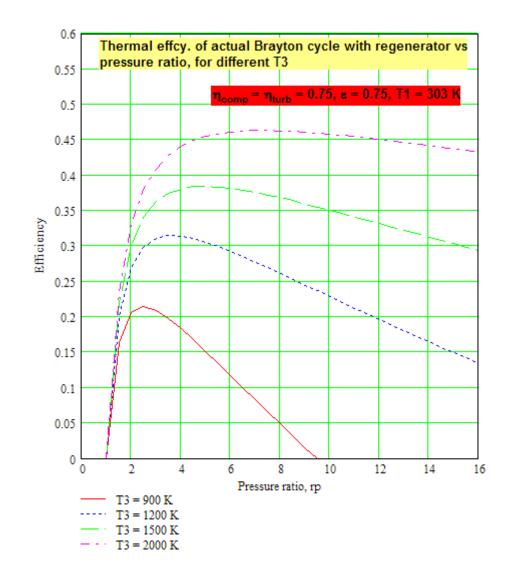
BB =	("Effcy"	"Wcomp (kJ/kg)"	"Wturb (kJ/kg)"	"Wnet (kJ/kg)"	"Qsupp (kJ/kg)"	"BWRatio"
DD =	0.281	254.464	377.862	123.398	438.368	0.673

#### Plot Thermal effcy vs rp for various T3:

 $\gamma := 1.4$  c<sub>p</sub> := 1.005  $\gamma := 1.4$  T1 := 303 K

 $\eta_{comp} := 0.8 \qquad \eta_{turb} := 0.8 \qquad \epsilon := 0.75 \ \dots \text{effcy of regenerator}$ 

rp := 1,1.5..16 ....define a range variable

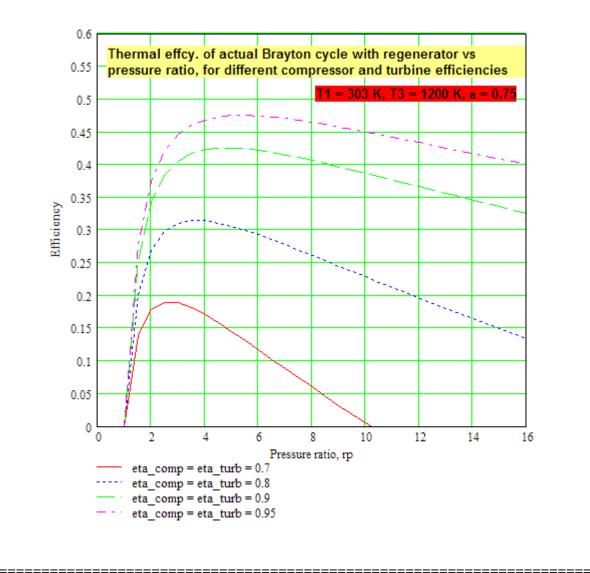


Plot Thermal effcy vs rp for various compressor and turbine efficiencies, for fixed T1,T3:

 $\gamma := 1.4$  c<sub>p</sub> := 1.005  $\gamma := 1.4$  T1 := 303 K T3 := 1200 K

 $\eta_{comp} := 0.8 \qquad \eta_{turb} := 0.8 \qquad \epsilon := 0.75 \ \dots \text{effcy of regenerator}$ 

rp := 1,1.5..16 .....define a range variable



**Prob.2.8** The extreme pressures and temps in an open cycle gas turbine plant are 1 bar and 5 bar, and 27 C and 550 C respectively. Calculate the efficiency of the cycle when (i) there is no regenerator, (ii) there is a regenerator with 60% effectiveness. Take  $\gamma = 1.4$  [VTU-Jan. 2003]

#### Mathcad Solution:

Use the Functions written earlier.

Data:

P1 := 1 bar P3 := 5 bar  $r_p$  := 5  $\gamma$  := 1.4  $\epsilon$  := 0.6 ...effectivenes of regen. T1 := 27 + 273 K T3 := 550 + 273 K

#### Case (i): when there is no regenerator:

```
\begin{split} B &:= Brayton\_cycle\_simple(cp, T1, T3, r_p, \gamma) \\ i.e. \quad B &= \begin{pmatrix} "Th.effcy." & "Wcomp (kJ/kg)" & "Wturb(kJ/kg)" & "Wnet (kJ/kg)" & "Back Work Ratio" \\ 0.369 & 176.022 & 304.887 & 128.865 & 0.577 \end{pmatrix} \end{split}
```

Thus, Thermal effcy. = 36.9% when there is no regenerator ... Ans.

Case (ii): when there is a regenerator with an effectiveness of 60 %:

We use the following program, written earlier:

```
\begin{split} Brayton\_actual\_regen(T1,T3,r_{p},\gamma,cp,\eta_{comp},\eta_{turb},e) &= & Eff cy \leftarrow Brayton\_actual\_regen\_EFF(r_{p},\gamma,cp,T1,T3,\eta_{comp},\eta_{turb},e), \\ W_{comp} \leftarrow W_{comp}(r_{p},\gamma,cp,T1,\eta_{comp}), \\ W_{turb} \leftarrow W_{turb}(r_{p},\gamma,cp,T3,\eta_{turb}), \\ W_{net} \leftarrow W_{nef}(r_{p},\gamma,cp,T1,T3,\eta_{comp},\eta_{turb}), \\ Q_{supp} \leftarrow Q_{m}(r_{p},\gamma,cp,T1,T3,\eta_{comp},\eta_{turb},e), \\ BWRatio \leftarrow BWRatio(r_{p},\gamma,cp,T1,T3,\eta_{comp},\eta_{turb},e), \\ A \leftarrow \begin{pmatrix} "Eff cy" & W_{comp} & W_{turb} & W_{net} & Q_{supp} & BWRatio \\ Eff cy' & W_{comp} & W_{turb} & W_{net} & Q_{supp} & BWRatio \end{pmatrix} \\ \end{split}
```

We have:

 $\gamma := 1.4$  cp := 1.005 kJ/kg.K r<sub>p</sub> := 5

T1 := 27 + 273 K T3 := 550 + 273 K ε := 0.6 ....effcy of regenerator

 $\eta_{comp} := 1$   $\eta_{turb} := 1$  ....assumed as 100 % since no values are given.

#### Then:

BB := Brayton\_actual\_regen(T1, T3,  $r_p$ ,  $\gamma$ , cp,  $\eta_{comp}$ ,  $\eta_{turb}$ ,  $\epsilon$ )

BB = ("Effcy" "Wcomp (kJ/kg)" "Wturb (kJ/kg)" "Wnet (kJ/kg)" "Qsupp (kJ/kg)" "BWRatio") 0.399 176.022 304.887 128.865 322.77 0.577

Thus, Thermal effcy. = 39.9% when there is a regenerator with  $\varepsilon = 0.6 \dots$  Ans.

\_\_\_\_\_

**Prob.2.9** In a Regenerative Brayton cycle, inlet conditions to compressor are: P1 = 100 kPa, T1 = 300 K. Regenerator efficiency = 80%. Max. temp is 1400 K. Compressor and turbine efficiencies are 90, 80 and 70% each. Plot (i) thermal efficiency, (ii) Back work ratio, (iii) net work developed in kJ/kg, when pressure ratio varies from 2 to 20.

#### Mathcad Solution:

We shall use the Mathcad Functions written above, viz:

 $Brayton\_actual\_regen\_EFF(r_p, \gamma, cp, T1, T3, \eta_{comp}, \eta_{turb}, \epsilon) := \frac{W_{net}(r_p, \gamma, cp, T1, T3, \eta_{comp}, \eta_{turb})}{Q_{in}(r_p, \gamma, cp, T1, T3, \eta_{comp}, \eta_{turb}, \epsilon)}$ 

 $BWRatio(r_{p}, \gamma, cp, T1, T3, \eta_{comp}, \eta_{turb}) \coloneqq \frac{W_{comp}(r_{p}, \gamma, cp, T1, \eta_{comp})}{W_{turb}(r_{p}, \gamma, cp, T3, \eta_{turb})}$ 

 $\mathrm{W}_{net}\!\left(r_{p},\gamma,cp,T1,T3,\eta_{comp},\eta_{turb}\right) \coloneqq \mathrm{W}_{turb}\!\left(r_{p},\gamma,cp,T3,\eta_{turb}\right) - \mathrm{W}_{comp}\!\left(r_{p},\gamma,cp,T1,\eta_{comp}\right) \; kJ/kg$ 

Data:

T1 := 300 K T3 := 1400 K  $\epsilon$  := 0.8 ....regen. effcy.  $\gamma$  := 1.4 cp := 1.005 kJ/kg.K





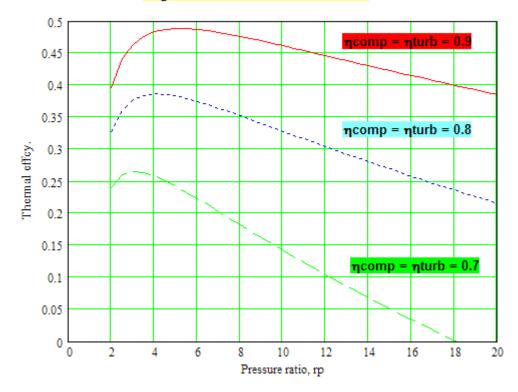
41

#### Thermal efficiency.:

 $r_p := 2, 2.5..20$  ...define a range variable

rp	effcy (eta_comp = eta_turb = 0.9)	effcy (eta_comp = eta_turb = 0.8)	effcy (eta_comp = eta_turb = 0.7)
2	0.397	0.327	0.24
4	0.483	0.386	0.265
6	0.487	0.374	0.258
8	0.476	0.352	0.242
10	0.462	0.328	0.223
12	0.446	0.304	0.202
14	0.43	0.28	0.182
16	0.415	0.258	0.162
18	0.4	0.236	0.142
20	0.385	0.215	0.123

Thermal effcy. vs Pressure ratio Regen. eff. = ε = 0.8



#### Back Work Ratio (BWR):

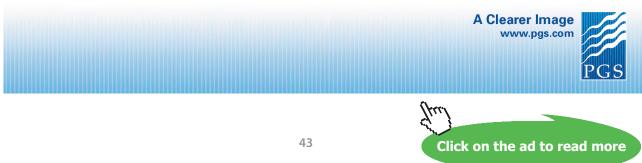
rp	BWR (eta_comp = eta_turb = 0.9)	BWR (eta_comp = eta_turb = 0.8)	BWR (eta_comp = eta_turb = 0.7)
2	0.322	0.408	0.533
4	0.393	0.498	0.65
6	0.441	0.559	0.73
8	0.479	0.607	0.792
10	0.511	0.646	0.844
12	0.538	0.681	0.889
14	0.562	0.712	0.93
16	0.584	0.739	0.966
18	0.604	0.765	0.999
20	0.623	0.788	



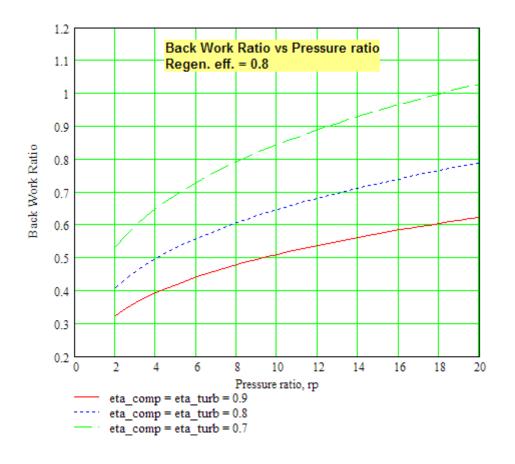
As a leading technology company in the field of geophysical science, PGS can offer exciting opportunities in offshore seismic exploration.

We are looking for new BSc, MSc and PhD graduates with Geoscience, engineering and other numerate backgrounds to join us.

To learn more our career opportunities, please visit www.pgs.com/careers

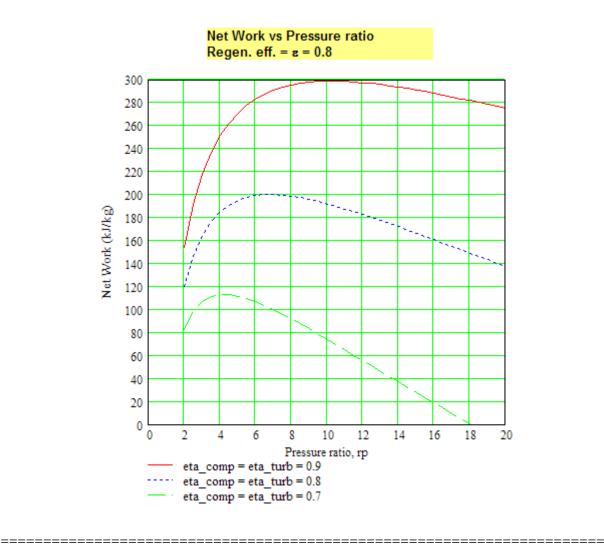


Download free eBooks at bookboon.com



#### Net Work:

rp	Wnet (eta_comp = eta_turb = 0.9)	Wnet (eta_comp = eta_turb = 0.8)	Wnet  eta_comp = eta_turb = 0.7)
2	154.14	119.69	82.619
4	251.335	184.968	112.787
6	283.409	199.041	106.676
8	295.411	198.404	91.689
10	298.639	191.842	73.909
12	297.345	182.526	55.335
14	293.491	171.855	36.754
16	288.101	160.526	18.496
18	281.761	148.913	0.705
20	274.823	137.225	-16.567



**Prob.2.10.** Write Mathcad Functions for efficiency etc of a Brayton cycle with intercooling, reheating and regenerator.

#### Mathcad Solution:

#### Assumed that:

The compressor has two stages, with equal pressure ratio in each stage.

Overall pressure ratio = rp, preassure ratio in each stage =  $rp^{0.5}$ 

'Perfect inter-cooling' between compressor stages, i.e. after compression in first stage, air is cooled back to initial temp before entry to second stage.

Similarly, turbine has two stages, pressure ratios in LP and HP turbines being equal, and re-heating back to HP turbine inlet temp after expansion, before entering LP turbine.

Regenerator effectiveness =  $\varepsilon$ .

$$\epsilon = \frac{T5 - T2a}{T4a - T2a} \qquad \dots \text{regen. effcy.}$$

See the diagram below:

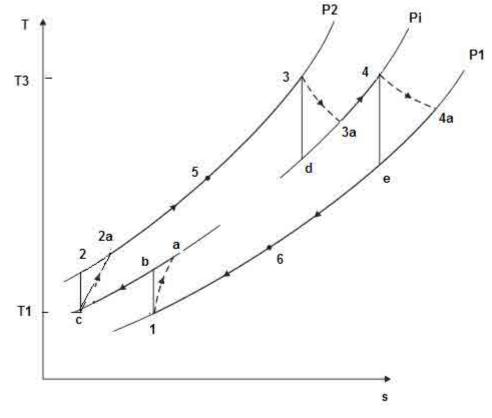


Fig.Prob.2.10

We have the following Mathcad Functions:

Total Compressor work input:

$$WK_{comp}(T1, r_{p}, \gamma, cp, \eta_{comp}) := c_{p} \cdot \frac{T1 \cdot \begin{pmatrix} 0.5 \cdot \frac{\gamma - 1}{\gamma} \\ r_{p} & -1 \end{pmatrix} \cdot 2}{\eta_{comp}} \qquad kJ/kg$$

#### Total Turbine work output:

$$WK_{turb}(T3, r_{p}, \gamma, cp, \eta_{turb}) := c_{p} \cdot \left[T3 \cdot \left(1 - \frac{1}{0.5 \cdot \frac{\gamma - 1}{\gamma}}\right) \cdot \eta_{turb}\right] \cdot 2 \qquad kJ/kg$$

#### Net Work output:

 $\mathbf{W}_{net}\big(\texttt{T1},\texttt{T3},\texttt{r}_{p},\textbf{\gamma},\texttt{cp},\eta_{comp},\eta_{turb}\big) \coloneqq \mathbf{WK}_{turb}\big(\texttt{T3},\texttt{r}_{p},\textbf{\gamma},\texttt{cp},\eta_{turb}\big) - \mathbf{WK}_{comp}\big(\texttt{T1},\texttt{r}_{p},\textbf{\gamma},\texttt{cp},\eta_{comp}\big)$ 

#### Back Work Ratio:

$$BWRATIO(T1, T3, r_p, \gamma, cp, \eta_{comp}, \eta_{turb}) \coloneqq \frac{WK_{comp}(T1, r_p, \gamma, cp, \eta_{comp})}{WK_{turb}(T3, r_p, \gamma, cp, \eta_{turb})}$$

#### Work Ratio:

$$WRATIO(T1, T3, r_p, \gamma, cp, \eta_{comp}, \eta_{turb}) \coloneqq \frac{WK_{turb}(T3, r_p, \gamma, cp, \eta_{turb}) - WK_{comp}(T1, r_p, \gamma, cp, \eta_{comp})}{WK_{turb}(T3, r_p, \gamma, cp, \eta_{turb})}$$



Temp. T2a:

$$T2a(T1, r_p, \gamma, \eta_{comp}) := \frac{T1 \cdot \begin{pmatrix} 0.5 \cdot \frac{\gamma - 1}{\gamma} \\ r_p & -1 \end{pmatrix}}{\eta_{comp}} + T1 \qquad K$$

Temp. T4a:

$$T4a(T3, r_{p}, \gamma, \eta_{turb}) := T3 - \begin{bmatrix} T3 \cdot \left(1 - \frac{1}{0.5 \cdot \frac{\gamma - 1}{\gamma}}\right) \cdot \eta_{turb} \\ r_{p} \end{bmatrix} K$$

#### T5, temp at exit of high pressure stream in regenerator:

$$\varepsilon = \frac{T5 - T2a}{T4a - T2a} \qquad \dots \text{regen. effcy.}$$

Then:

$$T5(T1, T3, r_p, \gamma, \eta_{comp}, \eta_{turb}, \epsilon) := T2a(T1, r_p, \gamma, \eta_{comp}) + \epsilon \cdot (T4a(T3, r_p, \gamma, \eta_{turb}) - T2a(T1, r_p, \gamma, \eta_{comp})) \quad K = K + \frac{1}{2} \left( \frac{1}{2} + \frac{1}{2} +$$

#### Heat supplied:

Thermal efficiency:

$$EFFCY(T1, T3, r_p, \gamma, \eta_{comp}, \eta_{turb}, \epsilon) := \frac{WK_{turb}(T3, r_p, \gamma, cp, \eta_{turb}) - WK_{comp}(T1, r_p, \gamma, cp, \eta_{comp})}{Q1(T1, T3, r_p, \gamma, cp, \eta_{comp}, \eta_{turb}, \epsilon)}$$

**Prob.2.11.** In a Regenerative Brayton cycle, with intercooling and reheating, overall pressure ratio is 9, inlet conditions to compressor are: T1 = 293 K. Regenerator efficiency = 80%. Max. temp is 898 K. Compressor and turbine have 2 stages and for each stage, efficiencies are 80% and 85% respectively. Find Thermal effcy and Back Work ratio etc.

(b) Plot (i) thermal efficiency, (ii) Back work ratio, (iii) net work developed in kJ/kg, when pressure ratio varies from 2 to 20.

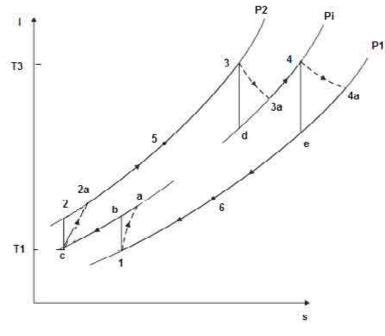


Fig.Prob.2.11

Mathcad Solution:

We shall use the Functions written above.

Data:

T1 := 293 K T3 := 898 K ε := 0.8 ....regen. effcy.

 $\gamma := 1.4$  cp := 1.005 kJ/kg.K r<sub>p</sub> := 9 ...overall pressure ratio

 $\eta_{comp} := 0.8$   $\eta_{turb} := 0.85$ 

#### Solution:

Total Compressor work input:

$$WK_{comp}(T1, r_p, \gamma, cp, \eta_{comp}) \coloneqq c_p \cdot \frac{T1 \cdot \begin{pmatrix} 0.5 \cdot \frac{\gamma - 1}{\gamma} \\ r_p & -1 \end{pmatrix} \cdot 2}{\eta_{comp}}$$

i.e.  $WK_{comp}(T1, r_p, \gamma, cp, \eta_{comp}) = 271.451$  kJ/kg .... Ans.

#### Total Turbine work output:

$$WK_{turb}(T3, r_p, \gamma, cp, \eta_{turb}) \coloneqq c_p \cdot \left[ T3 \cdot \left( 1 - \frac{1}{0.5 \cdot \frac{\gamma - 1}{\gamma}} \right) \cdot \eta_{turb} \right] \cdot 2$$

i.e.  $WK_{turb}(T3, r_p, \gamma, cp, \eta_{turb}) = 413.322$  kJ/kg .... Ans.

#### Net Work output:

$$W_{net}(T1, T3, r_p, \gamma, cp, \eta_{comp}, \eta_{turb}) := WK_{turb}(T3, r_p, \gamma, cp, \eta_{turb}) - WK_{comp}(T1, r_p, \gamma, cp, \eta_{comp})$$

i.e.  $W_{net}(T1, T3, r_p, \gamma, cp, \eta_{comp}, \eta_{turb}) = 141.871$  kJ/kg .... Ans.

#### Back Work Ratio:

 $\text{BWRATIO}(\text{T1}, \text{T3}, \textbf{r}_{p}, \gamma, \textbf{cp}, \eta_{comp}, \eta_{turb}) \coloneqq \frac{\text{WK}_{comp}(\text{T1}, \textbf{r}_{p}, \gamma, \textbf{cp}, \eta_{comp})}{\text{WK}_{turb}(\text{T3}, \textbf{r}_{p}, \gamma, \textbf{cp}, \eta_{turb})}$ 

i.e. BWRATIO $(T1, T3, r_p, \gamma, cp, \eta_{comp}, \eta_{turb}) = 0.657$  .... Ans.

### Technical training on *WHAT* you need, *WHEN* you need it

At IDC Technologies we can tailor our technical and engineering training workshops to suit your needs. We have extensive experience in training technical and engineering staff and have trained people in organisations such as General Motors, Shell, Siemens, BHP and Honeywell to name a few.

Our onsite training is cost effective, convenient and completely customisable to the technical and engineering areas you want covered. Our workshops are all comprehensive hands-on learning experiences with ample time given to practical sessions and demonstrations. We communicate well to ensure that workshop content and timing match the knowledge, skills, and abilities of the participants.

We run onsite training all year round and hold the workshops on your premises or a venue of your choice for your convenience.

For a no obligation proposal, contact us today at training@idc-online.com or visit our website for more information: www.idc-online.com/onsite/ OIL & GAS

ENGINEERING

ELECTRONICS

AUTOMATION & PROCESS CONTROL

> MECHANICAL ENGINEERING

INDUSTRIAL DATA COMMS

ELECTRICAL POWER



Phone: +61 8 9321 1702 Email: training@idc-online.com Website: www.idc-online.com



Download free eBooks at bookboon.com

Click on the ad to read more

Applied Thermodynamics: Software Solutions: Part-II

#### Work Ratio:

$$WRATIO(T1, T3, r_{p}, \gamma, cp, \eta_{comp}, \eta_{turb}) \coloneqq \frac{WK_{turb}(T3, r_{p}, \gamma, cp, \eta_{turb}) - WK_{comp}(T1, r_{p}, \gamma, cp, \eta_{comp})}{WK_{turb}(T3, r_{p}, \gamma, cp, \eta_{turb})}$$

i.e.  $WRATIO(T1, T3, r_p, \gamma, cp, \eta_{comp}, \eta_{turb}) = 0.343$  .... Ans.

Temp. T2a:

$$T2a(T1, r_{p}, \gamma, \eta_{comp}) := \frac{T1 \cdot \begin{pmatrix} 0.5 \cdot \frac{\gamma - 1}{\gamma} \\ r_{p} & -1 \end{pmatrix}}{\eta_{comp}} + T1$$

i.e. 
$$T2a(T1, r_p, \gamma, \eta_{comp}) = 428.05$$
 K....Ans

Temp. T4a:

$$T4a(T3, r_p, \gamma, \eta_{turb}) := T3 - \begin{bmatrix} T3 \cdot \left(1 - \frac{1}{0.5 \cdot \frac{\gamma - 1}{\gamma}}\right) \cdot \eta_{turb} \\ r_p \end{bmatrix}$$

i.e. 
$$T4a(T3, r_p, \gamma, \eta_{turb}) = 692.367$$
 K....Ans.

T5, temp at exit of high pressure stream in regenerator:

$$\varepsilon = \frac{T5 - T2a}{T4a - T2a} \qquad \dots regen. effcy.$$

 $T5(T1,T3,r_p,\gamma,\eta_{comp},\eta_{turb},\epsilon) \coloneqq T2a(T1,r_p,\gamma,\eta_{comp}) + \epsilon \cdot \left(T4a(T3,r_p,\gamma,\eta_{turb}) - T2a(T1,r_p,\gamma,\eta_{comp})\right)$ 

i.e.  $T5\big(T1,T3,r_p,\gamma,\eta_{comp},\eta_{turb},\epsilon\big)=639.504\quad \text{K....Ans.}$ 

#### Heat supplied:

$$\begin{array}{l} Q1 \big( T1, T3, r_p, \gamma, cp, \eta_{comp}, \eta_{turb}, \epsilon \big) \coloneqq cp \cdot \big( T3 - T5 \big( T1, T3, r_p, \gamma, \eta_{comp}, \eta_{turb}, \epsilon \big) \big) \\ \qquad \qquad + cp \cdot \big( T3 - T4a \big( T3, r_p, \gamma, \eta_{turb} \big) \big) \end{array}$$

i.e.  $Q1(T1,T3,r_p,\gamma,cp,\eta_{comp},\eta_{turb},\epsilon) = 466.45$  kJ/kg ... Ans.

#### Thermal efficiency:

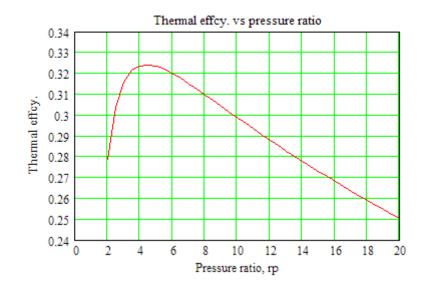
$$EFFCY(T1, T3, r_p, \gamma, \eta_{comp}, \eta_{turb}, \epsilon) := \frac{WK_{turb}(T3, r_p, \gamma, cp, \eta_{turb}) - WK_{comp}(T1, r_p, \gamma, cp, \eta_{comp})}{Q1(T1, T3, r_p, \gamma, cp, \eta_{comp}, \eta_{turb}, \epsilon)}$$

i.e.  $EFFCY(T1, T3, r_p, \gamma, \eta_{comp}, \eta_{turb}, \epsilon) = 0.304$  ...Ans.

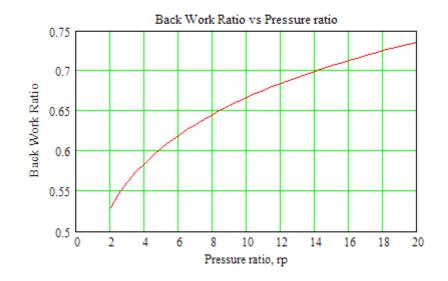
### (b) Plot (i) thermal efficiency, (ii) Back work ratio, and (iii) net work developed in kJ/kg, when pressure ratio varies from 2 to 20, other conditions remaining the same:

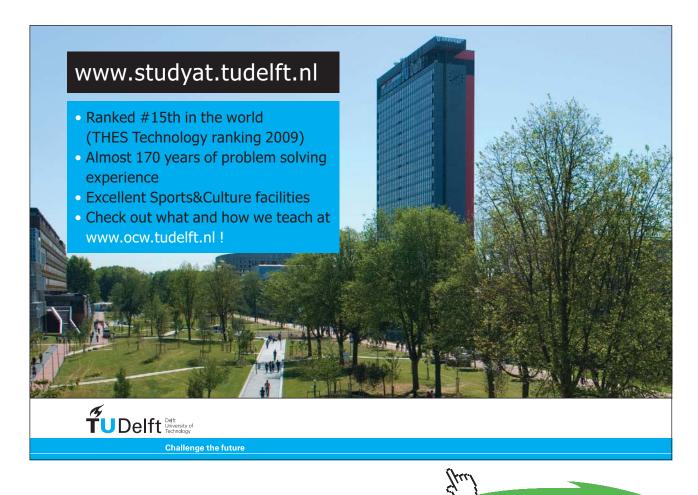
rp := 2,2.5.. 20 ....define a range variable

#### Thermal efficiency:

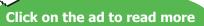


#### **Back Work Ratio:**

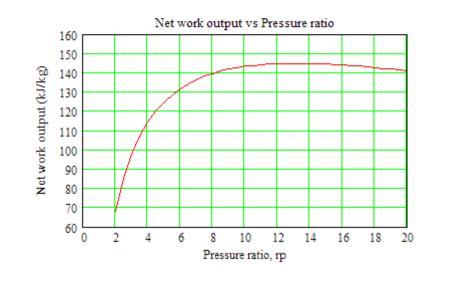




53



#### Net work output:





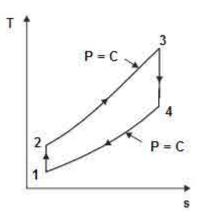
#### 2.3 Problems solved with EES:

Prob.2.12 Write EES Procedures for efficiency etc. of :

- i. Simple, Ideal, air standard Brayton cycle
- ii. Simple, actual Brayton cycle, i.e. including the isentropic efficiencies of compressor and turbine,
- iii. Actual Brayton cycle with regenerator, and
- iv. Regenerative Brayton cycle with 'perfect intercooling' and preheating (two stages in compressor and turbine)

#### **EES Procedures:**

1. Simple, Ideal, air standard Brayton cycle:



#### \$UnitSysyem SI Pa, K, kJ

PROCEDURE Simple\_Brayton\_ideal(cp, gamma,P1, T1, rp,T3:T2, T4, Q\_in,W\_comp, W\_turb, W\_net, eta\_th, BackWorkRatio)

"Thermal effcy. etc of Air standard, ideal, Brayton cycle"

"Inputs:cp, gamma, P1(kPa), T1 (K), rp,T3 (K)"

"P1, T1 .. at compressor inlet; T2 ... compressor exit temp after isentropic comprn;

T3 ... temp at turbine inlet; T4 ... at turbine exit after isentropic expn. "

"Outputs: T2 (K), T4 (K), Q\_in (kJ/kg),W\_comp (kJ/kg), W\_turb (kJ/kg), W\_net (kJ/kg), eta\_th, BackWorkRatio"

T2:= T1 \* (rp)^((gamma-1)/gamma) "...finds T2"

P2:= P1 \* rp

P3:=P2

P4:=P1

T4 := T3 \* (1/rp)^((gamma-1)/gamma) "....finds T4"

 $Q_{in} := cp * (T3 - T2) "kJ/kg ... heat supplied"$ 

W\_comp :=cp\*(T2-T1) "kJ/kg ... compressor work input"

W\_turb := cp\*(T3-T4) "kJ/kg .... turbine work output"

W\_net := W\_turb-W\_comp "kJ/kg .... net work output"

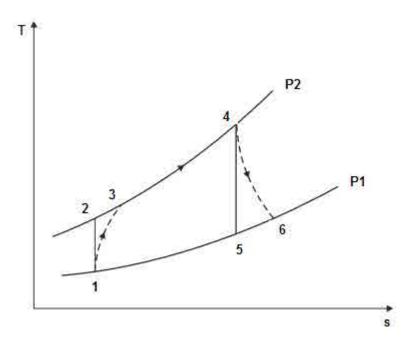
eta\_th=W\_net/Q\_in "....thermal effcy."

BackWorkRatio := W\_comp/W\_turb "... Back Work Ratio"

END

"\_\_\_\_\_\_"

ii. Simple, actual Brayton cycle, i.e. including the isentropic efficiencies of compressor and turbine:



PROCEDURE Simple\_Brayton\_actual(cp, gamma,P1, T1, rp,T4,eta\_comp, eta\_turb: T3, T6, Q\_in,W\_ comp, W\_turb, W\_net, eta\_th, BackWorkRatio)





"Thermal effcy. etc of Air standard, actual, Brayton cycle"

"Inputs: P1(kPa), T1 (K), rp,T4 (K),eta\_comp, eta\_turb

P1, T1 ... at compressor inlet; T2 ...compressor exit temp if comprn. were isentropic; T3 ... compr. exit for actual compression

T4 ... temp at turbine inlet; T5 ... at turbine exit if expn. were isentropic; T6 ... at turbine exit for actual expn. "

"Outputs: T3 (K), T6 (K), Q\_in (kJ/kg), W\_comp (kJ/kg), W\_turb (kJ/kg), W\_net (kJ/kg), eta\_th"

T2:= T1 \* (rp)^((gamma-1)/gamma) "...finds T2"

T3:= (T2 – T1) / eta\_comp + T1"finds T3"

P2:= P1 \* rp

P3:=P2

P4:=P3

P5:=P1

P6:=P1

T5 := T4 \* (1/rp)^((gamma-1)/gamma) "....finds T5"

T6 := T4 - (T4 - T5) \* eta\_turb "...finds T6"

Q\_in := cp \* (T4 – T3) "kJ/kg ... heat supplied"

W\_comp :=cp\*(T3-T1) "kJ/kg ... compressor work input"

W\_turb := cp\*(T4-T6) "kJ/kg .... turbine work output"

W\_net :=W\_turb-W\_comp "kJ/kg .... net work output"

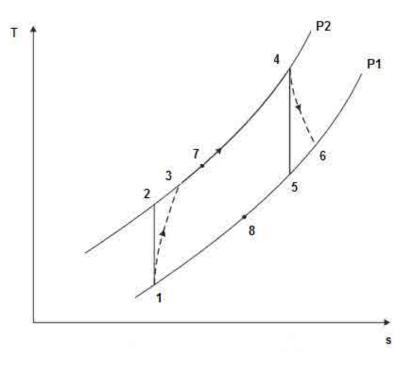
eta\_th=W\_net/Q\_in "....thermal effcy."

BackWorkRatio := W\_comp/W\_turb "... Back Work Ratio"

END

"\_\_\_\_\_\_"

#### iii. Actual Brayton cycle with regenerator:



PROCEDURE Regen\_Brayton\_actual(cp, gamma,P1, T1, rp,T4,eta\_comp, eta\_turb, epsilon: T3, T6, T7, Q\_in,W\_comp, W\_turb, W\_net, eta\_th, BackWorkRatio)

"Thermal effcy. etc of Air standard, regenerative, actual, Brayton cycle"

"Inputs: P1(kPa), T1 (K), rp,T4 (K),eta\_comp, eta\_turb, epsilon

P1, T1 .. at compressor inlet; T2 ...compressor exit temp if comprn. were isentropic; T3 ... compr. exit for actual compression

T4 ... temp at turbine inlet; T5 ... at turbine exit if expn. were isentropic; T6 ... at turbine exit for actual expn.

T7 ... temp at exit of high pressure stream of regenerator

epsilon = effectiveness of regenerator"

"Outputs: T2 (K), T6 (K), T7 (K), Q\_in (kJ/kg),W\_comp (kJ/kg), W\_turb (kJ/kg), W\_net (kJ/kg), eta\_th,BackWorkRatio"

T2:= T1 \* (rp)^((gamma-1)/gamma) "...finds T2"

T3:= (T2 – T1) / eta\_comp + T1"finds T3"

P2:= P1 \* rp

P3:=P2

P4:=P3

P5:=P1

P6:=P1

P7 := P2

T5 := T4 \* (1/rp)^((gamma-1)/gamma) "....finds T5"

T6 := T4 - (T4 - T5) \* eta\_turb "...finds T6"

T7 := T3 + epsilon \* (T6 – T3) "K..finds T7..temp at exit of high pressure stream of regenerator"

Q\_in := cp \* (T4 – T7) "kJ/kg ... heat supplied"

# Study at one of Europe's leading universities



DTU, Technical University of Denmark, is ranked as one of the best technical universities in Europe, and offers internationally recognised Master of Science degrees in 39 English-taught programmes.

DTU offers a unique environment where students have hands-on access to cutting edge facilities and work

closely under the expert supervision of top international researchers.

DTU's central campus is located just north of Copenhagen and life at the University is engaging and vibrant. At DTU, we ensure that your goals and ambitions are met. Tuition is free for EU/EEA citizens.

Visit us at www.dtu.dk



Click on the ad to read more

59

Download free eBooks at bookboon.com

W\_comp :=cp\*(T3-T1) "kJ/kg ... compressor work input"

W\_turb := cp\*(T4-T6) "kJ/kg .... turbine work output"

W\_net := W\_turb-W\_comp "kJ/kg .... net work output"

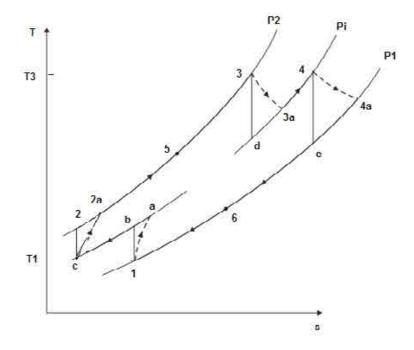
eta\_th=W\_net/Q\_in "....thermal effcy."

BackWorkRatio := W\_comp/W\_turb "... Back Work Ratio"

END

"\_\_\_\_\_"

iv. Regenerative Brayton cycle with 'perfect inter-cooling' and preheating (two stages in compressor and turbine):



PROCEDURE Brayton\_intercool\_reheat\_regen (cp, gamma, P1, T1, rp\_tot, T3, eta\_comp, eta\_turb, epsilon: T2a, T4a, T5, Q\_in,W\_comp, W\_turb, W\_net, eta\_th, BackWorkRatio)

"Thermal effcy. etc of Air standard, regenerative, actual, Brayton cycle, with intercooling and reheating – 2 stages for compr. and turbine"

"Inputs: cp, gamma,P1(kPa), T1(K), rp\_tot,T3(K),eta\_comp, eta\_turb, epsilon

P1, T1 .. at compressor inlet; T2a ... ... compr. exit for actual compression

rp\_tot = overall pressure ratio

T4a ... ...at turbine exit for actual expn.

T5 ... temp at exit of high pressure stream of regenerator

epsilon = effectiveness of regenerator"

"Outputs: T2a (K), T4a (K), T5(K), Q\_in(kJ/kg), W\_comp(kJ/kg), W\_turb(kJ/kg), W\_net(kJ/kg), eta\_th, BackWorkRatio"

rp = sqrt(rp\_tot) "...pressure ratio per stage"

T2:= T1 \* (rp)^((gamma-1)/gamma) "...finds T2"

T2a:= (T2 – T1) / eta\_comp + T1"finds T2a"

P2:= P1 \* rp\_tot

P3:=P2

P4a:=P1

P5:=P2

P6:=P1

T4 := T3 \* (1/rp)^((gamma-1)/gamma) "....finds T4"

 $T4a := T3 - (T3 - T4) * eta_turb "...finds T4a"$ 

T5 := T2a + epsilon \* (T4a - T2a) "K..finds T5..temp at exit of high pressure stream of regenerator"

Q\_in := cp \* (T3 – T5) + cp \* (T3 – T4a) "kJ/kg ... heat supplied"

W\_comp :=2\* cp \* (T2a-T1) "kJ/kg ... total compressor work input"

W\_turb := 2\* cp \* (T3-T4a) "kJ/kg .... total turbine work output"

W\_net :=W\_turb-W\_comp "kJ/kg .... net work output"

eta\_th=W\_net/Q\_in "....thermal effcy."

BackWorkRatio := W\_comp/W\_turb "... Back Work Ratio"

END

"\_\_\_\_\_"



For more information, visit **www.msm.nl** or contact us at +31 43 38 70 808 or via admissions@msm.nl

the globally networked management school

Click on the ad to read more

Download free eBooks at bookboon.com

**Prob.2.13.** Consider a simple Brayton cycle with P1 = 100 kPa, T1 = 300 K, T3 = 1300 K, with pressure ratio = 8.

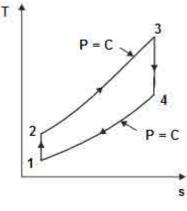


Fig.Prob.2.13

EES Solution: We shall use the EES Procedure written above.

#### "Data:"

P1=100 "kPa" T1=300 "K" T3 = 1300 "K" cp=1.005 "kJ/kg.K" gamma=1.4 rp = 8

CALL Simple\_Brayton\_ideal(cp, gamma,P1, T1, rp,T3 :T2, T4, Q\_in,W\_comp, W\_turb, W\_net, eta\_th, BackWorkRatio)

**Results:** 

Unit Settings: SI K Pa k	J mass deg		
BackWorkRatio = 0.418	cp = 1.005 [kJ/kg-K]	nth = 0.448	γ = 1.4
P1 = 100 [kPa]	Q <sub>in</sub> = 760.3 [kJ/kg]	rp = 8	T1 = 300 [K]
T2 = 543.4 [K]	T3 = 1300 [K]	T4 = 717.7 [K]	W <sub>comp</sub> = 244.7 [kJ/kg

Thus:

Net work output = W\_net = 340.6 kJ/kg ... Ans.

Thermal effcy. = eta\_th = 0.448 = 44.8% .... Ans.

Back Work Ratio = 0.418 .... Ans.

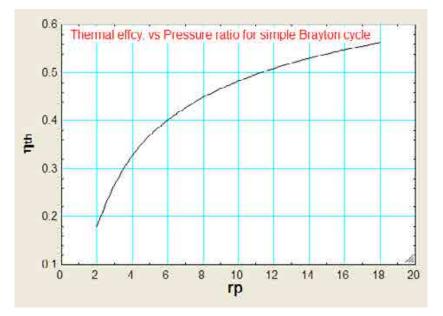
#### (b) Plot eta\_th vs rp, for rp = 2 to 18:

#### First, compute the Parametric Table:

#### T3 = 1300 K:

19	1 rp	2 Σ η <sub>th</sub>
Run 1	2	0.1797
Run 2	4	0.327
Run 3	6	0.4007
Run 4	8	0.448
Run 5	10	0.4821
Run 6	12	0.5083
Run 7	14	0.5295
Run 8	16	0.5471
Run 9	18	0.5621

#### Now, plot the result:



#### (c) Plot W\_net vs rp, for T3 = 900, 1200 and 1500 K:

#### T3 = 900 K:

19	1 rp	² ▼ W <sub>net</sub> [kJ/kg]
Run 1	2	96.47
Run 2	4	149.3
Run 3	6	160.8
Run 4	8	160.5
Run 5	10	155.4
Run 6	12	148.1
Run 7	14	139.6
Run 8	16	130.6
Run 9	18	121.4



65

Download free eBooks at bookboon.com

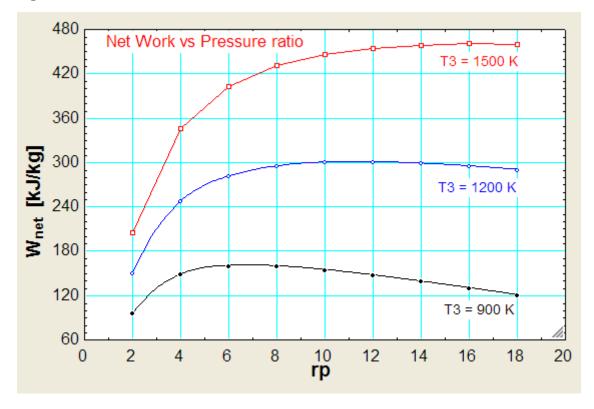
Click on the ad to read more

19	1 rp	² W <sub>net</sub> [kJ/kg]	19	1 rp	² ₩ <sub>net</sub> [kJ/kg]
Run 1	2	150.6	Run 1	2	204.8
Run 2	4	247.9	Run 2	4	346.5
Run 3	6	281.6	Run 3	6	402.4
Run 4	8	295.6	Run 4	8	430.6
Run 5	10	300.7	Run 5	10	446.1
Run 6	12	301.3	Run 6	12	454.6
Run 7	14	299.3	Run 7	14	458.9
Run 8	16	295.6	Run 8	16	460.5
Run 9	18	290.9	Run 9	18	460.4

#### T3 = 1200 K:

#### T3 = 1500 K:

#### Now, plot the results:



"**Prob.2.14**. A gas turbine operates on a pressure ratio of 6. Inlet temp to the compressor is 300 K and to the turbine is 577 C. If the volume of air entering the compressor is 240 m<sup>3</sup>/s, calculate the net power output of the cycle in MW. Also, compute its efficiency. Assume that the cycle operates under ideal conditions. [VTU-ATD-Jan.–Feb. 2005]"

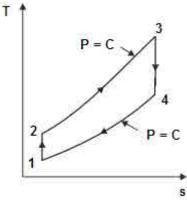


Fig.Prob.2.14

#### EES Solution: We shall use the EES Function written above.

#### "Data:"

P1=100 "kPa" V1 = 240 "m^3/s" T1=300 "K" T3 = 577+273 "K" cp=1.005 "kJ/kg.K" gamma=1.4 rp = 6 R\_air = 0.287 "kJ/kg.K"

#### "Calculations:"

m\_air = P1 \* V1 / (R\_air \* T1) "kg/s .... mass rate of air entering the compressor"

#### "Using the EES Function written above:"

CALL Simple\_Brayton\_ideal(cp, gamma,P1, T1, rp,T3 :T2, T4, Q\_in,W\_comp, W\_turb, W\_net, eta\_th, BackWorkRatio)

NetPower = m\_air \* W\_net / 1000"MW .... Net power developed in MW"

#### **Results:**

#### Unit Settings: SI K Pa kJ mass deg

BackWorkRatio = 0.5889	cp = 1.005 [kJ/kg-K]	$\eta_{th} = 0.4007$
γ = 1.4	m <sub>air</sub> = 278.7 [kg/s]	NetPower = 39.22 [MW]
P1 =100 [kPa]	Q <sub>in</sub> = 351.2 [kJ/kg]	rp = 6
R <sub>air</sub> = 0.287 [kJ/kg-K]	T1 = 300 [K]	T2 = 500.6 [K]
T3 = 850 [K]	T4 = 509.4 [K]	∨1 =240
W <sub>comp</sub> = 201.6 [kJ/kg]	W <sub>net</sub> = 140.7 [kJ/kg]	W <sub>turb</sub> = 342.3 [kJ/kg]

#### Thus:

Net power developed = 39.22 MW ... Ans.

Efficiency = eta\_th = 0.4007 = 40.07% ....Ans.

DESTINATIONS GATE ARRIVAL STRY IMPACT OW FASTER MENTS OW S SI FASTER GN Δ FASTER OW TACT C FASTER OW OPMEN T E E FASTER OW R FASTER 4

\_\_\_\_\_\_

#### **CLIVER WYMAN**



Oliver Wyman is a leading global management consulting firm that combines deep industry knowledge with specialized expertise in strategy, operations, risk usep industry knowned with specialized expension and experiments, tak management, organizational transformation, and leadership development. With offices in 50+ cities across 25 countries, Oliver Wyman works with the CEOs and executive teams of Global 1000 companies. OUR WORLD An equal opportunity employer.

#### **GET THERE FASTER**

Some people know precisely where they want to go. Others seek the adventure of discovering uncharted territory. Whatever you want your professional journey to be, you'll find what you're looking for at Oliver Wyman.

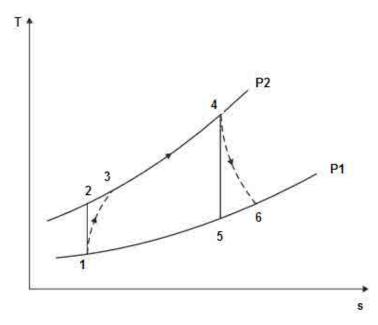
Discover the world of Oliver Wyman at oliverwyman.com/careers





"**Prob.2.15**. In an open cycle constant pressure gas turbine, air enters the compressor at 1 bar, 300 K. Pressure of air after compression is 8 bar. Isentropic efficiencies of compressor and turbine are 80% and 85% respectively. Temp of air at entry to turbine is 1300 K. Calculate the net work and the thermal efficiency of the cycle. Take cp = 1.005 kJ/kg.K"

Note: This is the same problem as in Prob.2.13, but with compressor and turbine efficiencies considered.





EES Solution: We shall use the EES Function written above.

#### "Data:"

P1=100 "kPa" T1=300 "K" T4 = 1300 "K" cp=1.005 "kJ/kg.K" gamma=1.4 rp = 8 eta\_comp = 0.8"...compressor isentropic effcy." eta\_turb = 0.85 "turbine isentropic effcy."

#### "Calculations:"

CALL Simple\_Brayton\_actual(cp, gamma,P1, T1, rp,T4,eta\_comp, eta\_turb:T3, T6, Q\_in,W\_comp, W\_turb, W\_net, eta\_th, BackWorkRatio)

#### **Results:**

#### Unit Settings: SI K Pa kJ mass deg

BackWorkRatio = 0.6147	cp = 1.005 [kJ/kg-K]	η <sub>comp</sub> = 0.8	
η <sub>th</sub> = 0.2741	ղ <sub>turb</sub> = 0.85	γ = 1.4	
P1 = 100 [kPa]	Q <sub>in</sub> = 699.2 [kJ/kg]	rp = 8	
T1 = 300 [K]	T3 = 604.3 [K]	T4 =1300 [K]	
T6 = 805 [K]	W <sub>comp</sub> = 305.8 [kJ/kg]	W <sub>net</sub> = 191.7 [kJ/kg]	

W<sub>turb</sub> = 497.5 [kJ/kg]

#### Thus:

Net work = W\_net = 191.7 kJ/kg .... Ans.

Thermal effcy. = eta\_th = 0.2741 = 27.41% ....Ans.

Comparing with Prob.2.13, there, we had:

Net work output = W\_net = 340.6 kJ/kg

Thermal effcy. =  $eta_th = 0.448 = 44.8\%$ 

(b) Plot eta\_th against pressure ratio, other conditions remaining the same:

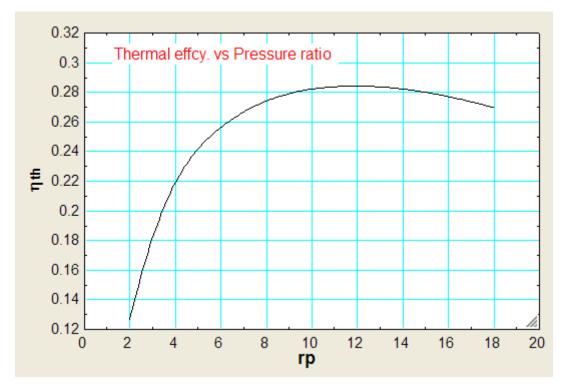
First, compute the Parametric Table:

19	1 rp	2 Σ η <sub>th</sub>
Run 1	2	0.1268
Run 2	4	0.2191
Run 3	6	0.2563
Run 4	8	0.2741
Run 5	10	0.2821
Run 6	12	0.2842
Run 7	14	0.2821
Run 8	16	0.277
Run 9	18	0.2695

#### Now, plot the results:

© 2010 EYGM Lin

d. All



## Day one and you're ready

Day one. It's the moment you've been waiting for. When you prove your worth, meet new challenges, and go looking for the next one. It's when your dreams take shape. And your expectations can be exceeded. From the day you join us, we're committed to helping you achieve your potential. So, whether your career lies in assurance, tax, transaction, advisory or core business services, shouldn't your day one be at Ernst & Young?

What's next for your future? ey.com/careers

JERNST & YOUNG Quality In Everything We Do



#### (c) Plot W\_net vs rp, for T4 = 900, 1200 and 1500 K:

#### T4 = 900 K:

19	1 rp	² ₩ <sub>net</sub> [kJ/kg]
Run 1	2	55.59
Run 2	4	68.29
Run 3	6	56.09
Run 4	8	38.58
Run 5	10	19.86
Run 6	12	1.162
Run 7	14	-17.07
Run 8	16	-34.68
Run 9	18	-51.64

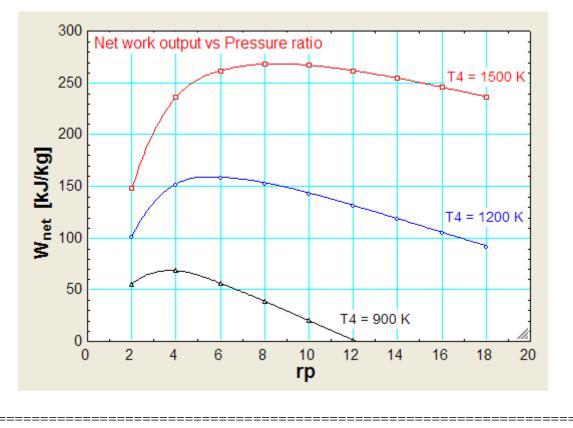
Note that beyond rp = 12, W\_net is -ve, i.e. cycle is not feasible.

T4 = 1200 K:

T4 = 1500 K:

19	1 rp	² ₩ <sub>net</sub> [kJ/kg]	▶ 19	1 rp	2 W <sub>net</sub> [kJ/kg]
Run 1	2	101.6	Run 1	2	147.7
Run 2	4	152.1	Run 2	4	235.9
Run 3	6	158.8	Run 3	6	261.5
Run 4	8	153.4	Run 4	8	268.2
Run 5	10	143.4	Run 5	10	266.9
Run 6	12	131.4	Run 6	12	261.7
Run 7	14	118.6	Run 7	14	254.3
Run 8	16	105.5	Run 8	16	245.8
Run 9	18	92.42	Run 9	18	236.5

#### Now, plot the results:



"**Prob.2.16**. In a regenerative gas turbine, air enters the compressor at 1 bar, 300 K. Pressure of air after compression is 8 bar. Isentropic efficiencies of compressor and turbine are 80% and 85% respectively. Temp of air at entry to turbine is 1300 K. Regenerator efficiency = 78%. Calculate the net work and the thermal efficiency of the cycle. Take cp = 1.005 kJ/kg.K"

Note: This is the same problem as in Prob.2.15, but with regenerator efficiency considered.

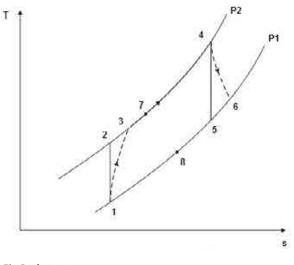


Fig.Prob.2.16

#### EES Solution: We shall use the EES Function written above.

#### "Data:"

```
P1=100 "kPa"
T1=300 "K"
T4 = 1300 "K"
cp=1.005 "kJ/kg.K"
gamma=1.4
rp = 8
eta_comp = 0.8"...compressor isentropic effcy."
eta_turb = 0.85 "turbine isentropic effcy."
epsilon = 0.78 "....regenerator effcy."
```

#### "Calculations:"

CALL Regen\_Brayton\_actual(cp, gamma,P1, T1, rp,T4,eta\_comp, eta\_turb, epsilon:T3, T6, T7, Q\_in, W\_comp, W\_turb, W\_net, eta\_th, BackWorkRatio)

#### **Results:**

#### Unit Settings: SI K Pa kJ mass deg

BackWorkRatio = 0.6147	cp = 1.005 [kJ/kg-K]	ε = 0.78
η <sub>comp</sub> = 0.8	$\eta_{th} = 0.3537$	η <sub>turb</sub> = 0.85
γ = 1.4	P1 = 100 [kPa]	Q <sub>in</sub> = 541.8 [kJ/kg]
rp = 8	T1 = 300 [K]	T3 = 604.3 [K]
T4 =1300 [K]	T6 =805 [K]	T7 = 760.9 [K]
W <sub>comp</sub> = 305.8 [kJ/kg]	W <sub>net</sub> = 191.7 [kJ/kg]	W <sub>turb</sub> = 497.5 [kJ/kg]

#### Thus:

Net work = W\_net = 191.7 kJ/kg ... (same as in Prob.2.15, without regen.)

Thermal effcy. = eta\_th = 0.3537 = 35.37% .... Ans. (compare this with 27.41% obtained in Prob.2.15, without regen.)

#### (b) Plot eta\_th vs Pressure ratio, rp, other conditions remaining the same:

#### First, compute the Parametric Table:

19	1 rp	2 Σ η <sub>th</sub>
Run 1	2	0.3262
Run 2	4	0.3879
Run 3	6	0.3764
Run 4	8	0.3537
Run 5	10	0.3287
Run 6	12	0.3037
Run 7	14	0.2794
Run 8	16	0.256
Run 9	18	0.2335



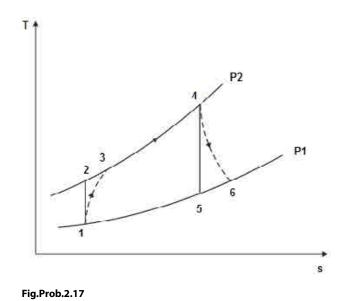
75

Click on the ad to read more



#### Now, plot the results:

"**Prob.2.17**. In an open cycle constant pressure gas turbine, air enters the compressor at 1 bar, 300 K. Pressure of air after compression is 4 bar. Isentropic efficiencies of compressor and turbine are 80% and 85% respectively. The air fuel ratio is 90 : 1. Calculate the power developed and the thermal efficiency of the cycle if the flow rate of air is 3 kg/s. Take cp = 1.005 kJ/kg.K and gamma = 1.4 for air and gases. Calorific Value of fuel = 42000 kJ/kg. [VTU- ATD-March 2001]"



### "EES Solution:"

#### "Data:"

P1=100 "kPa" T1=300 "K" P2=400 "kPa" eta\_comp=0.8 "compressor effcy." eta\_turb=0.85 "turbine effcy." AFratio=90 "air/fuel ratio" m\_a=3.0 "kg/s ... air flow rate" cp=1.005 "kJ/kg.K" gamma=1.4 CV=42000 "kJ/kg ... calorific value of fuel"

#### "Calculations:"

r\_p = P2/P1 "...pressure ratio"

T2/T1=(P2/P1)^((gamma-1)/gamma) "...finds T2"

(T2-T1)/(T3-T1)=eta\_comp "finds T3"

m\_f \* CV=(m\_a+m\_f) \* cp \* (T4-T3)"...finds T4"

m\_a/m\_f = AFratio "...finds mass flow rate of fuel, m\_f"

P3=P2

P4=P3

P5=P1

P6=P1

T5/T4=(P5/P4)^((gamma-1)/gamma) "....finds T5"

(T4-T6)/(T4-T5) = eta\_turb "...finds T6"

Q\_in=m\_f\*CV "kJ/s ... heat supplied"

W\_comp=m\_a\*cp\*(T3-T1) "kJ/s ... compressor work input"

W\_turb=(m\_a+m\_f)\*cp\*(T4-T6) "kJ/s .... turbine work output"

W\_net=W\_turb-W\_comp "kJ/s .... net work output"

eta\_th=W\_net/Q\_in "....thermal effcy."

BackWorkRatio=W\_comp/W\_turb "... Back Work Ratio"



Hellmann's is one of Unilever's oldest brands having been popular for over 100 years. If you too share a passion for discovery and innovation we will give you the tools and opportunities to provide you with a challenging career. Are you a great scientist who would like to be at the forefront of scientific innovations and developments? Then you will enjoy a career within Unilever Research & Development. For challenging job opportunities, please visit www.unilever.com/rdjobs.



Dove



Click on the ad to read more

#### **Results:**

#### Unit Settings: SI K kPa kJ mass deg

AFratio = 90	BackWorkRatio = 0.6887	cp = 1.005 [kJ/kg-K]
CV = 42000 [kJ/kg]	η <sub>comp</sub> = 0.8	η <sub>th</sub> = 0.1774
η <sub>turb</sub> = 0.85	γ = 1.4	m <sub>a</sub> = 3 [kg/s]
m <sub>f</sub> = 0.03333 [kg/s]	P1 =100 [kPa]	P2 = 400 [kPa]
P3 = 400 [kPa]	P4 = 400 [kPa]	P5 =100 [kPa]
P6 =100 [kPa]	Q <sub>in</sub> = 1400 [kJ/s]	r <sub>p</sub> = 4
T1 = 300 [K]	T2 = 445.8 [K]	T3 = 482.2 [K]
T4 = 941.5 [K]	T5 = 633.6 [K]	T6 = 679.8 [K]
W <sub>comp</sub> = 549.5 [kJ/s]	W <sub>net</sub> = 248.4 [kJ/s]	W <sub>turb</sub> = 797.9 [kJ/s]

Thus:

Net power developed = 248.4 kW .... Ans.

