Applied Thermodynamics: Software Solutions

Part-I (Gas Power cycles)

Dr. M. Thirumaleshwar

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Applied Thermodynamics: Software Solutions Part-I (Gas Power cycles)
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Contents


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and you're ready
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Dedication

This work is lovingly dedicated at the lotus feet of

Bhagavan Sri Sathya Sai Baba

"Education must implant elevating ideals and kindle the lamp of wisdom"

"Character is the most precious gift of education"

"Help Ever, Hurt Never!"

……Bhagavan Sri Sathya Sai Baba

Preface

"Thermodynamics"is an important subject in engineering studies and has applications in almost all fields of engineering. As such, it is included as a 'core subject' in the engineering syllabi of many Universities.

In engineering colleges, generally, the subject of Thermodynamics is taught over two semesters:

a) In the first half, **'Basic Thermodynamics'** is taught. This covers the topics of Units, Pressure, Temperature, Properties of Pure substances, Zeroth Law, Heat and Work, First Law of Thermodynamics for a closed system and for flow processes, Second Law of Thermodynamics, Heat engines, Refrigerators and Heat Pumps, Entropy, Availability and Irreversibility, Real and Ideal gases and Gas mixtures etc.
b) In the second half, **'Applied Thermodynamics'** is dealt with. Here, the topics studied are: Gas power cycles, Gas Turbine cycles, Vapour power cycles, Refrigeration cycles, Air compressors, Thermodynamic relations, Psychrometrics, Reactive Systems and Compressible fluid flow.

Thermodynamics is also considered as an abstract subject by students since many of the concepts introduced are unfamiliar to them. Therefore, the subject is better learnt by solving a large number of problems.

Solutions to problems in Basic Thermodynamics **by this Author** are already published by bookboon.com under the title **"Basic Thermodynamics: Software Solutions", in 5 volumes.**

This book contains solutions to problems in **Applied Thermodynamics**, as per the syllabus of B.E. courses in Visweswaraya Technological University (VTU), Karnataka, India (and other Universities as well).

In this book, problems are solved using three popular software, viz. **"Mathcad"**, **"Engineering Equation Solver (EES)"**and **"The Expert System on Thermodynamics (TEST)"**.

Comments are included generously in the codes so that the logic behind the solutions is clear. A brief overview of the software used is given in Chapter 1 of the book **Basic Thermodynamics: Software Solutions – Part-I**.

Advantages of using computer software to solve problems are many:

1) It helps in solving the problems fast and accurately
2) Parametric analysis (what-if analysis) and graphical visualization is done very easily. This helps in an in-depth analysis of the problem.
3) Once a particular type of problem is solved, it can be used as a *template* and solving similar problems later becomes extremely easy.
4) In addition, one can plot the data, curve fit, write functions for various properties or calculations and re-use them.
5) These possibilities create interest, curiosity and wonder in the minds of students and enthuse them to know more and work more.
6) In Thermodynamics, traditionally, one has to interpolate property values from Tables, and this is a very tedious process while solving problems. Use of suitable software allows one to get accurate property values with minimum effort.

This book is an expanded version of the teaching notes of the author, who has taught this subject over the past many years to Engineering students.

S.I. Units are used throughout this book. Wide variety of worked examples presented in the book should be useful for those appearing for University, AMIE and Engineering Services examinations.

This particular book may be used in conjunction with any of the standard Text Books on Engineering Thermodynamics.

The book is presented in ***five Parts*:**

Part-1 contains the following:

Chapter 1. Gas Power cycles

Part-2 contains problems on following topics:

Chapter 2. Cycles for Gas Turbines and Jet propulsion
Chapter 3. Vapour Power cycles

Part-3 contains problems on following topics:

Chapter 4. Refrigeration cycles
Chapter 5. Air compressors
Chapter 6. Thermodynamic relations

Part-4 contains problems on following topics:

Chapter 7. Psychrometrics
Chapter 8. Reactive systems

Part-5 contains problems on following topics:

Chapter 9. Compressible fluid flow

Acknowledgements: Firstly, I would like to **thank all my students**, who have been an inspiration to me and without whose active involvement, this work would not have been possible.

I am grateful to **Rev. Fr. Valerian D'Souza,** former Director of St. Joseph Engineering College (SJEC), Mangalore, for his love, deep concern and support in all my academic pursuits.

Sincere thanks are due to **Rev. Fr. Joseph Lobo**, Director, SJEC, for his kindness, regard and words of encouragement, and for providing a very congenial and academic atmosphere in the college. **He has, very graciously, given a Message to the book on Basic Thermodynamics to bless my effort.**

I would also like to thank **Dr. Joseph Gonsalves**, Principal, SJEC, for giving me all the facilities and un-stinted support in my academic activities.

Also, I should express my appreciation to **Dr. Thirumaleshwara Bhat**, Head, Dept. of Mechanical Engineering, SJEC, and other colleagues in Department, for their cooperation and encouragement in this venture.

I should mention my special thanks to **Bookboon.com** for publishing this book on the Internet. **Ms. Sophie** and her editorial staff have been most helpful.

Finally, the author would like to express his sincere thanks and appreciation to **his wife, Kala,** who has given continuous support and encouragement, and made many silent sacrifices during the period of writing this book. ***Indeed, without her active help, this book would not have become a reality.***

M. Thirumaleshwar
May 2014

About the Author

Dr. M. Thirumaleshwar graduated in Mechanical Engineering from Karnataka Regional Engineering College, Surathkal, Karnataka, India, in the year 1965. He obtained M.Sc (cryogenis) from University of Southampton, U.K. and Ph.D. (cryogenics) from Indian Institute of Science, Bangalore, India.

He is a Fellow of Institution of Engineers (India), Life Member, Indian Society for Technical Education, and a Foundation Fellow of Indian Cryogenics Council.

He has worked in India and abroad on large projects in the areas involving heat transfer, fluid flow, vacuum system design, cryo-pumping etc.

He worked as Head of Cryogenics Dept. in Bhabha Atomic Research Centre (BARC), Bombay and Centre for Advanced Technology (CAT), Indore, from 1966 to 1992.

He worked as Guest Collaborator with Superconducting Super Collider Laboratory of Universities Research Association, in Dallas, USA from 1990 to 1993.

He also worked at the Institute of Cryogenics, Southampton, U.K. as a Visiting Research Fellow from 1993 to 1994.

He was Head of the Dept. of Mechanical Engineering, Fr. Conceicao Rodrigues Institute of Technology, Vashi, Navi Mumbai, India for eight years.

He also worked as Head of Dept. of Mechanical Engineering and Civil Engineering, and then as Principal, Vivekananda College of Engineering and Technology, Puttur (D.K.), India.

He was Professor and coordinator of Post-graduate program in the Dept. of Mechanical Engineering in St. Joseph Engineering College, Vamanjoor, Mangalore, India.

A book entitled **"Fundamentals of Heat and Mass Transfer"**authored by him and published by M/s Pearson Education, India (2006) **has been adopted as a Text book** for third year engineering students by the Visweswaraya Technological University (V.T.U.), Belgaum, India.

He has authored a set of ***free e-books*** entitled **"Software Solutions to Problems on Heat Transfer"**wherein problems are solved using 4 software viz. Mathcad, EES, FEHT and EXCEL. This book, containing about 2750 pages, is presented in 9 parts and all the 9 parts can be downloaded *for free* from www.bookboon.com

He has also recently