Thermal efficiency = eta\_th = 0.1774 = 17.74% .... Ans.

#### (b) Plot eta\_th and W\_net vs pressure ratio, r\_p:

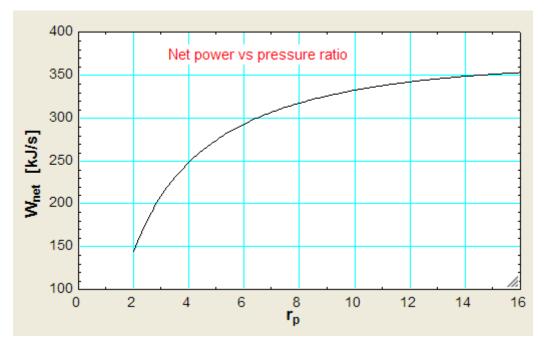
First, produce the Parametric Table:

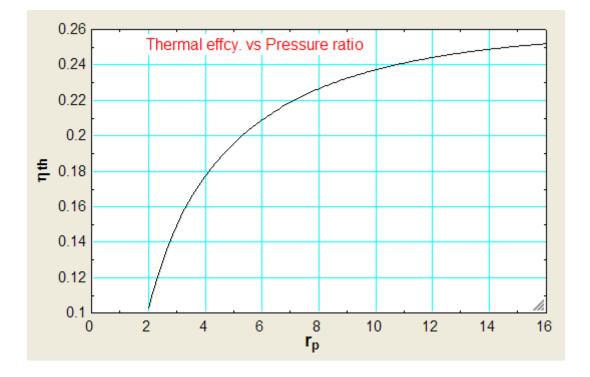
115	1 P2 [kPa]	2 r <sub>p</sub>	³ ₩ <sub>net</sub> [kJ/s]	4 Σ η <sub>th</sub>
Run 1	200	2	144.1	0.1029
Run 2	300	3	209.6	0.1497
Run 3	400	4	248.4	0.1774
Run 4	500	5	274.2	0.1959
Run 5	600	6	292.7	0.2091
Run 6	700	7	306.5	0.2189
Run 7	800	8	317.1	0.2265
Run 8	900	9	325.4	0.2324
Run 9	1000	10	332.1	0.2372
Run 10	1100	11	337.4	0.241
Run 11	1200	12	341.8	0.2442
Run 12	1300	13	345.4	0.2467
Run 13	1400	14	348.4	0.2488
Run 14	1500	15	350.8	0.2506
Run 15	1600	16	352.8	0.252

\_\_\_\_\_

#### Now, plot the graphs:

\_\_\_\_\_\_





Prob.2.18. In a Regenerative Brayton cycle, with intercooling and reheating, overall pressure ratio is 9, inlet conditions to compressor are: T1 = 293 K. Regenerator efficiency = 80%. Max. temp is 898 K. Compressor and turbine have 2 stages and for each stage, efficiencies are 80% and 85% respectively. Find Thermal effcy and Back Work ratio etc. Also:

- b) Plot eta\_th vs regenerator efficiency, ε, and,
- c) Plot (i) thermal efficiency, (ii) Back work ratio, (iii) net work developed in kJ/kg, when pressure ratio varies from 2 to 20.

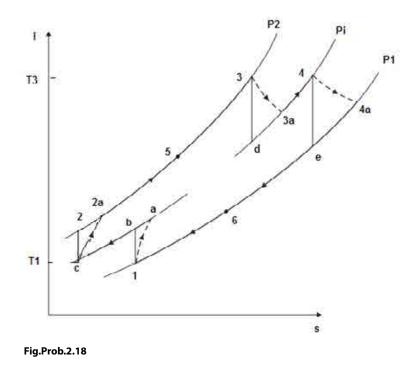








81



Note: This is the same as Prob.2.11, solved earlier with Mathcad.

Now, we shall solve it with EES, using the EES Procedure written above. (See Prob.2.12)

#### **EES Solution:**

#### "Data:"

P1=100 "kPa" T1=293 "K" T3 = 898 "K" cp=1.005 "kJ/kg.K" gamma=1.4 rp\_tot = 9 eta\_comp = 0.8"...compressor isentropic effcy." eta\_turb = 0.85 "turbine isentropic effcy." epsilon = 0.8 "....regenerator effcy."

#### "Calculations:"

CALL Brayton\_intercool\_reheat\_regen(cp, gamma,P1, T1, rp\_tot,T3,eta\_comp, eta\_turb, epsilon:T2a, T4a, T5, Q\_in,W\_comp, W\_turb, W\_net, eta\_th, BackWorkRatio)

#### **Results:**

#### Unit Settings: SI K Pa kJ mass deg

BackWorkRatio = 0.6568	cp = 1.005 [kJ/kg-K]	ε = 0.8
η <sub>comp</sub> = 0.8	$\eta_{th} = 0.3042$	η <sub>turb</sub> = 0.85
γ = 1.4	P1 = 100 [kPa]	Q <sub>in</sub> = 466.5 [kJ/kg]
rp <sub>tot</sub> = 9	T1 = 293 [K]	T2a = 428.1
T3 = 898 [K]	T4a = 692.4	T5 = 639.5 [K]
W <sub>comp</sub> = 271.5 [kJ/kg]	W <sub>net</sub> = 141.9 [kJ/kg]	W <sub>turb</sub> = 413.3 [kJ/kg]

#### Thus:

Net work output = W\_net = 141.9 kJ/kg .... Ans.

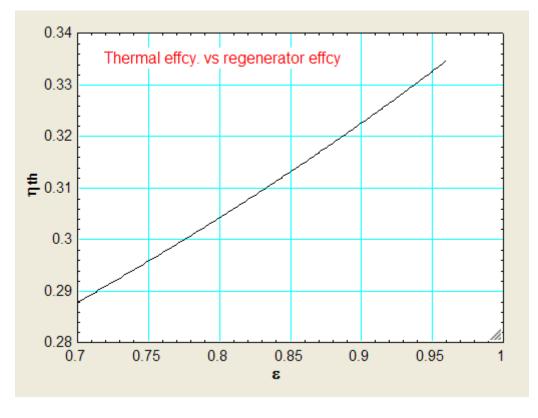
Thermal effcy. = eta\_th = 0.3042 = 30.42% ... Ans.

#### (b) Plot eta\_th vs regenerator efficiency, ε:

First, compute the Parametric Table:

114	1 E	2 ⊾ η <sub>th</sub>
Run 1	0.7	0.2878
Run 2	0.72	0.2909
Run 3	0.74	0.2941
Run 4	0.76	0.2974
Run 5	0.78	0.3007
Run 6	0.8	0.3042
Run 7	0.82	0.3077
Run 8	0.84	0.3112
Run 9	0.86	0.3149
Run 10	0.88	0.3187
Run 11	0.9	0.3225
Run 12	0.92	0.3265
Run 13	0.94	0.3305
Run 14	0.96	0.3346

#### Now, plot the results:

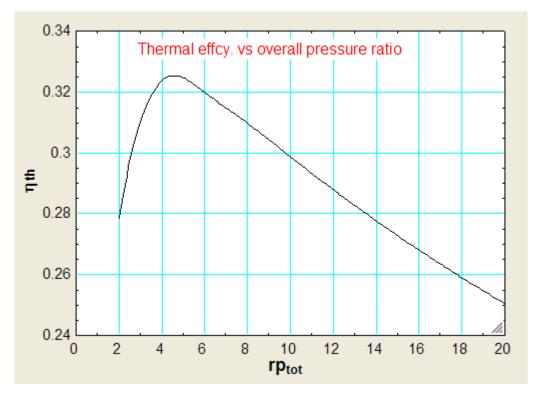


(c) Plot (i) thermal efficiency, (ii) Back work ratio, (iii) net work developed in kJ/kg, when pressure ratio varies from 2 to 20, other conditions remaining the same:

#### Parametric Table:

110	1 rp <sub>tot</sub>	2 η <sub>th</sub>	<sup>3</sup> BackWorkRatic	<sup>4</sup> W <sub>net</sub> [kJ/kg]
Run 1	2	0.2786	0.5298	68.02
Run 2	4	0.3236	0.5849	114.4
Run 3	6	0.3198	0.6198	131.7
Run 4	8	0.3097	0.6458	139.7
Run 5	10	0.2986	0.6667	143.3
Run 6	12	0.2878	0.6843	144.7
Run 7	14	0.2776	0.6995	144.8
Run 8	16	0.2679	0.713	144
Run 9	18	0.2589	0.7251	142.7
Run 10	20	0.2504	0.7361	141

#### Now, plot the results:



# Grant Thornton— $a^{\text{REALLY}}$ great place to work.

We're proud to have been recognized as one of Canada's Best Workplaces by the Great Place to Work Institute<sup>™</sup> for the last four years. In 2011 Grant Thornton LLP was ranked as the fifth Best Workplace in Canada, for companies with more than 1,000 employees. We are also very proud to be recognized as one of Canada's top 25 Best Workplaces for Women and as one of Canada's Top Campus Employers.



Priyanka Sawant Manager

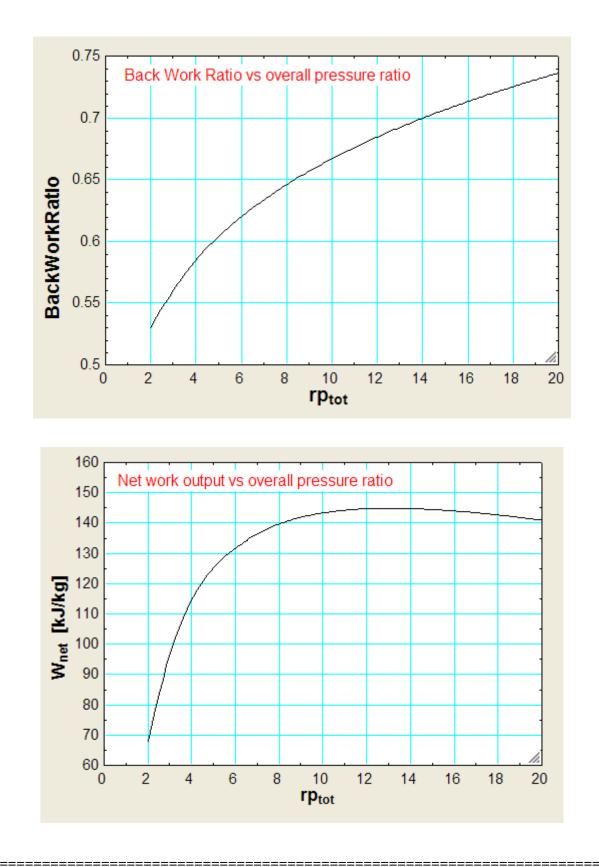


Audit • Tax • Advisory www.GrantThornton.ca/Careers



© Grant Thornton LLP. A Canadian Member of Grant Thornton International Ltd





"**Prob.2.19**. In a regenerative gas turbine cycle, air enters the compressor at 1 bar, 15 C. Pressure ratio = 6. The isentropic efficiencies of compressor and turbine are respectively 0.8 and 0.85. Max. temp in the cycle is 800 C. The regenerator efficiency = 0.78. Assume cp = 1.1 kJ/kg.K and gamma = 1.32 for the combustion products and find the cycle efficiency. [VTU – ATD – July 2003]

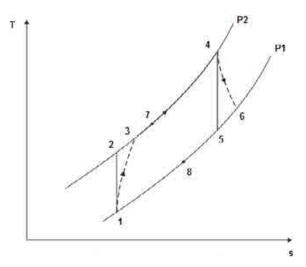


Fig.Prob.2.19

#### **EES Solution:**

#### "Data:"

P1=100"kPa" T1=15+273"K" rp = 6 "...pressure ratio" P2=P1 \* rp "kPa" "P3=P2" P5=P1 P6=P1 P7=P2P3=P2P4=P2P8=P1gamma=1.4 cp=1.005"kJ/kg.K" eta\_comp=0.8 eta\_turb=0.85 eta\_regen=0.78 cpg=1.1"kJ/kg.K" gamma\_g=1.32 T4=800+273"K"

#### "Calculations:"

T2/T1=(rp)^((gamma-1)/gamma)"...finds T2"

{(T2-T1)/(T3-T1)=eta\_comp"..finds T3"}

 $T3 = T1 + (T2 - T1) / eta\_comp$  "....finds T3"

T4/T5=(P4/P5)^((gamma\_g-1)/gamma\_g)"..finds T5"

(T4-T6)/(T4-T5)=eta\_turb"...finds T6"

cp \* (T7 – T3)/(cp \* (T6 – T3)) = eta\_regen "...finds T7"

cpg \* (T6-T8) = cp \* (T7-T3)"....finds T8"

W\_C=cp \* (T3-T1)"kJ/kg"

W\_T=cpg \* (T4-T6)"kJ/kg"

W\_net=W\_T - W\_C"kJ/kg"

 $Q_{in} = cpg * (T4 - T7) "kJ/kg"$ 

eta\_th=W\_net/Q\_in "...thermal effcy."



Low-speed Engines Medium-speed Engines Turbochargers Propellers Propulsion Packages PrimeServ

The design of eco-friendly marine power and propulsion solutions is crucial for MAN Diesel & Turbo. Power competencies are offered with the world's largest engine programme – having outputs spanning from 450 to 87,220 kW per engine. Get up front! Find out more at www.mandieselturbo.com

Engineering the Future – since 1758. **MAN Diesel & Turbo** 





#### **Results:**

#### Unit Settings: SI C kPa kJ mass deg

cp = 1.005 [kJ/kg-K]	cpg = 1.1 [kJ/kg-K]	η <sub>comp</sub> = 0.8	η <sub>regen</sub> = 0.78
η <sub>th</sub> = 0.2739	η <sub>turb</sub> = 0.85	γ = 1.4	γ <sub>g</sub> = 1.32
P1 = 100 [kPa]	P2 =600 [kPa]	P3 =600 [kPa]	P4 =600 [kPa]
P5 =100 [kPa]	P6 =100 [kPa]	P7 =100 [kPa]	P8 =600 [kPa]
Q <sub>in</sub> = 407.4 [kJ/kg]	rp = 6	T1 = 288 [K]	T2 = 480.5 [K]
T3 = 528.7 [K]	T4 =1073 [K]	T5 = 695 [K]	T6 = 751.7 [K]
T7 = 702.6 [K]	T8 = 592.7 [K]	W <sub>C</sub> = 241.9 [kJ/kg]	W <sub>net</sub> = 111.6 [kJ/kg]
W <sub>T</sub> = 353.5 [kJ/kg]			

#### Thus:

Net work output = W\_net = 111.6 kJ/kg .... Ans.

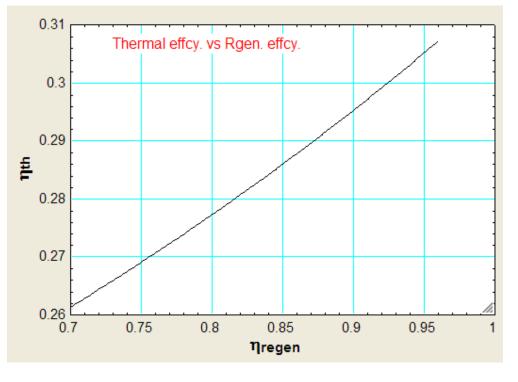
Thermal effcy. = eta\_th = 0.2739 = 27.39% .... Ans.

#### (b) Plot the variation of eta\_th with regen. effcy.:

First, compute the Parametric Table:

114	1 ▼ Nregen	2 Σ η <sub>th</sub>
Run 1	0.7	0.2613
Run 2	0.72	0.2644
Run 3	0.74	0.2675
Run 4	0.76	0.2707
Run 5	0.78	0.2739
Run 6	0.8	0.2773
Run 7	0.82	0.2807
Run 8	0.84	0.2842
Run 9	0.86	0.2878
Run 10	0.88	0.2915
Run 11	0.9	0.2952
Run 12	0.92	0.2991
Run 13	0.94	0.3031
Run 14	0.96	0.3072

#### Now, plot the results:



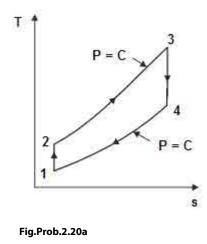
\_\_\_\_\_

**Prob.2.20.** The extreme pressures and temps in an open cycle gas turbine plant are 1 bar and 5 bar, and 27 C and 550 C respectively. Calculate the efficiency of the cycle when (i) there is no regenerator, (ii) there is a regenerator with 60% effectiveness. Take  $\gamma = 1.4$  [VTU-Jan. 2003]

**Note:** This is the same as Prob.2.8, solved with Mathcad. Now, we shall solve it with EES, using the EES Procedures already written in Prob. 2.12.

#### **EES Solution:**

a) Without regenerator:



#### "Data:"

P1=100"kPa" T1=27+273"K" P2=500"kPa" P3=P2 P4=P1 gamma=1.4 cp=1005"J/kg.K" T3=550+273"K" rp = 5 "Pressure ratio"

#### "Calculations:"

#### "Without regenerator:"

CALL Simple\_Brayton\_ideal(cp, gamma,P1, T1, rp,T3 :T2, T4, Q\_in,W\_comp, W\_turb, W\_net, eta\_th, BackWorkRatio)

#### **Results:**

#### Unit Settings: SI C kPa kJ mass deg

BackWorkRatio = 0.5773	cp = 1.005 [kJ/kg-K]	η <sub>th</sub> = 0.3686
γ = 1.4	P1 =100 [kPa]	P2 = 500 [kPa]
P3 = 500 [kPa]	P4 =100 [kPa]	Q <sub>in</sub> = 349.6 [kJ/kg]
rp = 5	T1 = 300 [K]	T2 = 475.1 [K]
T3 = 823 [K]	T4 = 519.6 [K]	W <sub>comp</sub> = 176 [kJ/kg]
W <sub>net</sub> = 128.9 [kJ/kg]	W <sub>turb</sub> = 304.9 [kJ/kg]	

#### Thus:

Net work output = W\_net = 128.9 kJ/kg ... Ans.

Thermal effcy. = eta\_th = 0.3686 = 36.85% ... Ans.

#### b) With regenerator:

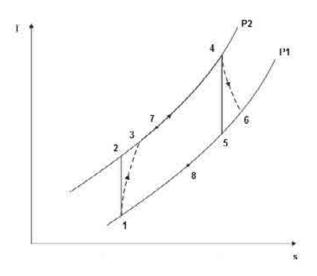


Fig.Prob.2.20b

# **XX RBS** Group

# CAREERKICKSTART

### An app to keep you in the know

Whether you're a graduate, school leaver or student, it's a difficult time to start your career. So here at RBS, we're providing a helping hand with our new Facebook app. Bringing together the most relevant and useful careers information, we've created a one-stop shop designed to help you get on the career ladder – whatever your level of education, degree subject or work experience.

And it's not just finance-focused either. That's because it's not about us. It's about you. So download the app and you'll get everything you need to know to kickstart your career.

So what are you waiting for?

Click here to get started.



#### "Data:"

P1=100"kPa" T1=27+273"K" P2=500"kPa" P3=P2 P5=P2 P6=P1 P4=P1 gamma=1.4 cp=1.005"kJ/kg.K" epsilon=0.60 "..regen. effcy." T4=550+273"K" rp = 5 eta\_comp = 1 "...compressor isentropic effcy."

#### "Calculations:"

#### "With regenerator:"

CALL Regen\_Brayton\_actual(cp, gamma,P1, T1, rp,T4,eta\_comp, eta\_turb, epsilon:T3, T6, T7, Q\_in,W\_ comp, W\_turb, W\_net, eta\_th, BackWorkRatio)

#### **Results:**

#### Unit Settings: SI C kPa kJ mass deg

BackWorkRatio = 0.5773	cp = 1.005 [kJ/kg-K]	<b>ε</b> = 0.6
η <sub>comp</sub> = 1	$\eta_{th} = 0.3992$	η <sub>turb</sub> = 1
γ = 1.4	P1 = 100 [kPa]	P2 = 500 [kPa]
P3 = 500 [kPa]	P4 =100 [kPa]	P5 = 500 [kPa]
P6 =100 [kPa]	Q <sub>in</sub> = 322.8 [kJ/kg]	rp = 5
T1 = 300 [K]	T3 = 475.1 [K]	T4 =823 [K]
T6 = 519.6	T7 = 501.8	W <sub>comp</sub> = 176 [kJ/kg]
W <sub>net</sub> = 128.9 [kJ/kg]	W <sub>turb</sub> = 304.9 [kJ/kg]	

Thus:

Net work output = W\_net = 128.9 kJ/kg ... Ans.

Heat supplied = Q\_in = 322.8 kJ/kg ... Ans.

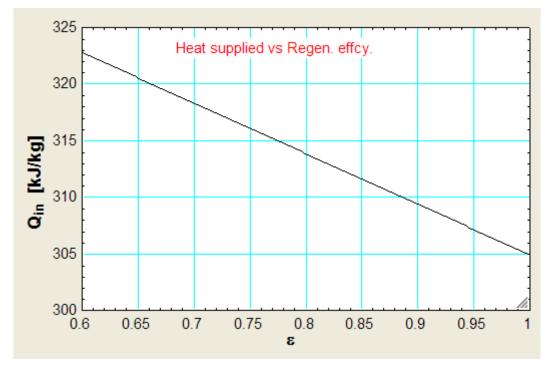
Thermal effcy. = eta\_th = 0.3992 = 39.92% ... Ans.

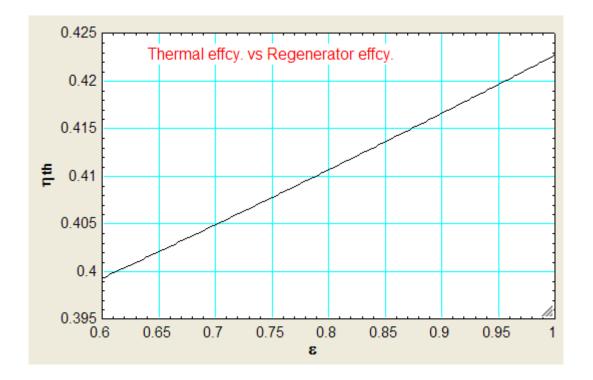
#### Plot Heat supplied (Q\_in) and Thermal effcy. (eta\_th) against regenerator effcy ( $\epsilon$ ):

19	1 Σ ε	2 Q <sub>in</sub> [kJ/kg]	3 ⊾ η <sub>th</sub>
Run 1	0.6	322.8	0.3992
Run 2	0.65	320.5	0.402
Run 3	0.7	318.3	0.4049
Run 4	0.75	316.1	0.4077
Run 5	0.8	313.8	0.4106
Run 6	0.85	311.6	0.4136
Run 7	0.9	309.4	0.4166
Run 8	0.95	307.1	0.4196
Run 9	1	304.9	0.4227

#### First, compute the Parametric Table:

#### Now, plot the results:





## ORACLE

## Be BRAVE enough to reach for the sky

Oracle's business is information - how to manage it, use it, share it, protect it. Oracle is the name behind most of today's most innovative and successful organisations.

Oracle continuously offers international opportunities to top-level graduates, mainly in our Sales, Consulting and Support teams.

If you want to join a company that will invest in your future, Oracle is the company for you to drive your career!

### https://campus.oracle.com

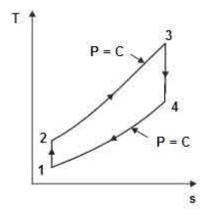


#### **ORACLE IS THE INFORMATION COMPANY**



95

**"Prob.2.21.** A simple gas turbine plant operating on Brayton cycle has air entering the compressor at 100 kPa and 27 C. Pressure ratio = 9. Max. cycle temp = 727 C. What will be the percentage change in cycle effcy. and net work output if the expansion in the turbine is divided in to two stages, each of pressure ratio 3, with intermediate reheating to 727 C? Assume compression and expansion are ideal, isentropic. [VTU – ATD – July 2006]"





**EES Solution:** 

"Case 1. Simple, ideal Brayton cycle:"

"Data:"

P1=100"kPa"

T1=27+273"K"

P3=P2

P4=P1

gamma=1.4

cp=1.005"kJ/kg.K"

T3=727+273**"K"** 

rp = 9 "...Pressure ratio"

P2 = P1 \* rp

#### "Calculations:"

CALL Simple\_Brayton\_ideal(cp, gamma,P1, T1, rp,T3 :T2, T4, Q\_in,W\_comp, W\_turb, W\_net, eta\_th, BackWorkRatio)

#### **Results:**

#### Unit Settings: SI C kPa kJ mass deg

BackWorkRatio = 0.562	cp = 1.005 [kJ/kg-K]	η <sub>th</sub> = 0.4662
γ = 1.4	P1 =100 [kPa]	P2 = 900 [kPa]
P3 = 900 [kPa]	P4 =100 [kPa]	Q <sub>in</sub> = 440.2 [kJ/kg]
rp = 9	T1 = 300 [K]	T2 = 562 [K]
T3 =1000 [K]	T4 = 533.8 [K]	W <sub>comp</sub> = 263.3 [kJ/kg]
W <sub>net</sub> = 205.2 [kJ/kg]	W <sub>turb</sub> = 468.6 [kJ/kg]	

Thus, for simple, ideal Brayton cycle:

W\_net = 205.2 kJ/kg ...Ans.

eta\_th = 0.4662 = 46.62% ... Ans.

#### "Case 2. Simple, ideal Brayton cycle, with two stage expansion:"

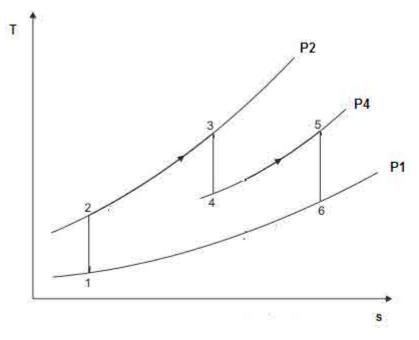


Fig.Prob.2.21b.

#### "Data:"

P1=100"kPa" T1=27+273"K" P3=P2 P6=P1 gamma=1.4 cp=1.005"kJ/kg.K" T3=727+273"K" rp\_comp = 9 "...pressure ratio for compression" rp\_expn= 3 "...pressure ratio for each stage of expansion"

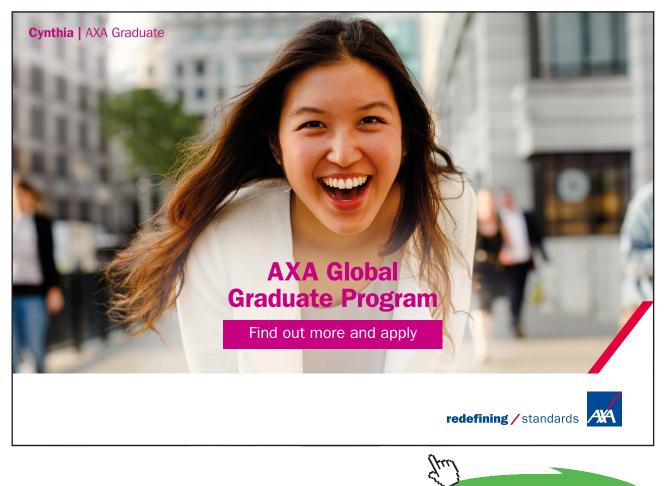
#### "Calculations:"

P2 = P1 \* rp\_comp "...pressure at exit of compressor"

 $P3/P4 = rp_expn^{((gamma - 1)/gamma)"...finds P4"}$ 

#### P5 = P4

 $T2/T1 = rp\_comp^((gamma - 1)/gamma)"...finds T2"$ 



Click on the ad to read more

 $T3/T4 = rp_expn^{((gamma - 1)/gamma)"...finds T4"}$ 

T5 = T3

T5/T6 = rp\_expn^((gamma - 1)/gamma)"...finds T6"

#### "Compressor work:"

 $W_{comp} = cp * (T2 - T1) "kJ/kg"$ 

#### "Turbine work, total for both the stages:"

 $W_turb_tot = cp * (T3 - T4) + cp * (T5 - T6) "kJ/kg"$ 

#### "Net work output:"

W\_net = W\_turb\_tot - W\_comp "kJ/kg"

#### "Heat supplied:"

 $Q_{in} = cp * (T3 - T2) + cp * (T5 - T4) kJ/kg$ 

#### "Thermal effcy."

eta\_th = W\_net / Q\_in

#### **Results:**

#### Unit Settings: SI C kPa kJ mass deg

cp = 1.005 [kJ/kg-K]	$\eta_{th} = 0.3913$	γ = 1.4
P1 =100 [kPa]	P2 = 900 [kPa]	P3 = 900 [kPa]
P4 = 657.5 [kPa]	P5 = 657.5 [kPa]	P6 =100 [kPa]
Q <sub>in</sub> = 710.9 [kJ/kg]	rp <sub>comp</sub> = 9	rp <sub>expn</sub> = 3
T1 = 300 [K]	T2 = 562 [K]	T3 =1000 [K]
T4 = 730.6 [K]	T5 =1000 [K]	T6 = 730.6 [K]
W <sub>comp</sub> = 263.3 [kJ/kg]	W <sub>net</sub> = 278.2 [kJ/kg]	W <sub>turb,tot</sub> = 541.5 [kJ/kg]

#### Thus, for simple, ideal Brayton cycle, with two stage expansion:

W\_net = 278.2 kJ/kg ...Ans.

eta\_th = 0.3913 = 39.13% ... Ans.

Therefore,

Change in Net work output = (278.2 - 205.2) \* 100 / 205.2

i.e.  $\frac{278.2 - 205.2}{205.2} \cdot 100 = 35.575$  % .... Ans.

i.e. Net work output has increased by 35.575%.

Change in Thermal effcy. = (0.3913 - 0.4662) \* 100 / 0.4662

i.e. 
$$\frac{0.3913 - 0.4662}{0.4662} \cdot 100 = -16.066$$
 % .... Ans.

i.e. Thermal effcy. has decreased by 16.066%. (This is due to the fact that heat supplied also has increased due to reheating)

\_\_\_\_\_

Prob.2.22. Write an EES Procedure for Propulsive efficiency etc of an ideal jet propulsion cycle.

T\_s diagram for Ideal Jet propulsion cycle is shown below:

#### Remember:

- 1-2: Isentropic compression in diffuser
- 2-3: Isentropic compression in compressor
- 3-4: constant pressure heat addition in burner
- 4-5: Isentropic expansion in turbine
- 5-6: Isentropic expansion in nozzle
- 6-1: Constant pressure heat rejection

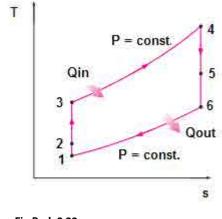


Fig.Prob.2.22

#### \$UnitSysyem SI Pa, K, kJ

PROCEDURE Ideal\_JetPropulsion\_cyclel(m, cp, gamma,P1, T1, rp,T4,V1 :P2, P3, P5, T2, T3, T5, T6, V6, F, W\_P,Q\_in,W\_comp, W\_turb, eta\_P,KE\_exit,Q\_exit)

#### "Thermal effcy. etc of Ideal Jet propulsion cycle"

"Inputs: m (kg/s), cp, gamma, P1(kPa), T1 (K), rp,T4 (K), V1 (m/s)"



#### **Masters in Management**

Designed for high-achieving graduates across all disciplines, London Business School's Masters in Management provides specific and tangible foundations for a successful career in business.

This 12-month, full-time programme is a business qualification with impact. In 2010, our MiM employment rate was 95% within 3 months of graduation\*; the majority of graduates choosing to work in consulting or financial services.



As well as a renowned qualification from a world-class business school, you also gain access to the School's network of more than 34,000 global alumni – a community that offers support and opportunities throughout your career.

For more information visit **www.london.edu/mm**, email **mim@london.edu** or give us a call on +44 (0)20 7000 7573.

\* Figures taken from London Business School's Masters in Management 2010 employment report



"P1, T1 .. at diffusor inlet; T2 ...diffusor exit temp after isentropic comprn;

rp = compressor pressure ratio; T4 ...at turbine inlet "

"**Outputs:** P2(kPa), P3, P5, T2, T3, T4.T5, T6, V6, F(N), W\_P(kW),Q\_in(kW),W\_comp(kW), W\_turb(kW), eta\_P,KE\_exit(kW),Q\_exit(kW)"

 $T2:= T1 + V1^2/(2 * cp*1000)$  ...finds T2 (K)"

P2:= P1 \* (T2/T1)^(gamma / (gamma - 1)) "kPa"

P3:=P2 \* rp "kPa"

T3 := T2 \*  $rp^{((gamma - 1)/gamma)}$  "K"

T5 := T4 - T3 +T2 "K"

P4 := P3 "kPa"

P5:=P4 \* (T5/T4)^(gamma / (gamma - 1)) "kPa"

P6 := P1"kPa"

T6 := T5 \* (P6/P5)^((gamma-1)/gamma) "....finds exit jet temp, T6(K)"

V6 := sqrt(2 \* cp\*1000 \* (T5 – T6)) "m/s ... velocity of exit jet"

F := m \* (V6 - V1) "N ... Net Thrust"

W\_P := F \* V1/1000 "kW ... Propulsive power"

 $Q_{in} := m * cp * (T4 - T3) "kW ... heat supplied"$ 

W\_comp := m\* cp \*(T3-T2) "kW ... compressor work input"

W\_turb := W\_comp "kW .... turbine work "

eta\_P := W\_P/Q\_in "....Propulsive effcy."

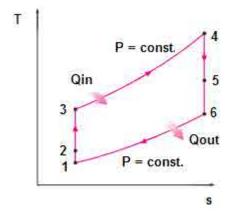
#### KE\_exit := $(m * (V6 - V1)^2 / 2)/1000$ "kW"

 $Q_{exit} = m * cp * (T6 - T1) "kW"$ 

END

**Prob. 2.23.** A turbojet aircraft flies at a velocity of 900 km/h at an altitude where pressure and temp are 40 kPa and -35 C. Compressor pressure ratio is 10 and inlet temp of gases to turbine is 950 C. Air flow rate is 45 kg/s. Using cold air standard assumptions, determine: (a) temp and pressure of gases at turbine exit, (b) velocity of gases at nozzle exit, and (c) propulsive power, heat supplied and the propulsive efficiency.

"





EES Solution: We shall use the EES Procedure written above.

#### "Data:"

m = 45 "kg/s" cp = 1.005 "kJ/kg.K" gamma = 1.4 P1 = 40 "kPa" T1 = -35 + 273 "K" rp = 10 T4 = 950 + 273 "K" V1 = 9E05/3600 "m/s"

#### "Calculations:"

CALL Ideal\_JetPropulsion\_cyclel(m, cp, gamma,P1, T1, rp,T4,V1 :P2, P3, P5, T2, T3, T5, T6, V6, F, W\_P,Q\_in,W\_comp, W\_turb, eta\_P,KE\_exit,Q\_exit)

#### **Results:**

Unit Settings: SI K Pa kJ mass deg					
cp = 1.005 [kJ/kg-K]	ηp= 0.2335	F=29715 [N]	γ = 1.4		
KE <sub>exit</sub> = 9811 [KW]	m = 45 [kg/s]	P1 = 40 [kPa]	P2 = 61.48 [kPa]		
P3 = 614.8 [kPa]	P5 = 275.7 [kPa]	Q <sub>exit</sub> = 14574 [kW]	Q <sub>in</sub> = 31814 [kW]		
rp = 10	T1 = 238 [K]	T2 = 269.1 [K]	T3 = 519.5 [K]		
T4 =1223 [K]	T5 = 972.6 [K]	T6 = 560.3 [K]	∨1 = 250 [m/s]		
V6 = 910.3 [m/s]	W <sub>comp</sub> = 11326 [KW]	W <sub>P</sub> = 7429 [KW]	W <sub>turb</sub> = 11326 [kW]		



# Get Internationally Connected at the University of Surrey

MA Intercultural Communication with International Business MA Communication and International Marketing



#### MA Intercultural Communication with International Business

Provides you with a critical understanding of communication in contemporary socio-cultural contexts by combining linguistic, cultural/media studies and international business and will prepare you for a wide range of careers.

#### **MA Communication and International Marketing**

Equips you with a detailed understanding of communication in contemporary international marketing contexts to enable you to address the market needs of the international business environment.

For further information contact: T: +44 (0)1483 681681 E: pg-enquiries@surrey.ac.uk www.surrey.ac.uk/downloads



Thus:

At turbine exit: T5 = 972.6 K, P5 = 275.7 kPa .... Ans.

Velocity of gases at nozzle exit = V6 = 910.3 m/s .... Ans.

Propulsive power = W\_P = 7429 kW .... Ans.

Heat supplied = Q\_in = 31814 kW ....Ans.

Propulsive efficiency = eta\_P = 0.2335 = 23.35% ... Ans.

#### Also:

Plot the variation of heat supplied and Propulsive efficiency as turbine inlet temp, T4 varies from 900 K to 1500 K, other conditions remaining same:

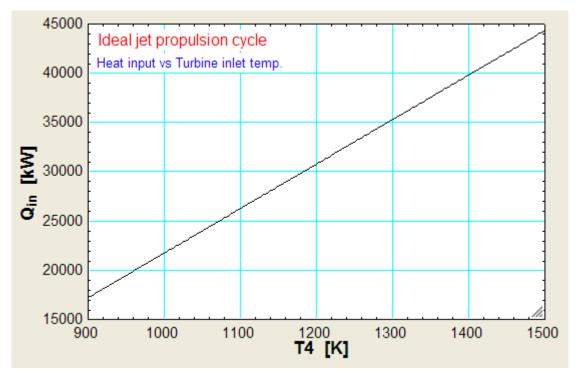
First, compute the Parametric Table:

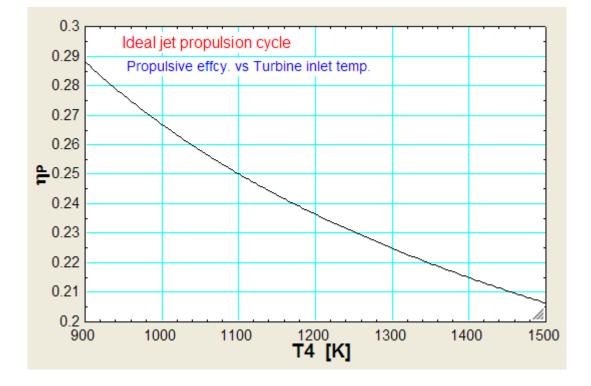
113	1 ▼ T4 [K]	2 Q <sub>in</sub> [kW]	3 Σ η <sub>Ρ</sub>
Run 1	900	17206	0.2881
Run 2	950	19468	0.2768
Run 3	1000	21729	0.2668
Run 4	1050	23990	0.258
Run 5	1100	26251	0.2501
Run 6	1150	28513	0.2429
Run 7	1200	30774	0.2363
Run 8	1250	33035	0.2303
Run 9	1300	35296	0.2248
Run 10	1350	37558	0.2197
Run 11	1400	39819	0.2149
Run 12	1450	42080	0.2105
Run 13	1500	44341	0.2063

\_\_\_\_\_

#### Now, plot the results:

=================





106

"**Prob.2.24.** In problem 2.23, if the isentropic efficiencies of compressor, turbine and nozzle are 80%, 85% and 90% respectively, other conditions remaining the same, find out the propulsive efficiency etc."

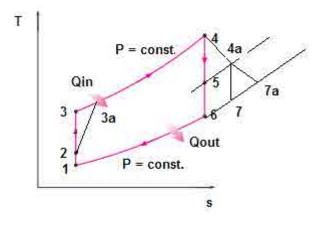


Fig.Prob.2.24

#### **EES Solution:**

#### "Data:"

m = 45 "kg/s" cp = 1.005 "kJ/kg.K" gamma = 1.4





P1 = 40 "kPa" T1 = -35 + 273 "K" rp = 10 T4 = 950 + 273 "K" V1 = 9E05/3600 "m/s"

eta\_comp = 0.8 "...compressor isentropic effcy."
eta\_turb = 0.85 "...turbine isentropic effcy."
eta\_nozzle = 0.9 "...nozzler isentropic effcy."

#### "Calculations:"

 $T2 = T1 + V1^2/(2 * cp*1000)$  "...finds T2 (K)"

 $P2 = P1 * (T2/T1)^{(gamma - 1)) "kPa"}$ 

P3 =P2 \* rp "kPa"

 $T3 = T2 * rp^{((gamma - 1)/gamma) "K"}$ 

 $(T3a - T2) = (T3 - T2) / eta_comp "....finds T3a (K)"$ 

W\_comp = m \* cp \* (T3a – T2) "kJ....compressor work"

W\_turb = m \* cp \* (T4 – T4a) "kJ .... turbine work"

W\_comp = W\_turb ".... finds T4a (K)"

 $(T4 - T4a) = eta\_turb * (T4 - T5) "....finds T5 (K)"$ 

P4 = P3 "kPa"

P5 =P4 \* (T5/T4)^(gamma / (gamma – 1)) " ... finds P5 = P4a, kPa"

P4a = P5 "kPa"

P7 = P1"kPa"

P7a = P1 "kPa"

 $T7 = T4a * (P7/P4a)^{((gamma-1)/gamma) \dots finds T7(K))}$ 

 $(T4a - T7a) = eta_nozzle * (T4a - T7) "...finds T7a (K)"$ 

V7a = sqrt(2 \* cp\*1000 \* (T4a – T7a)) "m/s ... velocity of exit jet"

F = m \* (V7a - V1) "N ... Net Thrust"

 $W_P = F * V1/1000$  "kW ... Propulsive power"

 $Q_{in} = m * cp * (T4 - T3a) "kW ... heat supplied"$ 

eta\_P = W\_P/Q\_in "....Propulsive effcy."

 $KE_{exit} = (m * (V7a - V1)^2 / 2)/1000 "kW"$ 

 $Q_{exit} = m * cp * (T7a - T1) "kW"$ 

### **Results:**

#### Unit Settings: SI K Pa kJ mass deg

cp = 1.005 [kJ/kg-K]	η <sub>comp</sub> = 0.8	$\eta_{\text{nozzle}} = 0.9$	ηp=0,1953
ŋturb = 0.85	F=22637 [N]	γ = 1.4	KE <sub>exit</sub> = 5694 [kW]
m = 45 [kg/s]	P1 = 40 [kPa]	P2 = 61.48 [kPa]	P3 = 614.8 [kPa]
P4 = 614.8 [kPa]	P4a = 175.4 [kPa]	P5 = 175.4 [kPa]	P7 = 40 [kPa]
P7a - 10	Q <sub>exit</sub> - 17629 [KW]	Q <sub>in</sub> - 28982 [kW]	rp - 10
T1 -238 [K]	T2 - 269.1 [K]	T3 - 519.5 [K]	T3a - 582.2 [K]
T4 = 1223 [K]	T4a = 909.9 [K]	T5 = 854.7 [K]	T7 = 596.5 [K]
T7a = 627.8 [K]	VI = 250 [m/s]	V7a = 753 [m/s]	W <sub>comp</sub> = 14158 [KW]
Wp = 5659 [kW]	W <sub>turb</sub> = 14158 [KW]	8 <del></del>	

### Thus:

At turbine exit: T4a = 909.9 K, P4a = 175.4 kPa .... Ans.

Velocity of gases at nozzle exit = V7a = 753 m/s .... Ans.

Propulsive power = W\_P = 5659 kW .... Ans.

Heat supplied = Q\_in = 28982 kW ....Ans.

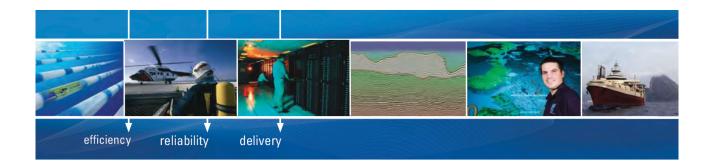
Propulsive efficiency = eta\_P = 0.1953 = 19.53% ... Ans.

### Also:

Plot the variation of exit jet velocity (V7a), Propulsive power (W\_P), heat supplied(Q\_in) and Propulsive efficiency(eta\_P) as turbine inlet temp (T4) varies from 900 K to 1500 K, other conditions remaining same:

1_13	T4 [K]	V7a [m/s]	W <sub>P</sub> [kW]	1_13	T4 [K]	Q <sub>in</sub> [kW]	ηρ
Run 1	900	488.3	2681	Run 1	900	14375	0.1865
Run 2	950	538.7	3248	Run 2	950	16636	0,1952
Run 3	1000	584.4	3762	Run 3	1000	18897	0.1991
Run 4	1050	626.5	4235	Run 4	1050	21158	0.2002
Run 5	1100	665.7	4677	Run 5	1100	23420	0.1997
Run 6	1150	702.6	5092	Run 6	1150	25681	0 1983
Run 7	1200	737.6	5485	Run 7	1200	27942	0 1963
Run 8	1250	770.8	5859	Run 8	1250	30203	0.194
Run 9	1300	802.6	6217	Run 9	1300	32465	0.1915
Run 10	1350	833.1	6560	Run 10	1350	34726	0.1889
Run 11	1400	862.5	6891	Run 11	1400	36987	0 1863
Run 12	1450	890.9	7210	Run 12	1450	39248	0 1837
Run 13	1500	918.4	7519	Run 13	1500	41510	0.1811

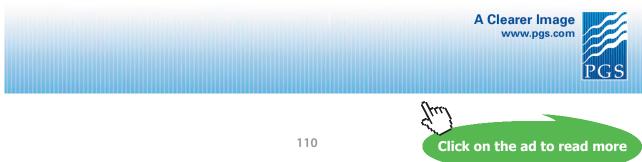
### First, compute the Parametric Table:



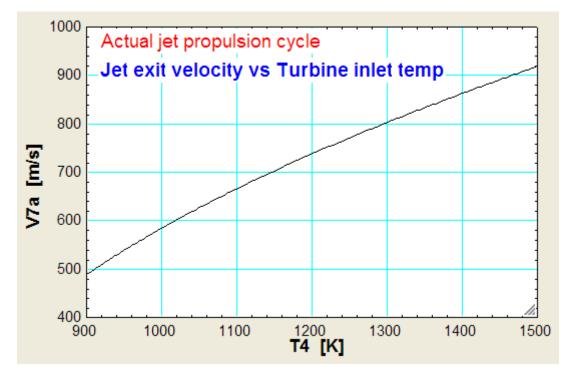
As a leading technology company in the field of geophysical science, PGS can offer exciting opportunities in offshore seismic exploration.

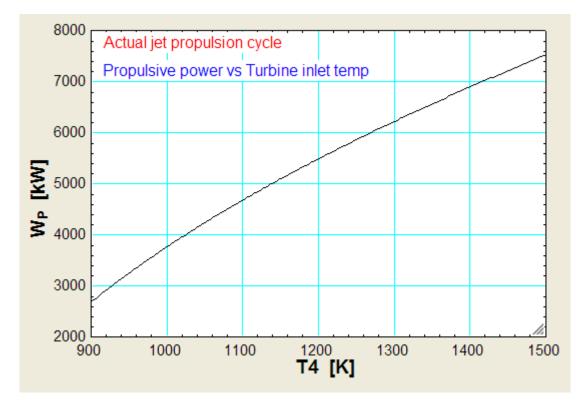
We are looking for new BSc, MSc and PhD graduates with Geoscience, engineering and other numerate backgrounds to join us.

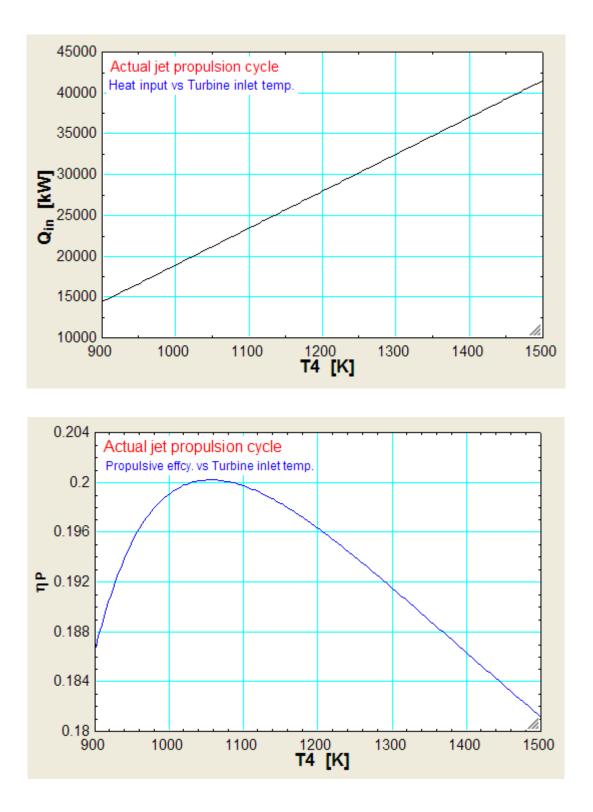
To learn more our career opportunities, please visit www.pgs.com/careers



### Now, plot the results:







### 2.4 Problems solved with TEST:

**Prob.2.25.** A GasTurbine power plant operates on simple Brayton cycle with air as working fluid and delivers 32 MW of power. Min. and max. temp. in cycle are 310K and 900K. Pressure at exit of compressor is 8 times the value at the inlet. Assuming isentropic eff. of 80% and 86% for compressor and turbine, determine the mass flow rate of air through the cycle. [VTU-ATD-July 2008]

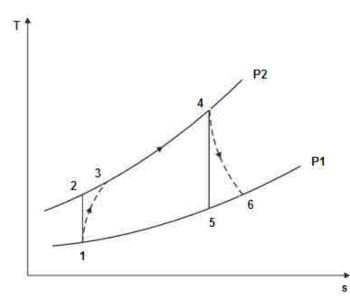


Fig.Prob.2.25



### **TEST Solution:**

Following are the steps:

We shall do the calculations assuming that the air mass flow rate is 1 kg/s and find out the net power produced. Then, it is a simple matter to compute the mass flow required to produce 32 MW.

1. From the TEST daemon tree, select the 'Vapour Power and Gas Power cycles' daemon:

Tables Desk0	a Converter	Closed	Open	System States	Flow States
Unsteady Closed	Generic	Steady Cycles	Open-Steady Generic	Specific	Open Processes
Uniform System	ns Non-Uniform N	an Mixing)	n-Uniform Semi I	Mixine Non-Unife	m Mixing
Uniform System	Non-Unitorm N	on-brixing	m-pononn senu i	Wixing	THE DEPOSITOR
I and the	an inde	- N (2	a de a	10 ml -	
Reciprocating	Cycles Psychrom		i astion and Chemie	cal Equilibrium	
<u>.</u>				cal Equilibrium	Systems

2. Clicking on 'Vapour Power and Gas Power cycles' brings up the window for material selection.

	Open Power-Cycle D Vapor (Steam) Power Cycles	aemons: Select a Material M Gas Power Cycles	Combined Cycles
lavigation top	at Medial		PC+IG Madel
	Pure Gas Models	Gas Mix	ture Models
	e = cous Pri Madel Ri Madel Ri Model	r-PG Model	jui - R <sup>a</sup> n-IS Model

3. Choose PG model (i.e. const. sp. heat), and select Air for working substance. Fill in the conditions for State 1, i.e. state at entry to compressor: p1= 100 kPa, T1= 310 K, and mdot1 = 1 kg/s. Press Enter. Immediately, all properties at State 1 are calculated:

Mixed	C/SI / C 8	Engli	sh	< Case-0	<b>V</b>  >	12.11	elp Messog	es On	Super	r-Iterate	Super-Calculate		Lood	Super-Initial	ize
	State Panel				GeMen 3	amet				Gado Parro	n th		110	E90H	
< DStat	e-1 X->	1	Calcula	te N	Plots	*	Indializ	•	Liona	ron Formata	o No Ves	(	Alf :		÷
* pt			1 7	1			NT.			UNT.			hT		
100.0	1Pa	×	310.0	<b>8</b> .	é	08	8866	an 199	3	77 07 442	10 A 10 A	~ 11	8914	\$1/9g	6
in .			1 16	Sel C		1	31						Ve		
0.3258	MAg K		0.0	1996	8	- 00		912	14	77 07442	ALAG .	el 🔢	8914	ALIAG.	8
1,0007			61911			1	mdott			Vah	dat1		At		
	k,//kg	×		Ruika	c (	1.0		KQ IR-	1	0.88956	er"3ie	* 88	965.83	1982 C	3
\$1841			Rt			1 8	pr.			10,62			RT		
28.97	i gikmi i	- 92	0.28699	a nag	C 18	1.0	0349	(4)48340	50	0.21651	KARGIK/	-	40054	UNDIAGE	16

4. For State 2: Enter p2, s2 = s1 (for isentropic process 1-2), and mdot2 = mdot1. Hit Enter. We get:

• Mixed	risi mi	Engli	sh <	Cose-0 🚽		🗸 Help Messag	es On	Supe	r-Iterate	Super Calculat	e	Load	Super Initial	izu.
St	ate Panel			1044	ice If a	0.01	1		DVDE E200			1100	Patrel	
< OState-2	¥ >		Calculate	No-Pic	etsi. M	hitala	1	formu	ion fuilletuv	No • Yes	3	40	1	¥.
< p2			12			v2			42			m2		
9.999	NE#	X	561,89705	N.	×	0.20155	m: HB9	~	103.39955	<b>8</b> ,830	18	204.03898	KURD	3
\$2			¥ 94	2		× 192			- 42			2		
<b>51</b>	LingK	~	0.0	1925		0.0	100 C	94	103.39956	king.	14	264 50890	uita) .	16
0002			ARE -			<ul> <li>mdot2.</li> </ul>			Vold	1012		A2		
	R.Mag	M		*wing	M	=mdof1	195	19	0.20155	m dia.	$\sim$	20156.057	192	
MM2			Rž			0.02			0.92			k2		
18.07	ApAmili	¥	0.28699	ALIAQUE -		100349	Notice K	14	0 71851	Alby K-		1 40654	Willow.	- 13

5. For State 3: It represents the state after actual compression, taking in to account the isentropic effcy. of compressor. Enter p3 = p2, T3 = T1 + (T2 - T1) / 0.8 where 0.8 is the compressor effcy. and mdot3 = mdot1. Hit Enter. We get:

19 Mixed	CEL CE	ingli	sh 🥑 🕵	nse-0 🛩 📐	10	Help Message	es Oit	Supe	r-Itorato	Super-Calculate		Load	Super-Init	aitee
്ട	tate Panel			Device	Pari	1	1		Cyde Pümił	il.		10	Pamil	
< DState-	5 M 5	Ì	Calculate	No-Plots		initialize	1	Furma	nos Contralação	I No Yes		. All		14. 1
/ p3			/ 73			y3			u3			63		
62	kPa;	M	#T1+(T2 T3)(0)	<b>K</b> . 1	2	22416	m'akp	3	148 5058	ELIKD .	*	327.8250	tuikg	3
53			VH3			1.13			+3			12		
03230	LingX	-	0.0	anda 🗸	~	0	an C		148 5068	king (	÷	327 8250	وقلبا	
ptell			600		i i	mdot3			Vald			A3		
	83/89	X		AURG	4	mdoff	199	19	0.22415	00209	*	22414.885	W.S.	
MAR			R3			6_p3			4.93			k3		
8.97	kg/kmal		0.28690	UN415	4	00349	KUNS R	24	0.71651	ALMER:	v.	1.40054	Unitation	e 9

6. For State 4: we have: p4 = p3, T4 = 900 K, mdot4 = mdot1. Hit Enter. We get:

Mixed Cal C	Englis	in <u>k</u> ec	ase 0 121 >	P Help Message	s On	Super-Iterate	Super Calculate	Load	Super Initialize
State Panel			1 Failes	Tanii	1	Gittle Excel		10	EaOel
< State-I × >	1	Calculate	No Piots	x Initialize	<b>1</b>	Formation Entransac	No Yes	AC	
p4		14		v4				14	
p5 iPa		HDD P	5	0.32285	m' tiky.	₩ 345.65498	Neg	803.9529	sing .
5/4	- 1.	< ligit		1 11		if.		10	
39858 Ling A	14	0.0	195	× 0.0	<b>#</b> 47	× 345.66498	alagi 🖓	003.9529	alleg //
poll		en-l		✓ mdot4		Volde	ot4	A4	
#.Ukg	*		4.1mg	emdott.	tón	* 0.32205	m124	32285 986	11 C 1

### Technical training on *WHAT* you need, *WHEN* you need it

At IDC Technologies we can tailor our technical and engineering training workshops to suit your needs. We have extensive experience in training technical and engineering staff and have trained people in organisations such as General Motors, Shell, Siemens, BHP and Honeywell to name a few.

Our onsite training is cost effective, convenient and completely customisable to the technical and engineering areas you want covered. Our workshops are all comprehensive hands-on learning experiences with ample time given to practical sessions and demonstrations. We communicate well to ensure that workshop content and timing match the knowledge, skills, and abilities of the participants.

We run onsite training all year round and hold the workshops on your premises or a venue of your choice for your convenience.

For a no obligation proposal, contact us today at training@idc-online.com or visit our website for more information: www.idc-online.com/onsite/ OIL & GAS ENGINEERING

**ELECTRONICS** 

AUTOMATION & PROCESS CONTROL

> MECHANICAL ENGINEERING

INDUSTRIAL DATA COMMS

ELECTRICAL POWER

Phone: +61 8 9321 1702 Email: training@idc-online.com Website: www.idc-online.com



Click on the ad to read more

116

• Mixed	C \$1 C 3	Engli	sh < 🗘	Саве-0 🛩 >	17 H	dp Message	s On	Supe	r-Iterate	Super Calculate		Load	Super Initial	īΰ
	State Panel			DAMO	s:114044		1		C//D01011111			100	65001	
CState	5 9 2	1	Calculate	No-Plots	~	Initialize	1	Format	inn En Knopp	CNs •Yes		AH)		*
< p5			75			v5			นอั			hō		
e1	ilite	×	496.6683	<u>×</u>	2 1.42	500	#*3Re	×	56 59599	klika		100 10155	k\$Rg	- 8
85			< Yala		1	25			40					
ed -	kang K		0.0	mik	~ 0.0		*1	2	66.59599	LUNg	4	199.10155	ki kig	1
(1950)			2014		1	mdot5			Vold	iot5		A5		
	KJRp.	12		RJIRT	× 200	ant i	KQN.	2	1.42506	121200	8	142505.55	1112	
Milts	CONTRACT.		RS	Contract.		<i>_6</i> 5	10000	-	C_1/5	Therefore	15711	. k5		
26.97	kglemni	1.46	0.28699	Ling K	1.00		illig K	~	TOTAL PARTY OF THE	alling of /	SQ	1.40054	leadora:	

7. For State 5: Enter p5 = p1, s5 = s4, mdot5 = mdot1, and hit Enter. We get:

8. For State 6: i.e. actual exit of turbine: Enter p6 = p5, T6 = T4 – 0.85 \* (T4 – T5) where 0.85 is isentropic effcy. of turbine. And mdot6 = mdot1. Hit Enter. We get:

• Mixed	C \$1 C \$	ingu	sh < CC	əse-0 ↔ >		Help Messager	s On	Supe	r-Iterate	Super Calculate		Load	Super Initial	izių
	State Panel			DANCE	Rath	+	1		C/DEFENS	( )		10:	Railol	
C CState	e (M. 201	1	Calculate	No-Plots	~	Initialize			mm Endings	No No Yes		Alt		
🖌 рб			1 76			vē			n6			16		
₽ <sup>E</sup>	iife -	×	T4-0.86*(T4-T	5 *	21	58715	#*3Re	×	97.06505	kJ/kg	×.	255,78072	ksikg	8
86			YWD.			20			- 40			.0		
60008	kang K		0.0	-ma	~	<b>10</b>	*	~	97.00555	11/kg	Ŷ	255,78072	ki ikg	
(ANR)			2200			mdot6			Vol	3015		A6		
	K.ING	12		RJINT		mdat	101	21	1.58715	1075200	3	158715.08	m.5	
1.01.00			R6			e_06			c_16			100		
26.97	kgrenni	14	0.28699	king K		00349	illigi K		IN THE REPORT	Linking of 2	91	1.40054	Investment (	13

9. Now, go to Device panel. For device A, enter State 1 and State 3 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And Qdot1 = 0 since in this process there is no external heat transfer. Hit Enter. We get:

• Mixed C SI C English	i 🧃 Cane O 😒 😒 🐼 Help Message	es On Super-Iterale	Super-Calculate	ad Super-Initialize
State Partie	Device Panel	COSIN POINT	1	10 Panil
Italize	< Dedce-6[1-3] × >	Calculate	C Non-Mixing	Alixing Device
State-1	State-Null 👻	et state-3	<b>8</b>	State-Null
Qdot :	Wdot_ext	T_B	Sdot_ge	
NW/	121 335.93448 WW M	280.15 K	0,10659	MW/K :
Jdot_net	Sdot_net			
15.93448 NW	✓ 0.10650: W/K			
	A STATE OF THE OWNER	s à certa	State-Null	
Mass, Energy, and Entro	py Equations:		It indicate	s that
Mass, Energy, and Entro	py Equations:	- Long	It indicate	s that
Mass, Energy, and Entro $0 = (m_{11} + m_{12}) - (m_{v1} + m_{v2})$	py Equations: $(1 = 1)$ $m_{e1}J_{e1} + \tilde{m}_{e2}J_{e2} + \hat{Q} - \hat{W}_{ext}$		It indicate a port is c	s that
$0 = (m_{11} + m_{12}) - (m_{e1} + m_{12})$	py Equations: $(1=1)$ $m_{e1}J_{e1} + m_{e2}J_{e2} + \dot{Q} - \dot{W}_{ext}$ $(2=3)$		It indicate	s that losed.

10. Similarly for Device B: enter State 3 and State 4 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And, Wdot\_ext = 0 since for this process no external work transfer occurs. Hit Enter. We get:

adol = 0.0 kW (Not Innat transfer rate)					
Mixed C SI. C English	Case 0 V S	Help Messages On	Super-Iterate	Super-Calculate	oad Super-initialize
, Navin Turnit	Device Pane	H C	62491 E1004		NO Baoel
Iniliatize	Cevice-B (3-4)	* >	Calculate	C Non-Mixing	· Mixing Device
State-3	State-N	ull 😤	State-4	*	State-Null 🛩
Qdor	Wdot_ext	1	T_B	Sdot_	gen.
276 <u>52698</u> WV V	P/0 AV	220 1	5 K	····	NWK .
Jdot_net	Sdot_net				
-276.12598 WW 💌	0.36518 W/K	( ).we			

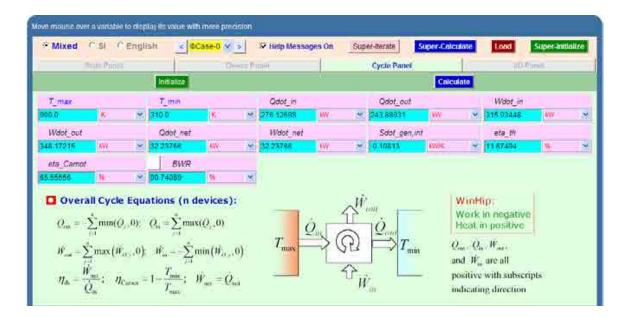
11. And, for Device C: enter State 4 and State 6 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And, Qdot = 0 since for this process no external heat transfer occurs. Hit Enter. We get:

Mixed CSI C	English	< CCase-0 W	> 🕼 Help Me	issages On	Super-Iterale	Super Calculate	Load Super-Init	ializo
District Balance		Des	vice Panel	1	02/09/20/	1001	100 19:6101	
Indialize		Device-C [4-6	< N 2		Calculate	C Non-Mixing	Mixing	Devic
noture State-4 🐱	Į.	USSOFE	State-Null 🙀		State-6		State-f	YUR 🎽
Qdot		Wdot_ext		1	T_B	Sdo	t_gen	
i fi	100	348,17215	107	2 2 M	(K)	× 0.10011	KVIIIS	0
Jdot_net		Sdot_net						
348.17215 NW		0.10811	MW/KS	~				

12. And, for Device D: enter State 6 and State 1 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And, Wdot\_ext = 0 since for this process no external work transfer occurs. Hit Enter. And, SuperCalculate. We get:

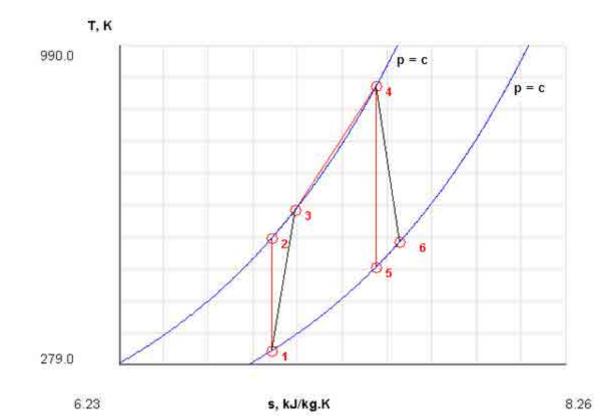
Mixed C SI C English	< DCase-D V > V He	Ip Messages On	Super-Iterate	Super-Calculate	Load Super Initial	kzu
State Partel	Device Panel		CyBe Face		10.Fanel	
Initialize	Oevice-D-(0-1)	-	Calculate	C Non Mixing	Mixing D	veivic
i a tuter State 8 😿	u-u.on. State-Null	*	State-1	¥.	state-Nu	dt 💽
Qdof	Widol_ext	1	7_B	Sd	lot_gen	
243.88931 W	p.p. w	× 198.3	K.	0.23713	IW/S:	2
Jdot_net	Sdot_net					
243.68931 W	0.50088 WWK	1000				

13. Now, go to cycle panel. It gives the major parameters of this cycle:

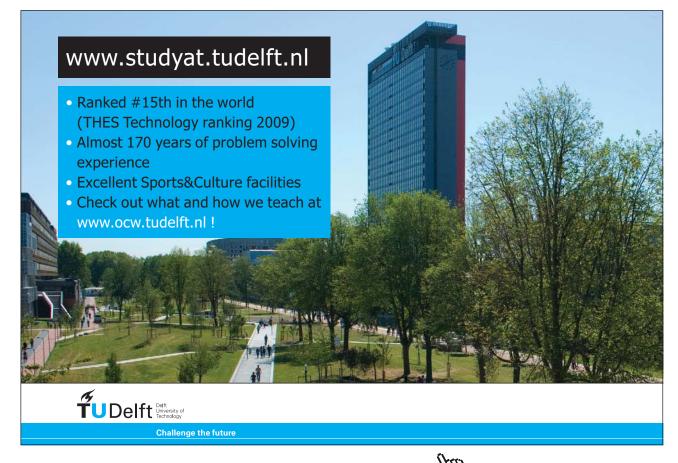


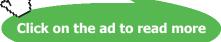
We observe that Wdot\_net = 32.23766 kW.

This is the net power developed when the air flow rate is 1 kg/s. **Therefore, to produce 32 MW, we need** a flow rate of 32E06/32237.66 = 992.63 kg/s .... Ans.



### 14. From the Plots widget, choose T-s diagram, and we get:





### 15. And I/O panel gives the TEST code etc:

### #~~~~OUTPUT OF SUPER-CALCULATE

#	Daemon Path: Systems>Open>SteadyState>Specific>PowerCycle>PG-Model; v-10.ca08
#	Start of TEST-code
States	{
	State-1: Air;
	Given: { p1= 100.0 kPa; T1= 310.0 K; Vel1= 0.0 m/s; z1= 0.0 m; mdot1= 1.0 kg/s; }
	State-2: Air;
	Given: { p2= 800.0 kPa; s2= "s1" kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; mdot2= "mdot1" kg/s; }
	State-3: Air;
"mdot	Given: { p3= "p2" kPa; T3= "T1+(T2-T1)/0.8" K; Vel3= 0.0 m/s; z3= 0.0 m; mdot3= 1" kg/s; }
	State-4: Air;
	Given: { p4= "p3" kPa; T4= 900.0 K; Vel4= 0.0 m/s; z4= 0.0 m; mdot4= "mdot1" kg/s; }
	State-5: Air;
	Given: { p5= "p1" kPa; s5= "s4" kJ/kg.K; Vel5= 0.0 m/s; z5= 0.0 m; mdot5= "mdot1" kg/s; }
	State-6: Air;
kg/s;	Given: { p6= "p5" kPa; T6= "T4-0.86*(T4-T5)" K; Vel6= 0.0 m/s; z6= 0.0 m; mdot6= "mdot1"

}

### Analysis {

Device-A: i-State = State-1; e-State = State-3; Mixing: true;

Given: { Qdot= 0.0 kW; T\_B= 298.15 K; }

Device-B: i-State = State-3; e-State = State-4; Mixing: true;

Given: { Wdot\_ext= 0.0 kW; T\_B= 298.15 K; }

Device-C: i-State = State-4; e-State = State-6; Mixing: true;

Given: { Qdot= 0.0 kW; T\_B= 298.15 K; }

Device-D: i-State = State-6; e-State = State-1; Mixing: true;

Given: { Wdot\_ext= 0.0 kW; T\_B= 298.15 K; }

}

#-----End of TEST-code -----

#-----Property spreadsheet starts:

#	State	p(kPa)	T(K)	v(m^3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	100.0	310.0	0.8897	-77.07	11.89	6.926
#	2	800.0	561.9	0.2016	103.39	264.64	6.926
#	3	800.0	624.8	0.2241	148.51	327.83	7.032
#	4	800.0	900.0	0.3229	345.66	603.95	7.399
#	5	100.0	496.6	1.4251	56.6	199.1	7.399
#	6	100.0	553.0	1.5872	97.07	255.78	7.507

#------Property spreadsheet ends------

### # Mass, Energy, and Entropy Analysis Results:

# Device-A: i-State = State-1; e-State = State-3; Mixing: true; # Given: Qdot= 0.0 kW; T\_B= 298.15 K; # Calculated: Wdot\_ext= -315.93448 kW; Sdot\_gen= 0.10659171 kW/K; Jdot\_net= -315.93448 kW; Sdot\_net= -0.10659171 kW/K;

# Device-B: i-State = State-3; e-State = State-4; Mixing: true; # Given: Wdot\_ext= 0.0 kW; T\_B= 298.15 K; Calculated: Qdot= 276.12698 kW; Sdot\_gen= -0.5599514 kW/K; Jdot\_net= -276.12698 # kW; Sdot\_net= -0.366183 kW/K; Device-C: i-State = State-4; e-State = State-6; Mixing: true; # # Given: Qdot= 0.0 kW; T\_B= 298.15 K; Calculated: Wdot\_ext= 348.17215 kW; Sdot\_gen= 0.10810609 kW/K; Jdot\_net= # 348.17215 kW; Sdot\_net= -0.10810609 kW/K; Device-D: i-State = State-6; e-State = State-1; Mixing: true; # Given: Wdot\_ext= 0.0 kW; T\_B= 298.15 K; # Calculated: Qdot= -243.88931 kW; Sdot\_gen= 0.23712797 kW/K; Jdot\_net= 243.88931 # kW; Sdot\_net= 0.5808808 kW/K;

### # Cycle Analysis Results:

#	Calculated: T_max= 900.0 K; T_min= 310.0 K; Qdot_in= 276.12698 kW;
#	Qdot_out= 243.88931 kW; Wdot_in= 315.93448 kW; Wdot_out= 348.17215
kW;	
#	Qdot_net= 32.23766 kW; Wdot_net= 32.23766 kW; Sdot_gen,int= -0.10813
kW/K;	
#	eta_th= 11.67494 %; eta_Carnot= 65.55556 %; BWR= 90.74089 %;





#

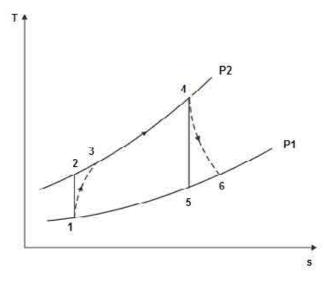
#\*\*\*\*\*CALCULATE VARIABLES: Type in an expression starting with an '=' sign ('= mdot1\*(h2-h1)', '= sqrt(4\*A1/PI)', etc.) and press the Enter key)\*\*\*\*\*\*\*\*

#Mass flow rate of air: mdot = 32\*MW / Wdot\_net = 32\*10^6/(32.23766\*10^3) kg/s

=32\*10^6/(32.23766\*10^3) = 992.6278768372147 kg/s ....required mass flow rate of air... Ans.

**Prob.2.26**. In an open cycle constant pressure gas turbine, air enters the compressor at 1 bar, 27 C. Pressure of air after compression is 5 bar. Isentropic efficiencies of compressor and turbine are 80% and 84% respectively. The air fuel ratio is 75 : 1. The air flow rate is 2.5 kg/s. Determine the power developed and the thermal efficiency of the cycle. For both air and combustion gases, take cp = 1.005 kJ/kg.K and  $\gamma = 1.4$ . Calorific Value of fuel = 42000 kJ/kg. [VTU- ATD-July 2004]

\_\_\_\_\_\_





### **TEST Solution:**

#### Following are the steps:

Steps 1 and 2 are the same as for Prob.2.25.i.e. select 'Vapour Power and Gas Power cycles' daemon from the 'daemon tree' and, for material model chose PG model (i.e. const. sp. heat) and select air as the working substance.

3. Choose PG model (i.e. const. sp. heat), and select Air for working substance. Fill in the conditions for State 1, i.e. state at entry to compressor: p1= 100 kPa,, T1= 27 C, and mdot1 = 2.5 kg/s. Hit Enter. Immediately, all properties at State 1 are calculated:

Mixed C SI C Er	ngtish	< Case-0 - >	P Help Messag	NO BR	Super-Iterate	Super Calculate	Load	Super Initiatize
State Panel	1	2000	PabM	1	Citiz Panill		801	Painti
< CStatu-1 v >	Calcula	No Plots	w Initiated	1	Formation Enfluence:	No • Yes	Alt	M
(pt)	1	79'	or:		U1			
0.0 SPat	27.0	Neglici -	0.86139	mi2Ag	· 84.13202	lang 🍝	2.00599	LUKg S
st	1	Veril	1 21		147		11	
8934 s//kg.rl	× 9.9	7/8	· 0.0		× -84,13202	178a. 🗠	2.00599	82/89
BRH	7.81		/ mdati		Volde	ot f	At	
KUNG	~	4,000	Ø 25	Agini -	2,15348	ariāka 🛁	215347.92	

4. For State 2: Enter p2, s2 = s1 (for isentropic process 1-2), and mdot2 = mdot1. Hit Enter. We get:

Mixed OSI CE	nglish	Case-U	Neip M	essages On	Super-Iterate	Super-Calculate	Load	Super-Initiali	ae
State Panel		1:Die	Nov Elakal		COSIN FUNI		10.5	and	
< DState-Z V >	Calcula	te No-Pl	ots 💌 🚺	ntialize	Formation tarburpy	No 💌 Yes	AR		
p2.		2	12		02		: 62		
10.0 (FA	* 475.592	30: 💉	▶ 0.27298	m134ig	41.57378	4.1/60	178.06235	10.00	11
87	1	4017	1 23		07		18		
alling #	× 40	ma	· 0.0	a.	# 41.57375	#1hg	170.08235	sing-	3
ph2	1002		<ul> <li>m</li> </ul>	dot2	Volde	x12	A2		
W.1Wg		w.J/kg	<ul> <li>mdott</li> </ul>	-kgra	WI 0.68244	101.5/A	88244.305	#89.	-2

5. For State 3: It represents the state after actual compression, taking in to account the isentropic effcy. of compressor. Enter p3 = p2, T3 = T1 + (T2 - T1) / 0.8 where 0.8 is the compressor effcy. and mdot3 = mdot1. Hit Enter. We get:

Mixed	CSI CI	ngli	sh 🕑 🕸 C	ase-0 🛩 🖂	F Help Message	es On	Super-Iterate	Super-Calculate	Load	Super-Initialize
-8	ate Panel		1	Olitical	REAL	1	Cashirdhaalif	1	145	Biann
- CState	3 14 3		Calculate	No-Plots	einator		Formation Contralpy:	No 🖲 Yes	Nit	
p3			< T3		v3		- 43		h3	
22	8918	18	111-12-11/04	665-C	× 0.29815	#172/KQ	× 73.0002	1/85	222.0752	KURg
53			Velt.		1 . 23		- 63		1 12	
98192	ALIAD K	¥	<u>n n</u>	HV6	~ 00		* 73.0002	ALLES - M	222.0782	<b>KLIK</b> g
/m69		_	pied		rndol3		Volde	xt3	A3	
	Kalka:	18		KJWg	· Incodota	Kg/s	M 0.74538	airtea 🖉	74638.01	m*2.

# Study at one of Europe's leading universities

DTI



DTU, Technical University of Denmark, is ranked as one of the best technical universities in Europe, and offers internationally recognised Master of Science degrees in 39 English-taught programmes.

DTU offers a unique environment where students have hands-on access to cutting edge facilities and work

closely under the expert supervision of top international researchers.

DTU's central campus is located just north of Copenhagen and life at the University is engaging and vibrant. At DTU, we ensure that your goals and ambitions are met. Tuition is free for EU/EEA citizens.

Visit us at www.dtu.dk



Click on the ad to read more

126

6. For State 4: we have: p4 = p3. To find T4, use the fact that energy supplied by the fuel is equal to increase in enthalpy of the gases as they pass through the combustion chamber. i.e.

$$m_{f} \cdot CV = cp(m_{a} + m_{f}) \cdot (T4 - T3)$$

i.e. 
$$CV = cp \cdot \left(1 + \frac{m_a}{m_f}\right) \cdot (T4 - T3)$$

i.e. 
$$T4 = T3 + \frac{CV}{\left[cp \cdot \left(1 + \frac{m_a}{m_f}\right)\right]}$$

i.e. 
$$T4 = T3 + \frac{42000}{1.005 \cdot (1 + 75)}$$

Also, mdot4 = mdot3 + mdot3/75. Hit Enter. We get:

Mixed C SI	CEng	lish	< PCase-0	× 8	Help Messages	On Supe	er-Iterate	Super-Calculate	Load	Super-Initial	Ú.
State	Panel			OmiliPair	et:		Citel Science		1100	NER AN C	
< @State 4	1.3	Calcut	ate I	lo-Plots 🐭	initiatize	Forma	tiger Ersthaltpyl	No Yes	- Dar		1
p4		1	74		v4		- 44		114		
p3	84) X	134.0	2200(71/1) de	es: 31	0.01377	nr0/kg 💌	499.99487	M89: S	773.8797	AURS)	10
34		1	Viele		1 .24				1.14		
70846 400	ġK 🎽	60	104	. en	0.0	<b>.</b>	486 99487	eJ/kg- 🐱	772.8707	418g.	115
1614		2003			ridol4		Voldo	14	A4		
KJ			(KA)	19 M	midot3+(mdot3/?	193 - 1 M	1.55488	117338	155488.3	#2	118

7. For State 5: Enter p5 = p1, s5 = s4, mdot5 = mdot4, and hit Enter. We get:

• Mixed CS	© 圭田	jtish	< 6C	se-0 v >	3	Help Messages (	on Supe	r-Iterate	Super Calculate		Load	Super Initial	izo
State	Panel			Denca	0.02	11		d/dePalli	1 (j		10F	SHH!	
e State 5	K (1)	e	alculate	No-Plots	N	Indiatizer	Toroat	ten Orthewy	No Ves		Air		9
/ p5			75			15		115			h5		
(H)	Pe I	- 67	4 8856	K	۲	193677 #	in an	184.3545	kang	-	78.02186	kultig .	ł
65		1	(Meth)			< DB		148			1.10		
10 N N N N N N N N N N N N N N N N N N N	Kg.K	× 0	0	-1998	~	0.00	* ×	184.3545	klikg	~	78.03180	KUAg	1
HALO			ces,			✓ mdot5		Volo	615		A5		
		- 1		#_Ukg	×	mdótő s	90 ×	4.90649	10.00	$\propto$	99549.28	82	-

8. For State 6: i.e. actual exit of turbine: Enter p6 = p5, T6 = T4 – 0.84 \* (T4 – T5) where 0.84 is isentropic effcy. of turbine. And mdot6 = mdot5. Hit Enter. We get:

Mixed Os	s usen	glish	a oca	se-0. 🖌 >	1	Help Messages O	n Supe	r-iterate	Super-Calculate		Load	Super-Initia	nlize
State	Panel		<u>P</u>	(Direct	Ebo	r în		Contraction (	V)		102	304	
< CState-6	Y 2	C	alculate	No-Plots	Y	Inidalize	hormat	ooo i milairigan	No Ves		-		M.
00		1	To			VB	1	- 776			he		
1	204	-	40.84174/76	449.5	2	11791 00	1Ag 👻	229 57697	aling -	1	41.36752	i Ling	- 7
56			Vel6:			20		89			15		
.79518 U	NOX	Y N	) j		× 1	a 👘	n (%	229:57697	M00-	5 4	41.36752	61/69	2
10-11			-		T)	mdatt		Volck	atti		Afi		
*	JPRy .	- i		kuliku	30) [	mido#i		5.36636	0//3/2		16538.0	11/2	2

9. Now, go to Device panel. For device A, enter State 1 and State 3 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And Qdot1 = 0 since in this process there is no external heat transfer. Hit Enter. We get:

• Mixed C 51 C English	<ul> <li>&lt; dCase-0 ♀ &gt;</li> <li>I Help Message</li> </ul>	es On Super-Iterate Super	-Calculate Lond Super-Initimize
CENTRAL FORMATION OF THE PARTY	Device Panel	La die Plana	HO Paliel
nitralize	K Device-A (1-3)	Calculate	Non Mixing • Mixing Device
Stale-1 🛩	State-Null 💌	At theme State-3 💉	State-Null 🚽
Qdot	Wdot_ext	✓ T.B	Sdot gen
0. (W)	······································	25:0 dec-C	M 0.22131 NWK S
Jdot_net	Sdot_net		
560.17303 W	M 022131 MMX M		
Steady Multi-Flow Mixin Mass, Energy, and Entrop	g Device - A by Equations:		State-Null: It indicates that
$0 = (m_1 + m_{12}) - (m_{e1} + m_{e2})$	$(1 = 1)$ $h_{s1} J_{s1} + \dot{m}_{s2} J_{s2} + \dot{Q} - \dot{W}_{ss1}$		a port is closed.

10. Similarly for Device B: enter State 3 and State 4 for i1-state and e1-state respectively. Also, since there is only one stream, select Null state for i2-state and e2-state. And, Wdot\_ext = 0 since for this process, no external work transfer occurs. Hit Enter. We get:

Mixed C SI C English	Case-0 V > V Hely	p Messages On	Super-Iterate	Super Calculate	Load Super Initialize
Diale Planet	Device Panel		Cupe Face	e di	10.5000
Initialize	< Device B (3:4) >>	1	Calculate	C Non-Mixing	Mixing Device
State-3 😽	State-Null		State-4	2	State-Null 🤗
Qdot -	Widot_ext	1	T 8	Sde	of gen
1405,3047 WW 🗡	ANV ANV	(H) 25.0	0.00	2.64510	NWK 1
Jelot_mit	Sdot_net				
-1405 3847 NW	-2.05823 VW/K	AK			



### MoM MAASTRICHT SCHOOL OF MANAGEMENT



For almost 60 years Maastricht School of Management has been enhancing the management capacity of professionals and organizations around the world through state-of-the-art management education.

Our broad range of Open Enrollment Executive Programs offers you a unique interactive, stimulating and multicultural learning experience.

Be prepared for tomorrow's management challenges and apply today.

For more information, visit www.msm.nl or contact us at +31 43 38 70 808 or via admissions@msm.nl

the globally networked management school



Click on the ad to read more

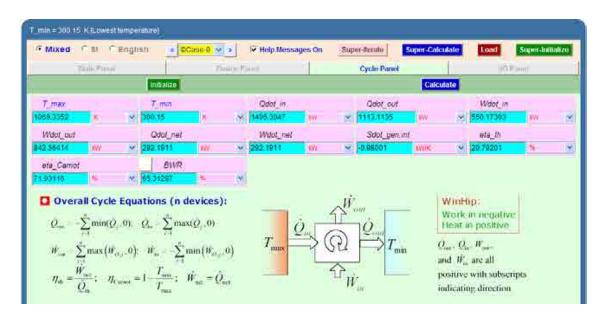
11. And, for Device C: enter State 4 and State 6 for i1-state and e1-state respectively. Also, since there is only one stream, select Null state for i2-state and e2-state. And, Qdot = 0 since for this process, no external heat transfer occurs. Hit Enter. We get:

		and the second second	Super-Calculate	Load Super-Initialize
Shim Parial	Device Panel	Studie Plane		10 Fand
toilliatize	< Davida-C (4.8) 💉 👻	Calculate	C Non-Mixing	Mixing Drvic
nisana State-4 💌	State-Null 😿	State-6	*	State-Null 💌
< Odol	Wdot_ext	1_B	Sdo	v[_gen
10 W 🔗 🗛	42.354/14 MW 💉 🛛	96.0 Sop-0	0.22728	W/K :

12. And, for Device D: enter State 6 and State 1 for i1-state and e1-state respectively. Also, since there is only one stream, select Null state for i2-state and e2-state. And, Wdot\_ext = 0 since for this process, no external work transfer occurs. Hit Enter. And, SuperCalculate. We get:

Mixed C SI C English	< dCase-0 > > P Help Messag	super-iterate	Super-Calculate	od Super-Initialize
SUD EXMI	Device Panel	Shite Fallet	il.	IIQ PEAN
IlliBize	< Device-D (6-1) × >	Calculate	C Non-Mixing	• Mixing Devic
Nilli State 6 💌	C 1117 State Null 💌	States State-1	-	alt Aldar State Mult 🐱
Qdat	✓ Wdot_ext	< T.B	Sdot ge	en l
113 1135	- <u>90</u>	A DOMESTIC IN CONTRACTOR OF THE OWNER OWNER OF THE OWNER	1,21658	WWK.

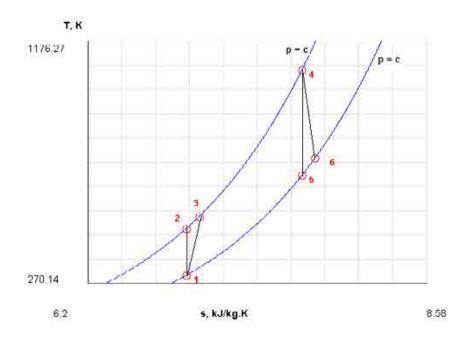
13. Now, go to cycle panel. It gives the major parameters of this cycle:



### We observe that: Wdot\_net = 292.1911 kW = Power developed .... Ans.

### And, thermal efficiency = eta\_th = 20.792% .... Ans.

14. From the Plots widget, choose T-s diagram, and we get:



### 15. And I/O panel gives the TEST code etc:

### #~~~~~OUTPUT OF SUPER-CALCULATE

### # Daemon Path: Systems>Open>SteadyState>Specific>PowerCycle>PG-Model; v-10.ca08

#-----Start of TEST-code -----

States {

State-1: Air;

Given: { p1= 100.0 kPa; T1= 27.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; mdot1= 2.5 kg/s; }

State-2: Air;

Given: { p2= 500.0 kPa; s2= "s1" kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; mdot2= "mdot1" kg/s; }

State-3: Air;

Given: { p3= "p2" kPa; T3= "T1+(T2-T1)/0.8" deg-C; Vel3= 0.0 m/s; z3= 0.0 m; mdot3= "mdot1" kg/s; }

State-4: Air;

Given: { p4= "p3" kPa; T4= "T3+42000/(76\*1.005)" deg-C; Vel4= 0.0 m/s; z4= 0.0 m; mdot4= "mdot3+(mdot3/75)" kg/s; }

State-5: Air;

Given: { p5= "p1" kPa; s5= "s4" kJ/kg.K; Vel5= 0.0 m/s; z5= 0.0 m; mdot5= "mdot4" kg/s; }

State-6: Air;

Given: { p6= "p5" kPa; T6= "T4-0.84\*(T4-T5)" deg-C; Vel6= 0.0 m/s; z6= 0.0 m; mdot6= "mdot5" kg/s; }

}

#### Analysis {

Device-A: i-State = State-1; e-State = State-3; Mixing: true;

Given: { Qdot= 0.0 kW; T\_B= 25.0 deg-C; }

Device-B: i-State = State-3; e-State = State-4; Mixing: true;

Given: { Wdot\_ext= 0.0 kW; T\_B= 25.0 deg-C; }

Device-C: i-State = State-4; e-State = State-6; Mixing: true;

Given: { Qdot= 0.0 kW; T\_B= 25.0 deg-C; }

Device-D: i-State = State-6; e-State = State-1; Mixing: true;

Given: { Wdot\_ext= 0.0 kW; T\_B= 25.0 deg-C; }

}

#-----End of TEST-code -----

### #-----Property spreadsheet starts:

#	State	p(kPa)	T(K)	v(m^3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	100.0	300.2	0.8614	-84.13	2.01	6.893
#	2	500.0	475.6	0.273	41.57	178.06	6.893
#	3	500.0	519.5	0.2982	73.0	222.08	6.982
#	4	500.0	1069.3	0.6138	466.99	773.88	7.706
#	5	100.0	674.9	1.9368	184.35	378.03	7.706
#	6	100.0	738.0	2.1179	229.58	441.37	7.796

#-----Property spreadsheet ends-----

### # Mass, Energy, and Entropy Analysis Results:

# Device-A: i-State = State-1; e-State = State-3; Mixing: true;

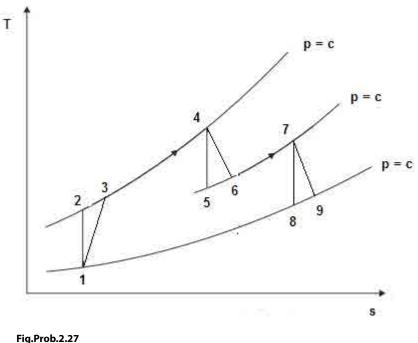
- # Given: Qdot= 0.0 kW; T\_B= 25.0 deg-C;
- # Calculated: Wdot\_ext= -550.17303 kW; Sdot\_gen= 0.22130843 kW/K; Jdot\_net= -550.17303 kW; Sdot\_net= -0.22130843 kW/K;
- # Device-B: i-State = State-3; e-State = State-4; Mixing: true;
- # Given: Wdot\_ext= 0.0 kW; T\_B= 25.0 deg-C;



Click on the ad to read more

# Calculated: Qdot= 1405.3047 kW; Sdot\_gen= -2.6451857 kW/K; Jdot\_net= -1405.3047 kW; Sdot net= -2.068229 kW/K; # Device-C: i-State = State-4; e-State = State-6; Mixing: true; Given: Qdot= 0.0 kW; T\_B= 25.0 deg-C; # Calculated: Wdot\_ext= 842.36414 kW; Sdot\_gen= 0.22728187 kW/K; Jdot\_net= # 842.36414 kW; Sdot\_net= -0.22728187 kW/K; Device-D: i-State = State-6; e-State = State-1; Mixing: true; # # Given: Wdot\_ext= 0.0 kW; T\_B= 25.0 deg-C; Calculated: Qdot= -1113.1135 kW; Sdot\_gen= 1.2165818 kW/K; Jdot\_net= 1113.1135 # kW; Sdot\_net= 2.5168192 kW/K; # Cycle Analysis Results: # Calculated: T\_max= 1069.3352 K; T\_min= 300.15 K; Qdot\_in= 1405.3047 kW; # Qdot\_out= 1113.1135 kW; Wdot\_in= 550.17303 kW; Wdot\_out= 842.36414 kW; Qdot\_net= 292.1911 kW; Wdot\_net= 292.1911 kW; Sdot\_gen,int= -0.98001 kW/K; # eta\_th= 20.79201 %; eta\_Carnot= 71.93116 %; BWR= 65.31297 %; #

**Prob.2.27.** In a reheat gas turbine cycle, comprising one compressor and two turbines, air is compressed from 1 bar, 27 C to 6 bar. The highest temp in the cycle is 900 C. The expansion in the first stage turbine is such that the work from it just equals the work required by the compressor. Air is reheated between the two stages of expansion to 850 C. Assume that the isentropic efficiencies of the compressor, the first stage and the second stage turbines are 85% each and that the working substance is air. Calculate the cycle efficiency. [VTU-ATD-July 2004]



100.2.27

### **TEST Solution:**

### Following are the steps:

Steps 1 and 2 are the same as for Prob.2.25.i.e. select 'Vapour Power and Gas Power cycles' daemon from the 'daemon tree' and, for material model chose PG model (i.e. const. sp. heat) and select air as the working substance.

3. Choose PG model (i.e. const. sp. heat), and select Air for working substance. Fill in the conditions for State 1, i.e. state at entry to compressor: p1= 100 kPa, T1= 27 C, and mdot1 = 1 kg/s. Hit Enter. Immediately, all properties at State 1 are calculated:

@ Mixed C	SI INE	nğli	in < Ioca	\$8-0 🔍 x	P Help Message	es On	Super-Iterate	Super Calculate	Load	Super Initialize
Sta	te Panel			Device	Cacito		CERN Prese		100	Cimil
< OState-1	<b>X</b> ( #	Ĭ	Calculate	No-Plots	No Initiatize	1	Commission Collimby	O No O Yes	Air	91
pT.			× TI		VT		01			
00.0	SPe:	×	87.A.1	deg-G	·· 0.85130	m13/9g	and the second se	ANK: I P	2.00889	kilkg:
-51			< 1. Units		1 21		- 62		11	
8934	UN¢X		0.0	10 <b>4</b>	~ 0.0	=	· -84,13202	king a	2.00099	40.02
phit			per!		mdot1		Vok	iot1	At	
	st.Ling	×		WARD :	~ 10	(gla	× 0.86139	#708 N	05139.01	m*2

4. For State 2: Enter p2 = 600 kPa, s2 = s1 (for isentropic process 1-2), and mdot2 = 1kg/s. Hit Enter. We get:

Mixed	C 81 / C 8	Engli	sh) 💌 🕫	ase 0   M   S	1	Help Message	s On	Supe	r-literate	Super-Calculate		Load	Super-Init	inkza
	State Panel	_	1	Onnor	(internet	11			Cien Onto			19.7	MIMI-	
1	978-2 M >		Calculate	No-Plots	*	inm alize	ť.	10000	an îm <del>a</del> y	Norrites		Ar.		e.
¥ p2			12			12	1		1 12			62		
KRO (I	693	1.41	501.04846	×	3	23966	m/34g	×	59-81322	aling -	¥	203.60738	aung .	- 3
\$2			/ Vierz			1 12			197			12		
as l	king K	•	0.0	617B -	-	10		×	59,81327	WAY:	Ψ.	203 60738	sing .	- 3
,dh/2			1 AME		1.4	mdot2			Volde	12		A2		
	kJ/Ng	100		k3/kg	4	0	ig/s:		0.23566	(intate)	×	23965.693	m/2	2
MM2			R2			C.02			6,12			k2-		
28.97	işlmi -	4	0.28699	KUK2.K	÷.	and the second	Wax-	2	0.71651	ELAND K	¥	1 40054	United	

5. For State 3: It represents the state after actual compression, taking in to account the isentropic effcy. of compressor. Enter  $p_3 = p_2$ ,  $T_3 = T_1 + (T_2 - T_1) / 0.85$  where 0.85 is the compressor effcy. and mdot3 = 1 kg/s. Hit Enter. We get:

Mixed C 6I C Er	tgilsh 🛛 🛃 🛍	ase-0 🛩 >	🖓 Help Messages On	Super-Iterate	Super-Calculate	Load	Super-Initialize
State Panel		Ilisona Pa	4946	Costa Transi		103	Parrol
< Blade 3 - M >	Calculate	No-Piets	i Million I	formation follows	Mu - Yan	T AL	
ρ2	13		v2 :	63		13	
2 km	- Td-(T2-0-1)-0	🐱 uep G 🛛 🖂	0.25661 10*304	✓ 85.21532	luing 👘 🖓	735 18381	king -
s3	Verio		13	62		1	
062 kung.K	× 0.0	· • • • · · · · · · · · · · · · · · · ·	0.0: mir	T: 85.21532	king 🖂	235 18391	katig
pbs3	1744		✓ mdot3	Valdo	13	A3	
A.J.Ng	198	6.3%g 📈	10 Kg/s	M 0.25861	1736 N	26661434	at 2



### **CLIVER WYMAN**



Oliver Wyman is a leading global management consulting firm that combines deep industry knowledge with specialized expertise in strategy, operations, risk usep industry knowned with specialized expension and experiments, tak management, organizational transformation, and leadership development. With offices in 50+ cities across 25 countries, Oliver Wyman works with the CEOs and executive teams of Global 1000 companies. elopment With OUR WORLD An equal opportunity employer.

### **GET THERE FASTER**

Some people know precisely where they want to go. Others seek the adventure of discovering uncharted territory. Whatever you want your professional journey to be, you'll find what you're looking for at Oliver Wyman.

Discover the world of Oliver Wyman at oliverwyman.com/careers





- Nove mouse over a variable to display its value with more precision Mixed CSI CEnglish < DCase-0 - + P Help Messages On Super-Iterate Super Calculate Load State Panel DiritiePad Cide Bai No: • Yes @State-4: 💌 = Calculate Initiatize No-Piets 💌 × · 74 144 14 *n*4 000 C (Gin 0.661 10:300 M 641 64160 M ALL R. D 1 1 1414 22 64 j4 k lag K itits AJA<u>u</u> 4 1.100 mdot4 Voldot4 A4 AARg **KARG** × #7.5% 1025 mix 113,049 LAM2 R4 9.44 R4 6.04 UND STREET 1.00.34 No. 71651 Lingx 1 40054 UnitLeas Agric: ¥
- 6. For State 4: we have: p4 = p3. T4 = 900 C, mdot4 = 1 kg/s. Hit Enter. We get:

7. For State 5: Enter s5 = s4, mdot5 = 1 kg/s, and T5 = T4 – (T4 – T6)/0.85 where 0.85 is the turbine isentropic effcy. Hit Enter. We get (after SuperCalculate later):

@ Mixed Co	SI RE	ngilli	ih < pc	ase 0 💌 >	12	Help Messag	es On	Supe	r-Iterate	Super Calcula	te	Load	Super Intil	alize
Stat	e Panel		1	159/cl	7	1	1		CASE PRANT			102	TRAFF	
< @State-5	M 2		Calculate	No-Plots	~	Induka	i i	Termi	ingen Ernningere	No Ye	8	ABC		Y
pä			¥ T5		11	vđi			45			h5		
232.99126	iten :	×	T4174-76983	Cash C	2	10253	miting.		342 14682	1149	đ	599.0255	1497	8
65			<ul> <li>39686</li> </ul>			1.34			indi-			34		
34 H	Xox	2	0.0	11/8		0	1000	~	342.14682	katikis	136	599.0256	1,150	18
per se la companya de			net .			1 Industrial			Valde	ata .		A5		
	kuling.	*		*180	*	¢.	Kala:	Ŷ	1 10253	mt Sta	14	110252.52	112	ð
KANAS			85			e p5			in left			1.kti		
28.97	kg(kno)	2	0.28698	k3/kg.K	21	00349	NIM R		0.71651	LINGK .	136	1.40054	Unitions	3

8. For State 6: i.e. actual exit of turbine: Enter p6 = p5, For T6, we have compressor work = first stage turbine work, i.e. cp \* (T4 – T6) = cp \* (T3 – T1). Therefore, T6 = T4 – (T3 – T1). And mdot6 = mdot5. Hit Enter. We get:



9. For State 7: Temp of reheating is T7 = 850 C, p7 = p6, mdot7 = 1 kg/s. Hit Enter. We get:

	nglis	11 S S M	196-0 × >	IN HO	lp Messages On	Supe	a Iterate	Super-Calculate	1.1	Load	Super-Initia	120
e Panel		1	DN///Kiel	PANT	1		COMPRESSION STREET			/ 801	FORMAL T	
¥ >		Calculate	No Piets	4	Indiatize	Korma	ikki Billingy	No Yes		Mi	8	~
		17			y7		- 07			h7\		
W/A	M	850.0	alg-C	1.38	144 I mil	NO 00	505,55362	A-WO	×	27.00257	8350	ī,
		¥ 1417		-	11					T		
Mg K	~	0.0	ive /	~ p.a		~	506 96382	4449	- 8	27 88257	Alky:	
		3667		1	mdot7		Vold			A7		
kJ/kg	×		kJR0	. 10	( to	3 · W	1.38344	100°D/w	× 1	36343.78	0121	18
	w > Wa	w >		V S Colculate No Pints V 17 Win M B50.0 eng.C V Ve/7 JAg.K V 0.0. m/k tel7	Colculate         No-Plats           ✓         177           Win         850.0         ang.0         11.397           Jágul         Ø.0         yal7         ✓           Jágul         Ø.0         yal7         ✓	Colculator     No-Plots     Infinitive       IT     V7       VN     550:0     eng.c     1.30344     eng.c       Vali7     Infinitive     27       JApiK     0.0     eng.c     0.0       JapiK     100     eng.c     1.30344	Colcutate     No-Plats     Initialitie     Portion       I/T     V/       VIN     VSD.0     ong-C     V.       VIN     VSD.0     ong-C     1.383344     mrd/rsg       VIN     VSD.0     ong-C     V.     1.383344       VIN     VIN     VIN     VIN     VIN       VIN     VIN     VIN     VIN     VIN	Colcutate         No-Plats         Integrate         Formutour Extlusion           ✓         17         y7         07           Win         850.0         eng-C         1.30344         ending         505.55362           V/VI         07         27         27         27           Val         0.0         molect         27         27           Val         0.0         molect         27         27           Val         0.0         molect         Val         27           Val         0.0         molect         Val         27	Colculate         No-Plats         Interfer         Formubor Etimulor         No<* Yes           ✓         17         V/         u7         u7           Wh         BSD.0         ong-C         M1389344         m*Msg         50555352         mMg           V         V/I         27         e7         e7         e7           Jagud         0.0         mes         10.0         m         804.86362         sJAg           Hei7         ✓         mdot7         Valdot7         Valdot7	Colcutate         No-Pints         Intestition         Formulation         No         Yes           ✓         17         V/         u7         u7         u7         u7         u7         u7         u8           Win         M         550.0         mig-C         M         1.50344         miding         505:55352         siNg         0	Colcutate         No-Plots         Intratice         Formation Exitianty         No         Yes         Nr           ✓         17         V7         07         h7         h7	Colcutatio         No-Pints         Intention         Formulation         No * Yes         No           *         17         v7         u7         h7           Win         550.0         mis/c*         mis/s         505:55352         million         027.88257         million           Vin         vin         50.0         mis/c*         vin         1.58344         million         505:55352         million         027.88257         million           Vini         Vini         50.0         million         27         e7         jif           Jaguk         0.0         million         27         e7         jif         Allion           jigut         vini         50.0         million         27.7         jif         Allion           jigut         million         jif         million         27         jif         jif

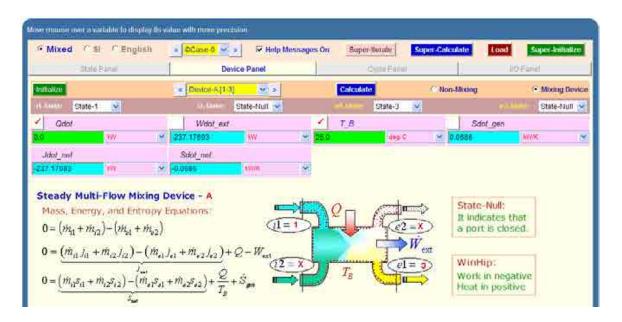
10. State 8: i.e. after isentropic expansion in second stage turbine. Enter p8 = p1, s8 = s7, mdot8 = 1 kg/s. Hit Enter. We get:

• Mixed	C 81 C 1	Engli	sn  🕫	labe 0 🛩 🕨		✓ Help Messag	es On	Super	Iterate	Super-Calcula	ate	Lo	ber	Super-Init	akze
82	State Panel			Claire	291	IN	1		STATE PRAVIL	1			003	Salvar-	
< OState	-8 - >		Calculate	No-Plots	¥.	Initializ	1	Formiuti	on Eidonhyy	No/• M	18	14	it		(W)
V pli			78			BALL			286		_		hB		
-01	85%	X	881.8258	×	100	2,53072	m1380	1.18	332.64374	KING:	1.5	585	/152	83/80	10
e8			× 148			1 20			65			1	18		
	M/Kg.K	4	0.D	inte :	142	0.0	=	2	332.84374	والله	10	685	7162	king	1
Bhill			1668.			< mdot8			Vold				:48		
	183/8g	×.		AU/Rd	$\sim$	1.0	19(9)	M	2.53072	int3/#	N	2530	72.42	11/2	18
MMS			R8			500			5.18			k	é		
28.97	Aphreni.	~	0.28599	suke K	140	1.00349	A159X	-	0.71651	LUNGN	×	1.40	054	Dat.as	

11. State 9: i.e. after actual expansion in second stage turbine. Enter p9 = p8, mdot9 = 1 kg/s, T9 = T7 - (T7 - T8) \* 0.85 where 0.85 is the isentropic effcy of second stage turbine. Hit Enter. We get:

· Mixed	C 31 C1	Engli	in 👱 🕫	Case-0 👻 🕒	i₩ He	lp Messages On	Super	r-Iterate	Super-Calculate	Load	Super-Initi	alize
\$	State Panel		1	Omitio	1 Pieboli			Croff Earlie		þ	0.026664	
< ¢Otst	8-9 × >-	- 1	Calculate	No-Plots	¥	Initialize	Corcourt	ung Ferboury	C No 🔿 Yes	At		
× 09			1 79		1	19		49		119		
≠p8	4Pa	M	=17-(17-16)10	85 1	2.63	461 #1300	N IX	358.58023	kulka 🖉	622.0411	4 NAME	17
69			× 1 1000		1	29				10		
01525	arreads or	Ŷ	0.0	ALC: NO	* 9.0		¥6	358.58023	king 👻	022.0411	ali sung	
3639.			2419		1	mdot9		Volde	19	AS		
	8.687	~	0	KJ/Rg	× 10	191	×	2,63461	miais y	263460.0	m'2	
MM9			RA		¢.	p9		0,19		89		
28.97	AgAmp)	×	0.28599	NARTH	* 1.00	3.49 URGW	4	0.71651	Allian .	1.40054	Unitiess	

12. Now, go to Device panel. For device A, enter State 1 and State 3 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And Qdot1 = 0 since in this process there is no external heat transfer. Hit Enter. We get:



13. Similarly for Device B: enter State 3 and State 4 for i1-state and e1-state respectively. Also, since there is only one stream, select Null state for i2-state and e2-state. And, Wdot\_ext = 0 since for this process, no external work transfer occurs. Hit Enter. We get:

Mixed C SI C English	CCase-0 > File Messages Or	Super-Iterate	Super Calculate	Load Super Initiatize
Balle Patrick	Device Panel	(()(5605566))		10.6368
Initialize	< Device-B (3-4) 💉 >	Calculate	C Non-Mixing	Mixing Device
1 State-3 😥	State-Nutl	State-4	×	State-Null S
Qdul	✓ Wdot_ext ✓	Т_В	Sdi	ol_gan
38.87335 NV M	(6:0) 🕺 👷 👷	0000	M -1.35768	MWKC 1
Jdot_riet	Sdot_net			
038.87335 · · · · · · · · · · · ·	-0.78511 +W/K 🗠			

© 2010 EYGM Lin

14. And, for Device C: enter State 4 and State 6 for i1-state and e1-state respectively. Also, since there is only one stream, select Null state for i2-state and e2-state. And, Qdot = 0 since for this process, no external heat transfer occurs. Hit Enter. We get:

Mixed C SI C English	Case-0 V N Help Messages (	On Super-Rerate Super-Calculate	Lood Super-Initialize
Phalad Pressel	Device Panel	Cysle Ranki	INS REPORT
initialize	★ Device C [4-6] X >	Calculate C Non-Mixin	9 🔍 Mixing Devic
State-4	State-Nutl 👻	State-6 💌	State-Null 🖌
C Qdot	Watot_ext	TB	Sdot_gen
30 XW/ X	237.17693 WW	dep:C: 💉 0.0457	AWW S

## Day one and you're ready

Day one. It's the moment you've been waiting for. When you prove your worth, meet new challenges, and go looking for the next one. It's when your dreams take shape. And your expectations can be exceeded. From the day you join us, we're committed to helping you achieve your potential. So, whether your career lies in assurance, tax, transaction, advisory or core business services, shouldn't your day one be at Ernst & Young?

What's next for your future? ey.com/careers

JERNST & YOUNG Quality In Everything We Do



15. And, for Device D: enter State 6 and State 7 for i1-state and e1-state respectively. Also, since there is only one stream, select Null state for i2-state and e2-state. And, Wdot\_ext = 0 since for this process, no external work transfer occurs. Hit Enter. We get:

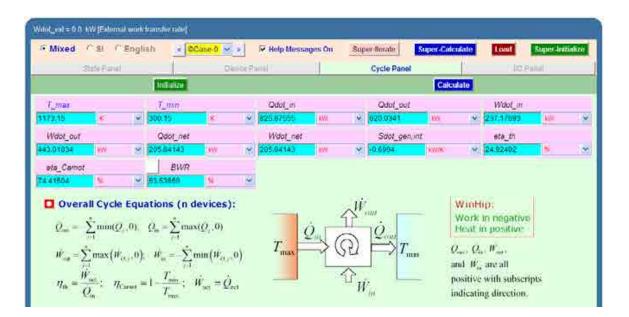
• Mixed C 81 C English	Cime 0 X >	Help Messages On	Super-Iterato	Super-Calculate	oad Super-Initialize
Elate Paret	Device Pane	el	Essis Radol		20(Parcel)
Initisiize	Dev(ce-D (5-7)	< >	Calculate	C Non-Mixing	Mixing Devic
ilitite Stale 6 🐱	CECHINI State-N	ult 👻	nt i iii State 7		State Null
Qdot	Wdat_ext	1	T_B	Sdot	pen )
187.00223 WW Y	0:0 evv	M 200	06947	(M) -0.44619	KWOK D
Jdol_net	Sdot_net				
187.00223 WW 19	-8 18200 KM/K	×			

16. For Device E: enter State 7 and State 9 for i1-state and e1-state respectively. Also, since there is only one stream, select Null state for i2-state and e2-state. And, Qdot = 0 since for this process, no heat transfer occurs. Hit Enter. We get:

Mixed C SI C English	Case-0 > P Help Message	es On Super-Iterate	Super-Calculate	oad Super Initialize
State Panel	Device Panel	Cicil Panal	1	NO-FIGHIEF
Nilatze	< Device-E17-0) / >	Calculate	C Non Mixing	Mixing Device
State:7	State-Null	State 9	*	State Null 💌
Qdol	Widot_ext	T_B	Stol	gen .
9 xw 🛛	205/84143 WW (M	25.0 Rep.1.	M. 0.04037	INNIK M

17. For Device F: enter State 9 and State 1 for i1-state and e1-state respectively. Also, since there is only one stream, select Null state for i2-state and e2-state. And, Wdot\_ext = 0 since for this process, no external work transfer occurs. Hit Enter and SuperCalculate. We get:

Mixed O'si C'English	< SCase-0 V > V Help Met	ssages On Super-Iterate	Super-Calculate	oad Super Initialize
HERE MADE	Device Panel	L. Sheet there		PRAY WHEEK
nitialize	Dovico-F (9-1) × >	Calculate	Non-Mixing	T Mixing Device
ISEInton State-9	17531111 State-Null 🥯	State-1	~	State-Null
Qdot	✓ Wdot_ext	✓ T_B	Sdot_g	jen i
120.0341 W. 🜱	0.0 eW	Performance Provide Pr	0.95776	KNUR.

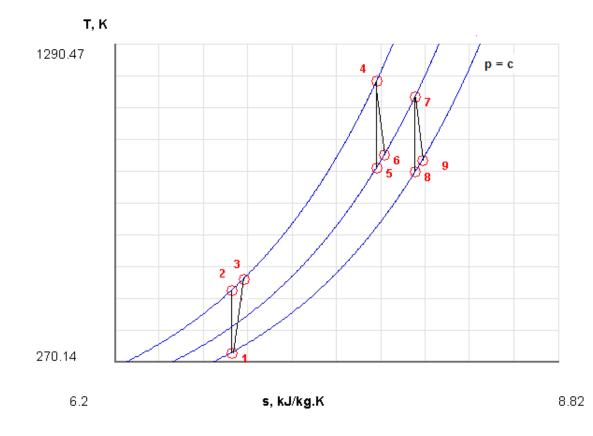


18. Now, go to cycle panel. It gives the major parameters of this cycle:

We observe that: Wdot\_net = 205.84143 kW = Power developed .... Ans.

And, thermal efficiency = eta\_th = 24.924% .... Ans.

19. From the Plots widget, choose T-s diagram, and we get:



### 20. And I/O panel gives the TEST code etc:

#~~~~~OUTPUT OF SUPER-CALCULATE

### # Daemon Path: Systems>Open>SteadyState>Specific>PowerCycle>PG-Model; v-10.ca08

#-----Start of TEST-code -----

States {

State-1: Air;

Given: { p1= 100.0 kPa; T1= 27.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; mdot1= 1.0 kg/s; }

State-2: Air;

Given: { p2= 600.0 kPa; s2= "s1" kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; mdot2= 1.0 kg/s; }

State-3: Air;



```
Given: { p3= "p2" kPa; T3= "T1+(T2-T1)/0.85" deg-C; Vel3= 0.0 m/s; z3= 0.0 m; mdot3= 1.0 kg/s; }
```

State-4: Air;

Given: { p4= "p3" kPa; T4= 900.0 deg-C; Vel4= 0.0 m/s; z4= 0.0 m; mdot4= 1.0 kg/s; }

State-5: Air;

```
Given: { T5= "T4-(T4-T6)/0.85" deg-C; s5= "s4" kJ/kg.K; Vel5= 0.0 m/s; z5= 0.0 m; mdot5= 1.0 kg/s; }
```

State-6: Air;

Given: { p6= "p5" kPa; T6= "T4-(T3-T1)" K; Vel6= 0.0 m/s; z6= 0.0 m; mdot6= 1.0 kg/s; }

State-7: Air;

Given: { p7= "p6" kPa; T7= 850.0 deg-C; Vel7= 0.0 m/s; z7= 0.0 m; mdot7= 1.0 kg/s; }

State-8: Air;

Given: { p8= "p1" kPa; s8= "s7" kJ/kg.K; Vel8= 0.0 m/s; z8= 0.0 m; mdot8= 1.0 kg/s; }

State-9: Air;

```
Given: { p9= "p8" kPa; T9= "T7-(T7-T8)*0.85" K; Vel9= 0.0 m/s; z9= 0.0 m; mdot9= 1.0 kg/s; }
```

}

Analysis {

Device-A: i-State = State-1; e-State = State-3; Mixing: true;

Given: { Qdot= 0.0 kW; T\_B= 25.0 deg-C; }

Device-B: i-State = State-3; e-State = State-4; Mixing: true;

Given: { Wdot\_ext= 0.0 kW; T\_B= 25.0 deg-C; }

Device-C: i-State = State-4; e-State = State-6; Mixing: true;

Given: { Qdot= 0.0 kW; T\_B= 25.0 deg-C; }

Device-D: i-State = State-6; e-State = State-7; Mixing: true;

Given: { Wdot\_ext= 0.0 kW; T\_B= 25.0 deg-C; }

Device-E: i-State = State-7; e-State = State-9; Mixing: true;

Given: { Qdot= 0.0 kW; T\_B= 25.0 deg-C; }

Device-F: i-State = State-9; e-State = State-1; Mixing: false;

Given: { Wdot\_ext= 0.0 kW; T\_B= 25.0 deg-C; }

}

#-----End of TEST-code -----

#-----Property spreadsheet starts

#	State	p(kPa)	T(K)	v(m^3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	100.0	300.2	0.8614	-84.13	2.01	6.893
#	2	600.0	501.0	0.2397	59.81	203.61	6.893
#	3	600.0	536.5	0.2566	85.22	239.18	6.962
#	4	600.0	1173.2	0.5611	541.38	878.06	7.747
#	5	232.99	895.1	1.1025	342.15	599.03	7.747
#	6	232.99	936.8	1.1539	372.03	640.88	7.793
#	7	232.99	1123.2	1.3834	505.55	827.88	7.975
#	8	100.0	881.8	2.5307	332.64	585.72	7.975
#	9	100.0	918.0	2.6346	358.58	622.04	8.015

#-----Property spreadsheet ends-----

#### # Cycle Analysis Results:

#	Calculated: T_max= 1173.15 K; T_min= 300.15 K; Qdot_in= 825.87555 kW;
#	Qdot_out= 620.0341 kW; Wdot_in= 237.17693 kW; Wdot_out= 443.01834 kW;
#	Qdot_net= 205.84143 kW; Wdot_net= 205.84143 kW; Sdot_gen,int= -0.6904 kW/K;
#	eta_th= 24.92402 %; eta_Carnot= 74.41504 %; BWR= 53.53659 %;

**Prob.2.28.** A gas turbine plant draws in air at 1.013 bar, 10 C and has a pressure ratio of 5.5. The max. temp in the cycle is limited to 750 C. Compression is conducted in an un-cooled rotary compressor having an isentropic efficiency of 82% and expansion takes place in a turbine with an isentropic efficiency of 85%. A heat exchanger with an efficiency of 70% is fitted between the compressor outlet and combustion chamber. For an air flow of 40 kg/s, find: (i) overall effcy. of the cycle, (ii) turbine output, (iii) air-fuel ratio if the calorific value of fuel used is 45.22 MJ/kg. [VTU – ATD – Jan. 2009]

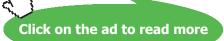


Hellmann's is one of Unilever's oldest brands having been popular for over 100 years. If you too share a passion for discovery and innovation we will give you the tools and opportunities to provide you with a challenging career. Are you a great scientist who would like to be at the forefront of scientific innovations and developments? Then you will enjoy a career within Unilever Research & Development. For challenging job opportunities, please visit www.unilever.com/rdjobs.



Dove





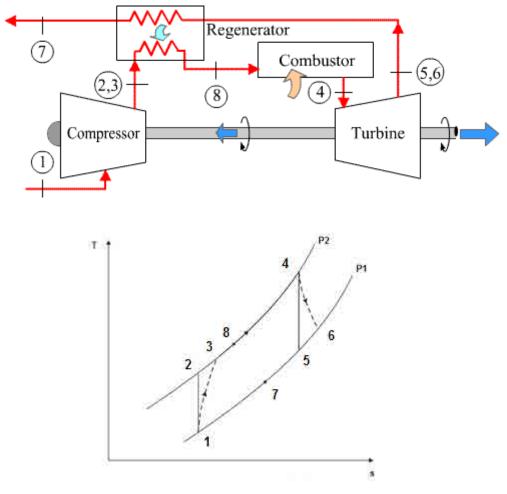


Fig. Prob.2.28 (a) and (b)

Process 1-2: Isentropic compression in Compressor

Process 1-3: Actual compression

Process 4-5: Isentropic expansion in Turbine

Process 4-6: Actual expansion in turbine

Process 3-8: heating in heat exchanger

Process 8-4: heat supply in combustion chamber

Process 6-7: cooling in heat exchanger

Working fluid: Air with const. sp. heat

#### **TEST Solution:**

We shall first do the calculations for air mass flow rate of 1 kg/s, and then it is quite easy to find out required quantities for an air flow rate of 40 kg/s.

#### Following are the steps:

Steps 1 and 2 are the same as for Prob.2.25.i.e. select 'Vapour Power and Gas Power cycles' daemon from the 'daemon tree' and, for material model chose PG model (i.e. const. sp. heat) and select air as the working substance.

3. Choose PG model (i.e. const. sp. heat), and select Air for working substance. Fill in the conditions for State 1, i.e. state at entry to compressor: p1= 1.013 bar, T1= 10 C, and mdot1 = 1 kg/s. Hit Enter. Immediately, all properties at State 1 are calculated:

• Mixed ( B)	CEngli	shi 🔄 ec	< × 0 aaa	₩ Help Message	is On	Super-Bern	do Super-Ca	siculate	Load	Soper-Initia	dize
State P	anel	1	.000000	16001		Exce.	EHRH!		10.0	11 1480	
CState 1		Galculate	No-Plots	• Initiatize	Î.	Terminine fi	ENIO CON	•D(65)	AP .		×
et et		4 . 71		ef		1					
.015	- 4P.	10.0	2-000	P.83217	m'54#	<del>2</del> 8.	1265	4	15.05241	Kikg.	Y
at		< Vell		1 21			el.		90		
83110 1010	8 (M)	0.8	MR2 (	× 0.0		M -96.	71265 V/M	s M	15,05241	8330	
int.		1 = 3		/ mdot1		- 1	Voldot1		AT.		
k.JA	g (41		k.Dkg	10	kip to	· 0.80	217 #34		80217 414	m/2	

4. For State 2: Enter p2 = 5.5 \* p1, s2 = s1 (for isentropic process 1-2), and mdot2 = mdot1. Hit Enter. We get:

R Mixed Cisi C	Englis	in 🦂 🔤	ase-0 (vi >	IF He	alp Message	s On	Super	-iteraté	Super Calcula	ite	Load	Super-Initial	ize
State Panel		1	1229058	Panel		li -	3	CERT PROPERTY			1.1997	1100011	
< SState 2 M +	Ĵ	Calculate	No-Plots	Y	Ininoisza	1	Formula	no Ennebor	No •Y	51	HI.	, 2	-
p2		T2			v2			v2			h2		
p1165 bar	9	187.90305	1995 G	¥ 0.23	749	m skg	*	31 15621	445	*	163 47221	Ramp.	2
32		✓ Vel2:		1	22			62			12		
ed NVKd X	1	0(0)	-15	× 00		in the	2	31,15621	12/10		163 42221	NJ/Rg:	
102		1000		1	mdat2			Volda	12		A2		
#J/lig	1		a.LWg		1.0.0	syn	*	0.23749	#255	v	23740.725	<b>#</b> 2.	17

For State 3: It represents the state after actual compression, taking in to account the isentropic effcy. of compressor. Enter p3 = p2, T3 = T1 + (T2 - T1) / 0.82 where 0.82 is the compressor effcy. and mdot3 = mdot1. Hit Enter. We get:

@ Mixed C	51 C.E	Engli	shi 🖃 🔹	Case-0 👻	PI PI	lelp Message	is On	Super	-Iterate	Super-Colculat	e	Load	Super-Initia	üze
Stat	e Panel			:Day	ka Pahul		li.	1	2506 Parmi	1		101	SIMI	
< CState-3	× >	ļ	Calculate	Tis	¥	Initiarue		Counter	ion Erdhilipet	TONO TOYES	i	Air		Ý
e3			- T3			163			83			h3		
4 <b>p</b> 2	QUT:	M	## <b>1</b> +( <b>1</b> 2: <b>T</b> 4)(	82 deg-C	M 03	675	m138g	v	59 137 18	8478g	$\mathbb{R}^{2}$	202,66065	A300);	- 8
53		-	V Total		1	- 23			- 113			- 12		
91277	ing N	.9	0.8	<b>151</b>	M 20	1	-m	٣	59.13718	using .	4	202.65055	simg.	
8611			36(8)		1	mdot3			Valdo	13		A3		
1.0	k Jikg	~	V	K3/Rd	1941	tiobit 1	ka/e	×.	0.2576	101519	100	25760.277	11/2:	
MAR			RJ			التورة			5.43			- 163		
6 87	agrimat		0 28699	KU59.K	· · · ·	0348	SURD.N		0.71851	siAg K.	*	1 40054	Unm.ess.	

6. For State 4: we have: p4 = p3. T4 = 750 C,

Now, to find T4:

Heat supplied by fuel results in increase of enthalpy of the air+fuel mixture reaching the Turbine inlet:

$$\begin{split} \mathbf{m_{f}} \cdot \mathbf{CV} &= \left[ \left( \mathbf{m_{a}} + \mathbf{m_{f}} \right) \cdot \mathbf{cp} \cdot (\mathbf{T4} - \mathbf{T8}) \right] = \left( \mathbf{m_{a}} + \mathbf{m_{f}} \right) \cdot (\mathbf{h4} - \mathbf{h8}) \\ \text{i.e.} \qquad \mathbf{CV} &= \left( \frac{\mathbf{m_{a}}}{\mathbf{m_{f}}} + 1 \right) \cdot (\mathbf{h4} - \mathbf{h8}) \end{split}$$

i.e. 
$$\frac{m_a}{m_f} = \frac{CV}{(h4 - h8)} - 1$$
 ...A/F ratio

And: 
$$mdot4 = (m_a + m_f) = m_a \cdot \left(1 + \frac{m_f}{m_a}\right) = mdot1 \cdot \left(1 + \frac{h4 - h8}{CV - h4 + h8}\right)$$

· Mixed CBI CEng	li50 e 90	asu 0 🔹 >	✓ Help Messag	es On	Super-Iterate	Super-Calculate	Load	Super-Initialize
State Panel		170411113	Panel		COSSICENSE .		HD-F	taria) I
< OState-4 × >	Calculate	T-s	v Interact	. N	mmuñco Enthalpys	No 💌 Yes	Air	<u>.</u>
p4	<ul> <li>✓ T4.</li> </ul>		yd		U.L.		h4	
an ar	750.0	1960-G	× 0.52702	in lug	✓ 433 0020	ang 🔗	777 53314	ing g
sd	< Net.		1 26		ed.		1 100	
KINGK Y	0.0	er/u	00	A	433 8029	sally 🤤	727 53314	1.3/Ng
polit	224		/ mdot4		Voldot	4	A4	
		#J/kg	the second se	kyle.	and the second s	11 San	63253 85	112

#### Enter these values for State 4, and hit Enter. We get:

7. For State 5: Enter s5 = s4, mdot5 = mdot4, and p5 = p1.Hit Enter. We get:

Mixed CSI CE	nglish	< CCase-0 V	Relo Mer	sades On	Super-Iterate	Super-Calculate	Load	Super-Initializ
State Panel	_	Can	662 FUHH	it.	Gran Bunkt		103	66000
< ©State-5. ♥ >	Chicu	Inte T-s	<ul> <li>International</li> </ul>	18126	Commission Collimate	No Yes	All 1	e.
p5		75	15		u5		h5	
p1 ter.	2 355.20	486 0ep-C	Mit 1.78015	m#389	* 151 02922	k//kp	931.3580	\$780
\$5	1	1465	1 23				1	
sa kung s	~ 0.0	-	~ 22		× 151.02922	lking.	~ 331,3586	1.00g
p6(8	200	E	🧭 md	of5	Volde	ot5	A5	
ku/Ap		RURD	M middl4	N(p(p))	1.79879	(ICON)	¥ 179878.56	

8. For State 6: i.e. actual exit of turbine: Enter p6 = p5,  $T6 = T4 - 0.85^{*}(T4 - T5)$  where 0.85 is the isentropic effcy of turbine. And mdot6 = mdot5. Hit Enter. We get:

• Mixed	CSI CI	ingli	sn  ec	ase 0 🛩 1	M Hu	lp Messages On	Super-Iterate	Super-Calculate	Load	Super-Initialize
1	itate Panel			12Nini	OFFINALL		CRIPTIN		100	PARAT
C State	8 M F		Calculate	T-S		Initialize	Pormation) Collision:	No 💌 Yes	an .	~
205			10			vő	00		115	
19	SAL:	X	-1440.857(14+1	deg-C	M. 1.94	92	193.46027	MAD: 🗙	390.7848	N/R0:
56			1 . 1019			20			1.10	
72148	LIAGK	~	0.0	and .	~ 06	-	Y 183 46027	uug 🛩	290.7848	ALD(g)
blug			305		1	mdot6	Voldo		A6	
	NJ/kg	×		hilling ;	- Mi Find	iti igis	91 106831	mi'āle 🖂	1968312	m12:

9. For State 7: p7 = p1, mdot7 = mdot4.

To find h7: For the heat exchanger, we have:

 $h^{0} - h^{3} = mdot6 \cdot (h^{0} - h^{7})$  ...for air flow of 1 kg/s through compressor

i.e.  $h7 = h6 - \frac{h8 - h3}{mdot6}$ 

Enter these values as shown below, and hit Enter. We get (after SuperCalculating later):

	SI CE	ngin	FRI 🤇 🖂 OCa	19-0 M	Ir Help Mes	sages On	Super-liera	ite St	aper Calcula	te.	Load	Super-hittia	\$20
Str	ne Panel		1	O.nece	DMM17	1	I DIGH	(Unnin)			100	Canas.	
< BState-7	<b>X</b> >		Calculate	T-s	× 100	LAUZA:	y consistent i	in ea i	No 🔹 re	8	Ar		¥
pT			17	-	V7		I.	ut.	_		1. 10		
ř1	100 ·	14	358 76896	den C	+ 1.75024	with the	~ 143	58078	kang -		16-08-4-1	anda watu -	
s7.			· VINT		1 22			e7			17		
63677	k20.g.X	1	0.0	mary -	× 2-0	111	153	58078	100		34.93216	x190	
2577			165/7		- mdo	017		Voldot7			A7		
	KJ/Kg	1961		kuko .	1.017590	82/82	· 1.81	t.	intrata)		181100.03	1012	



Discover the truth at www.deloitte.ca/careers



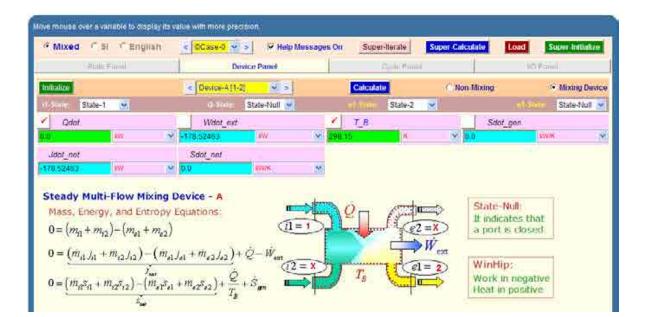


Download free eBooks at bookboon.com

10. State 8. i.e. exit of high pressure stream from heat exchanger. Enter p8 = p2, mdot8 = mdot4. And, T8 = T6 - 0.7 \* (T6 - T3), where 0.7 is the heat exchanger effcy. Hit Enter. We get:

Mixed	OSI: CE	ingtie	sit 🧃 🗰	icar-0 v >		🕅 Help Message	is On	Supe	istleri	abi	Super-Calculat	ie:	Load	Super-Initia	ili di k
14	State Panel		1	Tites	Ð	HHT	1		Taye	Tem	1		190	T:::::	
< Østate	8 4 >		Calculate	T-s	×	Initalize		1910119		in in	No - Tes		1 (hu		×
× p8			18			vB			_	68			18		
92	11a	×	-18-0.7*(16-13	deq-C-	×	0.28657	ir 144	×	99.	1341	8.UKg	×	259.00784	king:	
88			Vel0			1 28				el			18		
01072	MAg K	×.	0.0	1958	۲	0.0	111		00.4	4341	kaNg (	1.8	259 00784	64Ap	
343			203			< mdot8			1	Voldos	8		AS		
	8.14g	~		A.195	¥.	1.011596	ALC: N	~	0.20	199	-m <sup>1</sup> Na	÷	20909.533	And C	
MME			RU			80,08			.0	UNB.			k8.		
8.97	No/kmci :	12	0.28699	KINGK	×	1.00348	MARAN	×	8.71	1661	RERAIN	1.8	1.40064	VritLess	

11. Now, go to Device panel. For device A, enter State 1 and State 2 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And Qdot1 = 0 since in this process is isentropic. Hit Enter. We get:



12. Similarly for Device B: enter State 8 and State 4 for i1-state and e1-state respectively. Also, since there is only one stream, select Null state for i2-state and e2-state. And, Wdot\_ext = 0 since for this process, no external work transfer occurs. Hit Enter. We get:

@ Mixed C:SI C English	< OCase-0 VI > 97 H	elp Messages On	Super-Iterate	Super Calculate	Load Super-Initialize
STATE YOOM!	Device Panel		CALCULATION OF		BARROOK.
Initialize	Oovice B (B 4)	>	Calculate	T Non-Mixing	- Mixing Device
IlSimo State-6	state-tauti	<b>v</b>	state-4	<b>u</b>	State-t4uit 👻
Qdot	Wdot_ext	1	T_8	Sdd	ot_gen
473.94626	000 ·····	× 299.1		-0.97675	-
Jdot_net	\$dot_net				
473.04626 NW 5	0.60996	30			

13. And, for Device C: enter State 4 and State 6 for i1-state and e1-state respectively. Also, since there is only one stream, select Null state for i2-state and e2-state. And, Qdot = 0 since for this process, no external heat transfer occurs. Hit Enter. We get:

" Mixed C SI C English	< Case-0 • S	🖗 Help Messages C	Dn Super-Iterate	Super Calculate	Load Super-Initia	lizie
Diale Fisito)	Device	Panel	TRICEPSIII	()	100953(0)	
Initiatize	Dirace-C [4-6]	<b>x</b> >	Calculate	C Noo-Mixing	(* Mixing D	evici
noture State-4 💌	Ursum Sta	ate-Null 🐱	State-9	3	State-Nu	u 🛥
Qdot	Wdot_ext		T_8	Sdo	(_gen	
M	340.0733	w 💉 🎽	18 16 K.	M 0.09133	NVOK.	
Jdot net	Sdot net					
340.2733 WW V	0.09133	Wilk A				

14. And, for Device D: This is the heat exchanger. Enter State 3 and State 8 for i1-state and e1-state respectively. Also, select state 6 for i2-state and state 7 for e2-state. And, Qdot = 0 since for this heat exchanger, no external heat transfer occurs. Hit Enter. We get:

Mixing Devi State 7	16	Non Mixing		Cjell Emili		1	te Panel	De	11	Panis	
and the second se		Non Mixing	47 N		Provide State		-				
State-7				2	Calculat		5.71 × >	< Device-D (3.)	1		malizo
al annatorial a	(China)			State 8		i i	State-8 🔥	si states		M	State-3
	of gen	Sde			TB			Wdot_ext			Qdat.
KWINC'S S		0.11137	~	ж	8.15		100	-3.3825	~	WV.	0
kwae :	the state of the s	- terminal and the second seco	~	×	T B 215		W.	and the second second second	~	NW .	Qdof Qdof net

15. For Device E: enter State 7 and State 1 for i1-state and e1-state respectively. Also, since there is only one stream, select Null state for i2-state and e2-state. And, Wdot\_ext = 0 since for this process, no work transfer occurs. Hit Enter. We get:

" Mixed C SI C English	< CCase-0 V >	🖓 Help Messages On	Super-Iterate	Super Calculate	Load Super Initialize
Daatte Charlest	Device P	onel	Ojchi Ramil		10 Curel
innaize	Cevice-E (7-1)	× ×	Calculate	C:Non-Mixing	Mixing Device
1 State 7 😹	State	-Nult 😁	State-1	9	State Null
Qdot	Wdot_ext	× 1	T_B	Sdo	it_gen
353.85844 WW	0.0	W 🔀 🔀	15 N	× 0.29274	IWWK T
Jdot_net	Sdot_net				
15186844 WW 🛩	0.09414	WK 🖌			

# Grant Thornton— $a^{\text{REALLY}}$ great place to work.

We're proud to have been recognized as one of Canada's Best Workplaces by the Great Place to Work Institute<sup>™</sup> for the last four years. In 2011 Grant Thornton LLP was ranked as the fifth Best Workplace in Canada, for companies with more than 1,000 employees. We are also very proud to be recognized as one of Canada's top 25 Best Workplaces for Women and as one of Canada's Top Campus Employers.



Priyanka Sawant Manager



Audit • Tax • Advisory www.GrantThornton.ca/Careers



© Grant Thornton LLP. A Canadian Member of Grant Thornton International Ltd



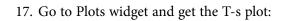
**GrantThornton** 

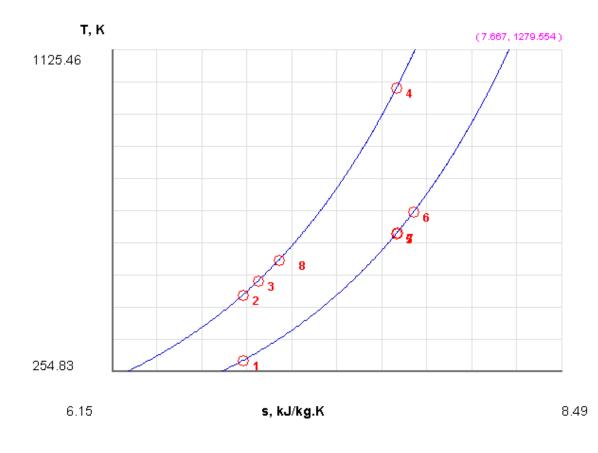
		sh < 🕅	Case-0 - P		Help Messa	ges On	Sup	er-Iterate	uper Calcula	ate	Load	Super Ini	iakze
: 314Hz	FERRICA CONTRACT		Divis	R FIRM				Cycle Panel		-	101	14040	_
		Induce							Calcula				
T_max		T_min			Odot_in			Qdot_out			Wdot_in		
023.15	8 M	283.15	<b>8</b> 0	M 42	3.04626	.W	×	353.06844	8W	184	181.90714	494	- 28
Wdot_out		Qdot_net			Vdot_net			Sdot_gen,int	6		eta_th		
40.2733	w ×	119 1776	#W	× 15	3.36613	WV.	1	0.48131	MWK	~	33.47794	8	
eta_Carnot		BWR											
2.32566		53 459 13		~									
Overall C	Cycle Equ		evices):		T <sub>max</sub> (	2	,₩ ĵ		W		p: n negativi i positivo	è	

16. Now, go to cycle panel. It gives the major parameters of this cycle:

Note that Net work = Wdot\_net = 158.366 kW/kg of air ....Ans.

Thermal efficiency = eta\_th = 33.478% ... Ans.





#### 18. I/O panel gives the TEST code etc:

#### #~~~~OUTPUT OF SUPER-CALCULATE

#	Daemon Path: Systems>Open>SteadyState>Specific>PowerCycle>PG-Model; v-10.ca08
#	Start of TEST-code
States	{
	State-1: Air;
	Given: { p1= 1.013 bar; T1= 10.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; mdot1= 1.0 kg/s; }
	State-2: Air;
}	Given: { p2= "p1*5.5" bar; s2= "s1" kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; mdot2= "mdot1" kg/s;
	State-3: Air;
	Given: { p3= "p2" bar; T3= "T1+(T2-T1)/0.82" deg-C; Vel3= 0.0 m/s; z3= 0.0 m; mdot3=

```
"mdot1" kg/s; }
```

```
State-4: Air;
```

```
Given: { p4= "p3" bar; T4= 750.0 deg-C; Vel4= 0.0 m/s; z4= 0.0 m; mdot4= "mdot1*(1+(h4-h8)/ (45220-h4+h8))" kg/s; }
```

State-5: Air;

Given: { p5= "p1" bar; s5= "s4" kJ/kg.K; Vel5= 0.0 m/s; z5= 0.0 m; mdot5= "mdot4" kg/s; }

State-6: Air;

```
Given: { p6= "p1" bar; T6= "T4-0.85*(T4-T5)" deg-C; Vel6= 0.0 m/s; z6= 0.0 m; mdot6= "mdot5" kg/s; }
```

State-7: Air;

```
Given: { p7= "p1" bar; h7= "h6-(h8-h3)/mdot6" kJ/kg; Vel7= 0.0 m/s; z7= 0.0 m; }
State-8: Air;
Given: { p8= "p2" bar; T8= "T6-0.7*(T6-T3)" deg-C; Vel8= 0.0 m/s; z8= 0.0 m; }
```

#### Analysis {

```
Device-A: i-State = State-1; e-State = State-2; Mixing: true;
```

```
Given: { Qdot= 0.0 kW; T_B= 298.15 K; }
```

Device-B: i-State = State-8; e-State = State-4; Mixing: true;

Given: { Wdot\_ext= 0.0 kW; T\_B= 298.15 K; }

Device-C: i-State = State-4; e-State = State-6; Mixing: true;

Given: { Qdot= 0.0 kW; T\_B= 298.15 K; }

Device-D: i-State = State-3, State-6; e-State = State-8, State-7; Mixing: false;

```
Given: { Qdot= 0.0 kW; T_B= 298.15 K; }
```

Device-E: i-State = State-7; e-State = State-1; Mixing: true;

Given: { Wdot\_ext= 0.0 kW; T\_B= 298.15 K; }

}

#-----End of TEST-code -----

#	State	p(kPa)	T(K)	v(m^3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	101.3	283.2	0.8022	-96.31	-15.05	6.831
#	2	557.15	461.1	0.2375	31.16	163.47	6.831
#	3	557.15	500.1	0.2576	59.14	202.66	6.913
#	4	557.15	1023.2	0.527	433.9	727.53	7.631
#	5	101.3	628.4	1.7802	151.03	331.36	7.631
#	6	101.3	687.6	1.9479	193.46	390.78	7.721
#	7	101.3	631.9	1.7902	153.58	334.93	7.637
#	8	557.15	556.3	0.2866	99.43	259.1	7.02

#### *#*-----Property spreadsheet starts:

#-----Property spreadsheet ends-----

#### # Cycle Analysis Results:

#	Calculated: T_max= 1023.15 K; T_min= 283.15 K; Qdot_in= 473.04626 kW;
#	Qdot_out= 353.86844 kW; Wdot_in= 181.90714 kW; <b>Wdot_out= 340.2733 kW;</b>
#	Qdot_net= 119.1778 kW; Wdot_net= 158.36613 kW; Sdot_gen,int= -0.48131 kW/K;
#	eta_th= 33.47794 %; eta_Carnot= 72.32566 %; BWR= 53.45913 %;



Low-speed Engines Medium-speed Engines Turbochargers Propellers Propulsion Packages PrimeServ

The design of eco-friendly marine power and propulsion solutions is crucial for MAN Diesel & Turbo. Power competencies are offered with the world's largest engine programme – having outputs spanning from 450 to 87,220 kW per engine. Get up front! Find out more at www.mandieselturbo.com

Engineering the Future – since 1758. **MAN Diesel & Turbo** 





Download free eBooks at bookboon.com

#\*\*\*\*\*CALCULATE VARIABLES: Type in an expression starting with an '=' sign ('= mdot1\*(h2-h1)', '= sqrt(4\*A1/PI)', etc.) and press the Enter key)\*\*\*\*\*\*\*\*

#### #A/F ratio:

=(45220 - h4 + h8) / (h4 - h8) = **95.534...** Ans.

#### **#Turbine output:**

=mdot4\*(h4 - h6) = 340.273 kW/ kg of air ...(same as Wdot\_out in 'Cycle Analysis esults, above)

#### Then, for 40 kg/s of air:

Tubine output = 340.273 \* 40 = 13610.92 kW ... Ans.

#### 2.5 References:

- 1. *Yunus A. Cengel & Michael A. Boles*, Thermodynamics, An Engineering Approach, 7<sup>th</sup> Ed. McGraw Hill, 2011.
- 2. Sonntag, Borgnakke & Van Wylen, Fundamentals of Thermodynamics, 6<sup>th</sup> Ed. John Wiley & Sons, 2005.
- 3. *Michel J. Moran & Howard N. Shapiro*, Fundamentals of Engineering Thermodynamics, 4<sup>th</sup> Ed. John Wiley & Sons, 2000.
- 4. P.K. Nag, Engineering Thermodynamics, 2<sup>nd</sup> Ed. Tata McGraw Hill Publishing Co., 1995.
- 5. *R.K. Rajput*, A Text Book of Engineering Thermodynamics, Laxmi Publications, New Delhi, 1998
- 6. Domkunndwar et al, A course in Thermal Engineering, Dhanpat Rai & Co., New Delhi, 2000
- 7. *HIH Saravanamutto, G.F.C. Rogers & H. Cohen*, Gas Turbine Theory, 5<sup>th</sup> Ed., Pearson Ed. Ltd., 2001.

## 3 Vapour Power Cycles

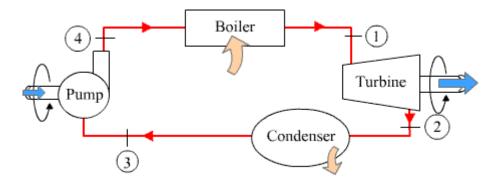
#### Learning objectives:

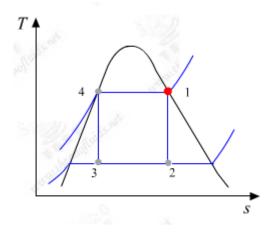
- 7. In this chapter, 'Vapour Power cycles' are analyzed with particular reference to Rankine cycle and its variations, used in Steam Power Plants.
- 8. Cycles dealt with are: Ideal Rankine cycle, Practical Rankine cycle with the isentropic efficiencies of turbine and pump considered, Reheat Rankine cycle (with both ideal and actual processes), Regenerative Rankine cycle and Reheat-Regenerative Rankine cycle.
- 9. Several useful Mathcad Functions are written for properties of steam in superheated and two-phase regions, since Mathcad does not have built-in Functions for steam, and are used in solving problems.
- 10. Also, many useful Functions/Procedures are written in EES for different variations of Rankine cycle.
- 11. Problems from University question papers and standard Text books are solved with Mathcad, EES and TEST.

#### 3.1 Definitions, Statements and Formulas used[1-7]:

While analyzing the following cycles, quantities of interest are: heat supplied in boiler ( $q_{in}$ , in kJ/kg), heat rejected in condenser ( $q_{out}$ , in kJ/kg), work output of turbine ( $w_t$ , in kJ/kg), work required by pump ( $w_{pump}$ , in kJ/kg), net work ( $w_{net}$ , in kJ/kg), thermal efficiency ( $\eta$ ), Specific Steam consumption (SSC, in kg/kWh), and work ratio.

#### 3.1.1 Carnot cycle for steam:





#### For Carnot cycle:

Process 1-2: Isentropic expansion in turbine

Process 2-3: Isothermal heat rejection in condenser

Process 3-4: Isentropic compression in pump

Process 4-1: Isothermal heat addition in boiler

## **XK RBS** Group

# CAREERKICKSTART

### An app to keep you in the know

Whether you're a graduate, school leaver or student, it's a difficult time to start your career. So here at RBS, we're providing a helping hand with our new Facebook app. Bringing together the most relevant and useful careers information, we've created a one-stop shop designed to help you get on the career ladder – whatever your level of education, degree subject or work experience.

And it's not just finance-focused either. That's because it's not about us. It's about you. So download the app and you'll get everything you need to know to kickstart your career.

So what are you waiting for?

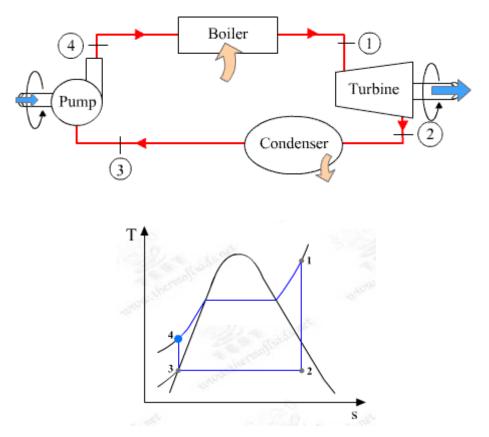
Click here to get started.



#### Then, per unit mass of steam circulating, we have, in units of kJ/kg:

$$q_{in} := h1 - h4$$
 $\eta_{carnot} = \frac{T1 - T2}{T1} = 1 - \frac{q_{out}}{q_{in}}$ With temp in Kelvin $q_{out} := h2 - h3$  $\eta := \frac{w_{net}}{q_{in}} \cdot 100$  $w_T := h1 - h2$  $SSC := \frac{3600}{w_{net}}$ Work Ratio: $WR := \frac{w_{net}}{w_T}$ 

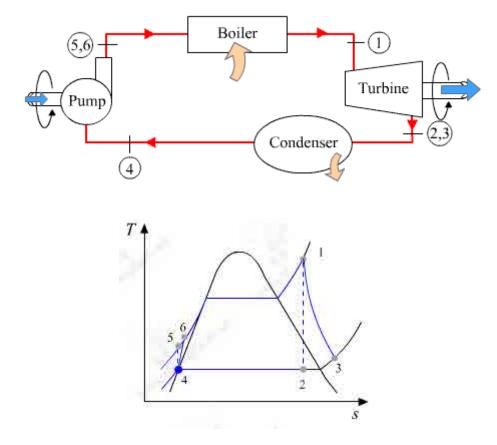
#### 3.1.2 Ideal Rankine cycle for steam:



#### Here, we have, per kg of steam circulating:

$q_{in} := h1 - h4$	Pump work: (with sp. vol = vf3 in m^3/kg, P1, P2 in bar):
$q_{out} := h2 - h3$	$w_p := vf_3 \cdot (P1 - P2) \cdot 10^2  kJpump work$
$w_T := h1 - h2$	$h4 := h3 + w_p$
$\mathbf{w}_{net} \coloneqq \mathbf{w}_T - \mathbf{w}_p$	$SSC := \frac{3600}{w_{net}}$
$\eta := \frac{w_{net}}{q_{in}} \cdot 100$	Work Ratio: WR := $\frac{w_{net}}{w_T}$

#### 3.1.3 Actual Rankine cycle for steam:



Here:

Process 1-2: Ideal isentropic expansion in turbine

Process 1-3: Actual expansion in turbine

Process 4-5: Ideal isentropic compression in pump

Process 4-6: Actual compression in pump

 $\begin{aligned} \eta_{turb} &= \frac{h1 - h3}{h1 - h2} \\ \eta_{pump} &= \frac{h5 - h4}{h6 - h4} \\ q_{in} &= h1 - h6 \\ q_{out} &= h3 - h4 \\ w_T &= h1 - h3 \end{aligned} \qquad \begin{array}{l} \text{Pump work, w_p_ideal (with sp. vol = vf3 in m^3/kg, P1, P2 in bar), in kJ/kg.} \\ w_p_ideal &= vf4 \cdot (P1 - P2) \cdot 10^2 \quad kJ/kg \\ h5 &= h4 + w_p_ideal \quad h6 = h4 + \frac{(h5 - h4)}{\eta_{pump}} \quad w_{p_actual} = h6 - h4 \\ \eta &= \frac{w_{net}}{q_{in}} \cdot 100 \\ ssc &= \frac{3600}{w_{net}} \quad kg/kWh \end{aligned}$ 

## ORACLE

### Be BRAVE enough to reach for the sky

Oracle's business is information - how to manage it, use it, share it, protect it. Oracle is the name behind most of today's most innovative and successful organisations.

Oracle continuously offers international opportunities to top-level graduates, mainly in our Sales, Consulting and Support teams.

If you want to join a company that will invest in your future, Oracle is the company for you to drive your career!

## https://campus.oracle.com

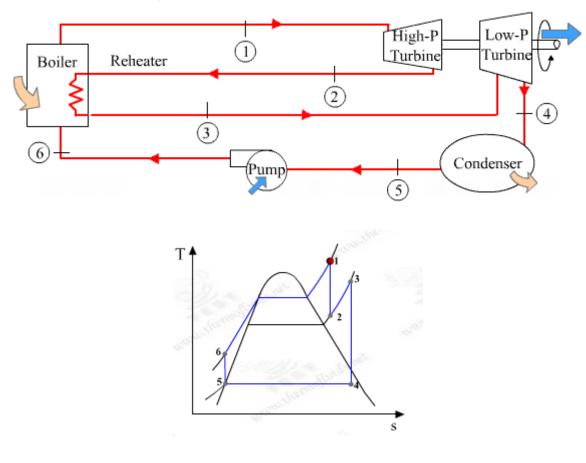


#### **ORACLE IS THE INFORMATION COMPANY**



Click on the ad to read more

Download free eBooks at bookboon.com



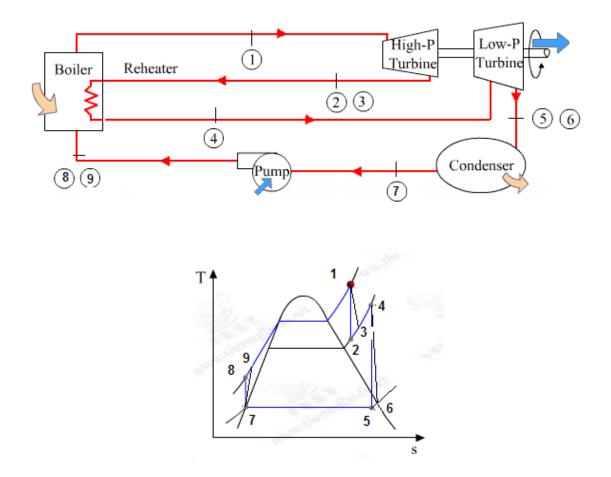
#### 3.1.4 Reheat Rankine cycle, with ideal processes for steam:

For this case, we have:

 $\begin{array}{ll} Q_{in} := (h1 - h6) + (h3 - h2) & \eta := \frac{W_{net}}{Q_{in}} \cdot 100 \\ Q_{out} := h4 - h5 & SSC := \frac{3600}{W_{net}} \\ W_P := vf5 \cdot (P6 - P5) \cdot 10^2 \quad kJ/kg & Work Ratio: WR := \frac{W_{net}}{W_T} \\ h6 := h5 + W_P & Work Ratio: WR := \frac{W_{net}}{W_T} \end{array}$ 

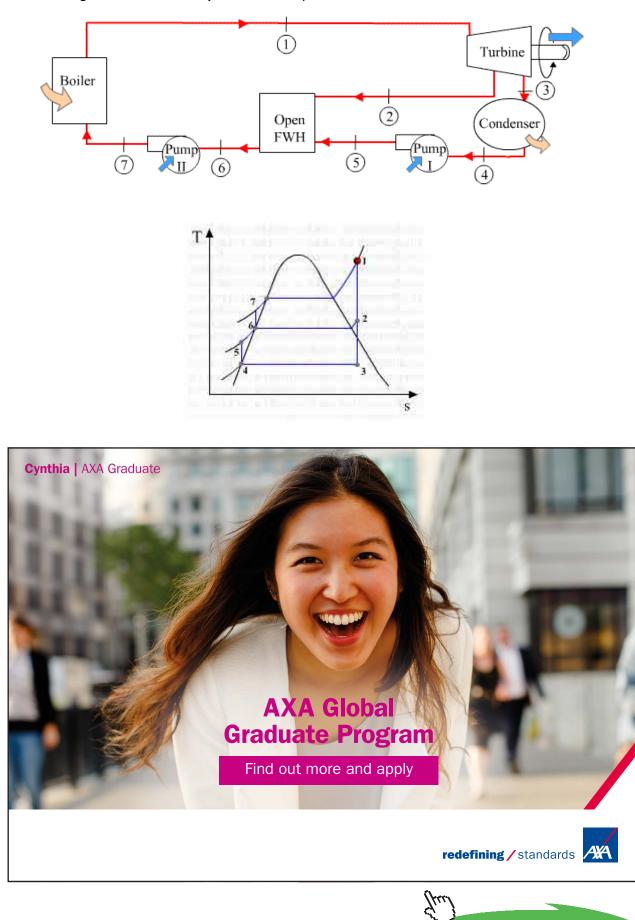
 $W_{net} := W_T - W_P$ 

#### 3.1.5 Actual, Reheat Rankine cycle for steam:



#### Various parameters are calculated as:

$q_{in} = (h1 - h9) + (h4 - h3)$	$\eta_{\text{pump}} = \frac{h8 - h7}{h9 - h7}$
$q_{out} = h6 - h7$	$\eta_{turb1} = \frac{h1 - h3}{h1 - h2}$
$w_{turb} = (h1 - h3) + (h4 - h6)$	$\eta_{turb2} = \frac{h4 - h6}{h4 - h5}$
$h8 = h7 + vf7 \cdot (P1 - P5) \cdot 10^2$	
$w_p = h9 - h7$	$\eta = \frac{W_{net}}{Q_{in}} \cdot 100$
$w_{net} = W_{turb} - w_p$	ssc - 3600
Work Ratio: WR = $\frac{w_{net}}{w_{turb}}$	$SSC = \frac{3600}{W_{net}}$



#### 3.1.6 Regenerative Rankine cycle, with ideal processes for steam:

Download free eBooks at bookboon.com

Click on the ad to read more

#### Various parameters are calculated as:

$q_{in} = h1 - h7$	$y = \frac{h6 - h5}{h2 - h5}$
$q_{out} = (h3 - h4) \cdot (1 - y)$	$h7 = h6 + vf6 \cdot (P7 - P6) \cdot 10^2$
$w_T = (h1 - h2) + (h2 - h3) \cdot (1 - y)$	$h5 = h4 + vf4 \cdot (P5 - P4) \cdot 10^2$
$wp_1 = (h5 - h4) \cdot (1 - y)$	$\eta = \frac{w_{net}}{q_{in}} \cdot 100$
wp2 = h7 - h6	$SSC = \frac{3600}{W_{net}}$
$\mathbf{w}_{net} = \mathbf{w}_T - \left(\mathbf{w}_{P1} + \mathbf{w}_{P2}\right)$	Work Ratio: WR = $\frac{w_{net}}{w_{net}}$
	wT

#### 3.1.7 Actual, Regenerative Rankine cycle for steam:

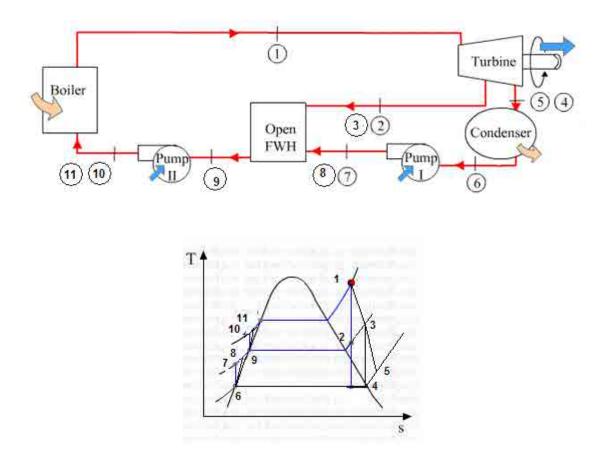


Fig.Prob.3.3.11 (a) Actual regenerative Rankine cycle with one open FWH, and (b) T-s diagram

#### Various quantities are calculated as:

$y = \frac{h9 - h8}{h3 - h8}$
$h7 = h6 + vf6 \cdot (P7 - P6) \cdot 10^2$
$h10 = h9 + vf9 \cdot (P10 - P9) \cdot 10^2$
$\eta = \frac{w_{net}}{q_{in}} \cdot 100$
$SSC = \frac{3600}{w_{net}}$
Work Ratio: WR = $\frac{w_{net}}{w_T}$

#### 3.2 Problems solved with Mathcad:

#### Note:

Mathcad does not have built-in functions for Water/Steam. So, generally, while solving problems on Rankine, cycle which uses Water/Steam as working substance, we have to refer to steam tables often to get properties of water/steam at various state points.

However, in our case, first, along with Mathcad, we shall use the *free* software SteamTab of M/s ChemicaLogic to get properties of water/steam.

For more information on SteamTab, see Chapter 1 of Part-I of the *free* e-book "**Basic Thermodynamics: Software Solutions**", by the same author, available from <u>www.bookboon.com</u>.

**Next, we shall develop few simple Mathcad Functions** based on published Steam Tables (Ref: TEST software, <u>www.thermofluids.net</u>). These Functions use the built-in linear interpolation function 'linterp' to get properties from the Tables.

**Prob.3.2.1** A steam power plant works on Rankine cycle between pressure ratio 20 bar and 0.05 bar. Steam supplied to the turbine is dry, saturated. Find thermal effcy., work ratio and Specific Steam Consumption (SSC). What would be the efficiency and work ratio in case of Carnot cycle operating in the same pressure limits? [M.U.]

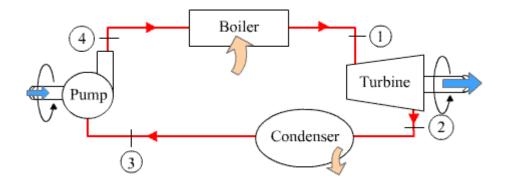


Fig.Prob.3.2.1 (a).Schematic diagram of simple, ideal Rankine cycle

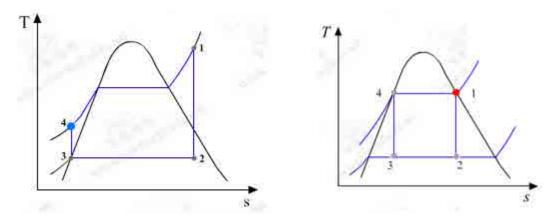


Fig.Prob.3.2.1 (b) and (c).T-s diagram of simple, ideal Rankine cycle, and of Carnot cycle

#### Mathcad Solution:

Fig.(a) above shows the schematic diagram, and fig. (b) shows the ideal Rankine cycle on the T-s diagram. (Ref. [7] for figures).

We need properties of Water/Steam at the salient points, and we shall use SteamTab of ChemicaLogic to get the properties.

We have:

**State 1: Inlet to turbine**: P1 = 20 bar, T1 = Tsat, sat. vap.

From 'Saturated – vapor' Tab of SteamTab, for sat. vap. we get: T1 = 212.377 C, h1 = 2798.29 kJ/kg, s1 = 6.33901 kJ/kg.C

NA	11.62	
Independent Variable:	- Units:	Close
Temperature Value, bar 20	If Metric/S1	
Pressure	C English	Calculate
Phase:		
Vapor C Liquid C Two	phase	
Property	Value Unit	~
emperature	212.377 °C	10-
Pressure	20 bar	
iteam quality	100 %	
/olume	0.099585 m <sup>3</sup> /	
Density	10.0417 kg/	
Compressibility factor	0.888836 dime	
Inthalpy	2798.29 kJ/	
intropy	6.33901 kJ/i	
telmoltz free energy	-478.638 kJ/l	-
nternal energy	2599.12 kJ/	
	-279.468 kJ/ł	(g
Sibbs free energy leat capacity at constant volume	2.15849 kJ/	ka.°C) 🛛 🚿



#### **Masters in Management**

Designed for high-achieving graduates across all disciplines, London Business School's Masters in Management provides specific and tangible foundations for a successful career in business.

This 12-month, full-time programme is a business qualification with impact. In 2010, our MiM employment rate was 95% within 3 months of graduation\*; the majority of graduates choosing to work in consulting or financial services.



As well as a renowned qualification from a world-class business school, you also gain access to the School's network of more than 34,000 global alumni – a community that offers support and opportunities throughout your career.

For more information visit **www.london.edu/mm**, email **mim@london.edu** or give us a call on **+44 (0)20 7000 7573**.

\* Figures taken from London Business School's Masters in Management 2010 employment report

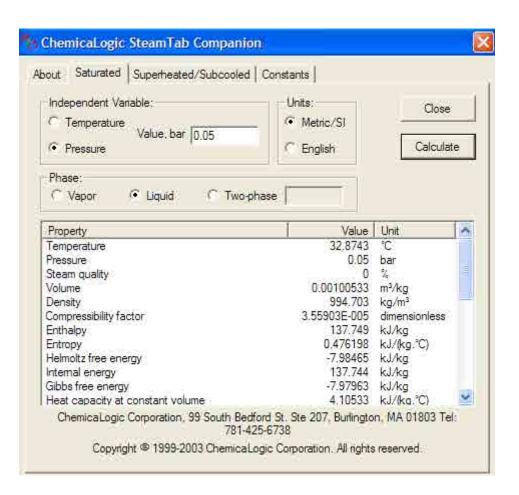


171 Download free eBooks at bookboon.com **State 2: Exit of turbine and inlet to condenser**: P2 = 0.05 bar, s2 = s1 = 6.33901 kJ/kg.C. Entering these values, we get from **'Superheated/Subcooled' Tab** of SteamTab:

Input: Pressure	Units:	a	ose
Pressure 0.05	Netric/SI		
Entropy	C English	Calc	culate
Property	Value	Unit	
Temperature	32.8743	°C	
Pressure	0.05	bar	
Steam quality	74.0479	0	
Volume		m³/kg	
Density	0.0479137	kg/m³	
Compressibility factor	0.738866		
Enthalpy		kJ/kg	
Entropy		kJ/(kg.℃)	100
Helmoltz free energy		kJ/kg	
ntemal energy		kJ/kg	
Gibbs free energy	-7.97962		
Heat capacity at constant volume	N/A	kJ∕(kg.℃)	
Heat capacity at constant pressure		, kJ/(kg.°C)	
Speed of sound		m/s	- 27
Coefficient of thermal expansion	N/A	. 1/°C	~

We get: we get: T2 = 32.8743 C, h2 = 1931.91 kJ/kg, s2 = 6.33901 kJ/kg.C, quality, x2 = 74.0479% = 0.7405.

**State 3: Exit of condenser and inlet to Pump:** P3 = 0.05 bar, sat.liq. Entering these values, we get from **'Saturated . liquid'** Tab of SteamTab:



We get: h3 = 137.749 kJ/kg, T3 = T2 = 32.8743C, vf3 = 0.00100533 m^3/kg

State 4: Exit of Pump and inlet to boiler: P4 = 20 bar, s4 = s3 = 0.476198 kJ/kg.C. Then, from 'Superheated/Subcooled' Tab of SteamTab:

out Saturated Superheated/Subcooled Input: Pressure 20 Entropy 0.476198	Constants Units:	Close Calculate	
Property	Value	Unit	
Temperature	32.9226	°C	
Pressure	20	bar	
Steam quality	Subcooled	%	
Volume	0.00100445	m³/kg	
Density	995.57	kg/m³	
Compressibility factor	0.0142215	dimensionless	
Enthalpy	139.753	kJ/kg	
Entropy	0,476198	101700 (MCH 101704 V	
Helmoltz free energy	-8.00678		
Internal energy	137.744		
Gibbs free energy	-5.99788		
Heat capacity at constant volume	4.09901		
Heat capacity at constant pressure	4,17443		
Speed of sound	1518.86	-1010-00	
Coefficient of thermal expansion	0.000329826	1/°C	Y
ChemicaLogic Corporation, 99 South Bed	ford St. Ste 207. Burlingto	on, MA 01803 Te	E

We get: h4 = 139.753 kJ/kg.

Now that we have got properties at the four salient points, we can complete the calculations:

Data:

P1 := 20 bar P2 := 0.05 bar P3 := 0.05 bar P4 := P1 Calculations: From SteamTab: h1 := 2798.29 kJ/kg h2 := 1931.91 kJ/kg h3 := 137.749 kJ/kg h4 := 139.753 kJ/kg x2 := 0.7405 vf3 := 0.00100533 m^3/kg Therefore:  $Q_{in} := h1 - h4$  i.e.  $Q_{in} = 2.659 \times 10^3$  kJ/kg .... heat supplied  $Q_{out} := h2 - h3$  i.e.  $Q_{out} = 1.794 \times 10^3$  kJ/kg .... heat rejected  $W_T := h1 - h2$  i.e.  $W_T = 866.38$  kJ/kg.....Turbine work output

Wp := h4 - h3 i.e. Wp = 2.004 kJ/kg.....Pump work required

Note: Pump work is also calculated as: vf3·(P1 - P2)·100 = 2.006 kJ...matches with the value already obtained.

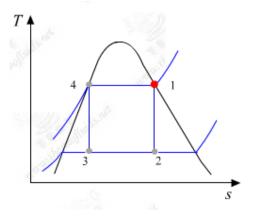
 $\eta := \frac{W_{net}}{Q_{in}} \cdot 100 \quad \text{ i.e. } \eta = 32.513 \quad \text{ \%, ...Thermal effcy....Ans.}$ 

SSC :=  $\frac{3600}{W_{net}}$  i.e. SSC = 4.165 kg/kWh... Specific steam consumption....Ans.

Work Ratio: WR :=  $\frac{W_{net}}{W_T}$  i.e. WR = 0.998 Work ratio.....Ans.

For Carnot cycle:

We have the T-s diagram:



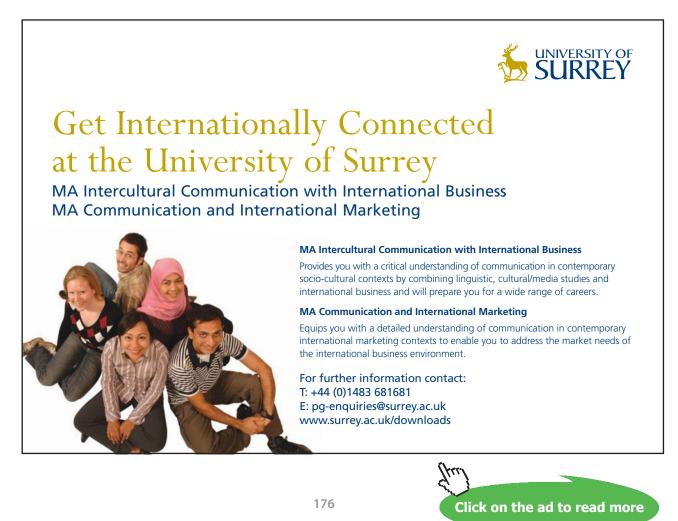
Properties at State points 1 and 2 are already obtained.

Get properties at State 4 and State 3:

**State 4:** P4 = P1 = 20 bar, sat. liquid state.

#### From 'Saturated – liquid' tab of SteamTab:

	Constants		
Independent Variable: Temperature Value, bar 20 Pressure	Units: Metric/SI English	Close Calculate	
Phase: C Vapor C Liquid C Two-	phase		
Property	Value	Unit	~
Temperature	212.377	°C	
Pressure	20	bar	
Steam quality	0	%	
Volume	0.00117675	100 C C C C C C C C C C C C C C C C C C	
Density	849.798		
Compressibility factor	0.010503		
Enthalpy	908.498		
Entropy	2.44675		
Helmoltz free energy	-281.821		
ntemal energy 906.145		2.512 2.5	
	시험과) 전기 가슴이면 가지 않고 <mark>있었</mark> 는 것 같아요. 이 것 이 것 같아요. 이 것 이 것 같아요. 이 것 이 것 이 것 이 것 이 것 이 것 이 것 이 것 이 것 이		
Gibbs free energy Heat capacity at constant volume	3 27375	kJ/(ka.°C)	N



Download free eBooks at bookboon.com

#### We get: h4 = 908.498 kJ/kg, s4 = 2.44675 kJ/kg.C

#### State 3: P3 = 0.05 bar, s3 = s4.

Input:		Units:		Close
Pressure	0.05	Metric	/SI	
Entropy	2.44675	English	i i	Calculate
Property		Valu	ue Unit	Î. D
Temperature		32.87	43 °C	
Pressure		0.	05 bar	
Steam quality		24.88	83 %	
Volume		7.015	58 m³/kg	
Density		0.142	54 kg/m³	
Compressibility factor		0.2483	64 dimensio	nless
Enthalpy		740.7	85 kJ/kg	
Entropy		2.446	75 kJ/(kg.*(	C)
Helmoltz free energy		-43.05	75 kJ/kg	
Internal energy		705.7	07 kJ/kg	
Gibbs free energy		-7.979	62 kJ/kg	
Heat capacity at constant	t volume	N.	/A kJ/(kg.*(	C)
Heat capacity at constan	t pressure	N.	/A kJ/(kg.*(	C)
Speed of sound		N.	/A m/s	
Coefficient of thermal exp	5.2522C ()	N	/A 1/°C	6

Entering these values in 'Superheated/subcooled' tab of SteamTab:

i.e. h3 = 740.785 kJ/kg.C, quality, x3 = 24.8883% = 0.2489

#### Now, complete the calculations in Mathcad:

Work of Turbine remains same. Now, compression is from point 3 to point 4.

#### From SteamTab:

h3 := 740.785 kJ/kg.... corresp. to 0.05 bar and s3 = s4

h4 := 908.498 kJ/kg

Therefore:

 $W_P := h4 - h3$  i.e.  $W_P = 167.713$  kJ/kg.....New pump work....Ans.

Work Ratio:

 $WR_{carnot} \coloneqq \frac{W_T - W_P}{W_T}$ 

i.e. WR<sub>carnot</sub> = 0.806 .....Ans.





Download free eBooks at bookboon.com

178

Prob.3.2.2. Write Mathcad programs/Functions for properties of steam:

As mentioned earlier, our Mathcad Functions are based on published Steam Tables (Ref: TEST software, <u>www.thermofluids.net</u>).

There are separate Tables for Superheated steam and for Saturated steam.

#### First, for Superheated steam:

For each pressure, the Table is copied as a matrix in Mathcad, each column is extracted as a vector, and linear interpolation is done for intermediate values.

Functions are written for the following pressures: 0.1, 0.5, 1.0, 5, 10, 14, 16, 20, 25, 30, 40, 60, 70, 80, 100, 150, 200 and 250 bar.

A sample set of Functions written for a pressure of 5 bar are shown below:

Steam at 5 bar:

	т	v	u	h	s
S5 :=	151.86	0.3749	2561.2	2748.7	6.8213
	200	0.4249	2642.9	2855.4	7.0592
	250	0.4744	2723.5	2960.7	7.2709
	300	0.5226	2802.9	3064.2	7.4599
	350	0.5701	2882.6	3167.7	7.6329
	400	0.6173	2963.2	3271.9	7.7938
	500	0.7109	3128.4	3483.9	8.0873
	600	0.8041	3299.6	3701.7	8.3522
	700	0.8969	3477.5	3925.9	8.5952
	800	0.9896	3662.1	4156.9	8.8211
	900	1.0822	3853.6	4394.7	9.0329
	1000	1.1747	4051.8	4639.1	9.2328
	1100	1.2672	4256.3	4889.9	9.4224
	1200	1.3956	4466.8	5146.6	9.6029
	1300	1.4521	4682.5	5408.6	9.7749)

T.....deg. C v....m^3/kg u, h....kJ/kg; s...kJ/kg.K....deg. C  $\begin{array}{ll} temp5 := \ S5^{\langle 0 \rangle} & \ length(temp5) = 15 \\ spvol5 := \ S5^{\langle 1 \rangle} & enth5 := \ S5^{\langle 3 \rangle} & entrop5 := \ S5^{\langle 4 \rangle} \\ HSTEAM5B(T) := \ linterp(temp5, enth5, T) & ex: & \ HSTEAM5B(250) = 2.961 \times 10^3 \\ SSTEAM5B(T) := \ linterp(temp5, entrop5, T) & ex: & \ SSTEAM5B(250) = 7.271 \end{array}$ 

Then, all the Functions written for the different pressures are combined into a single program with linear interpolation applied for any desired pressure:

This Function returns enthalpy (h, kJ/kg) and entropy (s, kJ/kg.C) when pressure (P, in bar) and temp (T, in C) are input.

$$\begin{split} \mathbf{h}_{and\_s\_SuperheatSteam}(\mathbf{P}, \mathbf{T}) \coloneqq & \text{return "P should be between 0.01 bar and 250 bar" if $\mathbf{P} < 0.01 \lor \mathbf{P} > 250$\\ \text{return "T should be between 45.81 C and 1300 C" if $\mathbf{T} < 45.81 \lor \mathbf{T} > 1300$\\ \text{if $\mathbf{P} \ge 0.1 \land \mathbf{P} < 0.5$}\\ & \mathbf{h} \leftarrow \text{HSTEAM01B}(\mathbf{T}) + \frac{(\mathbf{P} - 0.1)}{(0.5 - 0.1)} \cdot (\text{HSTEAM05B}(\mathbf{T}) - \text{HSTEAM01B}(\mathbf{T}))$\\ & s \leftarrow \text{SSTEAM01B}(\mathbf{T}) + \frac{(\mathbf{P} - 0.1)}{(0.5 - 0.1)} \cdot (\text{SSTEAM05B}(\mathbf{T}) - \text{SSTEAM01B}(\mathbf{T}))$\\ & \text{if $\mathbf{P} \ge 0.5 \land \mathbf{P} < 1$}\\ & \mathbf{h} \leftarrow \text{HSTEAM05B}(\mathbf{T}) + \frac{(\mathbf{P} - 0.5)}{(1 - 0.5)} \cdot (\text{HSTEAM1B}(\mathbf{T}) - \text{HSTEAM05B}(\mathbf{T}))$\\ & s \leftarrow \text{SSTEAM05B}(\mathbf{T}) + \frac{(\mathbf{P} - 0.5)}{(1 - 0.5)} \cdot (\text{SSTEAM1B}(\mathbf{T}) - \text{HSTEAM05B}(\mathbf{T}))$\\ & \text{if $\mathbf{P} \ge 1 \land \mathbf{P} < 5$}\\ & \mathbf{h} \leftarrow \text{HSTEAM105B}(\mathbf{T}) + \frac{(\mathbf{P} - 1)}{(5 - 1)} \cdot (\text{HSTEAM1B}(\mathbf{T}) - \text{HSTEAM1B}(\mathbf{T}))$\\ & \text{if $\mathbf{P} \ge 1 \land \mathbf{P} < 5$}\\ & \mathbf{h} \leftarrow \text{HSTEAM1B}(\mathbf{T}) + \frac{(\mathbf{P} - 1)}{(5 - 1)} \cdot (\text{HSTEAM10B}(\mathbf{T}) - \text{HSTEAM1B}(\mathbf{T}))$\\ & \text{if $\mathbf{P} \ge 5 \land \mathbf{P} < 10$}\\ & \mathbf{h} \leftarrow \text{HSTEAM1B}(\mathbf{T}) + \frac{(\mathbf{P} - 5)}{(10 - 5)} \cdot (\text{HSTEAM10B}(\mathbf{T}) - \text{HSTEAM1B}(\mathbf{T}))$\\ & \text{if $\mathbf{P} \ge 5 \land \mathbf{P} < 10$}\\ & \mathbf{h} \leftarrow \text{HSTEAM5B}(\mathbf{T}) + \frac{(\mathbf{P} - 5)}{(10 - 5)} \cdot (\text{HSTEAM10B}(\mathbf{T}) - \text{HSTEAM2B}(\mathbf{T}))$\\ & \text{if $\mathbf{P} \ge 1 \land \mathbf{N} \mathbf{P} < 14$}\\ & \mathbf{h} \leftarrow \text{HSTEAM10B}(\mathbf{T}) + \frac{(\mathbf{P} - 10)}{(10 - 5)} \cdot (\text{HSTEAM10B}(\mathbf{T}) - \text{HSTEAM2B}(\mathbf{T}))$\\ & \text{if $\mathbf{P} \ge 1 \land \mathbf{N} \mathbf{P} < 14$}\\ & \mathbf{h} \leftarrow \text{HSTEAM10B}(\mathbf{T}) + \frac{(\mathbf{P} - 10)}{(14 - 10)} \cdot (\text{HSTEAM14B}(\mathbf{T}) - \text{HSTEAM10B}(\mathbf{T}))$\\ & \text{if $\mathbf{P} \ge 10 \land \mathbf{P} < 14$}\\ & \mathbf{h} \leftarrow \text{HSTEAM10B}(\mathbf{T}) + \frac{(\mathbf{P} - 10)}{(14 - 10)} \cdot (\text{HSTEAM14B}(\mathbf{T}) - \text{HSTEAM10B}(\mathbf{T}))$\\ & \text{if $\mathbf{P} \ge 10 \land \mathbf{P} < 14$}\\ & \mathbf{h} \leftarrow \text{HSTEAM10B}(\mathbf{T}) + \frac{(\mathbf{P} - 10)}{(14 - 10)} \cdot (\text{HSTEAM14B}(\mathbf{T}) - \text{HSTEAM10B}(\mathbf{T}))$\\ & \text{if $\mathbf{H} = \text{STEAM10B}(\mathbf{T}) + \frac{(\mathbf{P} - 10)}{(14 - 10)} \cdot (\text{HSTEAM14B}(\mathbf{T}) - \text{HSTEAM10B}(\mathbf{T}))$\\ & \text{if $\mathbf{H} = \text{HSTEAM10B}(\mathbf{T}) + \frac{(\mathbf{P} - 10)}{(14 - 10)} \cdot (\text{HSTEAM14B}(\mathbf{T}) - \text{HSTEAM10B}(\mathbf{T}))$\\ & \text{if $\mathbf{H} = \text{HSTEAM10B}(\mathbf{T}) + \frac{(\mathbf{P} - 10)}{(14 - 10)} \cdot (\text{HSTEAM14B}(\mathbf{$$

Download free eBooks at bookboon.com

$$f P \ge 14 \land P < 16$$

$$h \leftarrow HSTEAMI4B(T) + \frac{(P-14)}{(16-14)} \cdot (HSTEAMI6B(T) - HSTEAMI4B(T))$$

$$s \leftarrow SSTEAMI4B(T) + \frac{(P-14)}{(16-14)} \cdot (SSTEAMI6B(T) - SSTEAMI4B(T))$$

$$f P \ge 16 \land P < 20$$

$$h \leftarrow HSTEAMI6B(T) + \frac{(P-16)}{(20-16)} \cdot (HSTEAM20B(T) - HSTEAMI6B(T))$$

$$s \leftarrow SSTEAMI6B(T) + \frac{(P-20)}{(25-20)} \cdot (HSTEAM20B(T) - SSTEAMI6B(T))$$

$$f P \ge 20 \land P < 25$$

$$h \leftarrow HSTEAM20B(T) + \frac{(P-20)}{(25-20)} \cdot (HSTEAM25B(T) - HSTEAM20B(T))$$

$$f P \ge 25 \land P < 30$$

$$h \leftarrow HSTEAM20B(T) + \frac{(P-20)}{(30-25)} \cdot (HSTEAM25B(T) - SSTEAM20B(T))$$

$$s \leftarrow SSTEAM20B(T) + \frac{(P-25)}{(30-25)} \cdot (HSTEAM30B(T) - HSTEAM25B(T))$$

$$s \leftarrow SSTEAM25B(T) + \frac{(P-25)}{(30-25)} \cdot (SSTEAM30B(T) - SSTEAM25B(T))$$

$$f P \ge 30 \land P < 40$$

$$h \leftarrow HSTEAM30B(T) + \frac{(P-30)}{(40-30)} \cdot (HSTEAM40B(T) - HSTEAM30B(T))$$

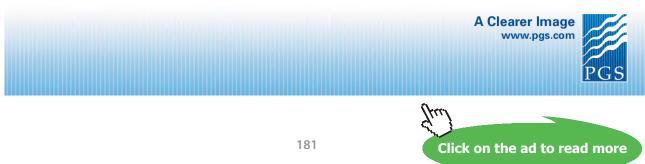
$$s \leftarrow SSTEAM30B(T) + \frac{(P-30)}{(40-30)} \cdot (SSTEAM40B(T) - SSTEAM30B(T))$$



As a leading technology company in the field of geophysical science, PGS can offer exciting opportunities in offshore seismic exploration.

We are looking for new BSc, MSc and PhD graduates with Geoscience, engineering and other numerate backgrounds to join us.

To learn more our career opportunities, please visit www.pgs.com/careers



$$\begin{split} \text{ff} \ P \ge 40 \land P < 60 \\ \text{h} \leftarrow \text{HSTEAM40B}(T) + \frac{(P-40)}{(60-40)} (\text{HSTEAM60B}(T) - \text{HSTEAM40B}(T)) \\ \text{s} \leftarrow \text{SSTEAM40B}(T) + \frac{(P-40)}{(60-40)} (\text{SSTEAM60B}(T) - \text{SSTEAM40B}(T)) \\ \text{if} \ P \ge 60 \land P < 70 \\ \text{h} \leftarrow \text{HSTEAM60B}(T) + \frac{(P-60)}{(70-60)} (\text{HSTEAM10B}(T) - \text{HSTEAM60B}(T)) \\ \text{s} \leftarrow \text{SSTEAM60B}(T) + \frac{(P-60)}{(70-60)} (\text{HSTEAM10B}(T) - \text{SSTEAM60B}(T)) \\ \text{s} \leftarrow \text{SSTEAM60B}(T) + \frac{(P-70)}{(70-70)} (\text{HSTEAM10B}(T) - \text{HSTEAM60B}(T)) \\ \text{s} \leftarrow \text{SSTEAM00B}(T) + \frac{(P-70)}{(80-70)} (\text{HSTEAM100B}(T) - \text{HSTEAM100B}(T)) \\ \text{s} \leftarrow \text{SSTEAM10B}(T) + \frac{(P-70)}{(80-70)} (\text{HSTEAM100B}(T) - \text{HSTEAM100B}(T)) \\ \text{s} \leftarrow \text{SSTEAM10B}(T) + \frac{(P-80)}{(100-80)} (\text{HSTEAM100B}(T) - \text{HSTEAM100B}(T)) \\ \text{s} \leftarrow \text{SSTEAM100B}(T) + \frac{(P-100)}{(100-80)} (\text{HSTEAM100B}(T) - \text{HSTEAM100B}(T)) \\ \text{if} \ P \ge 100 \land P < 150 \\ \text{h} \leftarrow \text{HSTEAM100B}(T) + \frac{(P-100)}{(150-100)} (\text{HSTEAM100B}(T) - \text{HSTEAM100B}(T)) \\ \text{s} \leftarrow \text{SSTEAM100B}(T) + \frac{(P-100)}{(150-100)} (\text{HSTEAM100B}(T) - \text{HSTEAM100B}(T)) \\ \text{s} \leftarrow \text{SSTEAM100B}(T) + \frac{(P-100)}{(150-100)} (\text{HSTEAM100B}(T) - \text{HSTEAM100B}(T)) \\ \text{s} \leftarrow \text{SSTEAM100B}(T) + \frac{(P-100)}{(120-100)} (\text{HSTEAM100B}(T) - \text{HSTEAM100B}(T)) \\ \text{s} \leftarrow \text{SSTEAM100B}(T) + \frac{(P-100)}{(200-120)} (\text{HSTEAM100B}(T) - \text{HSTEAM100B}(T)) \\ \text{s} \leftarrow \text{SSTEAM100B}(T) + \frac{(P-100)}{(200-120)} (\text{HSTEAM100B}(T) - \text{HSTEAM100B}(T)) \\ \text{s} \leftarrow \text{SSTEAM100B}(T) + \frac{(P-100)}{(200-120)} (\text{HSTEAM100B}(T) - \text{HSTEAM100B}(T)) \\ \text{s} \leftarrow \text{SSTEAM100B}(T) + \frac{(P-100)}{(200-120)} (\text{HSTEAM120B}(T) - \text{HSTEAM100B}(T)) \\ \text{s} \leftarrow \text{SSTEAM100B}(T) + \frac{(P-100)}{(200-120)} (\text{HSTEAM1200B}(T) - \text{HSTEAM100B}(T)) \\ \text{s} \leftarrow \text{SSTEAM100B}(T) + \frac{(P-200)}{(200-120)} (\text{HSTEAM1200B}(T) - \text{HSTEAM1200B}(T)) \\ \text{s} \leftarrow \text{SSTEAM1200B}(T) + \frac{(P-200)}{(200-200)} (\text{HSTEAM1200B}(T) - \text{HSTEAM1200B}(T)) \\ \text{s} \leftarrow \text{SSTEAM1200B}(T) + \frac{(P-200)}{(200-200)} (\text{HSTEAM1200B}(T) - \text{HSTEAM1200B}(T)) \\ \text{s} \leftarrow \text{SSTEAM1200B}(T) + \frac{(P-200)}{(200-200)} (\text{HSTEAM1200B}(T) - \text{HSTEAM1200B}(T)) \\ \text{s} \leftarrow \text{HSTEAM1200B}(T) + \frac{(P-200)}{(200-200)} (\text{HST$$

#### Next, we write Functions for properties of steam in the two-phase region:

Here, the Sat. pressure Table is used. Since the Table is rather large, we write it separately as a simple text file in Notepad and name it as satprop.prn, and read it from Mathcad with the built-in Function READPRN, i.e. we enter: READPRN("satprop.prn").

PROPERT	TIES OF SA	T. STEAM .	PRESSURE	TABLE (Ret	f: TEST)		
PRESS. (MPa) 0.00061 0.001 0.0015 0.002 0.0025	TEMP (C) 113 0.01 6.98 13.03 17.50 21.08	hf (kJ/kg) 0.01 29.3 54.71 73.48 88.49	hg (kJ/kg) 2501.4 2514.2 2525.3 2533.5 2540.0	sf (kJ/kg.K) 0.000 0.1059 0.1957 0.2607 0.3120	sg (kJ/kg.K 9.1562 8.9756 8.8279 8.7237 8.6432	vf (cc/g) 1.000 1.000 1.001 1.001 1.002	vg (cu.m/kg) 206.14 129.21 87.98 67.00 54.25
10.00 11.00 12.00 13.00 14.00 15.00 16.00 18.00 20.00 22.09	311.06 318.15 324.75 330.93 336.75 342.24 347.44 357.06 365.81 374.14	1407.65 1450.10 1491.30 1531.5 1571.1 1610.5 1650.1 1732.0 1826.3 2099.3	2724.7 2705.6 2684.9 2662.2 2637.6 2610.5 2580.6 2509.1 2409.7 2099.3	3.3596 3.4295 3.4962 3.5606 3.6232 3.6848 3.7461 3.8715 4.0139 4.4298	5.5527 5.4924 5.4323 5.3717 5.3098 5.2455 5.1044 4.9269	1.452 1.489 1.527 1.567 1.611 1.658 1.711 1.840 2.036 3.155	0.018026 0.015987 0.014263 0.012780 0.011485 0.010337 0.009306 0.007489 0.005834 0.003155

#### A part of the Sat. Table is shown below:

To write the Functions, we extract each column as a vector and use them to get interpolated values, in conjunction with the interpolation function 'linterp' in Mathcad.

SAT := READPRN("satprop.pm")	PsatMpa, Tsatdeg. C hfsat, hgsatkJ/kg;		
$psat := SAT^{\langle 0 \rangle}$ $length(psat) = 54$	visatcm-5/g		
tsat := $SAT^{(1)}$ hfsat := $SAT^{(2)}$	vgsatm^3/kg		
hgsat := $SAT^{\langle 3 \rangle}$ sfsat := $SAT^{\langle 4 \rangle}$	$sgsat := SAT^{\langle 5 \rangle}$ $vfsat := SAT^{\langle 6 \rangle}$ $vgsat := SAT^{\langle 7 \rangle}$		

Following very useful Functions are written to find out enthalpy, entropy, sp. volume of both the sat. liquid and sat. vapor conditions, as functions of sat. temp and sat. pressures. Note that pressure is in MPa in these Functions:

TSAT(P) := linterp(psat,tsat,P)	VGSATP(P) := linterp(psat, vgsat, P)	
PSAT(T) := linterp(tsat, psat, T)	VGSATT(T) := linterp(tsat, vgsat, T)	
HFSATP(P) := linterp(psat,hfsat,P)	VFSATP(P) := linterp(psat,vfsat,P)·10 <sup>-3</sup>	
$HFSATT(T) \coloneqq linterp(tsat, hfsat, T)$	$VFSATT(T) := linterp(tsat, vfsat, T) \cdot 10^{-3}$	
HGSATP(P) := linterp(psat,hgsat,P)	VFGSATP(P) := VGSATP(P) - VFSATP(P)	
HGSATT(T) := linterp(tsat,hgsat,T)	VFGSATT(T) := VGSATT(T) - VFSATT(T)	
HFGSATP(P) := HGSATP(P) - HFSATP(P)	$UGSATP(P) := HGSATP(P) - P \cdot 10^3 \cdot VGSATP(P)$	
	$UFSATP(P) := HFSATP(P) - P \cdot VFSATP(P) \cdot 10^{3}$	
HFGSATT(T) := HGSATT(T) - HFSATT(T)	UFGSATP(P) := UGSATP(P) - UFSATP(P)	
SFSATP(P) := linterp(psat, sfsat, P)	$UGSATT(T) := HGSATT(T) - PSAT(T) \cdot 10^{3} \cdot VGSATT(T)$	
SFSATT(T) := linterp(tsat, sfsat, T)	$UFSATT(T) := HFSATT(T) - PSAT(T) \cdot 10^{3} \cdot VFSATT(T)$	
SGSATP(P) := linterp(psat,sgsat,P)	UFGSATT(T) := UGSATT(T) - UFSATT(T)	
SGSATT(T) := linterp(tsat, sgsat, T)		
SFGSATP(P) := SGSATP(P) - SFSATP(P)		
SFGSATT(T) := SGSATT(T) - SFSATT(T)		

Further, following *additional functions* for finding out the entropy, enthalpy, quality etc in the two-phase region are written. They are very useful in calculations related to Rankine cycle.

In the following program: psat = sat. pr.(bar), tsat = sat. temp (C), s = entropy (kJ/kg.C), h = enthalpy (kJ/kg), x = quality:

$quality_Ps(psat, s) :=$	(return "psat should be between 0.006113 bar and 220.9 bar ! ") if psat < 0.006	113 ∧ psa	at > 220.9
	$PSAT \leftarrow \frac{psat}{c}$		
	10		
	$sf \leftarrow SFSATP(PSAT)$		
	$sfg \leftarrow SFGSATP(PSAT)$		
	$sf \leftarrow SFSATP(PSAT)$ $sfg \leftarrow SFGSATP(PSAT)$ $x \leftarrow \frac{s - sf}{sfg}$		

quality\_Ts(tsat, s) := return "tsat should be between 0.01 C and 374.14 C ! " if tsat < 0.01 \lambda tsat > 374.14  $sf \leftarrow SFSATT(tsat)$  $sfg \leftarrow SFGSATT(tsat)$  $\frac{s - sf}{sfg}$ 

$$\begin{array}{ll} \mbox{quality}_Th(tsat,h) := & \mbox{return "tsat should be between 0.01 C and 374.14 C ! " & \mbox{if tsat} < 0.01 \land tsat > 374.14 \\ \mbox{hf} \leftarrow \mbox{HFSATT}(tsat) \\ \mbox{hfg} \leftarrow \mbox{HFGSATT}(tsat) \\ & \mbox{x} \leftarrow \frac{h - hf}{hfg} \end{array}$$

entropy\_2phase\_Px(psat,x) := (return "psat should be between 0.006113 bar and 220.9 bar!") if psat < 0.006113 \lambda psat > 220.9  $PSAT \leftarrow \frac{psat}{}$ 10  $sf \leftarrow SFSATP(PSAT)$  $sfg \leftarrow SFGSATP(PSAT)$  $\leftarrow sf + x \cdot sfg$ 





Click on the ad to read more

```
entropy_2phase_Tx(tsat,x) := return "tsat should be between 0.01 C and 374.14 C ! " if tsat < 0.01 A tsat > 374.14
                                                      sf \leftarrow SFSATT(tsat)
sfg \leftarrow SFGSATT(tsat)
s \leftarrow sf + x \cdot sfg
entropy_2phase_Th(tsat,h) := | return "tsat should be between 0.01 C and 374.14 C ! " if tsat < 0.01 \land tsat > 374.14
                                                     sf \leftarrow SFSATT(tsat)

sfg \leftarrow SFGSATT(tsat)

x \leftarrow quality_Th(tsat,h)

s \leftarrow sf + x \cdot sfg
enthalpy_2phase_Px(psat,x) := |(return "psat should be between 0.006113 bar and 220.9 bar ! ") if psat < 0.006113 \land psat > 220.9
                                                 PSAT \leftarrow \frac{psat}{10}
hf \leftarrow HFSATP(PSAT)
hfg \leftarrow HFGSATP(PSAT)
h \leftarrow hf + x \cdot hfg
enthalpy_2phase_Tx(tsat, x) := | return "tsat should be between 0.01 C and 374.14 C ! " if tsat < 0.01 A tsat > 374.14
                                                     \begin{aligned} & \text{hf} \leftarrow \text{HFSATT(tsat)} \\ & \text{hfg} \leftarrow \text{HFGSATT(tsat)} \\ & \text{h} \leftarrow \text{hf} + x \cdot \text{hfg} \end{aligned}
enthalpy_2phase_Ts(tsat, s) := | return "tsat should be between 0.01 C and 374.14 C ! " if tsat < 0.01 \lambda tsat > 374.14
                                                      \begin{aligned} x \leftarrow quality\_Ts(tsat, s) \\ hf \leftarrow HFSATT(tsat) \\ hfg \leftarrow HFGSATT(tsat) \\ h \leftarrow hf + x \cdot hfg \end{aligned}
enthalpy_2phase_Ps(psat.s) = (return "psat should be between 0.006113 bar and 220.9 bar ! ") if psat < 0.006113 ^ psat > 220.9
                                                   x \leftarrow quality Ps(psat, s)
                                                   PSAT \leftarrow \frac{psat}{10}
hf \leftarrow HFSATP(PSAT)
                                                   hfg \leftarrow HFGSATP(PSAT)
                                                   h \leftarrow hf + x \cdot hfg
```

Further, for convenience and uniformity, we write the following program to get enthalpy and entropy when P and T are given in bar and deg.C respectively:

$$entropy(P,T) := \begin{cases} tsat \leftarrow TSAT\left(\frac{P}{10}\right) \\ s \leftarrow h\_and\_s\_SuperheatSteam(P,T)_{0,1} & \text{if } T \ge tsat \\ (return "State point in two phase region--- use 2 phase Functions") & otherwise \end{cases}$$

Now, let us solve the above Problem on Simple, Ideal Rankine cycle, using these Functions:

\_\_\_\_\_\_

Problem statement is repeated below:

**Prob.3.2.1** A steam power plant works on Rankine cycle between pressure ratio 20 bar and 0.05 bar. Steam supplied to the turbine is dry, saturated. Find thermal effcy., work ratio and Specific Steam Consumption (SSC). What would be the efficiency and work ratio in case of Carnot cycle operating in the same pressure limits? [M.U.]

(b) For the ideal Rankine cycle above, plot the thermal effcy and net work output as the condenser pressure varies from 6 kPa to 15 kPa (i.e. from 0.06 bar to 0.15 bar):

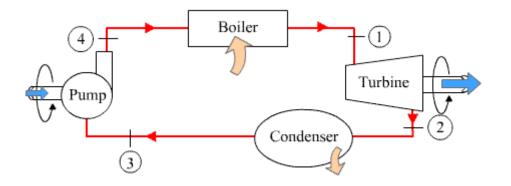


Fig.Prob.3.2.1 (a) Schematic diagram of simple, ideal Rankine cycle

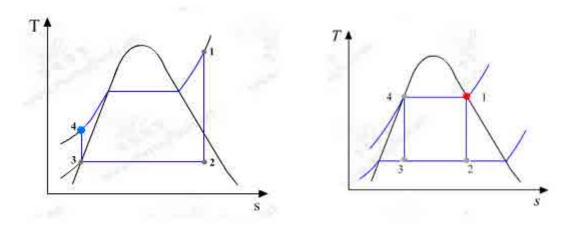


Fig.Prob.3.2.1 (b) and (c) T-s diagram of simple, ideal Rankine cycle, and of Carnot cycle

### Technical training on WHAT you need, WHEN you need it

At IDC Technologies we can tailor our technical and engineering training workshops to suit your needs. We have extensive experience in training technical and engineering staff and have trained people in organisations such as General Motors, Shell, Siemens, BHP and Honeywell to name a few.

Our onsite training is cost effective, convenient and completely customisable to the technical and engineering areas you want covered. Our workshops are all comprehensive hands-on learning experiences with ample time given to practical sessions and demonstrations. We communicate well to ensure that workshop content and timing match the knowledge, skills, and abilities of the participants.

We run onsite training all year round and hold the workshops on your premises or a venue of your choice for your convenience.

For a no obligation proposal, contact us today at training@idc-online.com or visit our website for more information: www.idc-online.com/onsite/ OIL & GAS ENGINEERING

**ELECTRONICS** 

AUTOMATION & PROCESS CONTROL

> MECHANICAL ENGINEERING

INDUSTRIAL DATA COMMS

ELECTRICAL POWER

Phone: +61 8 9321 1702 Email: training@idc-online.com Website: www.idc-online.com



Click on the ad to read more

188

#### Solution using Mathcad Functions:

Since we have to plot the thermal effcy and net work output as against condenser pressure (P2) later, we shall write the relevant quantities as functions of P2:

#### Calculations:

#### To find h1 and s1:

h1 := enthalpy\_2phase\_Px(P1,x1) kJ/kg..... using the Function written above, with pressure in MPa

i.e.  $h1 = 2.7995 \times 10^3$  kJ/kg... at inlet to turbine

s1 := SGSATP
$$\left(\frac{P1}{10}\right)$$
 kJ/kg.C.... using the Function written above, with pressure in MPa

Data:

P1 := 20 barP2 := 0.05 barP3 := 0.05 barP4 := P1
$$x1 := 1$$
 $x3 := 0$  $h1 = 2.8 \times 10^3$ kJ/kg....this value remains the same. $s1 = 6.341$ kJ/kg.C $s2 = 6.341$ kJ/kg.C $kJ/kg.C$ 

Now, write the relevant quantities as functions of condenser pressure P2:

 $h2(P2) := enthalpy_2phase_Ps(P2, s2)$  i.e.  $h2(P2) = 1.933 \times 10^3$  kJ/kg..at exit of turbine Also:  $x2(P2) := quality_Ps(P2, s2)$ 

i.e. x2(P2) = 0.741 ...quality of steam at point 2, after expn. in turbine

#### To find h3: i.e. at entry to pump:

```
h3(P2) := enthalpy_2phase_Px(P2,0) i.e. h3(P2) = 137.82 = 137.82 kJ/kg
```

#### To find h4: i.e. at exit of pump:

vf3(P2) := VFSATP
$$\left(\frac{P2}{10}\right)$$
 i.e. vf3(P2) = 1.005 × 10<sup>-3</sup> m^3/kg..sp. vol. of sat. liq. at 2

Therefore:  $w_p(P2) := vf3(P2) \cdot (P1 - P2) \cdot 10^2$  kJ...pump work

i.e. w<sub>p</sub>(P2) = 2.005 kJ...pump work

Then:

$$h4(P2) := h3(P2) + w_p(P2)$$

Therefore:

 $w_{net}(P2) := w_T(P2) - w_p(P2)$  i.e.  $w_{net}(P2) = 864.725$  kJ/kg.... Net work output

$$\eta(P2) := \frac{w_{net}(P2)}{q_{in}(P2)} \cdot 100 \qquad \text{i.e.} \qquad \eta(P2) = 32.512 \quad \text{, ...Thermal effcy....Ans.}$$

$$SSC(P2) := \frac{3600}{w_{net}(P2)}$$
 i.e.  $SSC(P2) = 4.163$  kg/kWh... Specific steam consumption....Ans.

Work Ratio:  $WR(P2) := \frac{w_{net}(P2)}{w_T(P2)}$  WR(P2) = 0.998 Work ratio.....Ans.

For Carnot Cycle:

\_\_\_\_\_

 $T_h := TSAT(2)$  i.e.  $T_h = 212.42$  C  $T_c := TSAT(0.005)$  i.e.  $T_c = 32.88$  C

 $\eta_{carnot} := \frac{(T_h + 273) - (T_c + 273)}{T_h + 273}$  i.e.  $\eta_{carnot} = 0.37$  ...Thermal effcy...Ans.

Work of Turbine remains same. Now, compression is from point 3 to point 4.

#### From Mathcad Functions written above:

s4 := SFSATP
$$\left(\frac{P4}{10}\right)$$
 i.e. s4 = 2.447 kJ/kg.C  
h4 := HFSATP $\left(\frac{P4}{10}\right)$  i.e. h4 = 908.79 kJ/kg

Work of Turbine remains same. Now, compression is from point 3 to point 4.

#### From Mathcad Functions written above:

s4 := SFSATP
$$\left(\frac{P4}{10}\right)$$
 i.e. s4 = 2.447 kJ/kg.C.... note that pressure is in MPa  
h4 := HFSATP $\left(\frac{P4}{10}\right)$  i.e. h4 = 908.79 kJ/kg.. note that pressure is in MPa

#### To find h3:

We have: s3 := s4 ... for isentropi compression in pump

Then:

h3 := enthalpy\_2phase\_Ps(P3,s3) i.e. h3 = 741.085 kJ/kg.... corresp. to 0.05 bar and s3 = s4

Also:  $x3 := quality_Ps(P3, s3)$ 

i.e. x3 = 0.249 ...quality at point 3

Therefore:

```
wp := h4 - h3 i.e. wp = 167.705 kJ/kg.....New pump work.... Ans.
```

Work Ratio:  $WR_{carnot} := \frac{WT - WP}{WT}$ 

i.e. WR<sub>carnot</sub> = 0.807 ....Ans.

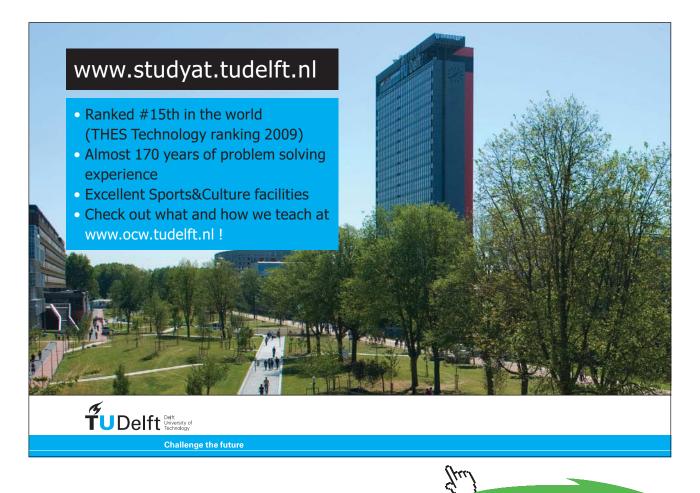
(b) For the ideal Rankine cycle above, plot the thermal effcy and net work output as the condenser pressure varies from 6 kPa to 15 kPa (i.e. from 0.06 bar to 0.15 bar):

We have already the relevant quantities as functions of condenser pressure P2:

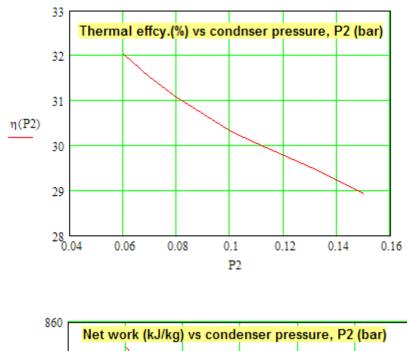
Now, plot the results:

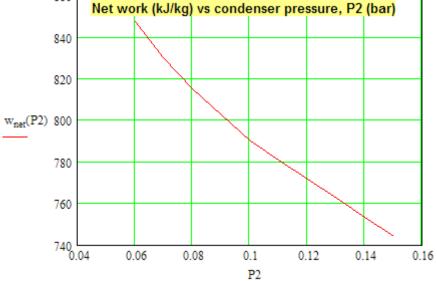
P2 := 0.06,0.07..0.15 bar....define a range variable

P2 =	$w_{net}(P2) =$	η(P2) =	SSC(P2) =	WR(P2) =	x2(P2) =
0.06	847.632	32.019	4.247	0.998	0.745
0.07	830.348	31.513	4.336	0.998	0.749
0.08	815.352	31.072	4.415	0.998	0.753
0.09	802.717	30.698	4.485	0.998	0.756
0.1	789.977	30.318	4.557	0.997	0.759
0.11	780.884	30.047	4.61	0.997	0.761
0.12	771.739	29.774	4.665	0.997	0.763
0.13	762.54	29.496	4.721	0.997	0.765
0.14	753.286	29.216	4.779	0.997	0.768
0.15	743.976	28.931	4.839	0.997	0.77



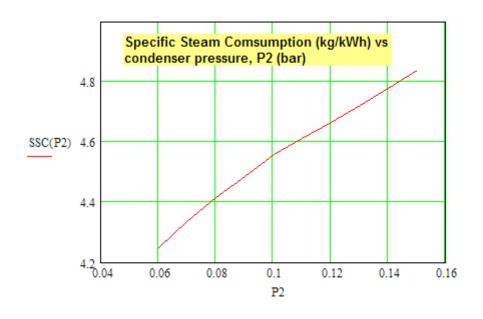






\_\_\_\_\_

===============







Click on the ad to read more

**Prob.3.2.2** In a reheat Rankine cycle, steam at 500 C expands in a HP turbine till it is saturated vap. It is then reheated at constant pressure to 400 C and then expanded in a LP turbine to 40 C. If the max. moisture content at the turbine exhaust is limited to 15%, find: (i) the reheat pressure, (ii) pressure of steam at the inlet to HP turbine, (iii) net specific work output, (iv) cycle efficiency, and (v) steam rate. Assume all ideal processes. [VTU-ATD-Dec. 2011]

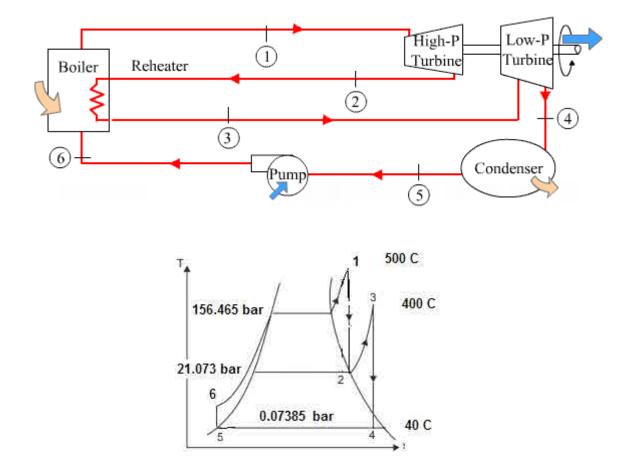


Fig.Prob.3.2.2 (a) Ideal Reheat, Rankine cycle, and (b) T-s diagram

#### Mathcad Solution:

Essentially, we have to find out the enthalpies at all the state points.

We shall use the Mathcad Functions written above, and start with State 4, since the temperature and quality are known at point 4.

#### Data:

T1 := 500 C x2 := 1 T3 := 400 C x4 := 0.85 T4 := 40 C T5 := T4 P5 := P4 P6 := P1 P3 := P2

#### Calculations:

P4 := PSAT(T4) i.e.  $P4 = 7.402 \times 10^{-3}$  MPa = 7402 Pa = 0.07402 bar i.e. P4 := 0.07402 bar P5 := P4

To find s4: use the Mathcad Function already written above.

s4 := entropy\_2phase\_Tx(T4,x4) i.e, s4 = 7.104 kJ/kg.C

#### To find h4:

 $h4 := enthalpy_2phase_Tx(T4, x4)$  i.e.  $h4 = 2.213 \times 10^3$  kJ/kg.C

#### To find P3:

Now: s3 := s4 ...for isentropic expn. in turbine-2

#### Using the 'Solve block' of Mathcad:

Let: P3 := 15 bar....guess value

Given

s3 = entropy(P3, T3)

P3 := Find(P3)

P3 = 21.01 bar....Ans..... Reheat pressure

#### Then find s2 at this reheat pressure:

P2 := P3  
s2 := SGSATP
$$\left(\frac{P2}{10}\right)$$
 ...Note: Pressure is in MPa  
i.e. s2 = 6.324 kJ/kg.C

And: s1 := s2 ....for isentropic expn. in turbine-1

#### Now, find P1:

#### Using the 'Solve block' of Mathcad:

P1 := 200 bar... guess value

Given

s1 = entropy(P1, T1)

P1 := Find(P1)

P1 = 154.956 bar....Ans..... Turbine-1 inlet pressure

Now:

P5 := P4 P6 := P1 T2 := TSAT $\left(\frac{P2}{10}\right)$  i.e. T2 = 214.756 C

P4 := 0.07402 bar T4 = 40 C

# Study at one of Europe's leading universities

DTU, Technical University of Denmark, is ranked as one of the best technical universities in Europe, and offers internationally recognised Master of Science degrees in 39 English-taught programmes.

DTU offers a unique environment where students have hands-on access to cutting edge facilities and work

closely under the expert supervision of top international researchers.

DTU's central campus is located just north of Copenhagen and life at the University is engaging and vibrant. At DTU, we ensure that your goals and ambitions are met. Tuition is free for EU/EEA citizens.

Visit us at www.dtu.dk



Click on the ad to read more

197

#### To find enthalpies at all points:

 h1 := enthalpy(P1,T1)
 i.e.
 h1 =  $3.302 \times 10^3$  kJ/kg

 h2 := enthalpy(P2,T2)
 i.e.
 h2 =  $2.8 \times 10^3$  kJ/kg

 h3 := enthalpy(P3,T3)
 i.e.
 h3 =  $3.246 \times 10^3$  kJ/kg

 h4 =  $2.213 \times 10^3$  kJ/kg

 h5 := enthalpy\_2phase\_Tx(T5,0)
 i.e.
 h5 = 167.578 kJ/kg

 For h6:

 vf5 := VFSATT(T5)
 i.e.
 vf5 =  $1.008 \times 10^{-3}$  m^3/kg...sp. vol. of liq. at inlet to pump

Therefore:  $W_P := vf5 \cdot (P6 - P5) \cdot 10^5$  i.e.  $W_P = 1.561 \times 10^4$  J = 15.61 kJ/kg ... pump work

i.e. Wp := 15.61 kJ/kg...pump work

And: h6 := h5 + Wp i.e. h6 = 183.188 kJ/kg

Therefore:

 $Q_{in} := (h1 - h6) + (h3 - h2)$  i.e.  $Q_{in} = 3.565 \times 10^3$  kJ/kg .... heat supplied  $Q_{out} := h4 - h5$  i.e.  $Q_{out} = 2.046 \times 10^3$  kJ/kg .... heat rejected

 $W_T := (h1 - h2) + (h3 - h4) \quad i.e. W_T = 1.535 \times 10^3 \text{ kJ/kg.....Turbine work output}$ 

 $W_{net} := W_T - W_P$  i.e.  $W_{net} = 1.519 \times 10^3$  kJ/kg.... Net work output

 $\eta := \frac{W_{net}}{Q_{in}} \cdot 100$  i.e.  $\eta = 42.612$  %, ...Thermal effcy....Ans.

 $SSC := \frac{3600}{W_{net}}$  i.e. SSC = 2.37 i.e. kg/kWh... Specific steam consumption....Ans.

Work Ratio: WR :=  $\frac{W_{net}}{W_T}$  i.e. WR = 0.99 Work ratio.....Ans.

**Note:** In the above analysis, Pump work is considered. But, many times, the pump work can be neglected since it is quite small compared to net work.

**Prob.3.2.3** Steam at 30 bar, 350 C is supplied to a steam turbine in a practical regenerative Rankine cycle and the steam is bled at 4 bar. The bled steam comes out as dry, saturated steam and heats the feed water in an open type feed water heater to its sat. liquid state. The rest of the steam in the turbine expands to a condenser pressure of 0.1bar. Assuming the turbine efficiency to be same before and after bleeding, determine: (i) the turbine effcy. (ii) steam quality at inlet to condenser, (iii) mass flow rate of bled steam per unit mass flow rate at turbine inlet, and (iv) the cycle efficiency. [VTU-ATD-Jan.–Feb. 2005]

(b) For this Regenerative Rankine cycle, plot the thermal effcy., net work output and SSC as the turbine inlet pressure, P1 varies from 15 bar to 100 bar:

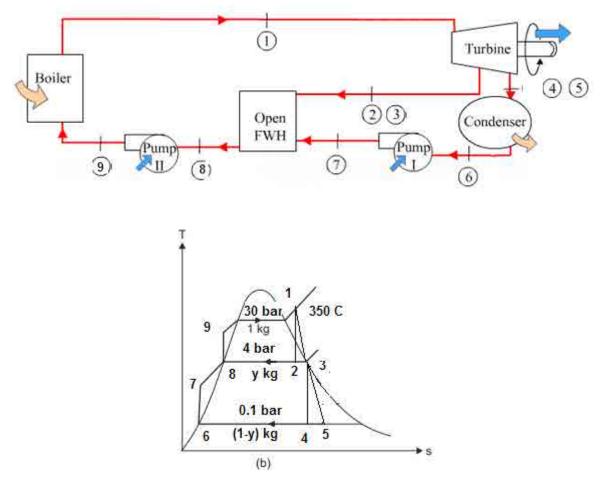


Fig.Prob.3.2.3 (a) Regenerative Rankine cycle, and (b) T-s diagram

#### **Solution using Mathcad Functions:**

Refer to the schematic diagram given above.

Since we have to plot the thermal effcy. and net work output against turbine input pressure (P1) later, we shall write the relevant quantities as functions of P1:

Data:

T1 := 350 C P1 := 30 bar P2 := 4 bar P3 := P2 P4 := 0.1 bar P5 := P4 P6 := P4

P7 := P2 P8 := P2 P9 := P1 x3 := 1 x6 := 0 x8 := 0

Calculations:

To find enthalpies at salient points:

h1(P1) := enthalpy(P1,T1) i.e.  $h1(P1) = 3.115 \times 10^3$  kJ/kg

s1(P1) := entropy(P1,T1) i.e. s1(P1) = 6.743 kJ/kg.C

And: s2(P1) := s1(P1) ...for isentropic expn. in turbine-1

Therefore: h2(P1) := enthalpy\_2phase\_Ps(P2, s2(P1))

i.e.  $h2(P1) = 2.675 \times 10^3$  kJ/kg



For almost 60 years Maastricht School of Management has been enhancing the management capacity of professionals and organizations around the world through state-of-the-art management education.

Our broad range of Open Enrollment Executive Programs offers you a unique interactive, stimulating and multicultural learning experience.

Be prepared for tomorrow's management challenges and apply today.

For more information, visit www.msm.nl or contact us at +31 43 38 70 808 or via admissions@msm.nl

the globally networked management school



And: at point 3, it is sat. vap., i.e. x3 = 1. Therefore:

$$h3 := enthalpy_2phase_Px(P3, x3)$$
 i.e.  $h3 = 2.739 \times 10^3$  kJ/kg

Therefore, turbine effcy:  $\eta_{turb}(P1) := \frac{h1(P1) - h3}{h1(P1) - h2(P1)}$ 

i.e. η<sub>turb</sub>(P1) = 0.855 = 85.5 %....turbine effcy....Ans.

And: s4 := s3 ... for isentropic expn. in turbine-2

Therefore:  $h4 := enthalpy_2phase_Ps(P4, s4)$ i.e.  $h4 = 2.185 \times 10^3$  kJ/kg

And:  $h5(P1) := h3 - \eta_{turb}(P1) \cdot (h3 - h4)$  i.e.  $h5(P1) = 2.265 \times 10^3$  kJ/kg

Also: h6 := enthalpy\_2phase\_Px(P6,x6) i.e. h6 = 191.83 kJ/kg

To find h7:

vf6 := VFSATP(P6) i.e. vf6 =  $1.043 \times 10^{-3}$  m^3/kg...sp. vol. of liq. at inlet to pump Therefore: W<sub>P</sub> := vf6·(P7 - P6)·10<sup>5</sup> i.e. W<sub>P</sub> = 406.77 J = 0.406 kJ/kg ... pump-1 work

i.e. Wp := 0.406 kJ/kg...pump work

And: h7 := h6 + Wp i.e. h7 = 192.236 kJ/kg

Now: h8 := enthalpy\_2phase\_Px(P8,x8) i.e. h8 = 604.74 kJ/kg

To find h9:

vf8 := VFSATP(P8)

i.e.  $vf8 = 1.252 \times 10^{-3}$  m^3/kg...sp. vol. of liq. at inlet to pump

Therefore:  $W_P(P1) := vf8 \cdot (P1 - P8) \cdot 10^5$  i.e.  $W_P(P1) = 3.255 \times 10^3$  J = 3.255 kJ/kg ... pump-2 work

i.e. Wp(P1) := 3.255 kJ/kg...pump-2 work

And: h9(P1) := h8 + Wp(P1) i.e. h9(P1) = 607.995 kJ/kg

#### Therefore:

#### Amount of steam bled from turbine: Let this fraction be y.

Then applying an energy balance to the open heater:

$$\mathbf{y} \cdot \mathbf{h}\mathbf{3} + (\mathbf{1} - \mathbf{y}) \cdot \mathbf{h}\mathbf{7} = \mathbf{1} \cdot \mathbf{h}\mathbf{8}$$

i.e.  $y := \frac{h8 - h7}{h3 - h7}$  i.e. y = 0.162 ....fraction bled from turbine ... Ans.

$$Q_{in}(P1) := (h1(P1) - h9(P1))$$
 i.e.  $Q_{in}(P1) = 2.507 \times 10^{2}$  kJ/kg .... heat supplied

 $Q_{out}(P1) := (h5(P1) - h6) \cdot (1 - y)$  i.e.  $Q_{out}(P1) = 1.737 \times 10^3$  kJ/kg .... heat rejected

$$W_T(P1) := (h1(P1) - h3) + (h3 - h5(P1)) \cdot (1 - y)$$
 i.e.  $W_T(P1) = 773.724$  kJ/kg......Turbine work putput

 $W_{P1} := (h7 - h6) \cdot (1 - y)$  i.e.  $W_{P1} = 0.34$  kJ/kg.....work required for Pump-1

 $W_{P2}(P1) := (h9(P1) - h8)$  i.e.  $W_{P2}(P1) = 3.255$  kJ/kg.....work required for Pump-2

 $W_{net}(P1) := W_T(P1) - (W_{P1} + W_{P2}(P1))$  i.e.  $W_{net}(P1) = 770.129$  kJ/kg.... Net work output

$$\eta(P1) := \frac{W_{net}(P1)}{Q_{in}(P1)} \cdot 100$$
 i.e.  $\eta(P1) = 30.715$  %, ...Thermal effcy....Ans.

$$SSC(P1) := \frac{3600}{W_{net}(P1)}$$
 i.e.  $SSC(P1) = 4.675$  kg/kWh... Specific steam consumption....Ans

Work Ratio:  $WR(P1) := \frac{W_{net}(P1)}{W_T(P1)}$  i.e. WR(P1) = 0.995 Work ratio.....Ans.

**Note:** In the above analysis, Pump work is considered. But, many times, the pump work can be neglected since it is quite small compared to net work.

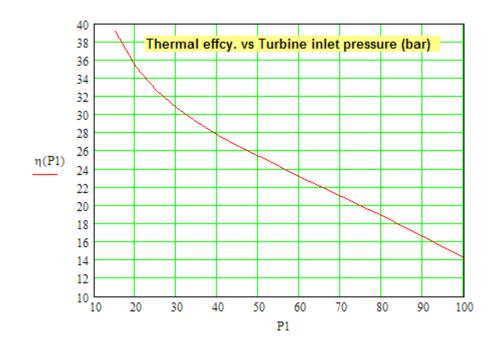
### (b) For the Regenerative Rankine cycle solved above, plot the thermal effcy., net work output and SSC as the turbine inlet pressure, P1 varies from 15 bar to 100 bar:

We have already written the relevant quantities as functions of pressure P1:

#### Now, to plot the results:

P1 := 15,20.. 100 bar.... define a range variable

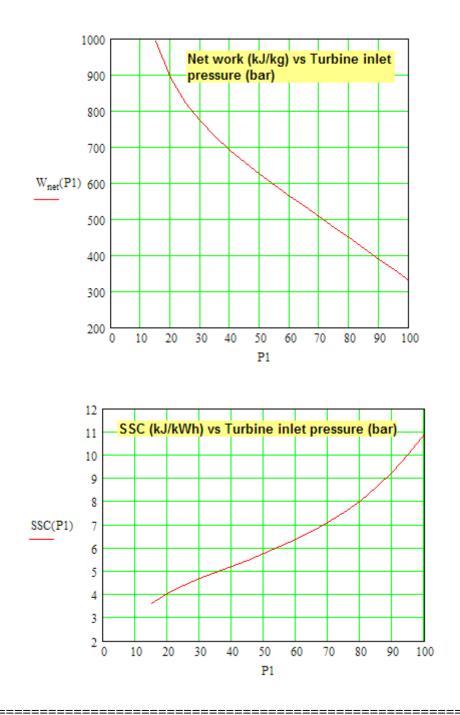
P1 =	η(P1) =	$W_{net}(P1) =$	SSC(P1) =
15	39.126	993.577	3.623
20	35.208	890.407	4.043
25	32.649	822.2	4.378
30	30.715	770.129	4.675
35	29.181	728.328	4.943
40	27.744	689.298	5.223
45	26.543	656.185	5.486
50	25.375	624.168	5.768
55	24.237	593.164	6.069
60	23.125	563.095	6.393
65	22.057	534.103	6.74
70	20.996	505.582	7.121
75	19.921	476.849	7.55
80	18.847	448.426	8.028
85	17.698	418.263	8.607
90	16.541	388.267	9.272
95	15.374	358.436	10.044
100	14.199	328.766	10.95





204

Click on the ad to read more



#### 3.3 Problems solved with EES

- i. It has built-in functions for properties of steam and several other fluids.
- ii. Also, the cycle can be 'overlaid' on the built-in property diagrams.
- iii. In EES, there is also a facility to enter data and perform calculations from a single window, called 'the diagram window'.

**Prob.3.3.1** Superheated steam enters the turbine of an ideal Rankine cycle at 8 MPa, 480 C. The condenser pressure is 8 kPa. The net power output of the cycle is 100 MW. Determine: (i) rate of heat transfer in the steam generator, (ii) thermal efficiency, (iii) mass flow rate of condenser cooling water in kg/s, if water enters the condenser at 15 C and exits at 35 C.

- b) Plot each of the quantities mentioned above for condenser pressures ranging from 6 kPa to 100 kPa.
- c) Plot each of the quantities in (a) as steam generator pressure varies from 4 MPa to 24 MPa, maintaining the turbine inlet temp at 480 C. [Ref: 3]

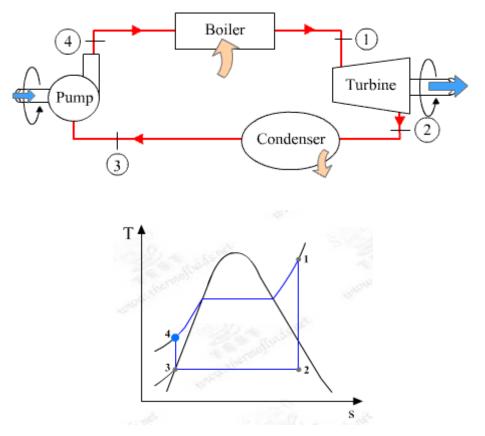


Fig.Prob.3.3.1 (a) Schematic diagram of simple, ideal Rankine cycle, and (b) T-s diagram

#### **EES Solution:**

#### "Data:"

Fluid\$ = 'Steam\_IAPWS'

#### P[1]=8000[kPa]"...at entry to turbine"

P[2]=8[kPa]"...at exit of turbine"

P[3]=P[2]"....at entry to pump"

- P[4]=P[1]"...at exit of pump"
- x[3]=0.0 "...sat. liq. at entry to pump"

T[1]=480[C]

Power = 1E05[kW] "...power developed"

- T\_cw1 = 15 [C] "..inlet temp of cooling water"
- T\_cw2 = 35 [C] "..exit temp of cooling water"
- cp\_w = 4.18 "kJ/kg.C ... sp. heat of cooling water"

#### "Calculations:"

h[1]=ENTHALPY(Fluid\$,T=T[1],P=P[1])"kJ/kg...enthalpy of fluid at entry to turbine"

s[1]=ENTROPY(Fluid\$,T=T[1],P=P[1]) "kJ/kg.C...entropy of fluid at entry to turbine"

s[2]=s[1] "...for isentropic expn. in turbine"

h[2]=ENTHALPY(Fluid\$,s=s[2],P=P[2])"kJ/kg...enthalpy of fluid at exit of turbine"

T[2]=TEMPERATURE(Fluid\$,s=s[2],h=h[2])"C...temp at exit of turbine"

x[2]=Quality(Fluid\$,T=T[2],s=s[2])"....quality of steam at exit of turbine"

v\_f=VOLUME(Fluid\$,P=P[3],x=x[3]) "m^3/kg ... sp. vol. of fluid entering the pump"

T[3]=T\_SAT(Fluid\$,P=P[3]) "...sat. temp. at condenser pressure"

h[3]=ENTHALPY(Fluid\$,T=T[3],x=x[3])"kJ/kg ... enthalpy at entry to pump"

w\_p = v\_f \* (P[4]-P[3]) ".kJ..pump work"

h[4]=h[3]+w\_p "kJ/kg ... enthalpy at the exit of pump"

q\_in=h[1]-h[4]"kJ/kg"

q\_out=h[2]-h[3]"kJ/kg"

 $w_{turb} = h[1] - h[2]$  "kJ/kg .... turbine work output"

w\_net = w\_turb - w\_p "kJ/kg ... net work output"

eta\_th=1- q\_out/q\_in

s[3]=ENTROPY(Fluid\$,P=P[3],h=h[3]) "kJ/kg.C ... entropy of fluid at entry to pump"

s[4] = s[3]"...isentropic compression in pump"

T[4]=TEMPERATURE(Fluid\$,P=P[4],s=s[4])"C...temp at exit of pump"

m\_steam = Power / w\_net "kg/s .... mass flow rate of steam"

m\_cw \* cp\_w \* (T\_cw2 - T\_cw1) = m\_steam \* q\_out "...kg/s ... finds mass flow rate of cooling water, by energy balance in the condenser"

Qtot\_in = q\_in \* m\_steam "kW .... total heat input in steam generator"



#### < OLIVER WYMAN



deep industry knowledge with specialized expertise in strategy, operations, risk usep industry kilowicege with specialized expension and a strategy, operations, risk management, organizational transformation, and leadership development. With difices in 50+ cities across 25 countries, Oliver Wyman works with the CEOs and executive teams of Global 1000 companies. OUR WORLD An equal opportunity employer.

nt consulting firm that combines

#### GET THERE FASTER

Some people know precisely where they want to go. Others seek the adventure of ring uncharted territory. Whatever you want your professional journey to be, you'll find what you're looking for at Oliver Wyman.

Discover the world of Oliver Wyman at oliverwyman.com/careers





#### **Results:**

#### Unit Settings: SI C kPa kJ mass deg

cp <sub>w</sub> = 4.18	η <sub>th</sub> = 0.3972	Fluid\$ = 'Steam_IAPWS'	m <sub>ew</sub> = 1816 [kg/s]
m <sub>steam</sub> = 79.48 [kg/s]	Power = 100000 [kW]	Qtot <sub>in</sub> = 251778 [kW]	q <sub>in</sub> = 3168 [kJ/kg]
q <sub>out</sub> = 1910 [kJ/kg]	T <sub>cw1</sub> =15 [C]	T <sub>cw2</sub> = 35 [C]	v <sub>f</sub> = 0.001008 [m <sup>3</sup> /kg]
w <sub>net</sub> = 1258 [kJ/kg]	w <sub>p</sub> = 8.06 [kJ/kg]	w <sub>turb</sub> = 1266 [kJ/kg]	

Sort	1 ⊾ h <sub>i</sub> [kJ/kg]	² ₽ <sub>i</sub> [kPa]	₃ ⊻ s <sub>i</sub> [kJ/kg-C]	<sup>4</sup> T <sub>i</sub> [C]	<sup>5</sup> X <sub>i</sub> ⊻
[1]	3350	8000	6.661	480	
[2]	2083	8	6.661	41.51	0.7949
[3]	173.8	8	0.5925	41.51	0
[4]	181.9	8000	0.5925	41.75	

Thus:

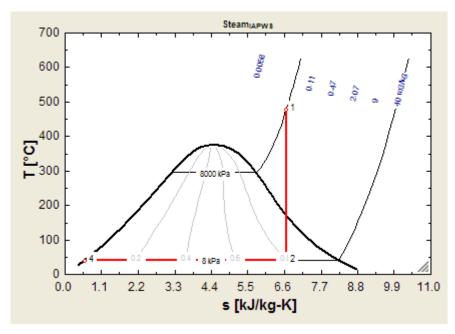
Heat input in the steam generator = Qtot\_in = 250175 kW....Ans.

Mass flow rate of steam = m\_steam = 78.98 kg/s .... Ans.

Mass flow rate of cooling water = m\_cw = 1804 kg/s ... Ans.

Thermal efficiency = eta\_th = 0.3972 = 39.72% ... Ans.

T-s plot of cycle:

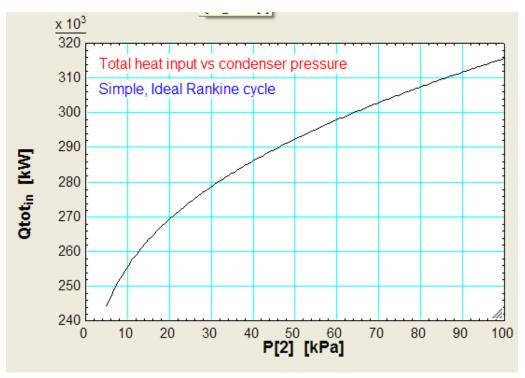


(b) Plot each of the quantities mentioned above for condenser pressure (P2) ranging from 6 kPa to 100 kPa.

115	1 ₽ <sub>2</sub> [kPa]	2 Qtot <sub>in</sub> [kW]	3 ∎ Nth	₄ ⊾ m <sub>cw</sub> [kg/s]
Run 1	5	244368	0.4092	1727
Run 2	11.79	258612	0.3867	1897
Run 3	18.57	267641	0.3736	2005
Run 4	25.36	274571	0.3642	2088
Run 5	32.14	280324	0.3567	2157
Run 6	38.93	285310	0.3505	2217
Run 7	45.71	289752	0.3451	2270
Run 8	52.5	293786	0.3404	2318
Run 9	59.29	297499	0.3361	2362
Run 10	66.07	300953	0.3323	2404
Run 11	72.86	304194	0.3287	2443
Run 12	79.64	307255	0.3255	2479
Run 13	86.43	310161	0.3224	2514
Run 14	93.21	312934	0.3196	2547
Run 15	100	315590	0.3169	2579

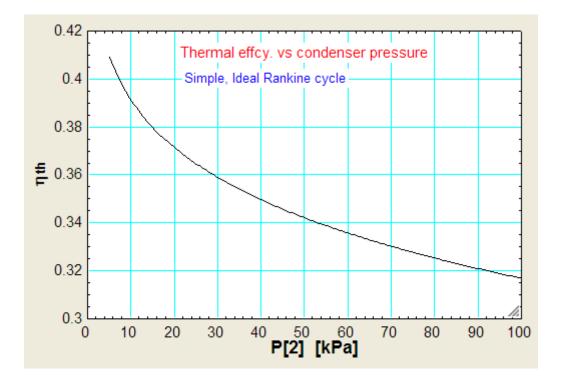
#### First, compute the Parametric Table:

#### Now, plot the results:



© 2010 EYGM Lim

d. All



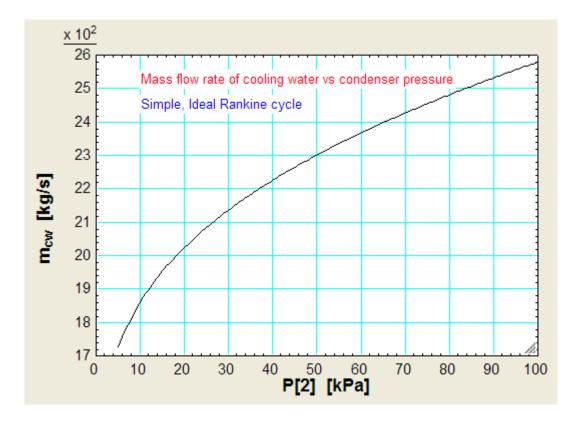
## Day one and you're ready

Day one. It's the moment you've been waiting for. When you prove your worth, meet new challenges, and go looking for the next one. It's when your dreams take shape. And your expectations can be exceeded. From the day you join us, we're committed to helping you achieve your potential. So, whether your career lies in assurance, tax, transaction, advisory or core business services, shouldn't your day one be at Ernst & Young?

What's next for your future? ey.com/careers

JERNST & YOUNG Quality In Everything We Do



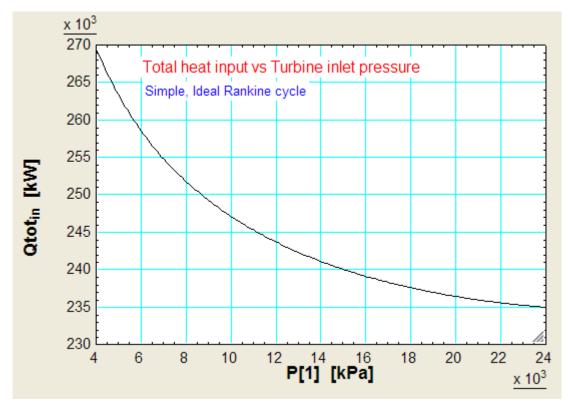


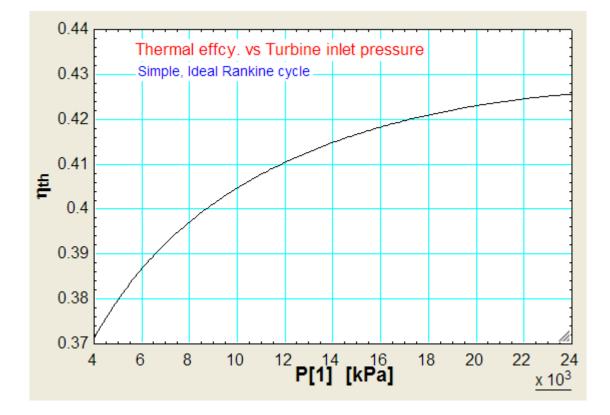
(c) Plot each of the quantities in (a) as steam generator pressure (P1) varies from 4 MPa to 24 MPa, maintaining T1 at 480 C.

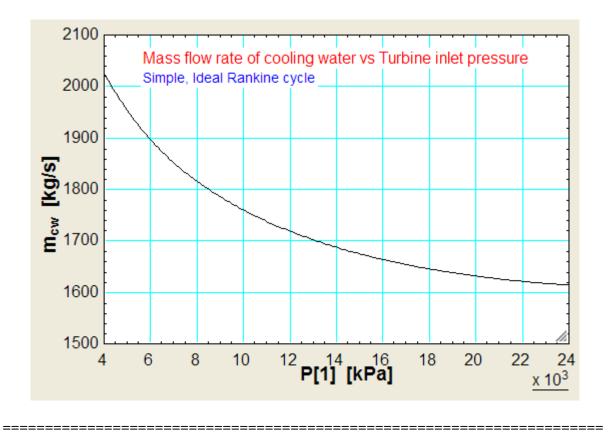
First, compute the Parametric Table:

111	1 ₽ <sub>1</sub> [kPa]	2 Qtot <sub>in</sub> [kW]	3 Σ η <sub>th</sub>	4
Run 1	4000	269416	0.3712	2027
Run 2	6000	258549	0.3868	1897
Run 3	8000	251778	0.3972	1816
Run 4	10000	247090	0.4047	1759
Run 5	12000	243657	0.4104	1718
Run 6	14000	241065	0.4148	1687
Run 7	16000	239079	0.4183	1664
Run 8	18000	237554	0.421	1645
Run 9	20000	236396	0.423	1632
Run 10	22000	235543	0.4246	1621
Run 11	24000	234952	0.4256	1614

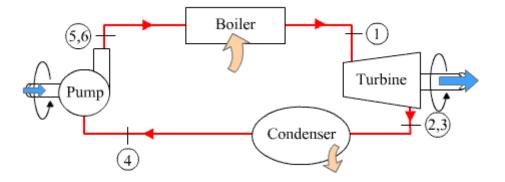
#### Now, plot the results:







**"Prob.3.3.2** Write an EES Procedure to calculate thermal effcy etc of a Simple, actual, Rankine cycle, i.e. considering the isentropic efficiencies of turbine and pump:"



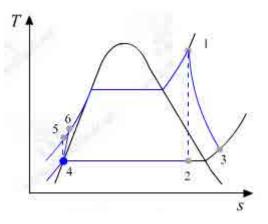


Fig.Prob.3.3.2 (a) Schematic diagram of simple, actual Rankine cycle, and (b) T-s diagram [Ref: 7]

#### **EES Solution:**

\$UnitSystem kPa C kJ

PROCEDURE Simple\_actual\_Rankine(P[1], T[1], P[2], eta\_turb, eta\_pump: T[3], w\_turb\_act, w\_p\_act, w\_net, eta\_th,q\_in, q\_out)

"Inputs:P1(kPa), T1 (C), P2 (kPa), eta\_turb, eta\_comp

**Outputs:** T3 (C...actual turbine outlet temp), w\_turb\_act (kJ/kg), w\_comp\_act (kJ/kg), w\_net (kJ/kg), eta\_th, q\_in (kJ/kg), q\_out (kJ/kg)"



#### Fluid\$ := 'Steam\_IAPWS'

- P[3]:=P[2]"....pressure at actual exit from turbine"
- P[4]:=P[2]"...pressure at inlet of pump"
- P[5] := P[1] "...pressure at exit of pump"
- P[6] := P[5]
- x[4]=0.0 "...sat. liq. at entry to pump"

#### "Calculations:"

- h[1] :=ENTHALPY(Fluid\$,T=T[1],P=P[1])"kJ/kg...enthalpy of fluid at entry to turbine"
- s[1] :=ENTROPY(Fluid\$,T=T[1],P=P[1]) "kJ/kg.C...entropy of fluid at entry to turbine"
- s[2] :=s[1] "...for isentropic expn. in turbine"

T[2] :=TEMPERATURE(Fluid\$,P=P[2],s=s[2])"C...temp at isentr. exit of turbine"

h[2] :=ENTHALPY(Fluid\$,s=s[2],P=P[2])"kJ/kg...enthalpy of fluid at exit of turbine"

w\_turb\_isentr := h[1] - h[2] "kJ/kg .... turbine work output, isentropic"

w\_turb\_act := eta\_turb \* w\_turb\_isentr "kJ/kg ... actual turbine output"

h[3] := h[1] - w\_turb\_act "kJ/kg ... enthalpy at actual turbine outlet"

T[3] :=TEMPERATURE(Fluid\$,P=P[3],h=h[3])"C...temp at actual exit of turbine"

- x[2] :=Quality(Fluid\$,T=T[2],s=s[2])"....quality of steam at isentropic exit of turbine"
- v\_f :=VOLUME(Fluid\$,P=P[4],x=x[4]) "m^3/kg ... sp. vol. of fluid entering the pump"
- T[4] :=T\_SAT(Fluid\$,P=P[4]) "...sat. temp. at condenser pressure"
- h[4] :=ENTHALPY(Fluid\$,T=T[4],x=x[4])"kJ/kg ... enthalpy at entry to pump"

w\_p\_isentr := v\_f \* (P[5]-P[4]) ".kJ..isentr. pump work"

- w\_p\_act := w\_p\_isentr / eta\_pump "kJ/kg .... actual pump work required"
- h[5] :=h[4]+w\_p\_isentr "kJ/kg ... enthalpy at the isentropic exit of pump"
- h[6] := h[4] + w\_p\_act "kJ/kg ... enthalpy at actual exit of pump"
- q\_in :=h[1]-h[6]"kJ/kg"

```
q_out :=h[3]-h[4]"kJ/kg"
```

w\_net := w\_turb\_act - w\_p\_act "kJ/kg .... net work output"

eta\_th :=1- q\_out/q\_in "...thermal effcy."

- s[3] :=ENTROPY(Fluid\$,P=P[3],h=h[3]) "kJ/kg.C ... entropy of fluid at actual exit of turbine"
- s[4] := ENTROPY(Fluid\$,P=P[4],x=x[4]) "kJ/kg.C ... entropy of fluid at inlet of pump"
- s[5] := s[4]"...isentropic compression in pump"
- T[5] :=TEMPERATURE(Fluid\$,P=P[5],s=s[5])"C...temp at isentropic exit of pump"
- s[6] :=ENTROPY(Fluid\$,P=P[6],h=h[6]) "kJ/kg.C ... entropy of fluid at actual exit of pump"

```
T[6] :=TEMPERATURE(Fluid$,P=P[6],s=s[6])"C...temp at actual exit of pump"
```

END

"\_\_\_\_\_"

### "Example: Verify the results obtained in Prob.3.3.1"

We have:

P[1]=8000 "kPa" T[1] = 480"C" P[2] = 8"kPa" eta\_turb = 1"...isentropic effcy. of turbine "
eta\_pump = 1"...isentropic effcy. of pump"

CALL Simple\_actual\_Rankine(P[1], T[1],P[2], eta\_turb, eta\_pump: T[3], w\_turb\_act, w\_p\_act, w\_net, eta\_th,q\_in,q\_out)

### **Results:**

Main Simple_actual_Rankine		
Unit Settings: SI C kPa I	kJ mass deg	
η <sub>pump</sub> = 1	η <sub>th</sub> = 0.3972	η <sub>turb</sub> = 1
q <sub>in</sub> = 3168 [kJ/kg]	q <sub>out</sub> = 1910 [kJ/kg]	w <sub>net</sub> = 1258 [kJ/kg]
w <sub>p,act</sub> = 8.06 [kJ/kg]	w <sub>turb,act</sub> = 1266 [kJ/kg]	

### We see that the results match.

Auxiliary results calculated are obtained from the 'Simple\_actual\_Rankine' tab in the Results:

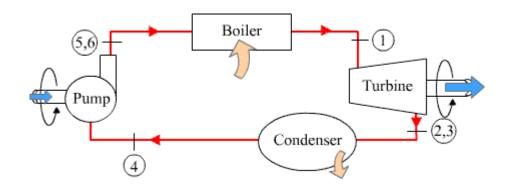
### Local variables in Procedure Simple\_actual\_Rankine (1 call, 0.02 sec)

η <sub>pump</sub> =1	η <sub>th</sub> =0.3972	ηturb=1
Fluid\$='Steam_IAPWS'	h <sub>1</sub> =3350 [kJ/kg]	h <sub>2</sub> =2083 [kJ/kg]
h3=2083 [kJ/kg]	h <sub>4</sub> =173.8 [kJ/kg]	h5=181.9 [kJ/kg]
h <sub>6</sub> =181.9 [kJ/kg]	P <sub>1</sub> =8000 [kPa]	P <sub>2</sub> =8 [kPa]
P3=8 [kPa]	P <sub>4</sub> =8 [kPa]	P5=8000 [kPa]
P <sub>6</sub> =8000 [kPa]	q <sub>in</sub> =3168 [kJ/kg]	q <sub>out</sub> =1910 [kJ/kg]
s <sub>1</sub> =6.661 [kJ/kg-C]	s <sub>2</sub> =6.661 [kJ/kg-C]	s3=6.661 [kJ/kg-C]
s <sub>4</sub> =0.5925 [kJ/kg-C]	s5=0.5925 [kJ/kg-C]	s <sub>6</sub> =0.5925 [kJ/kg-C]
T <sub>1</sub> =480 [C]	T <sub>2</sub> =41.51 [C]	T <sub>3</sub> =41.51 [C]
T <sub>4</sub> =41.51 [C]	T <sub>5</sub> =41.75 [C]	T <sub>6</sub> =41.75 <mark>[C]</mark>
v <sub>f</sub> =0.001008 [m <sup>3</sup> /kg]	w <sub>net</sub> =1258 [kJ/kg]	w <sub>p.act</sub> =8.06 [kJ/kg]
w <sub>p,isentr</sub> =8.06 [kJ/kg]	w <sub>turb,act</sub> =1266 [kJ/kg]	w <sub>turb,isentr</sub> =1266 [kJ/kg]
×2=0.7949	×4=0	

\_\_\_\_\_

**Prob.3.3.3** Superheated steam enters the turbine of an actual, simple Rankine cycle at 8 MPa, 480 C. The condenser pressure is 8 kPa. The net power output of the cycle is 100 MW. Isentropic effcy of turbine = 85%, and that of the pump is 70%. Determine: (i) thermal effcy., (ii) mass flow rate of steam, (iii) mass flow rate of condenser cooling water in kg/s, if water enters the condenser at 15 C and exits at 35 C.

- b) Plot each of the quantities mentioned above for condenser pressures ranging from 6 kPa to 100 kPa.
- c) Plot each of the quantities in (a) as steam generator pressure varies from 4 MPa to 24 MPa, maintaining the turbine inlet temp at 480 C. [Ref: 3]





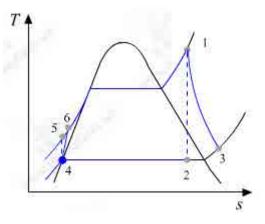
Hellmann's is one of Unilever's oldest brands having been popular for over 100 years. If you too share a passion for discovery and innovation we will give you the tools and opportunities to provide you with a challenging career. Are you a great scientist who would like to be at the forefront of scientific innovations and developments? Then you will enjoy a career within Unilever Research & Development. For challenging job opportunities, please visit www.unilever.com/rdjobs.



Dove







**Fig.Prob.3.3.3 (a)** Schematic diagram of simple, actual Rankine cycle, and (b) T-s diagram [Ref: 7]

### **EES Solution:**

We shall use the EES Procedure written above:

### "Data:"

P[1]=8000"kPa" T[1] = 480"C" P[2] = 8"kPa" eta\_turb = 0.85 eta\_pump = 0.7

cp\_w = 4.18"kJ/kg.C...sp. heat of condenser cooling water"

T\_cw1 = 15 "C... inlet temp of cooling water"

T\_cw2 = 35 "C ... exit temp of cooling water"

### "Calculations:"

CALL Simple\_actual\_Rankine(P[1], T[1],P[2], eta\_turb, eta\_pump: T[3], w\_turb\_act, w\_p\_act, w\_net, eta\_th,q\_in,q\_out)

Power = 100000 "kW"

### "Therefore:"

m\_steam = Power / w\_net "kg/s....mass flow rate of steam required to produce net power of 100 MW"

m\_w \* cp\_w \* (T\_cw2 - T\_cw1) = m\_steam \* q\_out "...finds mass flow rate of cooling water required, m\_w, by an energy balance in the condenser"

### **Results:**

### Unit Settings: SI C kPa kJ mass deg

cp <sub>w</sub> = 4.18 [kJ/kg-C]	η <sub>pump</sub> = 0.7	$\eta_{th} = 0.3365$	η <sub>turb</sub> = 0.85
m <sub>steam</sub> = 93.92 [kg/s]	m <sub>w</sub> = 2359 [kg/s]	Power = 100000 [kW]	q <sub>in</sub> = 3164 [kJ/k
q <sub>out</sub> = 2100 [kJ/kg]	T <sub>cw1</sub> = 15 [C]	T <sub>cw2</sub> =35 [C]	w <sub>net</sub> = 1065 [kJ/
w <sub>p,act</sub> = 11.51 [kJ/kg]	w <sub>turb,act</sub> = 1076 [kJ/kg]		

Thus:

Thermal effcy. = eta\_th = 0.3365 = 33.65%...Ans.

Mass flow rate of steam = m\_steam = 93.92 kg/s .... Ans.

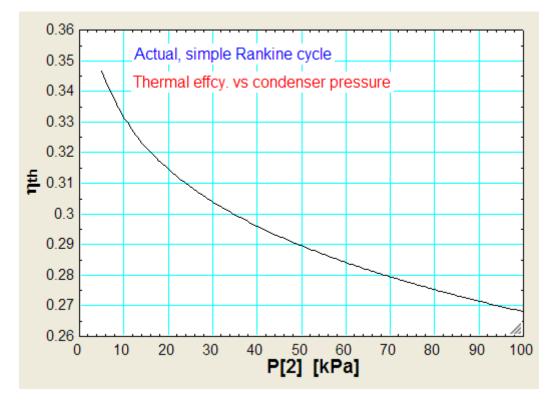
Mass flow rate of cooling water = m\_w = 2359 kg/s .... Ans.

(b) Plot each of the quantities mentioned above for condenser pressures (P2) ranging from 6 kPa to 100 kPa:

First, compute the Parametric Table:

115	1 ₽ <sub>2</sub> [kPa]	2 ν <sub>th</sub>	³ ⊻ m <sub>steam</sub> [kg/s]	4
Run 1	5	0.3468	90.11	2253
Run 2	11.79	0.3275	97.45	2456
Run 3	18.57	0.3164	102.2	2584
Run 4	25.36	0.3084	105.8	2683
Run 5	32.14	0.302	108.8	2764
Run 6	38.93	0.2967	111.5	2835
Run 7	45.71	0.2921	113.9	2899
Run 8	52.5	0.2881	116	2956
Run 9	59.29	0.2845	118	3009
Run 10	66.07	0.2812	119.8	3058
Run 11	72.86	0.2782	121.6	3104
Run 12	79.64	0.2754	123.2	3148
Run 13	86.43	0.2728	124.8	3189
Run 14	93.21	0.2703	126.3	3229
Run 15	100	0.268	127.8	3267

### Now, plot the results:



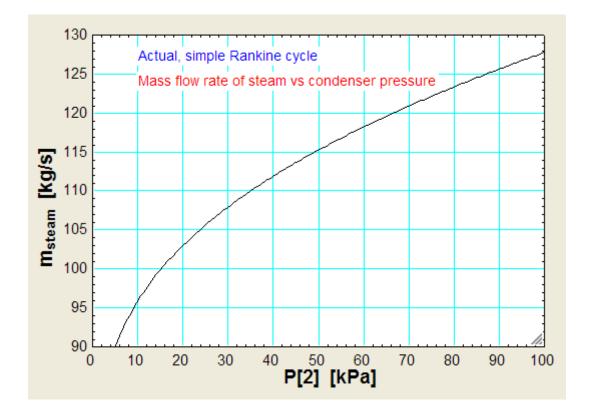


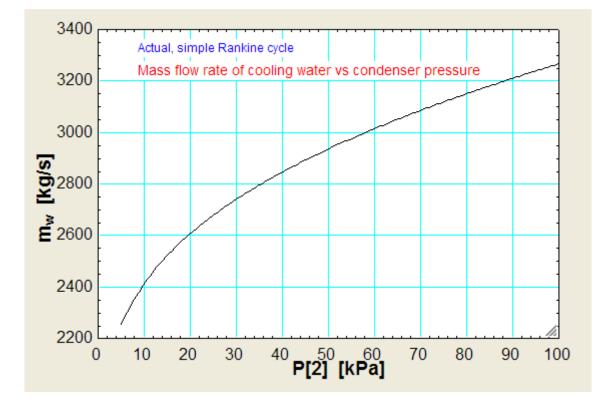
Discover the truth at www.deloitte.ca/careers



from Click on the ad to read more

222 Download free eBooks at bookboon.com



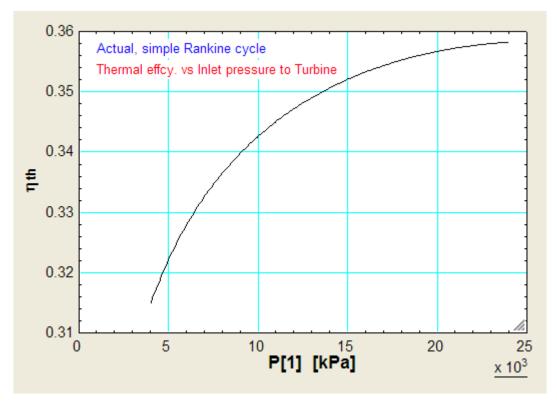


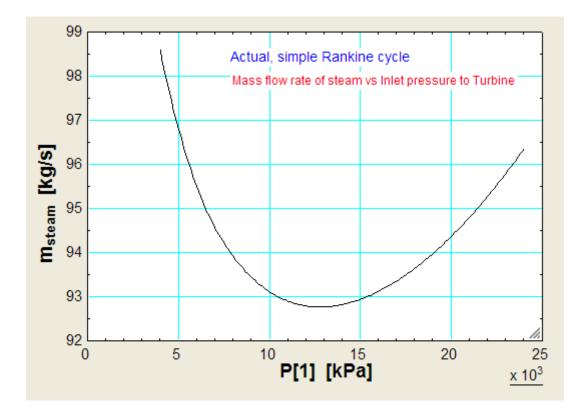
# (c) Plot each of the quantities in (a) as steam generator pressure (P1) varies from 4 MPa to 24 MPa, maintaining the turbine inlet temp at 480 C:

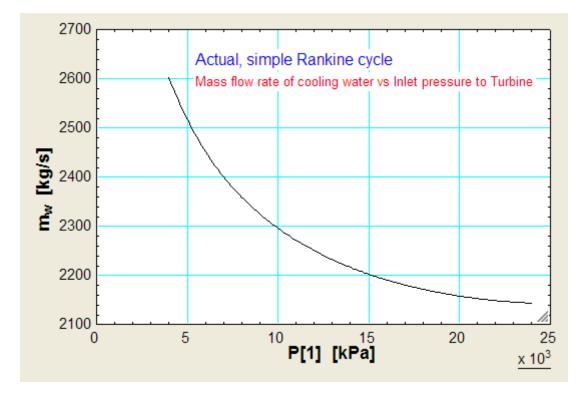
111	1 ₽ <sub>1</sub> [kPa]	2 Ν η <sub>th</sub>	3 ⊻ m <sub>steam</sub> [kg/s]	4
Run 1	4000	0.3149	98.59	2602
Run 2	6000	0.3279	95.51	2451
Run 3	8000	0.3365	93.92	2359
Run 4	10000	0.3426	93.11	2295
Run 5	12000	0.3472	92.79	2249
Run 6	14000	0.3506	92.82	2215
Run 7	16000	0.3533	93.12	2190
Run 8	18000	0.3552	93.65	2171
Run 9	20000	0.3567	94.37	2157
Run 10	22000	0.3577	95.28	2148
Run 11	24000	0.3582	96.37	2143

### First, compute the Parametric Table:

### Now, plot the results:







### (d) Use the Diagram Window in EES to input data and make calculations:

Diagram Window in EES can be used to input data. Simple diagrams can be made with the tool bar provided, or diagrams made in your favorite software can be copied in to the diagram window.

Advantages of using the diagram window are:

- 1. Drawings, plots and data and results cal all be shown in a single window, thus adding to the clarity of solution
- 2. Changing the data and doing the calculations to observe the results are done from a single window
- 3. Since the user need not know the details of calculations and has to o0nly input the data, press 'Calculate' button and observe the results, he need not be conversant with the software nor the details of calculations.
- 4. Can be distributed to those in the team who may not know details of EES.

### Following is the procedure to use the diagram window:

🧏 Diagram Window	
Cursor: 248, 24 Main	

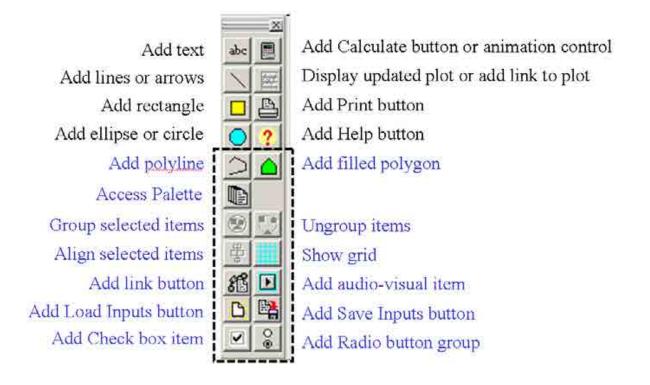
a) From the equations window, press  $^D$  (i.e. control + D). We get:

On the right, you see the vertical, diagram window tool bar.

You can also get the diagram window by clicking on the 'speed button' in the tool bar of eqn. window, as shown below:

S EES Professional:	
File Filt Search Options Calculate Tables Plots Windows Help Examples	
·····································	 ? /2

### Explanation of each button in the diagram window tool bar is given below (Ref: EES Manual):



# Grant Thornton— $a^{\text{REALLY}}$ great place to work.

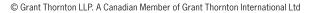
We're proud to have been recognized as one of Canada's Best Workplaces by the Great Place to Work Institute<sup>™</sup> for the last four years. In 2011 Grant Thornton LLP was ranked as the fifth Best Workplace in Canada, for companies with more than 1,000 employees. We are also very proud to be recognized as one of Canada's top 25 Best Workplaces for Women and as one of Canada's Top Campus Employers.



Priyanka Sawant Manager

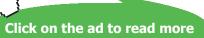


Audit • Tax • Advisory www.GrantThornton.ca/Careers









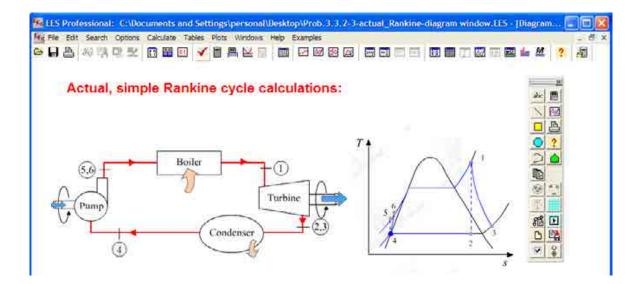
Download free eBooks at bookboon.com

b) After copying the schematic diagram and T-s diagram, press on the top, left button (i.e. Add text) on the tool bar:

fype <sup>©</sup> Text <sup>∩</sup> Formatted text <sup>∩</sup> Input variable <sup>∩</sup> Output variable	ΔΩΘ
ont Default	<ul> <li>✓ Horizontal</li> <li>Ć Vertical</li> </ul>
✓ Background Frame text ← Hide Location (pixels)	I Bold I Italic I Underline

Here, by choosing the radio buttons, we can enter text, formatted text, input variable or output variables.

Partly completed diagram window is shown below:



Туре	Select	input variable	
<ul> <li>Text</li> <li>Formatted text</li> <li>Input variable</li> <li>Output variable</li> <li>Include variable name</li> <li>Include units</li> </ul>	cp_w eta_p eta_tl eta_tu m_ste m_w Powe P[1] P[2]	h urb :am	
Slider input Tab order 6 🚖	드 Hic	le array variables	
Size 21 Color		C Vertical	
<ul> <li>✓ Background</li> <li>✓ Frame text</li> <li>✓ Hide</li> <li>✓ Location (pixels)</li> </ul>		<ul><li>✓ Bold</li><li>✓ Italic</li><li>✓ Underline</li></ul>	
Left 54 Top 71		Name	

c) Now, select the Input variable radio button, and we get:



Low-speed Engines Medium-speed Engines Turbochargers Propellers Propulsion Packages PrimeServ

The design of eco-friendly marine power and propulsion solutions is crucial for MAN Diesel & Turbo. Power competencies are offered with the world's largest engine programme – having outputs spanning from 450 to 87,220 kW per engine. Get up front! Find out more at www.mandieselturbo.com

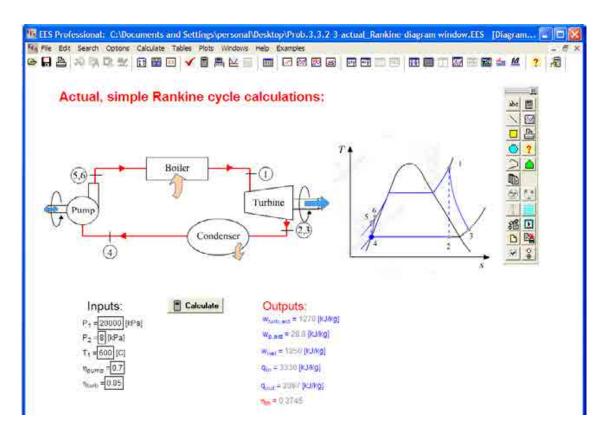
Engineering the Future – since 1758. **MAN Diesel & Turbo** 



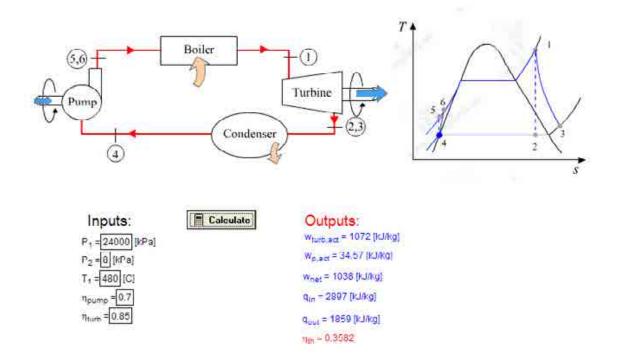


229

d) Choose the required Input variables and click OK one by one. They appear neatly on the Diagram window. You can drag them and position wherever you feel like. Do the same thing with Output variables too. And add a 'Calculate' button also, from the tool bar on the right. Final arrangement of Diagram window is shown below:



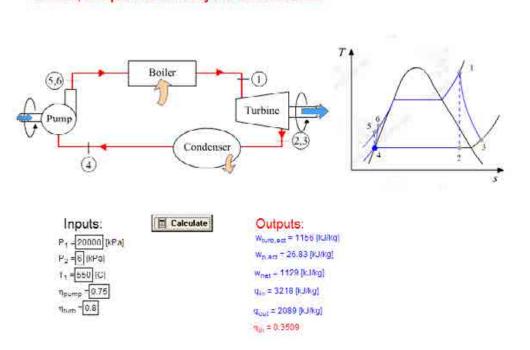
e) **To make calculations:** When the tool bar is visible in the diagram window, it is said to be in the '*Development mode*', i.e. you can add diagrams, text etc. To do calculations, you have to change to the '*Application mode*'. To do this, press (control+ D) again. The tool bar disappears and you are in the Applications mode. Thus, by pressing (control + D) you can alternate between these two modes easily. In Applications mode, now, we have:



### Actual, simple Rankine cycle calculations:

In Applications mode, we can input any new values we desire for the Input variables, and press **'Calculate'** button, and immediately the output variables update themselves.

As an example, make following entries for Input variables: P1 = 20 MPa, P2 = 6 kPa, T1 = 550 C, eta\_pump = 0.75 and eta\_turb = 0.8. And, click on **Calculate** button. We get:

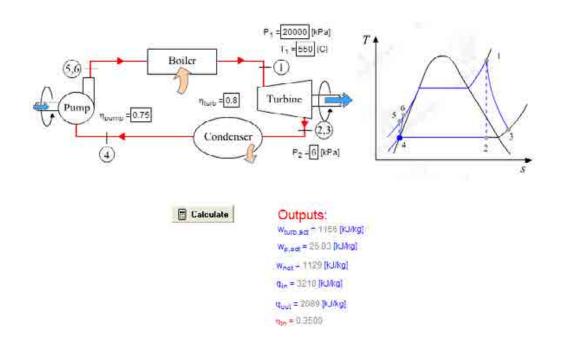


Actual, simple Rankine cycle calculations:

In the above screen shot, see how the results have changed.

f) In addition, you can position the Input variables, by the side of respective components in the schematic diagram itself for clarity. For example, eta\_turb can be placed by the side of the turbine, P1, T1 over the Turbine, eta\_pump near the pump etc. See below:





\_\_\_\_\_

\_\_\_\_\_

There are many other buttons in the tool bar, and many more possibilities of using the diagram window; Refer to the User Manual in EES to get more information.

Thus, Diagram window is a very convenient, useful facility in EES.

**Prob.3.3.4** An ideal Rankine cycle with reheat uses water as the working fluid. The conditions at the inlet to the first stage turbine are 14 MPa, 600 C and the steam is reheated between the turbine stages to 600 C. For a condenser pressure of 6 kPa, plot the cycle thermal efficiency versus reheat pressure for pressures ranging from 2 to 12 MPa. [Ref: 3]

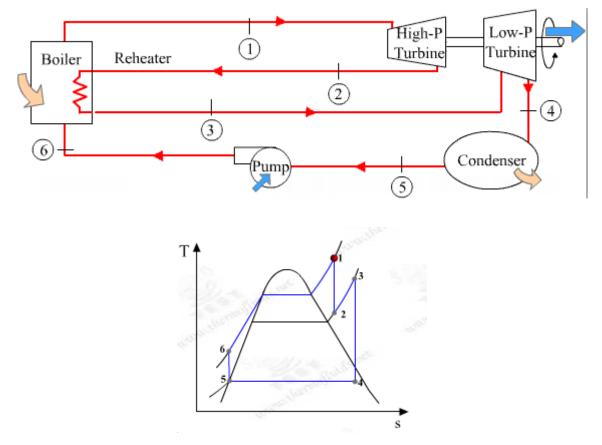


Fig.Prob.3.3.4 (a) Ideal Rankine cycle with reheat, and (b) T-s diagram

### **EES Solution:**

### "Data:"

Fluid\$ = 'Steam\_IAPWS'

- P[1]=14000[kPa]"...at entry to HP turbine"
- T[1]= 600[C] "...HP turbine inlet temp."
- T[3] = 600[C] "..reheat temp"
- P[2]=2000[kPa]"...reheat pressure.... at exit of HP turbine"
- P[3] = P[2]"...at inlet to LP turbine"
- P[4]=6 [kPa]"....at exit of LP turbine"
- P[5]=P[4]"...at inlet of pump"
- P[6] = P[1] "..at exit of pump, i.e. inlet to boiler"
- x[5] = 0 "...sat. liq. at entry to pump"

# **¾ RBS** Group

# CAREERKICKSTART

### An app to keep you in the know

Whether you're a graduate, school leaver or student, it's a difficult time to start your career. So here at RBS, we're providing a helping hand with our new Facebook app. Bringing together the most relevant and useful careers information, we've created a one-stop shop designed to help you get on the career ladder – whatever your level of education, degree subject or work experience.

And it's not just finance-focused either. That's because it's not about us. It's about you. So download the app and you'll get everything you need to know to kickstart your career.

So what are you waiting for?

Click here to get started.



Vapour Power Cycles

### "Calculations:"

- h[1]=ENTHALPY(Fluid\$,T=T[1],P=P[1])"kJ/kg...enthalpy of fluid at entry to HP turbine"
- s[1]=ENTROPY(Fluid\$,T=T[1],P=P[1]) "kJ/kg.C...entropy of fluid at entry to HP turbine"

s[2]=s[1] "...for isentropic expn. in HP turbine"

h[2]=ENTHALPY(Fluid\$,s=s[2],P=P[2])"kJ/kg...enthalpy of fluid at exit of HP turbine"

T[2]=TEMPERATURE(Fluid\$,s=s[2],h=h[2])"C...temp at exit of HP turbine"

h[3]=ENTHALPY(Fluid\$,T=T[3],P=P[3])"kJ/kg...enthalpy of fluid at entry to LP turbine"

s[3]=ENTROPY(Fluid\$,T=T[3],P=P[3]) "kJ/kg.C...entropy of fluid at entry to LP turbine"

s[4] = s[3] "...for isentropic expn. in LP turbine"

h[4]=ENTHALPY(Fluid\$,s=s[4],P=P[4])"kJ/kg...enthalpy of fluid at exit of LP turbine"

T[4]=TEMPERATURE(Fluid\$,s=s[4],h=h[4])"C...temp at exit of LP turbine"

x[2]=Quality(Fluid\$,T=T[2],s=s[2])"....quality of steam at exit of HP turbine"

x[4]=Quality(Fluid\$,T=T[4],s=s[4])"....quality of steam at exit of LP turbine"

v\_f=VOLUME(Fluid\$,P=P[5],x=x[5]) "m^3/kg ... sp. vol. of fluid entering the pump"

T[5]=T\_SAT(Fluid\$,P=P[5]) "...sat. temp. at condenser pressure"

h[5]=ENTHALPY(Fluid\$,T=T[5],x=x[5])"kJ/kg ... enthalpy at entry to pump"

w\_p = v\_f \* (P[6]-P[5]) ".kJ..pump work"

 $h[6] = h[5] + w_p "kJ/kg ... enthalpy at the exit of pump"$ 

q\_boiler = h[1]-h[6]"kJ/kg .... heat input in boiler"

q\_reheat = h[3]-h[2]"kJ/kg ... heat input in reheater"

q\_in = q\_boiler + q\_reheat "kJ/kg .... total heat input to cycle"

q\_out=h[4]-h[5]"kJ/kg"

w\_turb1 = h[1] - h[2] "kJ/kg .... HP turbine work output"

 $w_{turb2} = h[3] - h[4]$  "kJ/kg .... LP turbine work output"

w\_turb\_tot = w\_turb1 + w\_turb2 "kJ/kg ... total turbine work output"

w\_net = w\_turb\_tot - w\_p "kJ/kg .... net work output"

eta\_th=1- q\_out/q\_in "....thermal efficiency of cycle"

s[5]=ENTROPY(Fluid\$,P=P[5],h=h[5]) "kJ/kg.C ... entropy of fluid at entry to pump"

s[6] = s[5]"...isentropic compression in pump"

T[6]=TEMPERATURE(Fluid\$,P=P[6],s=s[6])"C...temp at exit of pump"

### **Results (with reheat pressure P2 = 2000 kPa):**

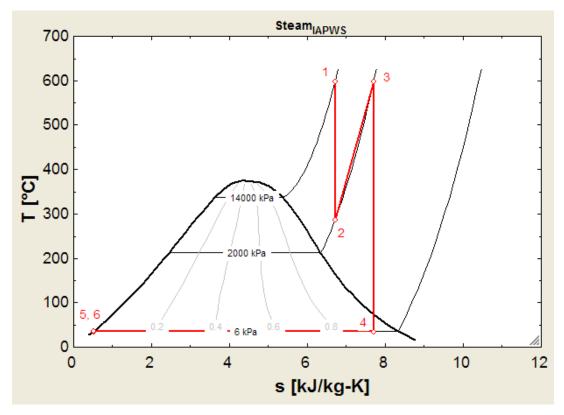
### Unit Settings: SI C kPa kJ mass deg

η <sub>th</sub> = 0.4608	Fluid\$ = 'Steam_IAPWS'	q <sub>boiler</sub> = 3426 [kJ/kg]
q <sub>in</sub> = 4121 [kJ/kg]	q <sub>out</sub> = 2222 [kJ/kg]	q <sub>reheat</sub> = 694.5 [kJ/kg]
v <sub>f</sub> = 0.001006 [m <sup>3</sup> /kg]	w <sub>net</sub> =1899 [kJ/kg]	w <sub>p</sub> =14.08 [kJ/kg]
w <sub>turb1</sub> = 595.6 [kJ/kg]	w <sub>turb2</sub> = 1317 [kJ/kg]	Wturb,tot = 1913 [kJ/kg]

Sort	¹ h <sub>i</sub> ⊻	² ► P <sub>i</sub> [kPa]	₃ ⊻ s <sub>i</sub>	₄	5 ⊾ Xi
[1]	3592	14000	6.719	600	
[2]	2996	2000	6.719	288	100
[3]	3691	2000	7.704	600	
[4]	2373	6	7.704	36.16	0.92
[5]	151.5	6	0.5208	36.16	0
[6]	165.6	14000	0.5208	36.53	

Thus, for a reheat pressure of 2 MPa, we have:

Thermal efcy of cycle = eta\_th = 0.4608 = 46.08% .... Ans.



### Cycle on the T-s plot, using Property plot of EES:

## ORACLE

### Be BRAVE enough to reach for the sky

Oracle's business is information - how to manage it, use it, share it, protect it. Oracle is the name behind most of today's most innovative and successful organisations.

Oracle continuously offers international opportunities to top-level graduates, mainly in our Sales, Consulting and Support teams.

If you want to join a company that will invest in your future, Oracle is the company for you to drive your career!

### https://campus.oracle.com

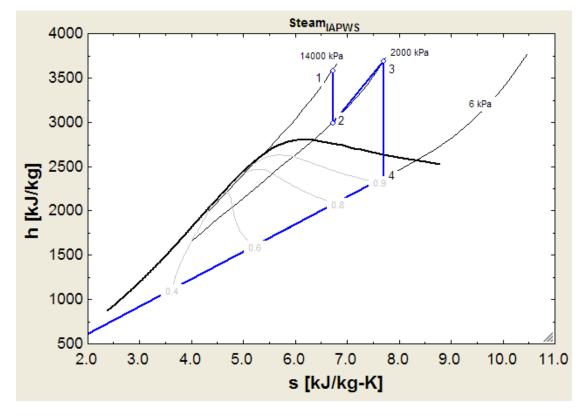


### **ORACLE IS THE INFORMATION COMPANY**





237 Download free eBooks at bookboon.com



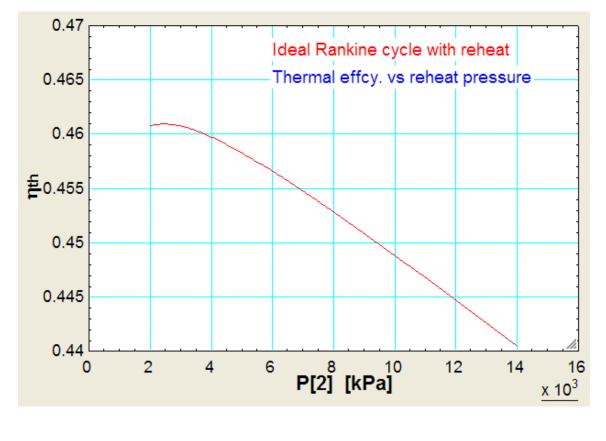
### Cycle on the h-s plot, using Property plot of EES:

(b) Plot Thermal effcy. vs reheat pressure (P2):

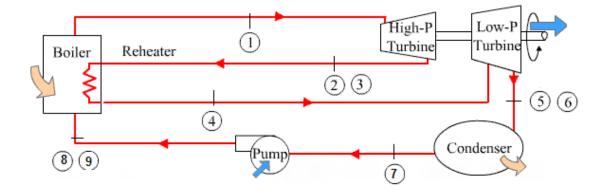
First, compute the Parametric Table:

113	1 ₽2 [kPa]	2 vnet [kJ/kg]	3 ▼ q <sub>in</sub> [kJ/kg]	4 ⊻ η <sub>th</sub>
Run 1	2000	1899	4121	0.4608
Run 2	3000	1847	4009	0.4607
Run 3	4000	1803	3921	0.4597
Run 4	5000	1763	3848	0.4583
Run 5	6000	1728	3784	0.4566
Run 6	7000	1695	3727	0.4547
Run 7	8000	1664	3675	0.4528
Run 8	9000	1635	3627	0.4508
Run 9	10000	1608	3582	0.4488
Run 10	11000	1581	3540	0.4467
Run 11	12000	1556	3500	0.4447
Run 12	13000	1532	3462	0.4426
Run 13	14000	1509	3426	0.4404

### Now, plot the results:



**Prob.3.3.5** An actual Rankine cycle with reheat uses water as the working fluid. The conditions at the inlet to the first stage turbine are 14 MPa, 600 C and the steam is reheated between the turbine stages to 600 C. For a condenser pressure of 6 kPa, plot the cycle thermal efficiency versus reheat pressure for pressures ranging from 2 to 12 MPa. Assume the isentropic efficiencies of both the turbines, and the pump as 0.8. [Ref: 3]



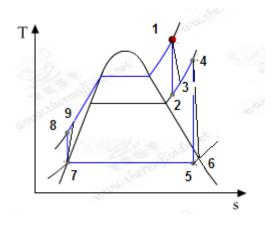


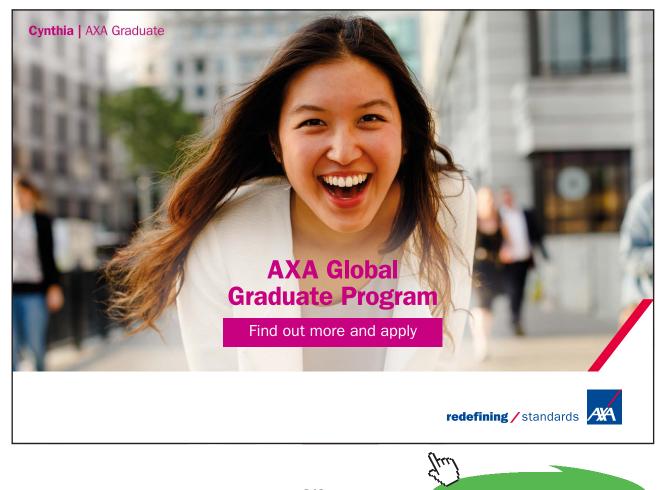
Fig.Prob.3.3.5 (a) Actual Rankine cycle with reheat, and (b) T-s diagram

### **EES Solution:**

### Let us first write an EES Procedure for Actual Rankine cycle with reheat:

### \$UnitSystem kPa C kJ

PROCEDURE Reheat\_Rankine\_actual(P[1],P[2], P[5], T[1],T[4],eta\_turb1,eta\_turb2,eta\_pump:w\_ turb1,w\_turb2,w\_p,w\_net,q\_boiler,q\_reheat,q\_in,q\_out,eta\_th)



Click on the ad to read more

{Reheat\_Rankine\_actual finds eta\_th etc for an actual, reheat Rankine cycle.

Pressures in kPa, Temps in C, Work in kJ/kg

**Inputs:** P[1], T[1] ... at inlet of HP Turbine, , P[2], T[4],... at inlet of LP Turbine, P[5] at incondenser (or inlet to pump)

eta\_turb1,eta\_turb2,eta\_pump ...isentropic efficiencies of HP turb, LP turb and pump

**Outputs:** w\_turb1,w\_turb2,w\_p .... actual wors of HP turb, LP turb and pump w\_net .... net work output, q\_boiler,q\_reheat,.... heat transferred in boiler and reheater q\_in,... total heat supplied, q\_out ... heat rej. in condenser eta\_th .... thermal effcy. }

Fluid\$ := 'Steam\_IAPWS'

P[3] := P[2]<sup>"</sup>...at actual exit of HP turbine"

P[4]:=P[2]"....at inlet of LP turbine"

P[6] :=P[5]"...at inlet of pump"

P[6] := P[5] "..at exit of LP Turbine, inlet of condenser"

P[7] := P[6] "..at inlet to pump"

P[8] := P[1]"at isentropic exit of pump"

P[9] := P[8]

x[7] := 0 "...sat. liq. at entry to pump"

Vapour Power Cycles

### "Calculations:"

- h[1]:=ENTHALPY(Fluid\$,T=T[1],P=P[1])"kJ/kg...enthalpy of fluid at entry to HP turbine"
- s[1]:=ENTROPY(Fluid\$,T=T[1],P=P[1]) "kJ/kg.C...entropy of fluid at entry to HP turbine"

s[2]:=s[1] "...for isentropic expn. in HP turbine"

h[2]:=ENTHALPY(Fluid\$,s=s[2],P=P[2])"kJ/kg...enthalpy of fluid at isentropic exit of HP turbine"

T[2]:=TEMPERATURE(Fluid\$,s=s[2],h=h[2])"C...temp at isentropic exit of HP turbine"

w\_turb1\_isentr := h[1] - h[2] "kJ/kg .... HP turbine isentr. work output"

w\_turb1 := eta\_turb1 \* w\_turb1\_isentr "kJ/kg .... HP turbine actual work output"

h[3] :=h[1] - w\_turb1"kJ/kg... enthalpy of fluid at iactual exit of HP turbine"

s[3] :=ENTROPY(Fluid\$,h=h[3],P=P[3]) "kJ/kg.C...entropy of fluid at actual exit of HP turbine"

T[3] := TEMPERATURE(Fluid\$,s=s[3],h=h[3])"C...temp at actual exit of HP turbine"

h[4] :=ENTHALPY(Fluid\$,T=T[4],P=P[4])"kJ/kg...enthalpy of fluid at inlet of LP turbine"

s[4] :=ENTROPY(Fluid\$,T=T[4],h=h[4]) "kJ/kg.C...entropy of fluid at inlet of LP turbine"

s[5] := s[4] "...for isentropic expn. in LP turbine"

h[5]=ENTHALPY(Fluid\$,s=s[5],P=P[5])"kJ/kg...enthalpy of fluid at isentropic exit of LP turbine"

w\_turb2\_isentr := h[4] - h[5] "kJ/kg .... LP turbine isentr. work output"

w\_turb2 := eta\_turb2 \* w\_turb2\_isentr "kJ/kg .... LP turbine actual work output"

h[6] :=h[4] - w\_turb2"kJ/kg... enthalpy of fluid at iactual exit of LP turbine"

s[6] :=ENTROPY(Fluid\$,P=P[6],h=h[6]) "kJ/kg.C...entropy of fluid at actual exit of LP turbine"

T[6] := TEMPERATURE(Fluid\$,s=s[6],h=h[6])"C...temp at actual exit of HP turbine"

T[7] :=T\_SAT(Fluid\$,P=P[7]) "...sat. temp. at condenser pressure"

s[7] :=ENTROPY(Fluid\$,T=T[7],x=x[7]) "kJ/kg.C...entropy of fluid at entry to pump"

h[7] :=ENTHALPY(Fluid\$,T=T[7],x=x[7])"kJ/kg ... enthalpy at entry to pump"

s[8] := s[7]"..for isentropic comprn. in pump"

v\_f=VOLUME(Fluid\$,P=P[7],x=x[7]) "m^3/kg ... sp. vol. of fluid entering the pump"

w\_p\_isentr := v\_f \* (P[8] - P[7]) "kJ/kg ... isentr. pump work"

w\_p := w\_p\_isentr/eta\_pump "kJ/kg .... actual pu,p work"

h[8] :=h[7] + w\_p\_isentr"kJ/kg ... enthalpy at isentr. exit of pump"

h[9] := h[7] + w\_p "kJ/kg ... enthalpy at actual exit of pump"

T[8] := TEMPERATURE(Fluid\$,s=s[8],P=P[8])"C...temp at isentr. exit of pump"

s[9] := ENTROPY(Fluid\$,P=P[9],h=h[9]) "kJ/kg.C...entropy of fluid at actual exit of pump"

T[9] := TEMPERATURE(Fluid\$,s=s[9],P=P[9])"C...temp at actual exit of pump"

x[3] :=Quality(Fluid\$,T=T[3],s=s[3])"....quality of steam at actual exit of HP turbine"

x[6] :=Quality(Fluid\$,T=T[6],s=s[6])"....quality of steam at actual exit of LP turbine"

 $q_boiler := h[1]-h[9]$ "kJ/kg"

 $q_reheat := h[4]-h[3]"kJ/kg"$ 

q\_in := q\_boiler + q\_reheat "kJ/kg .... total heat input to cycle"

q\_out :=h[6]-h[7]"kJ/kg"

w\_turb\_tot := w\_turb1 + w\_turb2 "kJ/kg ... total turbine work output"

w\_net := w\_turb\_tot - w\_p "kJ/kg .... net work output"

eta\_th :=1- q\_out/q\_in "....thermal efficiency of cycle"

### END

"\_\_\_\_\_"

### "Ex: Verify results of Prob.3.3.4"

We have:

"Data:"

P[1]=14000"kPa"

- P[2] = 2000 "kPa ... reheat pressure"
- P[5] = 6 "kPa"

T[1] = 600 "C"

T[4] = 600 ``C''

 $eta\_turb1 = 1$ 

```
eta\_turb2 = 1
```

eta\_pump= 1



### **Masters in Management**

Designed for high-achieving graduates across all disciplines, London Business School's Masters in Management provides specific and tangible foundations for a successful career in business.

This 12-month, full-time programme is a business qualification with impact. In 2010, our MiM employment rate was 95% within 3 months of graduation\*; the majority of graduates choosing to work in consulting or financial services.



As well as a renowned qualification from a world-class business school, you also gain access to the School's network of more than 34,000 global alumni – a community that offers support and opportunities throughout your career.

For more information visit **www.london.edu/mm**, email **mim@london.edu** or give us a call on **+44 (0)20 7000 7573**.

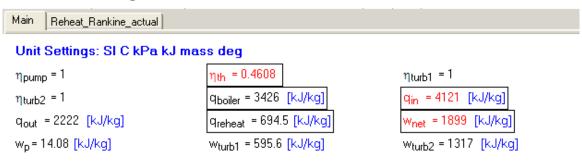
\* Figures taken from London Business School's Masters in Management 2010 employment report



### "Calculations:"

CALL Reheat\_Rankine\_actual(P[1],P[2], P[5], T[1],T[4],eta\_turb1,eta\_turb2,eta\_pump:w\_turb1,w\_ turb2,w\_p,w\_net,q\_boiler,q\_reheat,q\_in,q\_out,eta\_th)

### Results (for a reheat pressure of 2 MPa):



Click on this line to see the array variables in the Arrays Table window

ocal variables in Proced	Local variables in Procedure Reheat_Rankine_actual (1 call, 0.02 sec)				
η <sub>pump</sub> =1	ղ <sub>th</sub> =0.4608	ηturb1 =1			
Fluid\$='Steam_IAPWS'	h <sub>1</sub> =3592 [kJ/kg]	h <sub>2</sub> =2996 [kJ/kg]			
n <sub>4</sub> =3691 [kJ/kg]	h5=2373 [kJ/kg]	h <sub>6</sub> =2373 [kJ/kg]			
ng=165.5628 [kJ/kg]	hg=165.5628 [kJ/kg]	P <sub>1</sub> =14000 [kPa]			
P <sub>3</sub> =2000 [kPa]	P <sub>4</sub> =2000 [kPa]	P5=6 [kPa]			
<sup>⊃</sup> 7=6 [kPa]	P <sub>8</sub> =14000 [kPa]	Pg=14000 [kPa]			
q <sub>in</sub> =4121 [kJ/kg]	q <sub>out</sub> =2222 [kJ/kg]	q <sub>reheat</sub> =694.5 [kJ/kg]			
s <sub>2</sub> =6.719 [kJ/kg-C]	s <sub>3</sub> =6.719 [kJ/kg-C]	s <sub>4</sub> =7.704 [kJ/kg-C]			
s <sub>6</sub> =7.704 [kJ/kg-C]	s7=0.5208 [kJ/kg-C]	s <sub>8</sub> =0.5208 [kJ/kg-C]			
T <sub>1</sub> =600 [C]	T <sub>2</sub> =288 <mark>[C]</mark>	T <sub>3</sub> =288 <mark>[C]</mark>			
T <sub>6</sub> =36.16 [C]	T7=36.16 <mark>[C]</mark>	T <sub>8</sub> =36.53 [C]			
/f =0.001006 [m <sup>3</sup> /kg]	w <sub>net</sub> =1899 [kJ/kg]	w <sub>p</sub> =14.08 [kJ/kg]			
w <sub>turb1</sub> =595.6 [kJ/kg]	Wturb1,isentr=595.6 [kJ/kg]	w <sub>turb2</sub> =1317 [kJ/kg]			
w <sub>turb.tot</sub> =1913 [kJ/kg]	x <sub>3</sub> =100	×6=0.92			

Thus, we see that the results match very well with the results obtained earlier in Prob. 3.3.4.

### Now, let us solve the prob. 3.3.5 using this EES Procedure:

"Data:"

P[1]=14000"kPa"

P[2] = 2000 "kPa....reheat pressure"

P[5] = 6 "kPa"

T[1] = 600 **"C"** 

T[4] = 600 "C"

eta\_turb1 = 0.8

 $eta_turb2 = 0.8$ 

eta\_pump= 0.8

### "Calculations:"

CALL Reheat\_Rankine\_actual(P[1],P[2], P[5], T[1],T[4],eta\_turb1,eta\_turb2,eta\_pump:w\_turb1,w\_ turb2,w\_p,w\_net,q\_boiler,q\_reheat,q\_in,q\_out,eta\_th)

### **Results:**

Main Reheat_Rankine_actual						
Unit Settings: SI C kPa kJ mass deg						
η <sub>pump</sub> = 0.8	$\eta_{th} = 0.3784$	η <sub>turb1</sub> = 0.8				
η <sub>turb2</sub> = 0.8	q <sub>boiler</sub> = 3423 [kJ/kg]	q <sub>in</sub> = 3998 [kJ/kg]				
q <sub>out</sub> = 2485 [kJ/kg]	q <sub>reheat</sub> = 575.4 [kJ/kg]	w <sub>net</sub> = 1513 [kJ/kg]				
w <sub>p</sub> =17.61 [kJ/kg]	w <sub>turb1</sub> = 476.4 [kJ/kg]	w <sub>turb2</sub> = 1054 [kJ/kg]				

Click on this line to see the array variables in the Arrays Table window

Main	Reheat_Rankine_actual
------	-----------------------

### Local variables in Procedure Reheat\_Rankine\_actual (1 call, 0.08 sec)

η <sub>pump</sub> =0.8	ղլի =0.3784	η <sub>turb1</sub> =0.8
ηturb2 =0.8	Fluid\$='Steam_IAFWS'	h1=3592 [kJ/kg]
h2=2996 [kJ/kq]	h3=3115 [kJ/kq]	h <sub>4</sub> =3691 [kJ/kq]
h5-2373 [kJ/kg]	hg-2637 [kJ/kg]	h <sub>/</sub> -151.5 [kJ/kg]
hg=165.5628 [kJ/kg]	hg=169.0839 [kJ/kg]	P <sub>1</sub> =14000 [kPa]
P <sub>2</sub> =2000 [kPa]	P <sub>0</sub> =2000 [kPa]	P <sub>4</sub> =2000 [kPa]
P5=6 [kPa]	Pg=6 [kPa]	P7=6 [kPa]
Pg=14000 [kPa]	Pg=14000 [kPa]	q <sub>boiler</sub> =3423 [kJ/kq]
q <sub>in</sub> -3998 [kJ/kg]	q <sub>out</sub> =2485 [kJ/kg]	q <sub>reheat</sub> =575.4 [kJ/kg]
s1=6.719 [kJ/kg-C]	s <sub>2</sub> =6.719 [kJ/kg-C]	s3=6.922 [kJ/kg-C]
s <sub>4</sub> =7 704 [k.l/kg-C]	s5=7.704 [k.l/kg-C]	s <sub>6</sub> =8 544 [k.l/kg-C]
s7=0.5208 [kJ/kg-C]	sg=0.5208 [kJ/kg-C]	sg=0.5323 [kJ/kg-C]
T <sub>1</sub> =600 [C]	T <sub>2</sub> =288 [C]	T <sub>3</sub> =340 [C]
T <sub>4</sub> -600 [C]	T <sub>6</sub> -73.07 [C]	T <sub>7</sub> -36.16 [C]
Tg=36.53 [C]	Tg=37.39 [C]	vf =0.001006 [m <sup>3</sup> /kg]
w <sub>net</sub> =1513 [kJ/kg]	w <sub>p</sub> =17.61 [kJ/kg]	W <sub>p,isent</sub> =14.08 [kJ/kg]
wturb1 = 476.4 [kJ/ky]	Wturb1,isentr = 595.6 [kJ/ky]	w <sub>turb2</sub> =1054 [kJ/ky]
Wturb2,isentr=1317 [kJ/kg]	w <sub>turb,tot</sub> =1530 [kJ/kg]	×3=100
×6=100	×7=0	



## Get Internationally Connected at the University of Surrey

MA Intercultural Communication with International Business MA Communication and International Marketing



#### MA Intercultural Communication with International Business

Provides you with a critical understanding of communication in contemporary socio-cultural contexts by combining linguistic, cultural/media studies and international business and will prepare you for a wide range of careers.

#### **MA Communication and International Marketing**

Equips you with a detailed understanding of communication in contemporary international marketing contexts to enable you to address the market needs of the international business environment.

For further information contact: T: +44 (0)1483 681681 E: pg-enquiries@surrey.ac.uk www.surrey.ac.uk/downloads



Click on the ad to read more

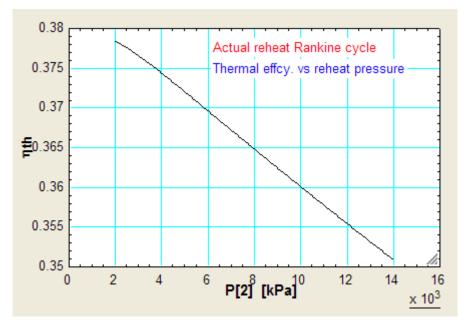
247 Download free eBooks at bookboon.com Thus: we see that the thermal effcy. when the isentropic efficiencies of HP and LPturbines and the pump are considered, becomes eta\_th = 0.3784 = 37.84% ... Ans.

(b) Plot the cycle thermal efficiency versus reheat pressure for pressures ranging from 2 to 12 MPa:

First, compute the Parametric Table:

113	1 ₽ <sub>2</sub> [kPa]	2 ▼ W <sub>net</sub> [kJ/kg]	3 ▼ q <sub>in</sub> [kJ/kg]	4 Σ η <sub>th</sub>
Run 1	2000	1513	3998	0.3784
Run 2	3000	1471	3907	0.3766
Run 3	4000	1436	3835	0.3744
Run 4	5000	1404	3775	0.372
Run 5	6000	1376	3722	0.3696
Run 6	7000	1349	3675	0.3672
Run 7	8000	1325	3632	0.3648
Run 8	9000	1302	3592	0.3624
Run 9	10000	1280	3554	0.3601
Run 10	11000	1259	3519	0.3577
Run 11	12000	1239	3485	0.3554
Run 12	13000	1220	3453	0.3531
Run 13	14000	1201	3423	0.3509

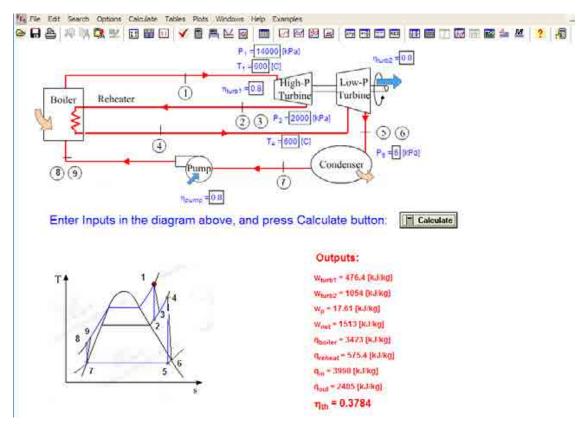
### Now, plot the results:



\_\_\_\_\_

### (c) Use the Diagram Window in EES to input data and make calculations:

As explained in Prob. 3.3.3, we shall have Diagram window input for data, and calculations as shown below:



In the above, Inputs are from the diagram window. When you press Calculate button, above results are obtained. This confirms the results obtained in part (a) of the above problem.

**Prob.3.3.6.** A reheat cycle has the first stage supply conditions of 70 bar and 500 C. The reheat is at 3 bar and to the same temp. (i) Given that the efficiency of the first stage turbine is 80%, how much energy is added per kg of steam in the reheat coils? (ii) Assume that the same expansion efficiency exists in the second turbine. What is the thermal efficiency if the condenser pressure is 0.03 bar? [VTU-ATD-June–July 2008]

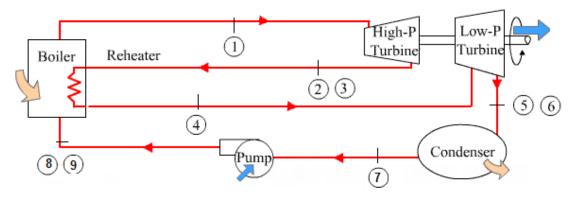


Fig.Prob.3.3.6 Actual, reheat Rankine cycle

### **EES Solution:**

We shall use the EES Procedure developed in the previous problem, with Diagram window input of data.





Here, we have:

P[1]=7000"kPa"

P[2] = 300 "kPa....reheat pressure"

P[5] = 3 "kPa"

T[1] = 500 **"C"** 

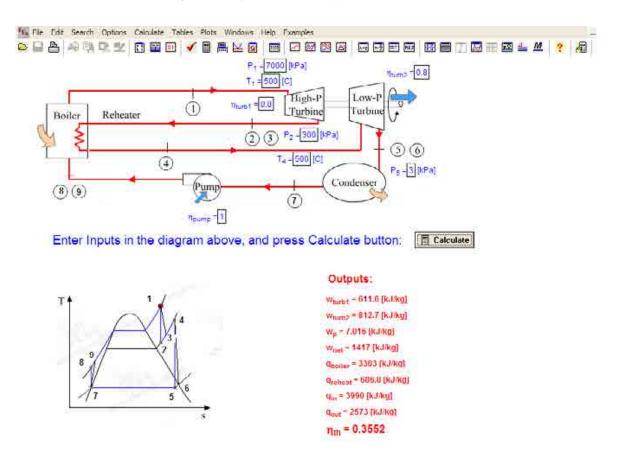
T[4] = 500 **"C"** 

eta\_turb1 = 0.8"...first stage turbine effcy."

eta\_turb2 = 0.8 "...second stage turbine effcy."

eta\_pump= 1"...pump effcy. assumed as 100%"

Make these entries in the schematic diagram in the EES Diagram window as shown below, and click on 'Calculate' button. Immediately, the Output results are updated:



### Thus:

Heat supplied in reheat coils = q\_reheat = 686.8 kJ/kg .... Ans.

```
Thermal efficiency = eta_th = 0.3552 = 35.52% ... Ans.
```

\_\_\_\_\_

**Prob.3.3.7.** A steam power plant incorporates an ideal reheat cycle to improve the existing efficiency. Steam at 30 bar and 250 C is supplied at high pressure turbine. Reheat pressure is 3 bar, reheat temp is 250 C. Condenser pressure is 0.04 bar. Determine the cycle effcy. [VTU-ATD-Dec. 2009–Jan. 2010]

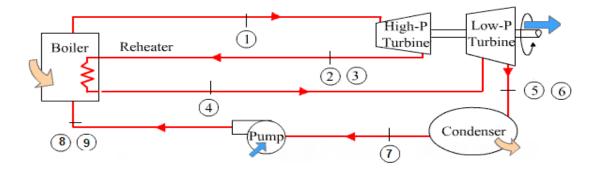


Fig.Prob.3.3.7 Actual, reheat Rankine cycle

### **EES Solution:**

Let us use the EES Procedure written earlier, but, with the both the turbines and the pump having effcy. = 1, each.

### "Data:"

P[1]=3000"kPa"

- P[2] = 300 "kPa"
- P[5] = 4 "kPa"
- T[1] = 250 "C"
- T[4] = 250 "C"
- $eta_turb1 = 1$
- $eta\_turb2 = 1$
- eta\_pump= 1

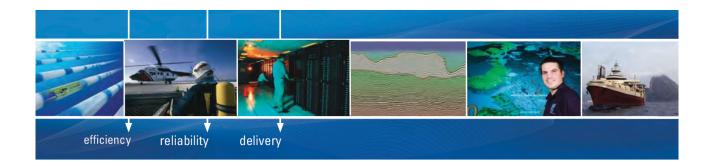
#### "Calculations:"

CALL Reheat\_Rankine\_actual(P[1],P[2], P[5], T[1],T[4],eta\_turb1,eta\_turb2,eta\_pump:w\_turb1,w\_ turb2,w\_p,w\_net,q\_boiler,q\_reheat,q\_in,q\_out,eta\_th)

#### **Results:**

mass deg	
$\eta_{th} = 0.3426$	η <sub>turb1</sub> = 1
q <sub>boiler</sub> = 2732 [kJ/kg]	q <sub>in</sub> = 3261 [kJ/kg]
q <sub>reheat</sub> = 528.6 [kJ/kg]	w <sub>net</sub> = 1117 [kJ/kg]
w <sub>turb1</sub> = 417.3 [kJ/kg]	w <sub>turb2</sub> = 702.8 [kJ/kg]
	q <sub>boiler</sub> = 2732 [kJ/kg] q <sub>reheat</sub> = 528.6 [kJ/kg]

Thus: Thermal effcy. = eta\_th = 0.3426 = 34.26%.... Ans.



As a leading technology company in the field of geophysical science, PGS can offer exciting opportunities in offshore seismic exploration.

We are looking for new BSc, MSc and PhD graduates with Geoscience, engineering and other numerate backgrounds to join us.

To learn more our career opportunities, please visit www.pgs.com/careers



Download free eBooks at bookboon.com

#### Local variables in Procedure Reheat\_Rankine\_actual (1 call, 0.11 sec)

η <sub>pump</sub> =1	η <sub>th</sub> =0.3426	ηturb1 =1
η <sub>turb2</sub> =1	Fluid\$='Steam_IAPWS'	h <sub>1</sub> =2857 [kJ/kg]
h2=2439 [kJ/kg]	h3=2439 [kJ/kg]	h <sub>4</sub> =2968 [kJ/kg]
h5=2265 [kJ/kg]	h <sub>6</sub> =2265 [kJ/kg]	h7=121.4 [kJ/kg]
h <sub>8</sub> =124.3987 [kJ/kg]	hg=124.3987 [kJ/kg]	P <sub>1</sub> =3000 [kPa]
P <sub>2</sub> =300 [kPa]	P3=300 [kPa]	P <sub>4</sub> =300 [kPa]
P5=4 [kPa]	P6=4 [kPa]	P7=4 [kPa]
Pg=3000 [kPa]	Pg=3000 [kPa]	q <sub>boiler</sub> =2732 [kJ/kg]
q <sub>in</sub> =3261 [kJ/kg]	q <sub>out</sub> =2144 [kJ/kg]	q <sub>reheat</sub> =528.6 [kJ/kg]
s <sub>1</sub> =6.289 [kJ/kg-C]	s <sub>2</sub> =6.289 [kJ/kg-C]	s <sub>3</sub> =6.289 [kJ/kg-C]
s <sub>4</sub> =7.518 [kJ/kg-C]	s5=7.518 [kJ/kg-C]	s <sub>6</sub> =7.518 [kJ/kg-C]
s7=0.4224 [kJ/kg-C]	s <sub>8</sub> =0.4224 [kJ/kg-C]	sg=0.4224 [kJ/kg-C]
T <sub>1</sub> =250 [C]	T <sub>2</sub> =133.5 [C]	T <sub>3</sub> =133.5 <mark>[C]</mark>
T <sub>4</sub> =250 [C]	⊤ <sub>6</sub> =28.96 <mark>[C]</mark>	T <del>7=</del> 28.96 <mark>[C]</mark>
T <sub>8</sub> =29.03 [C]	⊤g=29.03 <mark>[C]</mark>	∨ <sub>f</sub> =0.001004 [m <sup>3</sup> /kg]
w <sub>net</sub> =1117 [kJ/kg]	w <sub>p</sub> =3.008 [kJ/kg]	w <sub>p,isentr</sub> =3.008 [kJ/kg]
w <sub>turb1</sub> =417.3 [kJ/kg]	Wturb1,isentr=417.3 [kJ/kg]	w <sub>turb2</sub> =702.8 [kJ/kg]
Wturb2,isentr =702.8 [kJ/kg]	w <sub>turb,tot</sub> =1120 [kJ/kg]	×3=0.868
×6=0.8813	x7 =0	

And,

Steam quality after expn. in first stage =  $x[3] = 0.868 \dots$  Ans.

Steam quality after expn. in second stage =  $x[6] = 0.8813 \dots$  Ans.

**Prob. 3.3.8** A steam power plant operates on a Reheat Rankine cycle and has a net power output of 80 MW. Steam enters the HP turbine at 100 bar, 500 C and the LP turbine at 10 bar and 500 C after being reheated. It leaves the LP turbine at 0.1 bar. Assuming ideal processes (and using Mollier chart) determine: (i) quality of steam at exit of LP turbine, (ii) thermal effcy. (iii) mass flow rate of steam. [VTU-ATD-Dec. 2009–Jan. 2010]

\_\_\_\_\_

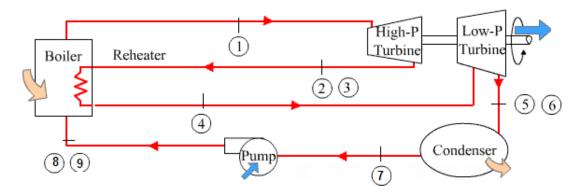


Fig.Prob.3.3.8 Actual, reheat Rankine cycle

#### **EES Solution:**

We shall use the EES Procedure written for Actual, reheat Rankine cycle, but with turbine and pump efficiencies put equal to 1:

We have:

#### "Data:"

P[1]=10000"kPa"

P[2] = 1000 **"kPa"** 

P[5] = 10 **"kPa"** 

T[1] = 500 **"C"** 

T[4] = 500 **"C"** 

eta\_turb1 = 1

eta\_turb2 = 1

eta\_pump= 1

#### "Calculations:"

CALL Reheat\_Rankine\_actual(P[1],P[2], P[5], T[1],T[4],eta\_turb1,eta\_turb2,eta\_pump:w\_turb1,w\_ turb2,w\_p,w\_net,q\_boiler,q\_reheat,q\_in,q\_out,eta\_th) m\_steam = 80E03/w\_net "kg/s ... mass flow rate of steam required for an output of 80 MW"

#### **Results:**

Unit Settings: SI C kPa	ı kJ mass deg		
η <sub>pump</sub> = 1	nth = 0.4134	ηturb1 = 1	ηturb2 = 1
m <sub>steam</sub> = 50.02 [kg/s]	q <sub>boiler</sub> = 317 <mark>3 [kJ/kg]</mark>	q <sub>in</sub> = 3869 [kJ/kg]	q <sub>out</sub> = 2269 [kJ/kg]
q <sub>reheat</sub> = 695.4 [kJ/kg]	wnet = 1599 [kJ/kg]	w <sub>p</sub> =10.09 [kJ/kg]	w <sub>turb1</sub> = 591.5 [kJ/kg]

Thus: Thermal effcy. = eta\_th = 0.4134 = 41.34% .....Ans.

#### Mass flow rate of steam required to produce 80 MW net power = m\_steam = 50.02 kg/s ... Ans.

And, for quality of steam at exit of LP turbine, see the results in the 'Reheat\_Rankine\_actual' tab in the Results:

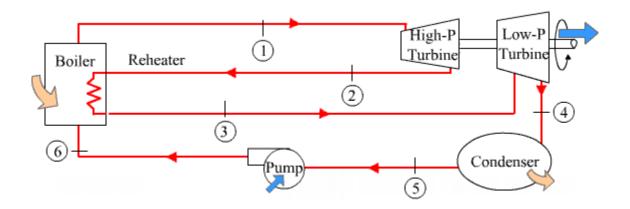
Local variables in Procedure	Reheat_Rankine_actual (1 call, 0.13 se	ec)
η <sub>pump</sub> =1	ղեհ =Ո 4134	ŋturb1 =1
ղահ2 =1	Fluid\$="Steam_IAPWS"	h1=3375 [kJ/kg]
h2=2784 [kJ/kg]	h3=2784 [kJ/kg]	h4=3479 [kJ/kg]
h5=2461 [kJ/kg]	hg=2461 [kJ/kg]	h7=191.8 [kJ/kg]
hg=201.8977 [kJ/kg]	hg=201.8977 [kJ/kg]	P1=10000 [kPa]
Pz=1000 [kPa]	P3=1000 [kPa]	P4=1000 [kPa]
P <sub>J</sub> =10 [kPa]	P6=10 [kPa]	P <sub>7</sub> =10 [kPa]
Pg=10000 [kPa]	Pg=10000 [kPa]	q <sub>boiler</sub> =3173 [kJ/kg]
q <sub>in</sub> =3869 [kJ/kg]	q <sub>out</sub> =2269 [kJ/kg]	q <sub>reheat</sub> =695.4 [kJ/kg
s <sub>1</sub> =6.599 [kJ/kg-C]	s2=6.599 [kJ/kg-C]	s <sub>3</sub> =6.599 [kJ/kg-C]
s4=/./64 [kJ/kg-C]	s5=7./64 [kJ/kg-C]	s <sub>6</sub> =7.76 <mark>4 [kJ/kg-C]</mark>
s7=0.6492 [kJ/kq-C]	sg=0.6492 [kJ/kq-C]	sg=0.6493 [kJ/kq-C]
T <sub>1</sub> -500 [C]	T <sub>2</sub> -182.3 [C]	T <sub>3</sub> -182.3 [C]
T₄=500 [C]	T <sub>6</sub> =45.8 <mark>1 [C]</mark>	T <del>7=</del> 45.81 [C]
Tg=46.14 <mark>[C]</mark>	Tg=46.14 [C]	v <sub>f</sub> =0.00101 [m <sup>3</sup> /kg]
w <sub>net</sub> -1599 [kJ/kg]	wp-10.09 [kJ/kg]	wp,isentr=10.09 [kJ/kg]
w <sub>turb1</sub> =591.5 [kJ/kg]	Wturb1,isentr=591.5 [kJ/kg]	wturb2=1018 [kJ/kg]
Wturb2,isentr=1018 [kJ/kg]	Wturb,tot=1609 [kJ/kg]	x3=100
×6-0.9407	×/-0	

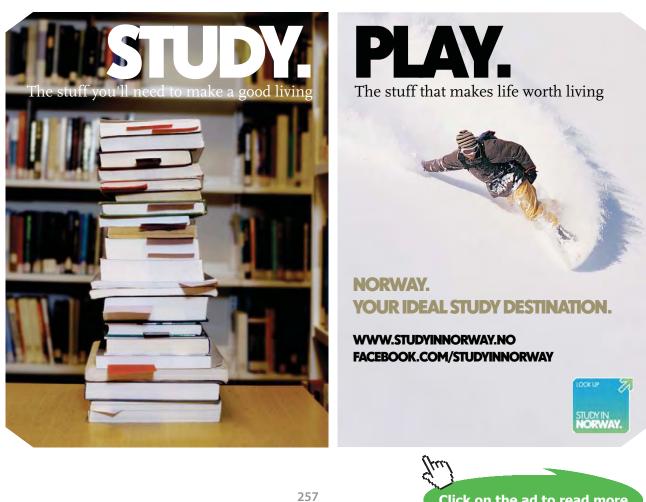
#### We see that:

Quality of steam at exit of LP turbine = x[6] = 0.9487 ....Ans.

"Prob. 3.3.9 In a reheat cycle, steam at 500 C expands in a HP turbine till it is sat. vap. It is then reheated at constant pressure to 400 C and then expanded in a LP turbine to 40 C. If the max. moisture content at the turbine exhaust is limited to 15%, find (i) the reheat pressure, (ii) pressure of steam at inlet to the HP turbine, (iii) net specific work output, (iv) thermal efficiency, and (v) steam rate. Assume all ideal processes. [VTU-ATD-Dec. 2011]"







Click on the ad to read more

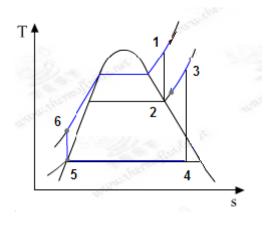


Fig.Prob.3.3.9 Ideal Reheat Rankine cycle and T-s diagram

#### **EES Solution:**

#### "Data:"

T[1]=500[C]"...HP turbine inlet temp"

#### T[3]=400[C]"...LP turbine inlet temp"

x[5]=0"...sat. liq. to pump inlet"

x[2]=1"..sat. vap. at exit of HP turbine"

x[4]=0.85"..quality of steam at exit of LP turbine"

T[4]=40[C]"...temp at exit of LP turbine"

"\_\_\_\_\_"

"Calculations:"

"See Diagram window for fig."

P[3]=P[2]

P[5]=P[4]

P[6]=P[1]

T[5]=T[4]

#### P[4]=P\_sat(Steam\_NBS,T=T[4])"finds P[4]"

- s[4]=Entropy(Steam\_NBS,x=x[4],P=P[4])"finds s[4]"
- h[4]=Enthalpy(Steam\_NBS,x=x[4],P=P[4])

s[3]=s[4]

- h[3]=Enthalpy(Steam\_NBS,T=T[3],s=s[3])"finds h[3]"
- P[3]=Pressure(Steam\_NBS,T=T[3],s=s[3])"finds P[3]"
- h[2]=Enthalpy(Steam\_NBS,x=x[2],P=P[2])"finds h[2]"
- s[2]=Entropy(Steam\_NBS,x=x[2],P=P[2])"finds s[2]"
- T[2]=Temperature(Steam\_NBS,P=P[2],x=x[2])"finds T[2]"
- s[1]=s[2]
- h[1]=Enthalpy(Steam\_NBS,T=T[1],s=s[1])"finds h[1]"
- P[1]=Pressure(Steam\_NBS,T=T[1],h=h[1])"finds P[1]"
- h[5]=Enthalpy(Steam\_NBS,T=T[5],x=x[5])"finds h[5]"
- s[5]=Entropy(Steam\_NBS,x=x[5],P=P[5])"finds s[5]"

s[6]=s[5]

#### "Pump Work:"

v\_f=VOLUME(steam\_NBS,P=P[5],x=x[5])"...sp. vol. of liq. at pump inlet"

```
w_p=v_f*(P[6]-P[5])"...pump work"
```

h[6]=h[5]+w\_p"finds h[6]"

```
T[6]=TEMPERATURE(steam_NBS,P=P[6],h=h[6])"finds T6"
```

#### "Turbine Work:"

w\_turb=(h[1]-h[2])+(h[3]-h[4]) "...total turbine work"

#### "Thermal effcy.:"

q\_in=(h[1]-h[6])+(h[3]-h[2]) "...heat input"

 $q_out=h[4]-h[5]$ 

w\_net=w\_turb-w\_p "...net work output"

eta\_th=w\_net/q\_in "....thermal effcy."

"Steam rate:"

SSC=3600/w\_net"kg/kWh"

### Technical training on WHAT you need, WHEN you need it

At IDC Technologies we can tailor our technical and engineering training workshops to suit your needs. We have extensive experience in training technical and engineering staff and have trained people in organisations such as General Motors, Shell, Siemens, BHP and Honeywell to name a few.

Our onsite training is cost effective, convenient and completely customisable to the technical and engineering areas you want covered. Our workshops are all comprehensive hands-on learning experiences with ample time given to practical sessions and demonstrations. We communicate well to ensure that workshop content and timing match the knowledge, skills, and abilities of the participants.

We run onsite training all year round and hold the workshops on your premises or a venue of your choice for your convenience.

For a no obligation proposal, contact us today at training@idc-online.com or visit our website for more information: www.idc-online.com/onsite/ OIL & GAS ENGINEERING

**ELECTRONICS** 

AUTOMATION & PROCESS CONTROL

> MECHANICAL ENGINEERING

INDUSTRIAL DATA COMMS

ELECTRICAL POWER

IDC

Phone: +61 8 9321 1702 Email: training@idc-online.com Website: www.idc-online.com



Download free eBooks at bookboon.com

Click on the ad to read more

#### **Result:**

#### Unit Settings: SI C kPa kJ mass deg

η <sub>th</sub> = 0.4264	q <sub>in</sub> = 3565 [kJ/kg]	q <sub>out</sub> = 2045 [kJ/kg]
SSC = 2.368 [kg/kWh]	v <sub>f</sub> = 0.001008 [m <sup>3</sup> /kg]	w <sub>net</sub> = 1520 [kJ/kg]
w <sub>p</sub> =15.65 [kJ/kg]	w <sub>turb</sub> = 1536 [kJ/kg]	

And:

Sort	¹ ► ►	² ► P <sub>i</sub> [kPa]	₃ ▼ Si	4 ▼ T <sub>i</sub> [C]	<sup>5</sup> X <sub>i</sub> ⊻
[1]	3302	15539	6.322	500	
[2]	2800	2099	6.322	214.9	1
[3]	3246	2099	7.103	400	
[4]	2212	7.381	7.103	40	0.85
[5]	167.5	7.381	0.5723	40	0
[6]	183.2	15539	0.5723	40.47	

#### Thus:

Reheat pressure = P[2] = 2099 kPa = 20.99 bar ... Ans.

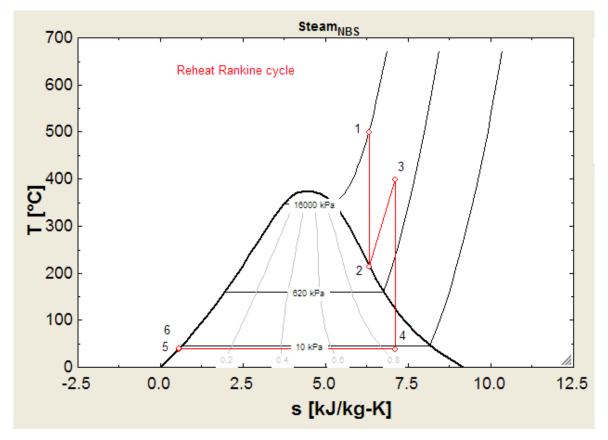
Inlet pressure to HP turbine = P[1] = 15539 kPa = 155.39 bar ... Ans.

Net work output = w\_net = 1520 kJ/kg ... Ans.

Thermal effcy. = eta\_th = 0.4264 = 42.64% ... Ans.

SSC = 2.368 kg/kWh ... Ans.

#### (b) Plot the cycle on a T-s diagram:

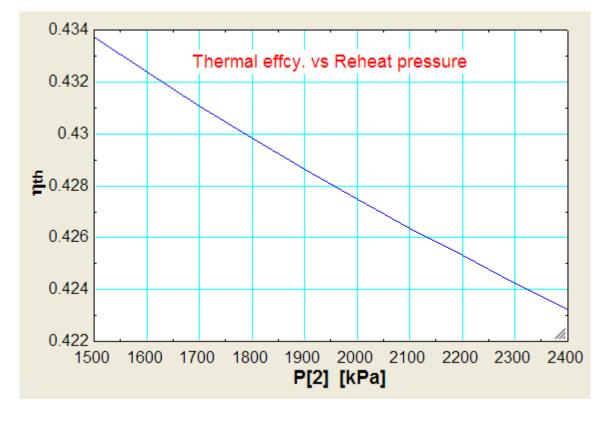


(c) Plot Thermal effcy. vs reheat pressure:

First, produce the Parametric Table:

110	1 Ν η <sub>th</sub>	² ₽ <sub>2</sub> [kPa]
Run 1	0.4337	1500
Run 2	0.4324	1600
Run 3	0.4311	1700
Run 4	0.4298	1800
Run 5	0.4286	1900
Run 6	0.4275	2000
Run 7	0.4264	2100
Run 8	0.4253	2200
Run 9	0.4243	2300
Run 10	0.4232	2400

#### Now, plot the results:



"**Prob.3.3.10** Steam enters a steam turbine using reheat cycle at 150 bar and 350 C. The reheat pressure is 25 bar and exhaust pressure is 0.05 bar. Temp of reheated steam is 300 C. Calculate the cycle efficiency and power developed for a steam flow rate of 3000 kg/h. [VTU-ATD-Jan.–Feb. 2003]"

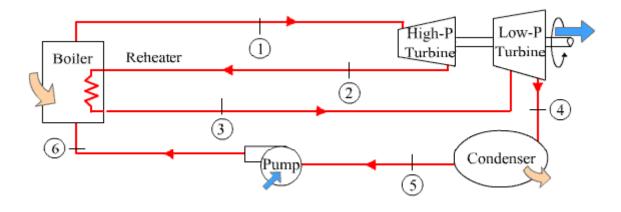


Fig.Prob.3.3.10 Ideal Reheat Rankine cycle

Note: T-s diagram is drawn later.

#### **EES Solution:**

#### "Data:"

P[1]=15000[kPa]"....at HP turbine inlet"

P[2]=2500[kPa]"..reheat pressure"

P[3]=P[2]"...at inlet to LP turbine"

P[4]=5[kPa]"...condenser pressure"

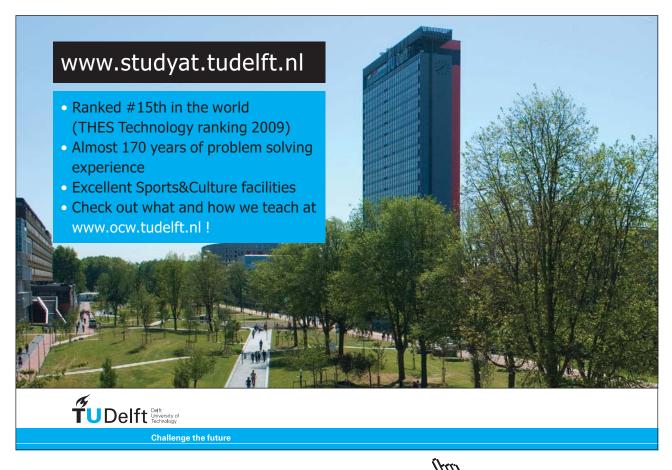
P[5]=P[4]"...at inlet to pump"

P[6]=P[1]"...outlet of pump"

T[1]=350[C]"...at inlet to HP turbine"

T[3]=300[C]"..reheat temp... at inlet to LP turbine"

x[5]=0"...at inlet to pump...sat. liq."





#### "Calculations:"

- T[4]=T\_SAT(steam,P=P[4])"...condenser pressure"
- T[5]=T[4]"....inlet to pump"
- h[1]=ENTHALPY(steam,T=T[1],P=P[1])"finds h1"
- s[1]=ENTROPY(steam,T=T[1],P=P[1])"..finds s1"
- s[2]=s[1]"...for isentropic expn. in HP turbine"
- h[2]=ENTHALPY(steam,s=s[2],P=P[2])"finds h2"
- T[2]=TEMPERATURE(steam,P=P[2],h=h[2])"finds T2"
- x[2]=QUALITY(Steam,h=h[2],P=P[2])"finds x2"
- s[3]=ENTROPY(steam,T=T[3],P=P[3])"...entropy at state point 3, entry to LP turbine"
- s[4]=s[3] ]"...for isentropic expn. in LP turbine"
- h[3]=ENTHALPY(steam,s=s[3],P=P[3])"finds h3"
- h[4]=ENTHALPY(steam,s=s[4],P=P[4])"finds h4"
- x[4]=QUALITY(Steam,h=h[4],P=P[4])"finds x4"
- h[5]=ENTHALPY(steam,P=P[5],x=x[5])"finds h5"
- s[5]=ENTROPY(steam,P=P[5],x=x[5])"finds s5"
- s[6]=s[5]"...for isentropic compression in pump"

#### "Pump Work:"

- v\_f=VOLUME(steam,P=P[5],x=x[5])"...sp. vol. at entry to pump"
- w\_p=v\_f\*(P[6]-P[5])"...pump work, isentropic"

h[6]=h[5]+w\_p"..enthalpy at state point 6, at exit of pump"

T[6]=TEMPERATURE(steam,P=P[6],h=h[6])"finds T6"

#### "Turbine Work:"

w\_turb=(h[1]-h[2])+(h[3]-h[4])"...combined work of both HP and LP turbines"

#### "Thermal effcy.:"

q\_in=(h[1]-h[6])+(h[3]-h[2])"...heat input"

q\_out=h[4]-h[5]"...heat rejected in condenser"

w\_net=w\_turb-w\_p"...net work output"

eta\_th=w\_net/q\_in"...thermal effcy."

#### "Power:"

m=3000/3600"kg/s ... mass flow rate of steam"

Power=m \* w\_net "..net power developed"

#### **Results:**

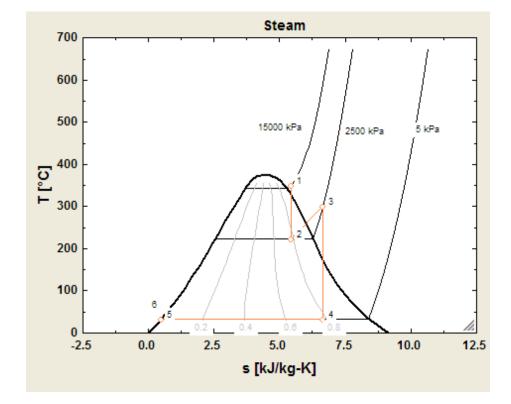
#### Unit Settings: SI C kPa kJ mass deg

η <sub>th</sub> = 0.4009	m = 0.8333 [kg/s]	Power = 1052 [kW]	q <sub>in</sub> = 3150 [kJ/kg]
q <sub>out</sub> = 1887 [kJ/kg]	v <sub>f</sub> = 0.001005 [m <sup>3</sup> /kg]	w <sub>net</sub> = 1263 [kJ/kg]	w <sub>p</sub> =15.07 [kJ/kg]
w <sub>turb</sub> = 1278 [kJ/kg]			

Sort	¹ h <sub>i</sub> ⊻	² ₽ <sub>i</sub> [kPa]	3 ⊾ Sj	<sup>4</sup> T <sub>i</sub> [C]	<sup>5</sup> x <sub>i</sub> ⊻
[1]	2691	15000	5.44	350	
[2]	2397	2500	5.44	224	0.7797
[3]	3008	2500	6.642	300	
[4]	2025	5	6.642	32.88	0.7789
[5]	137.7	5	0.4761	32.88	0
[6]	152.8	15000	0.4761	33.26	

Thus: Thermal effcy. = eta\_th = 0.4009 = 40.09% .... Ans.

#### Power developed for a steam flow rate of 3000 kg/h = Power = 1052 kW ... Ans.



#### Cycle on the T-s diagram:

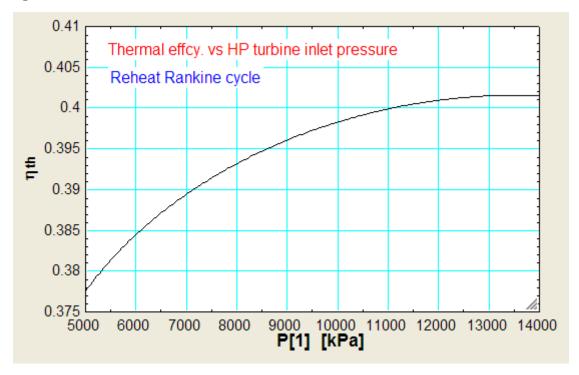




#### Parametric Table:

110	1 ₽ <sub>1</sub> [kPa]	2 ⊾ η <sub>th</sub>
Run 1	5000	0.3776
Run 2	6000	0.3845
Run 3	7000	0.3894
Run 4	8000	0.3932
Run 5	9000	0.3961
Run 6	10000	0.3983
Run 7	11000	0.3999
Run 8	12000	0.4009
Run 9	13000	0.4015
Run 10	14000	0.4015

#### Now, plot the results:

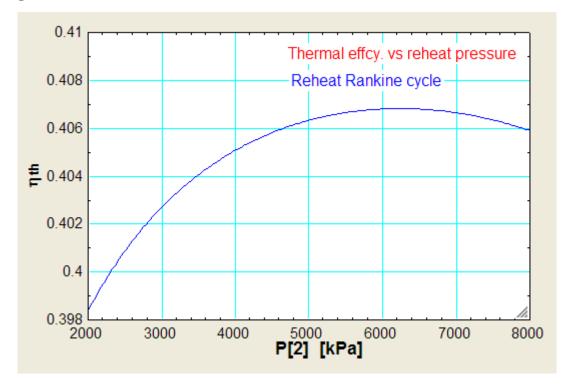


#### b) Plot eta\_th vs reheat pressure, P[2]:

#### **Parametric Table:**

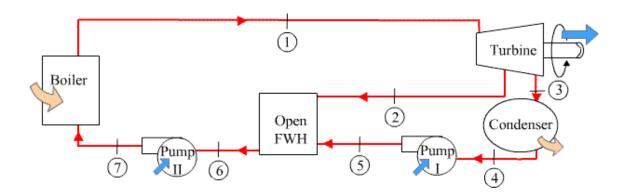
113	1 ₽ <sub>2</sub> [kPa]	2 Σ η <sub>th</sub>
Run 1	2000	0.3984
Run 2	2500	0.4009
Run 3	3000	0.4027
Run 4	3500	0.4041
Run 5	4000	0.4051
Run 6	4500	0.4058
Run 7	5000	0.4063
Run 8	5500	0.4067
Run 9	6000	0.4068
Run 10	6500	0.4068
Run 11	7000	0.4066
Run 12	7500	0.4063
Run 13	8000	0.4059

Now, plot the results:



#### **Regenerative Rankine cycle:**

**Prob.3.3.11** In a regenerative Rankine cycle, with one open feed water heater (FWH), steam enters the first turbine stage at 12 MPa, 520 C and expands to 1 MPa, where some of the steam is extracted and diverted to the open FWH operating at 1 MPa. The remaining steam expands through the second turbine stage to the condenser pressure of 6 kPa. Sat. liquid exits the open FWH at 1 MPa. For isentropic processes in turbines and pumps, determine for the cycle (a) thermal efficiency (b) fraction of steam entering the first turbine stage that is diverted to the open FWH, and (c) the mass flow rate of steam entering the first turbine stage, if the net power output is 330 MW. [Ref: 3]



## Study at one of Europe's leading universities



DTU, Technical University of Denmark, is ranked as one of the best technical universities in Europe, and offers internationally recognised Master of Science degrees in 39 English-taught programmes.

DTU offers a unique environment where students have hands-on access to cutting edge facilities and work

closely under the expert supervision of top international researchers.

DTU's central campus is located just north of Copenhagen and life at the University is engaging and vibrant. At DTU, we ensure that your goals and ambitions are met. Tuition is free for EU/EEA citizens.

Visit us at www.dtu.dk



Click on the ad to read more

270

Download free eBooks at bookboon.com

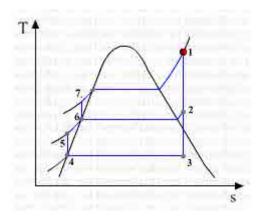


Fig.Prob.3.3.11 (a) Ideal regenerative Rankine cycle with one open FWH, and (b) T-s diagram

#### **EES Solution:**

#### "Data:"

P[1]=12000[kPa]"...at entry to first stage turbine"

P[2]=1000[kPa]"...at exit of first stage turbine, and inlet of second stage turbine, inlet to open FWH"

P[3]=6[kPa]"...at exit of second stage turbine, inlet to condenser"

P[4]=P[3]" exit of condenser, inlet to pump-1"

P[5]=P[2]" exit of pump-1, inlet to open FWH, sat. liq."

P[6]=P[5]"...exit of open FWH, sat. liq., inlet to pump-2"

P[7]=P[1]"...exit of pump-2, inlet to boiler"

T[1]=520[C]

x[4] = 0"...sat. liq."

x[6] = 0"...sat. liq."

Power = 330E03"kW...total power developed"

"\_\_\_\_\_"

#### "Calculations:"

- h[1]=ENTHALPY(steam,T=T[1],P=P[1])"finds h1"
- s[1]=ENTROPY(steam,T=T[1],P=P[1])"..finds entropy"
- s[2]=s[1]"...for isentropic expn. in first stage turbine"
- h[2]=ENTHALPY(steam,s=s[2],P=P[2])"finds h2"
- T[2]=TEMPERATURE(steam,P=P[2],h=h[2])"finds T2, after expn in first stage"
- x[2]=QUALITY(Steam,h=h[2],P=P[2])"finds x2"
- s[3]=s[2]"..for isentropic expn in second stage turbine"
- s[4]= ENTROPY(steam,T=T[4],x=x[4])"..finds entropy"
- h[3]=ENTHALPY(steam,s=s[3],P=P[3])"finds h3"
- x[3]=QUALITY(Steam,h=h[3],P=P[3])"finds x3, Quality of steam entering the Condenser"
- h[4]=ENTHALPY(steam,x=x[4],P=P[4])"finds h4"
- T[4]=T\_SAT(steam, P=P[4])"finds T4"
- s[5]=s[4]"...isentr. comprn. in pump-1"
- h[5]=ENTHALPY(steam,s=s[5],P=P[5])"finds h5"
- T[5]=TEMPERATURE(steam, P=P[5],s=s[5])"finds T5"
- T[6]=T\_SAT(steam, P=P[6])"finds T6"
- h[6] = ENTHALPY(steam,x=x[6],P=P[6])"finds h6"
- s[6]=ENTROPY(steam,T=T[6],x=x[6])"..finds entropy"
- s[7] = s[6] "...for isentropic comprn in pump-2"

"At point 2, fraction 'y' is diverted to Open Feed water heater, and (1- y) expands in second stage turbine to T3"

#### "Heat balance around the Open FWH:"

y \* h[2]+(1-y) \* h[5] = h[6]"finds y"

T[7]=TEMPERATURE(steam, P=P[7],s=s[7])"finds T7"

h[7] = ENTHALPY(steam,s=s[7],P=P[7])"finds h7"

"Pump-1 Work:"

```
v_f1=VOLUME(steam,P=P[4],x=x[4])"..m^3/kg...sp. vol. of liq. at entry to pump-1"
```

w\_p1= (1- y) \* v\_f1 \* (P[5]-P[4])"..kJ/kg .... work input to pump-1"

#### "Pump-2 Work:"

v\_f2 = VOLUME(steam,P=P[6],x=x[6])"...m^3/kg ... sp. vol. of liq. at entry to pump-1"

w\_p2=v\_f2 \* (P[7]-P[6])"..kJ/kg .... work input to pump-2"



the globally networked management school

Click on the ad to read more

Download free eBooks at bookboon.com

#### "Turbine Work:"

w\_turb1=(h[1]-h[2])"kJ/kg .... work output of stage-1 of turbine"

w\_turb2=(1- y) \* (h[2]-h[3])"kJ/kg .... work output of stage 1 of turbine"

w\_turbtotal=w\_turb1+w\_turb2"kJ/kg .... combined work output of stage 1 an 2 of turbine"

#### "Thermal effcy.:"

q\_in=(h[1]-h[7])"kJ/kg ... heat supplied"

q\_out=(1-y)\*(h[3]-h[4])"kJ/kg ... heat rejected"

w\_net=w\_turbtotal-(w\_p1+w\_p2)"kJ/kg ... net work output"

eta\_th=w\_net/q\_in"...thermal effcy."

#### "Specific Steam Consumption (SSC):"

SSC=3600/w\_net"kg/kWh"

"Mass flow rate of steam for a net power output of 330 MW:"

m\_steam = Power / w\_net "kg/s"

#### **Results:**

#### Unit Settings: SI C kPa kJ mass deg

η <sub>th</sub> = 0.4554
q <sub>in</sub> = 2627 [kJ/kg]
v <sub>f1</sub> = 0.001006 [m <sup>3</sup> /kg]
w <sub>p1</sub> = 0.7666 [kJ/kg]
w <sub>turb2</sub> = 571.5 [kJ/kg]

m <sub>steam</sub> = 275.8 [kg/s]
q <sub>out</sub> =1430 [kJ/kg]
v <sub>f2</sub> = 0.001127 [m <sup>3</sup> /kg]
w <sub>p2</sub> = 12.4 [kJ/kg]
w <sub>turbtotal</sub> = 1210 [kJ/kg]

Power = 330	1000 <mark>[kW]</mark>
SSC = 3.009	[kg/kWh]
w <sub>net</sub> = 1196	[kJ/kg]
w <sub>turb1</sub> = 638	[kJ/kg]
y = 0.2337	

Sort	1 ⊾ h <sub>i</sub>	² ▼ P <sub>i</sub> [kPa]	₃ ▼ Si	4 ▼ T <sub>i</sub> [C]	<sup>5</sup> X <sub>i</sub> ⊻
[1]	3402	12000	6.556	520	
[2]	2764	1000	6.556	179.9	0.9932
[3]	2018	6	6.556		0.773
[4]	151.5	6	0.5208	36.17	0
[5]	152.5	1000	0.5208	36.19	
[6]	762.9	1000	2.139	179.9	0
[7]	775.2	12000	2.139	181.4	

#### Also:

Thus:

Thermal effcy. = eta\_th = 0.4554 = 45.54% ... Ans.

Fraction of steam flowing in to the HP turbine that is diverted to open FWH = 0.2337 ... Ans.

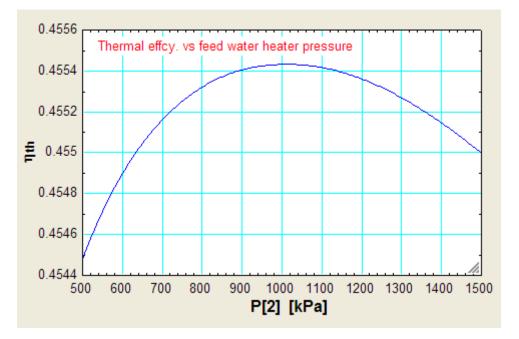
Steam flow rate required for a net power output of 330 MW = m\_steam = 275.8 kg/s .... Ans.

(b)Plot eta\_th and fraction 'y' for various feed water heater pressures, ranging from 0.5 to 1.5 MPa:

First, compute the Parametric Table:

111	1 ₽ <sub>2</sub> [kPa]	2 Ν <sub>th</sub>	з 🗵
Run 1	500	0.4545	0.1966
Run 2	600	0.4549	0.2061
Run 3	700	0.4552	0.2143
Run 4	800	0.4553	0.2214
Run 5	900	0.4554	0.2279
Run 6	1000	0.4554	0.2337
Run 7	1100	0.4554	0.2391
Run 8	1200	0.4554	0.244
Run 9	1300	0.4553	0.2486
Run 10	1400	0.4551	0.2529
Run 11	1500	0.455	0.257

#### Now, plot the results:





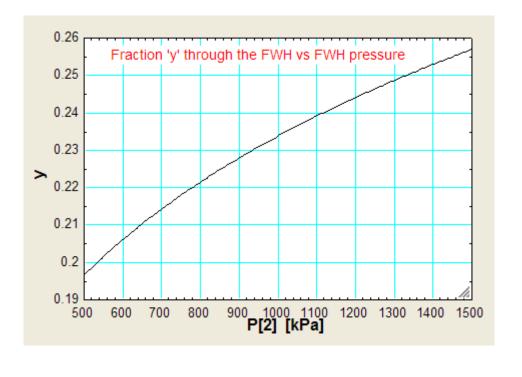
276

Click on the ad to read more

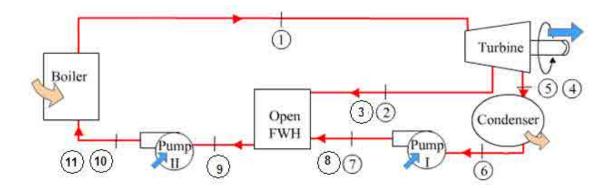
Download free eBooks at bookboon.com

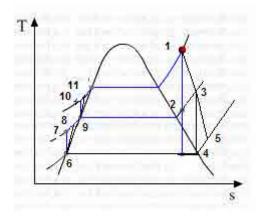
======

=====



**Prob.3.3.12** In the regenerative Rankine cycle of Prob.3.3.11, include the isentropic efficiencies of both the turbines and both the pumps, and calculate thermal efficiency and the fraction 'y' flowing through the open FWH. Take all isentropic efficiencies as 0.8.





**Fig.Prob.3.3.11** (a) Actual regenerative Rankine cycle with one open FWH, and (b) T-s diagram

#### **EES Solution:**

#### "Data:"

- P[1]=12000[kPa]"...at entry to first stage turbine"
- P[2]=1000[kPa]"...at exit of first stage turbine, isentropic"
- P[3] = P[2]"...actual exit of turbine-1, inlet to open FWH"
- P[4]=6[kPa]"...at isentropic exit of second stage turbine"
- P[5]=P[4]" actual exit of second stage turbine, and inlet to condenser"
- P[6]=P[4]" exit of condenser, sat.liq., inlet to pump-1."
- P[7]=P[2]"...isentropic exit of pump-1"
- P[8] = P[7] ".actual exit of pump-1, and inlet to open FWH"
- P[9] = P[8]"...exit of open FWH, sat.liq., inlet to pump-2"
- P[10] = P[1] "...isentropic exit of pump-2"
- P[11] = P[10] "..actual exit of pump-2, inlet to boiler"
- T[1]=520[C]

x[6] = 0"...sat. liq."

#### x[9] = 0"...sat. liq."

eta\_turb1 = 0.8"..isentropic effcy. of turbine-1"

eta\_turb2 = 0.8"..isentropic effcy. of turbine-2"

eta\_pump1 = 0.8"..isentropic effcy. of pump-1"

eta\_pump2 = 0.8<sup>"</sup>..isentropic effcy. of pump-2"

Power = 330E03"kW...total power developed"

"

#### "Calculations:"

h[1]=ENTHALPY(steam,T=T[1],P=P[1])"finds h1"

s[1]=ENTROPY(steam,T=T[1],P=P[1])"..finds entropy"

s[2]=s[1]"...for isentropic expn. in first stage turbine"



#### < OLIVER WYMAN



ver Wyman is a leading global management consulting firm that combines deep industry knowledge with specialized expertise in strategy, operations, risk usep industry knowned with specialized expension and experimentary potential is the management, organizational transformation, and leadership development. With offices in 50+ cities across 25 countries, Oliver Wyman works with the CEOs and executive teams of Global 1000 companies. OUR WORLD An equal opportunity employer.

#### GET THERE FASTER

Some people know precisely where they want to go. Others seek the adventure of ering uncharted territory. Whatever you want your professional journey to be, you'll find what you're looking for at Oliver Wyman.

Discover the world of Oliver Wyman at oliverwyman.com/careers





279 Download free eBooks at bookboon.com

Vapour Power Cycles

h[2]=ENTHALPY(steam,s=s[2],P=P[2])"finds h2"

- T[2]=TEMPERATURE(steam,P=P[2],h=h[2])"finds T2, after isentr. expn in first stage"
- x[2]=Quality(Steam,T=T[2],h=h[2])"...quality after isentr expn in turbine-1 stage"
- w\_turb1\_isentr=(h[1]-h[2])"kJ/kg ....isentropic work output of stage-1 of turbine"
- w\_turb1=(h[1]-h[2]) \* eta\_turb1"kJ/kg ....actual work output of stage-1 of turbine"
- $h[3] = h[1] w_turb1 "kJ/kg .... enthalpy at state point 3"$
- T[3]=TEMPERATURE(steam,P=P[3],h=h[3])"finds T3, after actual expn in first stage turbine"
- s[3]=ENTROPY(steam,h=h[3],T=T[3])"..finds entropy at point 3"
- x[3]=Quality(Steam,T=T[3],h=h[3])"...quality after actual expn in turbine-1 stage"
- s[4] = s[3] "...isentr. expn. in stage-2 of turbine"
- h[4]=ENTHALPY(steam,s=s[4],P=P[4])"finds h4, after isentr. expn in stage-2"
- w\_turb2\_isentr=(h[3]-h[4])"kJ/kg ....isentr work output of stage-2 of turbine"
- w\_turb2= w\_turb2\_isentr \* eta\_turb2"kJ/kg ....actual work output of stage-2 of turbine"
- $h[5] = h[3] w_turb2$  "kJ/kg .... enthalpy at state point 5"
- T[4]=TEMPERATURE(steam,P=P[4],h=h[4])"finds T4, after isentr expn in second stage turbine"
- T[5]=TEMPERATURE(steam,P=P[5],h=h[5])"finds T5, after actual expn in second stage turbine"
- s[5]=ENTROPY(steam,h=h[5],T=T[5])"..finds entropy at point 5"
- x[4]=Quality(Steam,T=T[4],h=h[4])"...quality after isentr expn in turbine-2 stage"
- x[5]=Quality(Steam,T=T[5],h=h[5])"...quality after actualr expn in turbine-2 stage"
- T[6]=T\_SAT(steam, P=P[6])"finds T6"
- s[6]= ENTROPY(steam,T=T[6],x=x[6])"..finds entropy"

Vapour Power Cycles

s[7] = s[6] "...for isentr compression in pump-1"

h[6]=ENTHALPY(steam,x=x[6],P=P[6])"finds h6, at exit of condenser, and entry to pump-1"

v\_f6 = Volume(Steam,x=x[6],P=P[6])"...m^3/kg...sp. vol. of liq. at point 6, entry to pump-1"

w\_p1\_isentr = v\_f6 \* (P[7] - P[6]) "kJ/kg ....isentr work required for pump"

w\_p1 = w\_p1\_isentr / eta\_pump1 ".kJ/kg ... actual work of pump-1"

h[7] = h[6] + w\_p1\_isentr "kJ/kg ... enthalpy at isentr exit of pump-1"

h[8] = h[6] + w\_p1 "kJ/kg .... enthalpy at actual exit of pump-1"

T[7]=TEMPERATURE(steam,P=P[7],h=h[7])"finds T7, after isentr comprn in pump-1"

T[8]=TEMPERATURE(steam,P=P[8],h=h[8])"finds T8, after actual comprn in pump-1"

s[8]=ENTROPY(steam,h=h[8],T=T[8])"..finds entropy at point 8"

"At point 3, fraction 'y' is diverted to Open Feed water heater, and (1 - y) expands in second stage turbine to T5"

#### "Heat balance around the Open FWH:"

h[9] = ENTHALPY(steam,x=x[9],P=P[9])"finds h9"

y = (h[9] - h[8]) / (h[3] - h[8])"finds y"

T[9]=T\_SAT(steam, P=P[9])"finds T9"

s[9]= ENTROPY(steam,T=T[9],x=x[9])"..finds entropy"

s[10] = s[9] "...for isentr. comprn in pump-2"

v\_f9 = Volume(Steam,x=x[9],P=P[9])"...m^3/kg...sp. vol. of liq. at point 9"

w\_p2\_isentr = v\_f9 \* (P[10] - P[9])"kJ/kg ... isentr work of pump-2"

w\_p2 = w\_p2\_isentr / eta\_pump2 ".kJ/kg ... actual work of pump-2"

h[10] = h[9] + w\_p2\_isentr "kJ/kg ... enthalpy at isentr exit of pump2"

 $h[11] = h[9] + w_p2$  "kJ/kg .... enthalpy at actual exit of pump-2"

T[10]=TEMPERATURE(steam,P=P[10],h=h[10])"finds T10, after isentr comprn in pump-2"

T[11]=TEMPERATURE(steam,P=P[11],h=h[11])"finds T11, after actual comprn in pump-2"

s[11]=ENTROPY(steam,h=h[11],T=T[11])"..finds entropy at point 11"

#### "Turbine Work:"

w\_turbtotal=w\_turb1+(1 - y) \* w\_turb2"kJ/kg .... combined work output of stage 1 an 2 of turbine"

#### "Thermal effcy.:"

D 2010 EYGM Lir

- q\_in=(h[1]-h[11])"kJ/kg ... heat supplied"
- q\_out=(1- y) \* (h[5]-h[6])"kJ/kg ... heat rejected"
- w\_net=w\_turbtotal-(w\_p1\* (1 y) + w\_p2)"kJ/kg ... net work output"

eta\_th=w\_net/q\_in"...thermal effcy."

# and you're ready

Day one. It's the moment you've been waiting for. When you prove your worth, meet new challenges, and go looking for the next one. It's when your dreams take shape. And your expectations can be exceeded. From the day you join us, we're committed to helping you achieve your potential. So, whether your career lies in assurance, tax, transaction, advisory or core business services, shouldn't your day one be at Ernst & Young?

What's next for your future? ey.com/careers

ERNST & YOUNG Quality In Everything We Do

Click on the ad to read more

282

SSC=3600/w\_net"kg/kWh"

"Mass flow rate of steam for a net power output of 330 MW:"

```
m_steam = Power / w_net "kg/s"
```

#### **Results:**

#### Unit Settings: SI C kPa kJ mass deg

η <sub>pump1</sub> = 0.8	η <sub>pump2</sub> = 0.8	η <sub>th</sub> = 0.3755
η <sub>turb1</sub> = 0.8	η <sub>turb2</sub> = 0.8	m <sub>steam</sub> = 335 [kg/s]
Power = 330000 [kW]	q <sub>in</sub> = 2624 [kJ/kg]	q <sub>out</sub> = 1639 [kJ/kg]
SSC = 3.654 [kg/kWh]	∨ <sub>f6</sub> = 0.001006	∨ <sub>f9</sub> = 0.001127
w <sub>net</sub> = 985.2 [kJ/kg]	w <sub>p1</sub> = 1.251 [kJ/kg]	W <sub>p1,isentr</sub> = 1 [kJ/kg]
w <sub>p2</sub> = 15.5 [kJ/kg]	w <sub>p2,isentr</sub> = 12.4 [kJ/kg]	w <sub>turb1</sub> = 510.4 [kJ/kg]
Wturb1,isentr = 638 [kJ/kg]	w <sub>turb2</sub> = 632.1 [kJ/kg]	W <sub>turb2,isentr</sub> = 790.1 [kJ/kg]
w <sub>turbtotal</sub> = 1002 [kJ/kg]	y = 0.2228	

#### And:

Sort	1 h <sub>i</sub>	² ₽ <sub>i</sub> [kPa]	₃ ⊾ Si	<sup>4</sup> T <sub>i</sub> [C]	<sup>5</sup> X <sub>i</sub> ⊻
[1]	3402	12000	6.556	520	
[2]	2764	1000	6.556	179.9	0.9932
[3]	2892	1000	6.825	227.6	100
[4]	2102	6	6.825	36.17	0.8075
[5]	2260	6	7.336	36.17	0.8729
[6]	151.5	6	0.5208	36.17	0
[7]	152.5	1000	0.5208	36.19	
[8]	152.7	1000	0.5216	36.25	
[9]	762.9	1000	2.139	179.9	0
[10]	775.3	12000	2.139	181.5	
[11]	778.4	12000	2.146	182.2	

#### Thus:

When the isentropic efficiencies of both the turbines and pumps are taken in to account,

Thermal effcy. = eta\_th = 0.3755 = 37.55% .... Ans.

Fraction y passing through the open FWH = y = 0.2228 ....Ans.

Mass flow of steam for a net output of 330 MW = m\_steam = 335 kg/s ... Ans.

÷.

Note: Compare these values with those obtained in Prob. 3.3.11, where all the isentropic efficiencies were 100%.

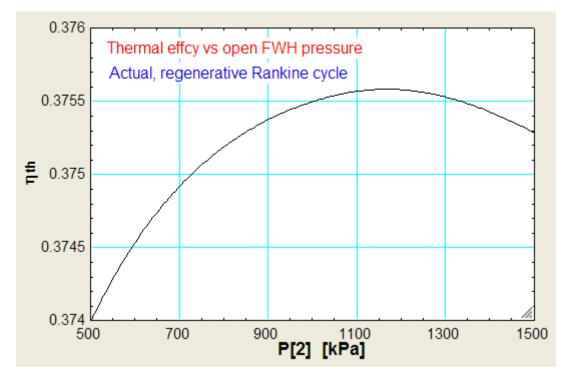
(b)Plot eta\_th and fraction 'y' for various feed water heater pressures, ranging from 0.5 to 1.5 MPa:

First, compute the Parametric Table:

111	1 ₽ <sub>2</sub> [kPa]	2 η <sub>th</sub>	з у
Run 1	500	0.374	0.1852
Run 2	600	0.3745	0.1947
Run 3	700	0.3749	0.2029
Run 4	800	0.3752	0.2102
Run 5	900	0.3754	0.2168
Run 6	1000	0.3755	0.2228
Run 7	1100	0.3756	0.2283
Run 8	1200	0.3756	0.2333
Run 9	1300	0.3755	0.2381
Run 10	1400	0.3754	0.2425
Run 11	1500	0.3753	0.2467

Click on the ad to read more

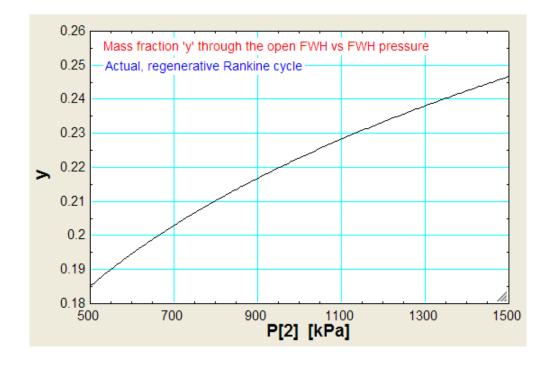
#### Now, plot the results:





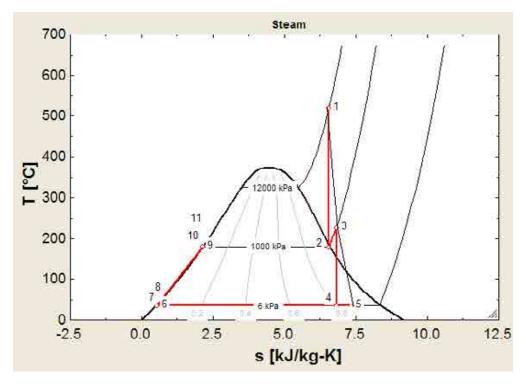
285

Download free eBooks at bookboon.com



c) Plot the cycle on T-s diagram in EES:

We first get the Property plot for Steam, and then overlay the T-s diagram over it using the Array Table:



Download free eBooks at bookboon.com

"**Prob. 3.3.13** In a regenerative Rankine cycle of Prob. 3.3.11, include the isentropic efficiencies of both the turbines and both the pumps, and calculate thermal efficiency and the fraction 'y' flowing through the open FWH. Take all isentropic efficiencies as 0.8 **Use the Diagram Window in EES to enter input variables.**"

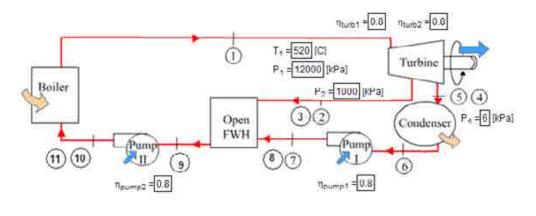
#### **EES Solution:**

The EES program is the same as used for Prob.3.3.12.

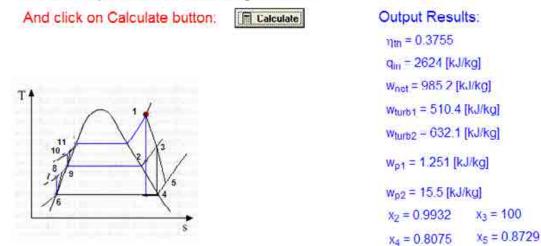
But, now make inputs from the Diagram Window of EES.

See Prob. 3.3.3 for the detailed procedure and steps.

Diagram window looks as follows, with data as given in previous problem:



Enter the Input variables in the diagram above:

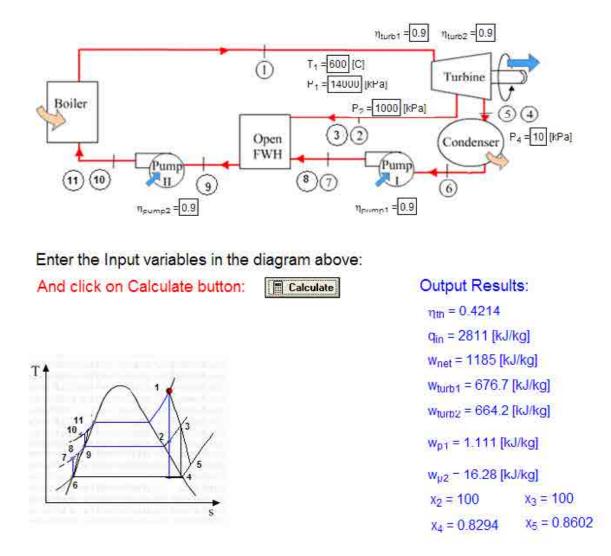


Note in the above: quality, x[3] = 100 means that it is in the superheated region.

#### Now, we shall change the data as:

Turbine inlet pressure, P[1] = 14000 kPa, P[2] = 1000 kPa, condenser pressure, P[4] = 10 kPa, T[1] = 600 C, all isentropic efficiencies as 90%.

First, make these changes in the Diagram window when it is in 'development mode' (i.e. when the Diagram window tool bar is visible). Then, change the Diagram window to the 'Application mode' by pressing (control + D), and the tool bar disappears, Now, click on the 'Calculate' button, and we get:



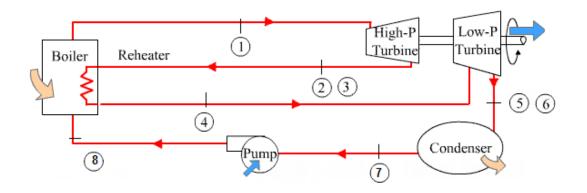
Now, observe from Output Results that values of eta\_th etc. have changed. Quality = 100 indicates 'superheated region'.

Thus, calculation with Diagram window inputs is very convenient.

Vapour Power Cycles

#### 3.4 Problems solved with TEST:

**Prob. 3.4.1** A reheat cycle has the first stage supply conditions of 70 bar, 500 C. The reheat is at 3 bar and to the same temp. (i) Given that the efficiency of the first turbine is 80%, how much energy is added per kg of steam in reheat coils? (ii) Assume that the expansion efficiency exists in the second turbine. What is the thermal effcy. if the condenser pressure is 0.03 bar? [VTU-ATD-June–July, 2008]





Hellmann's is one of Unilever's oldest brands having been popular for over 100 years. If you too share a passion for discovery and innovation we will give you the tools and opportunities to provide you with a challenging career. Are you a great scientist who would like to be at the forefront of scientific innovations and developments? Then you will enjoy a career within Unilever Research & Development. For challenging job opportunities, please visit www.unilever.com/rdjobs.











Dove

289 Download free eBooks at bookboon.com

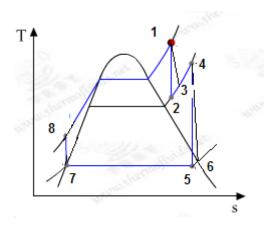
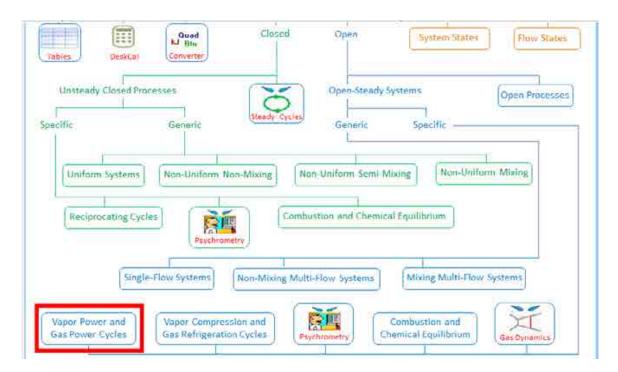


Fig.Prob.3.4.1(a) Actual Rankine cycle with reheat, and (b) T-s diagram

#### **TEST Solution:**

#### Following are the steps:

16. From the TEST daemon tree, select the 'Vapour Power and Gas Power cycles' daemon:



17. Clicking on 'Vapour Power and Gas Power cycles' brings up the window for material selection.





Discover the truth at www.deloitte.ca/careers

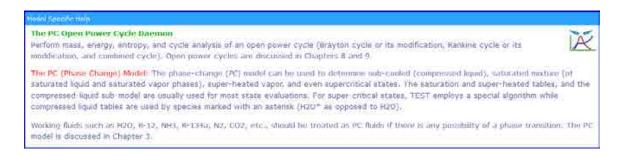


Click on the ad to read more

Download free eBooks at bookboon.com

291

Hovering the mouse pointer over 'Vapor (Steam) Power Cycles', brings up the following explanatory message:



18. Click on 'Vapor (Steam) Power Cycles', and H2O is selected by default for working substance. Fill in the conditions for State 1, i.e. state at entry to compressor:
p1= 7000 kPa, T1= 500 C, and mdot1 = 1 kg/s. Press Enter. Immediately, all properties at

State 1 are calculated:

Mixed OSI CE	nglish 💽 😒	350 0 × >	W Help Mes	sages On S	oper-florate	Super-Calculate	Load	Super-Initialize
State Panel	h	D INFO	Tarait (	1	George Prenting	1	10	Paon
< UStale-t M >	Calculate	No-P	ota 🔛	Instanze	Supamaa	md vapor	H20	1
< _ pt	1 11				1 1		- 11	
(000.0 sPa	- Source	dep C .		Instian	*	fraction 👻	0.04814	milling (
1945	hit		(ht)		1100	£	1 et	
3073-291 LINE	* 3410.2654	UND: 3	6.70737	jung.K	× 0.0	(165 M	0.0	
41	11		pin(f)		201		- ma	lot1
1073 291 ±18g	* 3410.2654	Alles .		#3Mg	×.	аланд м	1.0	199
Voldot?	At:		Mitt					
0.04814 ==12%	4813.9204	#2: 8	10.0	kpikmol	M			

19. For State 2: Enter p2, s2 = s1 (for isentropic process 1-2), and mdot2 = mdot1. Hit Enter. We get:

• Mixed 0 81	C Engl	ish 💽 🚾	060-0 × >	M Holp Mer	isages On	Super	Iterate Su	per-Calculate	Load	Super-Initializ
Stato Pa	inel	11P	Deeper	Eamil	1	ç	and Portaliti	1		ά€ann
< CStale-2 v	2	Calculate	No.F	Piots 💉	Initialize		Saturated Mixtu	ile i	HOD	×
p2		- 72		12			142	_	1.1	2
02.0		133.65	dep.C	0.96345	fractitin	~	0.99993	stattin 👻	0 58372	<b>-1</b> 3g
102		. 112		× 52			<		1 2	2
471.102 4.00	e in	2545.2175	<b>NING</b> (	Y 51	KING K	1 M	b.ø	100 (M	0.0	m,
- 44		.11		and the					1 1	ndot2
471.102	ų.	2646.2175	<u>1109</u>	4	A.J.Kg			k.Mag 🖌 🐱	=mulut1	k Lufus

20. For State 3: It represents the state after actual expansion, taking in to account the isentropic effcy. of turbine. Enter  $p_3 = p_2$ ,  $h_3 = h_1 - (h_1 - h_2) * 0.8$  where 0.8 is the turbine effcy. and mdot3 = mdot1. Hit Enter. We get:

Mixed C SI C Er	glish	< CCase-0	1015	P Help Mes	sages On	Super-	Iterate	Super Calculate	1	ioad	Super hittak	20
State Panel			SHICE PL	itheri	1	1	THE THAT	e (1)		-10.1	197741	
< CState 3 > >	Cal	culate	No-Pio	ta 💌	Interior		Superhe	sted vapor	18	80	×	1_
✓ p3		73		- 13			73			3		
194 194	* 168.23	307 🗢	26 ×		frection	164		fraction	0.6	6388	m'24a	1
ü <b>9</b> 5	1	har		83			2 Vi	19	1	23		
2599.8625 NJ/Re	😢 🖬 tab	1-62/10:81 6.4		7.16288	36,g/KG	- 36	0.0	With State	0.0		<b>.</b>	- 98
107		a'		meti			, mail		1	mdo	13	
2599.8625 ¥1Ag	2798.0	27 834	9 ×		k,/Ap	199	í.	kJ/kg	1	idot1	+ph	16
Veldet3		A3		AMMS:								
0.60388 m*3/a	96388	23. #*	1	18.0	kolkino)							

21. For State 4: we have: p4 = p3, T4 = T1, mdot4 = mdot1. Hit Enter. We get:

Mixed C SI C I	English	< Case 0 v	15	V Help Mess	agus On	Super	Iterate	Super-Calculate	L	.oad	Super-Initiali	ze.
State Panel		1	111102.2	19.0%	1	\$	Cvthe Bacol	i ilu		INC PA	set	
< CState-4 💉 >	Cn	Iculate	No-Pio	its 💌	Indiator		Superfiea	ted Vapor	H2	0	¥	
< p4	1	T4		x4			y4			v4		
alia dia	2 ET	deg C	×		fraction	16-		fraction 🔗	1 1	8667	milita	1
u4		84		- 54			× . 546		×	27		
120.0365 (MAg	· 3485	NJ/Kg	Ŷ	8.32487	MARK :	(w)	6.0	wa 🗠	0.0		w.	1
el		H.		pho i			pold		1	mdot4		
129 1965 MAy	W 34851	1387 bing	14		ku/kp	100		kJihy 😽		clot1	Agra	
Voldot4		A4		AMA2	Jane	1965		22508	E	2017	a contraction of the second	
18667 0/3/8	11866	7.445: 0/2:	÷,	18.0	<b>lighmul</b>	(w)						

22. For State 5: Enter p5 = 3 kpa, s5 = s4, mdot5 = mdot1, and hit Enter. We get:

Mixed C 31 C	Englis	sh < 🛙	ase-0 👻 🗧	M Help Mes	sages On	Super-B	erate S	uper Calculate	Load	Super Initiatiz
State Panel		1	Dented	Hanel I		Ci	OIL PSHIT	li	1840	::E##0)
< OState 6 💉 >	ĺ.	Calculate	No-	Piots 💌	Initialize	J	Saturated Mut	ture -	H20	(N)
ρδ		15		x5			y5		10	
N	~	24.07739	eeg-C:	× 0:96926	fraction	100	.9	frector	44.29203	with the second
<i>4</i> 5		h5		× 35			S SMS		1 25	
337.619 #J/kg	19	2470.3904	ktikg .	× 34	AUND N.	19il	up I	den .	× 0.0	*
e5		5		2005			885		- ma	1015
337.615 #Illeg	M	2470.3904	Alleg.		ASRO	- M		w.song	< Emdott	Agen (

23. For State 6: i.e. actual exit of turbine-2: Enter p6 = p5, h6 = h4 - (h4 - h5) \* 0.8 where 0.8 is isentropic effcy. of turbine. And mdot6 = mdot1. Hit Enter. We get:

	@ Mixed C SI C E	nglish	ase-0 🖌 🖂 🖂 Help Me	ssages On	Super-Iterate	Super Calculate	Load	Super Inibalize
76         x6         y6         v6           pt:         we w         92,5549         west w         mestical         mestical         mestical         96,7798         writing           u0         ✓         h0         x6         ✓         Vid         ✓         c6           604 9563         wile,         Maximum         Ø0         mix         Ø0         mix         Ø0         mix           e8         j6         j6	State Panel	1	Decci Pierro		beine		HR.	(Summer)
IDE         IDE         DESCRIPTION         Maximum         Maximum         Maximum         Sec. 1770%         Maximum           U0         ✓	< CState-6 M >	Calculate	No-Plots 😒	Interce	Superhe	ated Vapor	1420	
IDE         IDE         DESCRIPTION         Maximum         Maximum         Maximum         Sec. 1770%         Maximum           U0         ✓	/ p8.	76	x6.		10		16	
u0         ✓         h6         s6         ✓         Vnff         ≤5           H604 9663         KX89,         M         Inte-Over 65/9.8         KX89,         M         Inte-Over 65/9.8         KX89,         M         0.0         m         0.0         m           id0         jd         galo         galo         galo         m         m         0.0         m	05 US	· 92.8549		Machine	*	Manhod 👻	56.47796	##38g. /
48 16 16 16 16 16 16 16 16 16 16 16 16 16	uð.	< h6			1 V	atti I	1 26	
	604 0663 WWW.	M 1484 (N4 65)/0 (	tuikg 💉 8.77108	at a present	A 10.0	WA- M	0.0	(m)
501.9663 Alles 🗸 2573.5 Vila Vila Killes 🖌 Killes Vila Killes V	60	0	2.6		200		* md	010
	501.9663	2873.5	MAR	£30p	*	AJ/Rg 😒	-mulot t	Rale-
	0 17796 m'31	- 6617790,5	16.0	kghirter	- 64			

24. For State 7: i.e. entry to pump: Enter p7 = p6, x7 = 0 (for sat. liq.), and mdot7 = mdot1. Hit Enter. We get:

C Mixed C 51	CEng	lish 👱 🚾	ase-0 v	P Help Mes	sages On	Super-It	terate S	iper-Calculate	Los	ad 🛔	Soper-Initialize
State P	anel		()	10 Parcel		.e	3080 Planet #			I RRE-	007
< @State-7		Calculate	N	-Piots 👻	Initiatize	-	Saturated Mot	N/C	H20	<u>į</u>	
/ pT		17		🖌 x7			y7		1	VT.	
-gð:	Par 😸	24.07739	deg-C.	2.9	hetter	2	0.0	hacton 💌	0.001		mithy .
u7		67		67			< Shite		1	2)	
01.02052	÷ . *	101.02362	81/60	× 0.35448	kalkog H (	(V)	ulu i	- WA	0.0		and the
e7		T		3007			2417		-1	mdol7	
01 02062 40		101.02362	(ung	2	stake .	M		nulling 💌	=mda	11	NO/R Y
Voldot7		A7		MMT							
001 #3	16 V	100.3013		18.0	kykowi	9					

25. For State 8: i.e. exit of pump: Enter p8 = p1, s8 = s7 (for isentropic compression 7-8), and mdot8 = mdot1. Hit Enter. We get:

State Panel         Define (* anel         Calls frame)         FD           < @State-9          Colc/Ate         No Profs         Md2200         Subcooled Liquid         H00           ✓         p6         78         <6         y8         y8         y8         y8           rp1         the         24.07644         dep C         fraction          fraction         6001	rm# *
✓ p6 78 48 y8 v8	<u>.</u> *
	m*24g
u8 1/8 🖌 a8 🖌 1/e/8 🖌 28	
01 015555 Ullig: 🛩 109.03775 Ullig: 🗠 #37 Ullig: 🗠 0.0	<b>1</b>
ed ja one put 🖌 mak	810
11.01665 4182 🗸 100.03775 4182 X auto V auto V auto V	Agen

26. Now, go to Device panel. For device A, enter State 1 and State 3 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And Qdot1 = 0 since in this process there is no external heat transfer. Hit Enter. We get:

• Mixed C S		-		ages on Sup		aper-Calculate	I nad Super-Initiatize
Shirk	Carre	D	wice Panel		STREEME		而无望自己
vilialize		< Device-A (t-	8 <b>v</b> 5	Calcul	ite	Non-Mixing	Mixing Device
State 1	M	: 12 21000	State-tault 💌		Stato 3 😽		State Mull
Odót		Wdot_ex		* T_B		Sdot	gen
0	AWE .	9 611.2383	WV I	~ 25.5	dep-Cr	M 0.36551	KWK
Jdot_net		Sdot_net					
112383	W7	✓. 0.36551	KW/W				
Contraction of the second	$(m_{e1} + n)$					A STATE OF A	Null: stes that s closed.
a 65° a 1	m . 1 . )-(	ma1 ja1 + ma2 ja2)-	$-Q-W_{\text{sat}}$	_	el=		

#### Note that work of Turbine-1 is 611.2383 kW.

27. Similarly for Device B: enter State 3 and State 4 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And, Wdot\_ext = 0 since for this process no external work transfer occurs. Hit Enter. We get:

Mixed C.BI C.English	< ¢Cimii 0 ≫ >	😔 Help Mess	ages On	Super-I	tecale	Super-Calo	ulate	load Supe	er-Anitialize
State Parod	Devic	e Panel		10	active Proceed			( ) Contract (	
Initialize	Cence-B [3-4]	N N		Calculate		C Nor	a-Mixing	÷	lixing Devic
n Sizze State-3 🐱	0.5000 8	tate-Null 🐱		in Her	State-4	× .		Siline S	itate Nuit 😽
Qdor	Widot_ext		1	TB			Sdot	gon	
386.9116 XWV	0.0	W.	25.0		dað 2	સં	1 14182	85006	
Joint net	Sdot_net								
686 9116 WW	1.15200	WWR -	100						

Note that Qdot for process 3-4 is amount of reheat = 686.9116 kW (Ans.)

28. And, for Device C: enter State 4 and State 6 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And, Qdot = 0 since for this process no external heat transfer occurs. Hit Enter. We get:

@ Mixed C SI C English	< DCsse-D W >	V Help Mess	ages On	Super-Iterat	e Super	Calculate	Load	Super-Initialize
: Ditable (Cappell	Device	Panel		(0)11A	EstiH	1	.HQ.M	UDHI
mitratize	* Device-C (4-6)	× >		Calculate	(	Non-Mixing		··· Mixing Device
ii Shite State-4 🐱	ta terte	te Null 😽		Sta	te-6 😽		2.00	State Null 👻
< Qdot	Wolat_ext		1	T_B		Sdi	of_gen	
10 W S	812.43866	kτγ.	31 25.0		Org-D	× 0.44611		WAY 18
Jdot_net	Sdot_net							
012 43855 WW	-0.44611	www.	÷.					

Note that work output of Turbine-2 is: 812.438 kW.

# Grant Thornton— $a^{\text{REALLY}}$ great place to work.

We're proud to have been recognized as one of Canada's Best Workplaces by the Great Place to Work Institute<sup>™</sup> for the last four years. In 2011 Grant Thornton LLP was ranked as the fifth Best Workplace in Canada, for companies with more than 1,000 employees. We are also very proud to be recognized as one of Canada's top 25 Best Workplaces for Women and as one of Canada's Top Campus Employers.



Priyanka Sawant Manager



Audit • Tax • Advisory www.GrantThornton.ca/Careers



© Grant Thornton LLP. A Canadian Member of Grant Thornton International Ltd



296 Download free eBooks at bookboon.com 29. And, for Device D: enter State 6 and State 7 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And, Wdot\_ext = 0 since for this process no external work transfer occurs. Hit Enter. We get:

C Mixed C SI C English	Case-0 ∨ > ♥ Help Message	s On Super-Ite	rate Super-Calculate	Load Super-Initialize
Statin Pallel	Device Panel	1 30	Cie Cippel	IQ7384
mination	< Dence 0 [5-7] M >	Calculate	C Non-Mixing	(• Mixing Devic
a Kate-6 🔍	CSTUD State-fault 🖌	al serie	State-7 🔍	State-Null 🖌
Qdot	Wdot_ext	× T_B	SI	dot_gen
2572,4763	0.0 m 💉	25.0	069-C Y 0.21152	with:
Jdot_nnt	Sdot_net			
2572 4763 NW (*	8 4165 MM/K 🛩			

#### Note that process 6-7 is heat removal in condenser; heat removed is: 2572.4763 kW.

30. Now, for Device E: enter State 7 and State 8 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And, Qdot = 0 since for this process (in the pump) no external heat transfer occurs. Hit Enter.

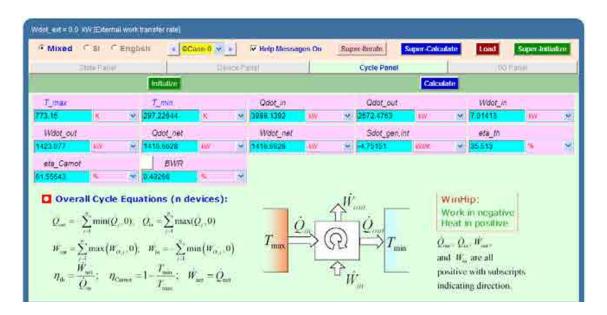
Mixed C SI C English	¢Case-0 ≥	Help Me	ssages On	Super-Iterate	Super-Calculate	Load Super-Instals
HEADE MARKET	Dev	ice Panel	the state	TREM PARM	111	HO FROM
rimalize	Device+E (7-8	XX		Calculate	CNon-Moung	Te Mixing De
11 State-7	x2+54abre	State-Null 💌		State-8		State-Null
Qdot	Wdot_ext		1	T_B	So	lot_gen
W W	-7.01412	67	× 23	969-C	9 0.0	1008.
Jdot_net	Sdot_net					
7.01413	0.0	AVV/15	18			

#### Note that pump work is 7.01413 kW (Ans.)

31. And, for Device F: enter State 8 and State 1 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And, Wdot\_ext = 0 since for this process (in the boiler) no external work transfer occurs. Hit Enter. And, SuperCalculate.

Mixed C Si C English	< ©Case-0 ✓ > IF Help Messages On	Super-Iterate	Super Calculate	Load Super-Initialize
Thirth Parents	Device Panel	Self III	41	FD Frank
Initialize	< DevcerF(8-1)	Calculate	Non Moxing	Mixing Device
H Skitter State-8 💌	Di-State-Null	State-1	• I	State-Null 🧕
Qdat	< Wdot_ext <	T_B	Sdot	çevi
1302 2275 AW	2.0 · · · · · · · · · · · · · · · · · · ·	dag-i	· · · · · · · · · · · · · · · · · · ·	NW/K >
Jdol_net	Sdot_net			
3302.2275 XW	and the second se			

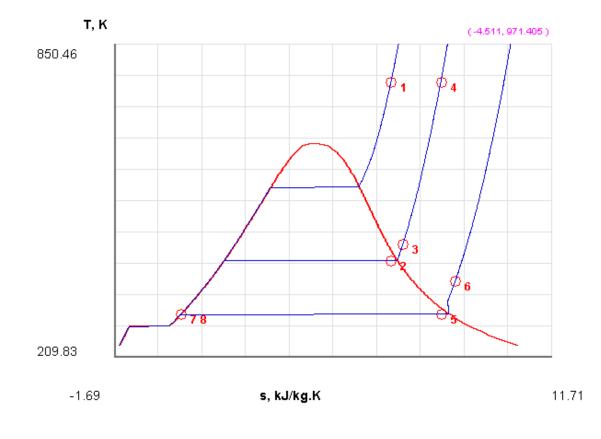
#### Note that heat supplied in boiler is Qdot = 3302.2275 kW.



32. Now, go to cycle panel. It gives the major parameters of this cycle:

#### We observe that Wdot\_net = 1416.6628 kW, eta\_th = 35.513% ... Ans.

33. From the Plots widget, choose T-s diagram, and we get:



#### 34. I/O panel gives the TEST code etc:

#~~~~~OUTPUT OF SUPER-CALCULATE

#### # Daemon Path: Systems>Open>SteadyState>Specific>PowerCycle>PC-Model; v-10.cb01

#-----Start of TEST-code -----

States {

State-1: H2O;

Given: { p1= 7000.0 kPa; T1= 500.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; mdot1= 1.0 kg/s; }

State-2: H2O;

Given: { p2= 300.0 kPa; s2= "s1" kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; mdot2= "mdot1" kg/s; }

State-3: H2O;



Low-speed Engines Medium-speed Engines Turbochargers Propellers Propulsion Packages PrimeServ

The design of eco-friendly marine power and propulsion solutions is crucial for MAN Diesel & Turbo. Power competencies are offered with the world's largest engine programme – having outputs spanning from 450 to 87,220 kW per engine. Get up front! Find out more at www.mandieselturbo.com

Engineering the Future – since 1758. **MAN Diesel & Turbo** 





Download free eBooks at bookboon.com

Given: { p3= "p2" kPa; h3= "h1-(h1-h2)\*0.8" kJ/kg; Vel3= 0.0 m/s; z3= 0.0 m; mdot3= "mdot1" kg/s; }

State-4: H2O;

Given: { p4= "p3" kPa; T4= "T1" deg-C; Vel4= 0.0 m/s; z4= 0.0 m; mdot4= "mdot1" kg/s; }

State-5: H2O;

Given: { p5= 3.0 kPa; s5= "s4" kJ/kg.K; Vel5= 0.0 m/s; z5= 0.0 m; mdot5= "mdot1" kg/s; }

State-6: H2O;

Given: { p6= "p5" kPa; h6= "h4-(h4-h5)\*0.8" kJ/kg; Vel6= 0.0 m/s; z6= 0.0 m; mdot6= "mdot1" kg/s; }

State-7: H2O;

Given: { p7= "p6" kPa; x7= 0.0 fraction; Vel7= 0.0 m/s; z7= 0.0 m; mdot7= "mdot1" kg/s; }

State-8: H2O;

Given: { p8= "p1" kPa; s8= "s7" kJ/kg.K; Vel8= 0.0 m/s; z8= 0.0 m; mdot8= "mdot1" kg/s; }

```
}
```

#### Analysis {

Device-A: i-State = State-1; e-State = State-3; Mixing: true;

Given: { Qdot= 0.0 kW; T\_B= 25.0 deg-C; }

Device-B: i-State = State-3; e-State = State-4; Mixing: true;

Given: { Wdot\_ext= 0.0 kW; T\_B= 25.0 deg-C; }

Device-C: i-State = State-4; e-State = State-6; Mixing: true;

Given: { Qdot= 0.0 kW; T\_B= 25.0 deg-C; }

#### Device-D: i-State = State-6; e-State = State-7; Mixing: true;

Given: { Wdot\_ext= 0.0 kW; T\_B= 25.0 deg-C; }

Device-E: i-State = State-7; e-State = State-8; Mixing: true;

Given: { Qdot= 0.0 kW; T\_B= 25.0 deg-C; }

Device-F: i-State = State-8; e-State = State-1; Mixing: true;

Given: { Wdot\_ext= 0.0 kW; T\_B= 25.0 deg-C; }

}

#-----End of TEST-code -----

#-----Property spreadsheet starts:

# State	p(kPa)	T(K)	х	v(m3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
# 01	7000.0	773.2		0.0481	3073.29	3410.27	6.797
# 02	300.0	406.7	1.0	0.5837	2471.1	2646.22	6.797
# 03	300.0	441.4		0.6639	2599.86	2799.03	7.163
# 04	300.0	773.2		1.1867	3129.94	3485.94	8.325
# 05	3.0	297.2	1.0	44.292	2337.61	2470.39	8.325
# 06	3.0	365.8		56.178	2504.97	2673.5	8.771
# 07	3.0	297.2	0.0	0.001	101.02	101.02	0.354
# 08	7000.0	297.2		0.001	101.02	108.04	0.354

#### # Cycle Analysis Results:

#	Calculated: T_max= 773.15 K; T_min= 297.22644 K; Qdot_in= 3989.1392 kW;
#	Qdot_out= 2572.4763 kW; Wdot_in= 7.01413 kW; Wdot_out= 1423.677 kW;
#	Qdot_net= 1416.6628 kW; Wdot_net= 1416.6628 kW; Sdot_gen,int= -4.75151 kW/K;
#	eta_th= 35.513 %; eta_Carnot= 61.55643 %; BWR= 0.49268 %;
#*****CA	LCULATE VARIABLES: Type in an expression starting with an '=' sign ('= mdot1*(h2-h1)',
'= sqrt(4*.	A1/PI)', etc.) and press the Enter key)*******

#### #Reheat = (h4-h3) =h4-h3 = 686.91162109375 kW; Thermal effcy. = 35.51%....(Ans.)

#### (b) Plot the variation of eta\_th and Wdot\_net with reheat pressure (P2); vary P2 from 3 bar to 33 bar:

#### The procedure is quite simple:

- i. Go to State 2 in the States panel, change the value pf P2 to desired value
- ii. Click on Calculate and then SuperCalculate.
- iii. Go to Cycle panel read off the values of eta\_th and Wdot\_net
- iv. Repeat this procedure for the next value of P2
- v. Tabulate the values of P2 and eta\_th and Wdot\_net, and plot the graphs using EXCEL

Following are the results:

P2 (kPa)	Wdot_net (kW)	eta_th (%)
300	1416.6628	35.513
800	1373.5829	35.807
1300	1338.7622	35.742
1800	1308.7335	35.587
2300	1281.5952	35.392
2800	1258.3715	35.21
3300	1235.8524	35.0
3800	1216.2567	34.815
4300	1196.2806	34.6
4800	1178.3009	34.404

## **X KBS** Group

# CAREERKICKSTART

### An app to keep you in the know

Whether you're a graduate, school leaver or student, it's a difficult time to start your career. So here at RBS, we're providing a helping hand with our new Facebook app. Bringing together the most relevant and useful careers information, we've created a one-stop shop designed to help you get on the career ladder – whatever your level of education, degree subject or work experience.

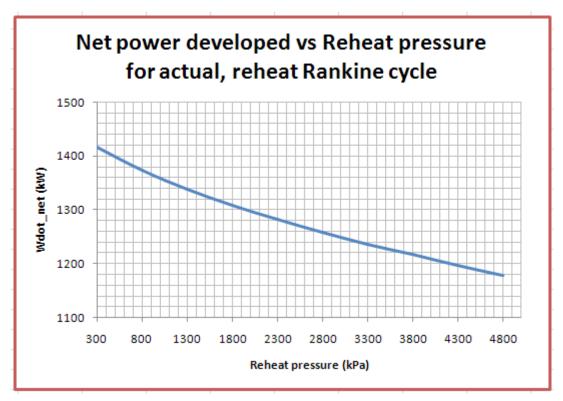
And it's not just finance-focused either. That's because it's not about us. It's about you. So download the app and you'll get everything you need to know to kickstart your career.

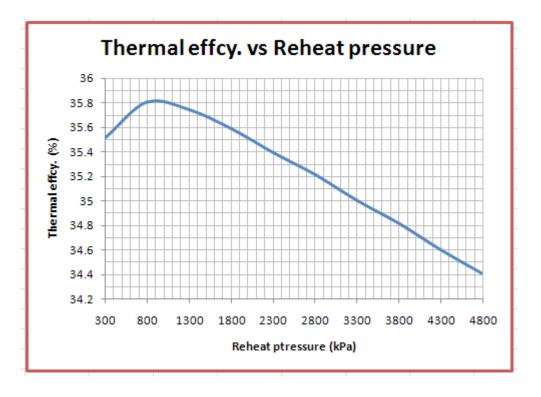
So what are you waiting for?

Click here to get started.



#### Now, plot the results in EXCEL:





 **Prob.3.4.2** In an ideal reheat, regenerative cycle, the HP turbine receives steam at 20 bar, 300 C. After expansion to 7 bar, the steam is reheated to 300 C and expands in an intermediate pressure turbine to 1 bar. A fraction of steam is now extracted for feed water heating in an open type feed water heater. The remaining steam expands in a low pressure turbine to a final pressure of 0.05 bar. [VTU]

#### Determine:

a) Cycle thermal effcy. (b) SSC in kg/kWh (c) Quality of steam entering the condenser

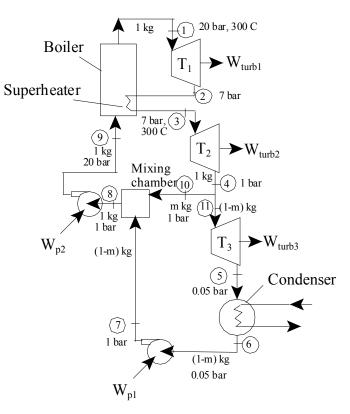


Fig.Prob.3.4.2. Regenerative Rankine cycle with reheat

#### **TEST Solution:**

Steps 1 and 2 are the same as for the previous problem.

Click on 'Vapor (Steam) Power Cycles', and H2O is selected by default for working substance. Fill in the conditions for State 1, i.e. state at entry to compressor: p1= 2000 kPa, T1= 300 C, and mdot1 = 1 kg/s. Press Enter. Immediately, all properties at State 1 are calculated:

Mixed C.SI C.E	inglish [s	Casa-0 M >	₩ Help Me	ssages On	Super-Berc	to Super-Calcula	te 🕺	oad	Super-Initia	dižu
State Panel		Tupyer.	1904		1000	Cope		190.0	7011	
< 65km 1 ~ >	Calculate		lots 😽	Innatur	Su	pemeated Vapor	(B)	0		
/ p1	¥ T1		<b>.</b>			11				
444 0.000	✓ 300.0.	165-C (1		frection.		traction	Y 0.	2547	11/2/10	18
lut.	h1		\$1		1	WEI	1	12		
772.5413 44/10	× 3023.4758	HANG: S	6.76620	MANg.K	× 0.0	1906	~ 0.0	0	m	1
+1	1 11		pint		1	81	1	mdos	H.	
772 5413	<ul> <li>✓ 3023 4758</li> </ul>	UNS Y		k.192	×	ALLAND	1 × 11	1	Agris.	- 1
Voldot1	At		64641							
12647 m'3%	12546.718	1012 3	18:0	Ngiliman (	×					

## ORACLE

## Be BRAVE enough to reach for the sky

Oracle's business is information - how to manage it, use it, share it, protect it. Oracle is the name behind most of today's most innovative and successful organisations.

Oracle continuously offers international opportunities to top-level graduates, mainly in our Sales, Consulting and Support teams.

If you want to join a company that will invest in your future, Oracle is the company for you to drive your career!

# Oprove and the second s

## https://campus.oracle.com



#### **ORACLE IS THE INFORMATION COMPANY**



305

Download free eBooks at bookboon.com

4. For State 2: Enter p2 = 700 kPa, s2 = s1 (for isentropic process 1-2), and mdot2 = 1 kg/s. Hit Enter. We get:

92 j2 j2 ph2 gp3 🖌 mdot2	@ Mixed C SI C En	glish 💽 🗱	ase-0 M >	Se Help Mes	sages On Si	uper-Iterate	Super-Calculate	I	ad Sup	er-Initiañ	TE.
p2         T2         x2         y2         x2           y0000         x94         176,47418         uep1         x2         y2         x2           y2         176,47418         uep1         x2         rection         x2         rection         x2           y2         h2         x2         x2         x2         x2         x2         x2           y2         h2         x3         x3         x300         x3         x300	State Panel	1	(D190)	PROH.		703CHI 7144	•• [		10.5001		
19%         176 47418         1eg 2         Machine         M	< OState-2 M   >	Calculate	No-	Ploto 💌	Initiatize	Supern	eated vapor	188	5)		
V000         VPA         V         VPA         V<	1 02	72		+2			8		12		
OZ         OZ<	700.0	176 47418	deg C		Inection			0.28	175	m'15%g	1
92	U2	h2		1 82		1	(e)[2	1	22		
502.1048 4.8c × 2705.4077 4.5c × 4 4.5c × 4 5.5c × 5.5c	2592,9848 W/V	× 2788 1077	CNC 2	e est	NIRG/K	× 0.0	mis N	0.0		-m	10
259219948 418g V 2793 1077 115g V 4289 V 3106 V 159	97	. 14		phia.		957		1	mdot2		
	1592 USAU +J#g	2799 1077	Alling .	4	w.244g	8		1.0		123	
	0.28175	- 28174,729	MR : 7	0.81	kpikmol	M					

5. For State 3: It represents the state after reheating. Enter p3 = p2, T3 = 300 C and mdot3 = 1 kg/s. Hit Enter. We get:

Mixed Call Ca	ingitsh	Case-0	Help	Messages On	Super-Iterate	Super Calculate	Load	Super Indulize
Stato Panel		1	Arrest Press		Cost Party		190	Wannin
< ØStatu-3 v >	C	alculato	No-Piots	Industry	Supernea	sted Vapor	1120	~
p3	*	73		£)	13		1 10	
2 494	~ 1000	.000-1		\$reict/off	~ [	traction 🗠	0.37151	m*390
u3		h3	0	3	🖌 Ve	G	1 23	
798:9507 + mg	M: 3059.	0005 1000	7,29740	a filigai	× 00		0.0	
63		18	jie d		(pand)		🖌	at3
798 0507 AJNg	98 <b>305</b> 9	0985 Wike		AUNP	5w)	626g	10	NgYa

6. For State 4: we have: p4 = 100 kPa, s4 = s3, mdot4 = 1 kg/s. Hit Enter. We get:

			¢Case-0 ♥	> I Help Mes	soges on	Super-Itera	te Super-Calcula	re j	Lood	Super-Initial	ize
State	Panel	1	De	Con Tomas	111	1251	Tissel		ING C	000##	
a CState 4	* >	Calcula	te 1	No-Plots 💌	Initialize	Sat	urated Moture	1	120	~	i.
p4		74		14		-	yd		14		
00.0	670	99.61999	100	× 0.98979	mantan.	· 0.99	999 Italita	9 1	87871	m*3/6g	1
04 ·		64		1 754		1	/\/www.		28		
484.734 : 0	2940	2652:4053	40.00	1911	KARBA H.	M 00	1996	Y R	0	m	
4		1.12		init		P			midal4	1.	
484,734	liky .	2652 4053	4,044	¥	A.J/ky		Allay	~ 1	D .	Ages	

7. For State 5: Enter p5 = 5 kPa, s5 = s4, mdot5 = 1- (h8 - h7) / (h4 - h7), and hit Enter. WE get this expression for mdot5 from a heat balance on the mixing chamber. We get:

Mixed CSI CE	ngilan 🤄 🕫 🛛	35e-0 V >	C Help Mess	sages On	Super-Iter	ate S	iper Calculate	L	.oad	Super Initial	ize
State Panel		104-088	1100		1010	in Panat	1		HO FIL	141	
< 05tate-5 😥 >	Galculate	No-Pio	ts 💌	mittalize	5	atorated Mot	VICE:	) Hz	80)	×	1
p5	75		хő			y5			v5		
R. Mar	22.85497	ang-T. 😽	0.86131	traction	× 0.	13385	tradition 🔗	24	34996	er sky	1
45	115		1 35			1/9/5		1	25		
103.9026 XANG	2225.2979	HOME: 1985	1841	KIAQ X	- ei <b>o</b>	0	mia 🤗	0.0	0	m	
- 101	10		· mite			n i film		1	mdot5		
103-9026 4JAg	· 2225 2978	eung 🛩		Adday	~		.A.24g	-1	the informa-	hi igo	

Note that x5 = 0.861. This is the quality of steam entering the condenser .... Ans.

8. For State 6: i.e. exit condenser: Enter p6 = p5, x6 = 0 (for sat. liq.) and mdot6 = mdot5. Hit Enter. We get:

Change Downall				er-Iterate Super-Calcula	te Load	Super-Initialize
State Panel		Cesica Pacel		COSIN PLACE		No Maniel
K OState 6 X >	Calculate	No-Piots 💌	untionzo -	Saturaled Mixture	HEO	×
< p6	76	10		16		6
198 BP8	× 32,85487	sep C 💌 👬	fraction 👻	0.0 fraction	· 0.00101	
6	h6	36		Vet6		26
37.71167 N/Ng/	M. 137,71667	MNg: MS 0.47601	IOABK S	0.0	× 0.0	
-00	10	000		000	🖌 n	mdot6
37,71167 #48g	· 137.71067	1/81 ···	#140 V	AU Rp	< militz	Park.

9. For State 7: i.e. exit of pump-1: Enter p7 = 100 kPa, s7 = s6 (for isentropic comprn. in pump), and mdot7 = mdot5. Hit Enter. We get:

Mixed C BI C	English	< 00	asa-0 🐖	1	✓ Help Messa	iges On	Super	Berate	Super Calcula	le .	Load	Super Initia	dize
State Panel		1	0.0	ice Pip	998		4	Dice Panel			HO F	Saner	
< State 7 . · · · >		Calculate	1	Vo-Plot	s. × .	Instalize		Subcooled	Luquid		0820	~	
pT		17			x7						v7		
1978 - 1978 -	× 32	85079	seg-C	1		fraction	1	E.	trection	1	0.00101	ert200g	
U7		67			× 37			< 94	10		1 21		
\$7.6942 #J/kg:	× 13	2,79474	kalka	. 🖌	=50	end of	1941	0.0	100	×.	0.0	m	
e7	-	IT			.p0(7			J#\$/(7			- mdo	07.	
07.6942 Autog	- 1 M	7.79474	8-19g	M		A.//Rg	m	1	w.J.Mg	1.55	amdore	legan :	
Voldot7		A7			MMT:								
aE_4 m'Se	<b>N</b>	36138	m2		0.000	Rg/kmg/	- 40						

Download free eBooks at bookboon.com

10. For State 8: i.e. exit of mixing chamber and entry to pump-2: Enter p8 = 100 kPa, x8 = 0 (for sat. liq.), and mdot8 = 1 kg/s. Hit Enter. We get:

@ Mixed	CSI CE	nğli	in sec	ase-0 🛁 >	P Help Mes	sages On	Super-Ite	rate Super Ca	iculate	Load	Super Initialize
St	ate Panel		1	(De)	e Cartel	1	Q <sub>2</sub>	NA ERON	1	1	0.P. now[]
< Cistale	8		Calculate	No	Piots 👻	maanze		Saturated Mixture		HOO	
✓ p8			78		1 18			- y8		18	
100.0	898	×.	9961889	849 F	÷ 40	fraction	÷ 0	0- tract	10) (¥	0.00104	m120g
a8 .			h0		58			Steel		1 26	
17,3387	MAR:	125	437,44	NUME :	9 1.3025	KIRGK.	(M)	0 010	1	0.0	
64			1.11		SHARE -			and .		< m	dot8
17 3357	alling:	×	417.44	4.6kg	*	Raidig	1.2	100	1 14	11.0	kgra:
Voido/8			18		7.0.15						
0.00104	1735	-	1043	w/2	18.0	រដ្ឋាលនៅ	1				

11. For State 9: i.e. exit of pump-2 and entry boiler: Enter p8 = 2000 kPa, s9 = s8 (for isentropic comprn. in pump), and mdot9 = 1 kg/s. Hit Enter. We get:

Mixed Cisi CiEr	nglish	< Case-0	5. 5	Help Mess	ages On	Super-Iter	ate Sup	er Calculate	Ľ	bso	Super Initial	izu
State Panel		1	Soloe Fan	el.		00	H SAME			IIG E	uuel	
< Clate-9	Ca	culate	No-Plots	×	Initialize	9	upro la palaonau	10	H2	0	~	U_
<b>г</b> р9		79		πĦ			y9			v9		
xP#	· 99.619	Neph 20	3		fraction		1	frection 😽	0.0	8104	m*14p	1
u9	1	19		1 39		1	Ve9		1	293		
117 3357	419.42	17 00/06	1001	-98	KUKG/K	9	R. S.	1958. M	0.0		m.	- 18
49	1	2		10.0			geli (		1	mdote	1	
17.3357 1.5%g	· 418.42	17 LUNG	1		WJokg	*		#,18g 🛸	1.0		Ages.	2
Voidol9	-tall	17 auks 19		44549	ajtkg			a.18g 🖓	5.0		ips.	
00104	1043	. 012	3		lagikanal	×						

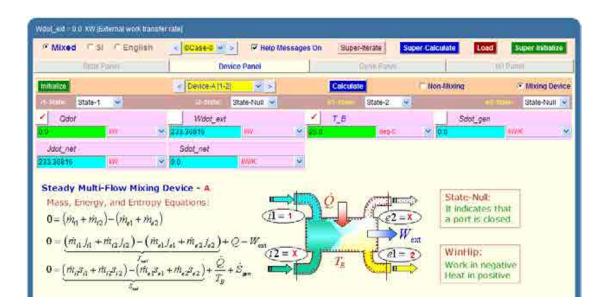
12. For State 10: i.e. exit of Turbine-2 and entry to mixing chamber: Enter p10 = 100 kPa, h10 = h4 and mdot10 = (1 - mdot5) kg/s. (See the schematic diagram of system). Hit Enter. We get:

Mixed Cisi CiEn	giish 🔜 🕫	ese-0 😒 s 📔 🐼 H	elp Messages On	Super-Iterate Super	Calculate	oad Super-Initialize
State Panel	1	Para Paras	1	Orrigh Classer	1	1071000
< OCtate-10 V >	Calculate	No-Picts	Interes	Saturaled Midure	HZ	
× p10	710		x10	y10		×10
100.0	80.01898	0.98 0.98	979 Hection	1991 0.98889	tactos 🛛 🖂 🗖 🗖	7621: mt0/kg 9
u10	< n10		o10	<ul> <li>Valno</li> </ul>	1	2/0
2484 734 8,000	· Mit	ALAS	746 Aling.6	¥ 0.0		
010	110	A	NIQ:	pertil	1	mdot10
2484 734 1489	· 2652 4053	NUNE M.	76.58g		unita 🕑 🔫	mitility (Chitam)
Valdat10	A10	L.	BATO .			
0.18646 mtbte.	× 18646.430	m12 × 18.0	Rightrol	-		

1.07971 with anot will be a set and a set and a set and a set a se	Mixed Cisi CE	ngili	sh < 🕫	ase-U 💌	2	P Help Mess	ages On	Super-	iterate	Super-Calculate	1	oad S	uper-Initiali	26
✓ p11         T11         x11         y11         v11           sp4         she         y yuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuuu	State Panel			1.Pr	hice The	1944	1	10	2266 214004			10.Ean	61.	
ipit         <	< State-11 >		Calculate		No Plo	ta 😿	Indialized		Gaturated M	xture	)H2	0	×	m I
ipit         <		1	Ttt			att			.y11			vff		
2484-754 sing w ena sing w 7/29746 sing x 00 ms w 00 ms w 00 ms s eff		×		ang-c	×	0.98979			0.36350	trentino	1.0		määg	đ
eff //f parti // mdotff	UTT .		× 1111			611			× 1 14431		1	270		
	2484.7.24 NJX8	[M]	=hA	(100g)	1×	7.29746	anag K	391	0.0	mie i Xe	6.0		6	1
	114		/rt			ODITE			DOIT		1	mdot11		
	484 T34 Allip	*	2652 4053	kallig :	×	-	warmy.		-	ALING M	m	0015	ispre	
	1.49025 million	×	149025-02	1022	1.63	18.0	ky/hmut	SET						

13. State 11: i.e. entry to turbine-3. Enter p11 = p4, h11 = h4 and mdot11 = mdot5. Hit Enter:

14. Now, go to Device panel. For device A, enter State 1 and State 2 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And Qdot = 0 since in this process there is no external heat transfer. Hit Enter. We get:



Note that work of Turbine-1 is 233.368 kW.

15. Similarly for Device B: enter State 2 and State 3 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And, Wdot\_ext = 0 since for this process no external work transfer occurs. Hit Enter. We get:

Mixed CSI CEnglish	< ©Case-0 ¥ >	P Help Messages On	Super-Iterate	Super-Calculate	Load Super R	vlialize
Elale Facel	Device Pa	nel	Code Rather		KO Razel	
milialize	Cevice-B (2-3)	× ×	Calculate	Won Mixing	· Mixin	ng Devic
State-2	O.Shiilii State-	fault 🖌	State-3	¥.	State	-Nuli 🍝
Qdot	✓ Wdot_ext	1	7_0	Sde	ot_gen	
708-90086 Wr 🖓	0.0	( 🔿 🖂	0697	· · · · · · · · · · · · · · · · · · ·	enm.	3
Jdot_ool	Sdot_not					
268 00088	0.5312 89	× ×				

#### Note that Qdot for process 2-3 is amount of reheat = 268.9 kW (Ans.)

16. And, for Device C: enter State 3 and State 4 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And, Qdot = 0 since for this process no external heat transfer occurs. Hit Enter. We get:

@ Mixed C SI C English	< Case-0	P Help Messa	iges On	Super-Iterate	Super-C	aiculate	Load	Super-Initial	ize
State Earnel	Devic	e Panel	10	Carrier	Summer I	1	1003	Bi#4441 [	
tribalize	< Device-C (3-4)	N >		Calculate	-	Non-Mixing		• Mixing D	evice
State-3	0-500- (S	itate-Null 👻		State	-d 👻		-	State-Nu	11 -4
<ul> <li>Qdot</li> </ul>	Widot_ext		1	TB		Sd	ot gen		
00 OV O	406.80327	AWV .	26.0	1	1975 I	0.0		WV/K	X
Jdot net	Sdot net								
ACION NIME	- ATTACAL STREET								

#### Note that work output of Turbine-2 is: Wdot\_ext = 406.6 kW.

17. And, for Device D: enter State 11 and State 5 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And, Qdot = 0 since for this process no external heat transfer occurs. Hit Enter. We get:

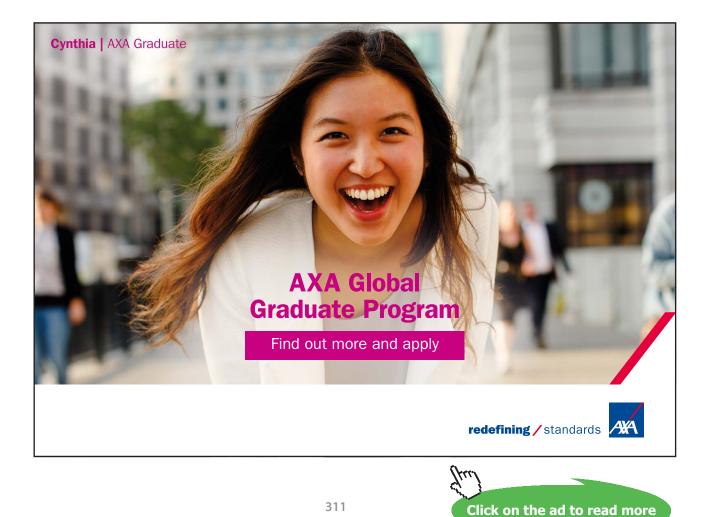
Mixed C SI C English	Case 0 W S	IV Help Mossages On	Super-Iterate	Super-Calculate	Load Super-Initialize
State Provel	Devico Pr	truct (	(Ophin Fanis)	1	150 ffam) (
misalize	< Deace-0111-5	M N	Calculate	Tion Mixing	Mixing Device
n Shire State-11 👻	0.Smm State	-taun 🐱	State-5	<b>2</b>	State-Null State-Null State-
Qdot	Wdor_ext	×	T_B	Sdot	C gen
an	370,5005	Y 🗶 🕅	seg-C	× 0.0	855/97
Jdot_net	Sdot_net				
379.6096 WW	0.0. IW	18 Tech			

#### Note that process 11-5 is expansion in turbine-3; Work = Wdot\_ext = 379.61 kW.

18. Now, for Device E: enter State 5 and State 6 for i1-state and e1-state respectively. Also, select Null state for i2-state and e2-state. And, Wdot\_ext = 0 since for this process (in the condenser) no external work transfer occurs. Hit Enter. We get:

Mixed CBI C English	Canif d 🗹 5 🕅 Help	Messages On	Super-Iberate	Super-Calculate	Load Super-Initialize
ADDREST MORE	Device Ponel	1	12508 (1968		112779/041
nipalize	< Device-E (5-6) x >	-	Calculate	Non-Mixing	Mixing Devic
icon State-6 💌	NCTION State-Null 💌	i	distri State-6	<b>v</b>	State-Null
Qdot	✓ Wdot_ext	1	1_8	Sd	al_gan
1855-425 W ~	4W	₩ 25.0	deg C	✓ 0.16028.	1006

Note that heat removed in condenser is 1855.425 kW (Ans.)



19. And, for Device F: enter State 6 and State 7 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And, Qdot = 0 since for this process (in the pump-1) no external heat transfer occurs. Hit Enter. We get:

• Mixed C SI C English	< dCase-0 😒 >	V Help Mes	sages On	Super-	terste	Super-Calculate	Load	Super-Initialize
State Flane	Devic	e Panel	1	1	HIPETON		IIR	(304)
initialize.	< Devce-F (0-7)			Calculate	1	Non-Mo	pog	··· Mixing Devic
IS Inter-6. 🥑	12 Matter S	itate Null 😒		steam	State-7	×.	94 Bitt	State-Null 💌
Qdot	Wdot_ext		1	T_B			Sdol_gen	
· · · · · · · · · · · · · · · · · · ·	0.09838	<i>KW</i>	Y 200		11-gatt	~ 0.0		KUZOK.

#### Note that required for pump-1 is Wdot\_ext = 0.069 kW.

20. Device G: enter State 8 and State 9 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And, Qdot = 0 since for this process (in the pump-2) no external heat transfer occurs. Hit Enter. We get:

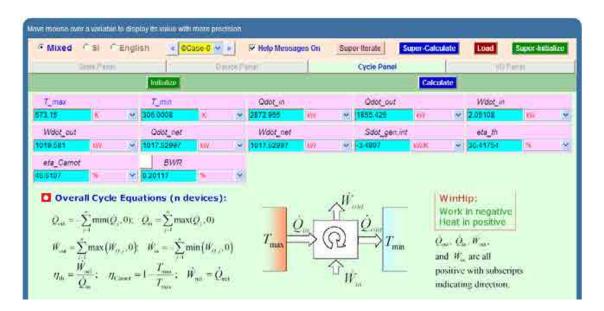
• Mixed OSI CEnglish	Case-0 v	≥ Freip Me	essages On	Super-Ib	erate	Super-Calculate	Load	Super Initializ
Same Parm	De	wice Panel		10	QL(Pas)		10	Tann
Inibailze	< Device-G (8-	91 🛛 🖂 🖂		Calculate	1	Mon-Mixing	R	Mixing De
i EVIII State 8 💌	o atalai	State-Nuti 💌		William (	State-9	<b>v</b> ]		State Null
Qdor	Wdot_set		*	TB		S	idot_gan	
4	-198169	197.	× 250		deg-C	¥ 0.0		1444 K
Jdot net	Sdot_net							
1,98169 (XW)	0.0	NWR	×					

#### Note that required for pump-2 is Wdot\_ext = 1.98 kW.

21. Device H: enter State 9 and State 1 for i1-state and e1-state respectively. Also, since there is only one stream select Null state for i2-state and e2-state. And, Wdot\_ext = 0 since for this process (in the boiler) no external work transfer occurs. Hit Enter. We get:

• Mixed C 51 C English	Case-0 💌 🔄 🖙 Help Me	ssages On	Super-Iterate	Super-Calculate	Load Super-Initialize
These Parent	Device Panel	1	Citik Fatel	1	IO:Famil.
Initiatize	< Device-H(9-1) / >		Calculate	Non Mixing	Mixing Device
State-9	State-Null 👻		State-1	8	State-Null N
Qdot	Wdot_ext	1	T_B	Sa	of gen
1604.0542 WW Y	6.0 WX	1551 25 0	itep;C	× 3.27028	evok (
Jdot_net	Sdot_net				
2604.0542 NW	548378 WWK	1946			

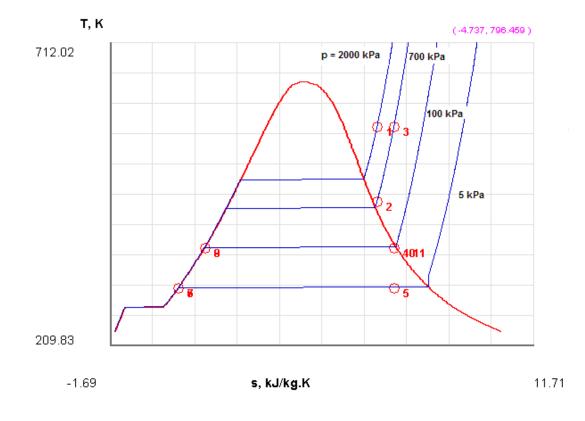
#### Note that heat supplied in boiler = Qdot = 2604.05 kW.



22. Now, go to cycle panel. It gives the major parameters of this cycle:

We observe that Wdot\_net = 1017.53 kW, eta\_th = 35.418% ... Ans.

23. From the Plots widget, choose T-s diagram, and we get:



#### 24. I/O panel gives the TEST code etc:

#~~~~~OUTPUT OF SUPER-CALCULATE

#### # Daemon Path: Systems>Open>SteadyState>Specific>PowerCycle>PC-Model; v-10.cb01

#-----Start of TEST-code -----

States {

State-1: H2O;

Given: { p1= 2000.0 kPa; T1= 300.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; mdot1= 1.0 kg/s; }

State-2: H2O;

Given: { p2= 700.0 kPa; s2= "s1" kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; mdot2= 1.0 kg/s; }

State-3: H2O;



#### Masters in Management

Designed for high-achieving graduates across all disciplines, London Business School's Masters in Management provides specific and tangible foundations for a successful career in business.

This 12-month, full-time programme is a business qualification with impact. In 2010, our MiM employment rate was 95% within 3 months of graduation\*; the majority of graduates choosing to work in consulting or financial services.



As well as a renowned qualification from a world-class business school, you also gain access to the School's network of more than 34,000 global alumni – a community that offers support and opportunities throughout your career.

For more information visit **www.london.edu/mm**, email **mim@london.edu** or give us a call on **+44 (0)20 7000 7573**.

\* Figures taken from London Business School's Masters in Management 2010 employment report



314

Vapour Power Cycles

```
Given: { p3= "p2" kPa; T3= 300.0 deg-C; Vel3= 0.0 m/s; z3= 0.0 m; mdot3= 1.0 kg/s; }
State-4: H2O;
Given: { p4= 100.0 kPa; s4= "s3" kJ/kg.K; Vel4= 0.0 m/s; z4= 0.0 m; mdot4= 1.0 kg/s; }
```

State-5: H2O;

```
Given: { p5= 5.0 kPa; s5= "s4" kJ/kg.K; Vel5= 0.0 m/s; z5= 0.0 m; mdot5= "1-(h8-h7)/(h4-h7)" kg/s; }
```

State-6: H2O;

Given: { p6= "p5" kPa; x6= 0.0 fraction; Vel6= 0.0 m/s; z6= 0.0 m; mdot6= "mdot5" kg/s; }

State-7: H2O;

Given: { p7= 100.0 kPa; s7= "s6" kJ/kg.K; Vel7= 0.0 m/s; z7= 0.0 m; mdot7= "mdot6" kg/s; }

State-8: H2O;

Given: { p8= 100.0 kPa; x8= 0.0 fraction; Vel8= 0.0 m/s; z8= 0.0 m; mdot8= 1.0 kg/s; }

State-9: H2O;

Given: { p9= 2000.0 kPa; s9= "s8" kJ/kg.K; Vel9= 0.0 m/s; z9= 0.0 m; mdot9= 1.0 kg/s; }

State-10: H2O;

Given: { p10= 100.0 kPa; h10= "h4" kJ/kg; Vel10= 0.0 m/s; z10= 0.0 m; mdot10= "(1-mdot5)" kg/s; }

State-11: H2O;

```
Given: { p11= "p4" kPa; h11= "h4" kJ/kg; Vel11= 0.0 m/s; z11= 0.0 m; mdot11= "mdot5" kg/s;
```

}

}

#### Analysis {

Device-A: i-State = State-1; e-State = State-2; Mixing: true;

Given: { Qdot= 0.0 kW; T\_B= 25.0 deg-C; }

Device-B: i-State = State-2; e-State = State-3; Mixing: true;

Given: { Wdot\_ext= 0.0 kW; T\_B= 25.0 deg-C; }

Device-C: i-State = State-3; e-State = State-4; Mixing: true;

Given: { Qdot= 0.0 kW; T\_B= 25.0 deg-C; }

Device-D: i-State = State-11; e-State = State-5; Mixing: true;

Given: { Qdot= 0.0 kW; T\_B= 25.0 deg-C; }

Device-E: i-State = State-5; e-State = State-6; Mixing: true;

Given: { Wdot\_ext= 0.0 kW; T\_B= 25.0 deg-C; }

Device-F: i-State = State-6; e-State = State-7; Mixing: true;

Given: { Qdot= 0.0 kW; T\_B= 25.0 deg-C; }

Device-G: i-State = State-8; e-State = State-9; Mixing: true;

Given: { Qdot= 0.0 kW; T\_B= 25.0 deg-C; }

Device-H: i-State = State-9; e-State = State-1; Mixing: true;

Given: { Wdot\_ext= 0.0 kW; T\_B= 25.0 deg-C; }

}

#-----End of TEST-code -----

#State	p(kPa)	T(K)	Х	v(m3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#01	2000.0	573.2		0.1255	2772.54	3023.48	6.766
#02	700.0	449.6		0.2817	2592.88	2790.11	6.766
#03	700.0	573.2		0.3715	2798.95	3059.01	7.297
#04	100.0	372.8	1.0	1.6767	2484.73	2652.41	7.297
#05	5.0	306.0	0.9	24.3499	2103.9	2225.3	7.297
#06	5.0	306.0	0.0	0.001	137.71	137.72	0.476
#07	100.0	306.0		0.001	137.69	137.79	0.476
#08	100.0	372.8	0.0	0.001	417.34	417.44	1.303
#09	2000.0	372.8		0.001	417.34	419.42	1.303
#10	100.0	372.8	1.0	1.6767	2484.73	2652.41	7.297
#11	100.0	372.8	1.0	1.6767	2484.73	2652.41	7.297

#### #-----Property spreadsheet starts:

#### # Cycle Analysis Results:

- # Calculated: T\_max= 573.15 K; T\_min= 306.0008 K; Qdot\_in= 2872.955 kW;
- # Qdot\_out= 1855.425 kW; Wdot\_in= 2.05108 kW; Wdot\_out= 1019.581 kW;
- # Qdot\_net= 1017.52997 kW; Wdot\_net= 1017.52997 kW; Sdot\_gen,int= -3.4807 kW/K;
- # eta\_th= 35.41754 %; eta\_Carnot= 46.6107 %; BWR= 0.20117 %;

#### 3.5 References:

 Yunus A. Cengel & Michael A. Boles, Thermodynamics, An Engineering Approach, 7<sup>th</sup> Ed. McGraw Hill, 2011.

- 9. Sonntag, Borgnakke & Van Wylen, Fundamentals of Thermodynamics, 6<sup>th</sup> Ed. John Wiley & Sons, 2005.
- 10. *Michel J. Moran & Howard N. Shapiro*, Fundamentals of Engineering Thermodynamics, 4<sup>th</sup> Ed. John Wiley & Sons, 2000.
- 11. P.K. Nag, Engineering Thermodynamics, 2<sup>nd</sup> Ed. Tata McGraw Hill Publishing Co., 1995.
- 12. *R.K. Rajput*, A Text Book of Engineering Thermodynamics, Laxmi Publications, New Delhi, 1998
- 13. Domkunndwar et al, A course in Thermal Engineering, Dhanpat Rai & Co., New Delhi, 2000
- 14. www.thermofluids.net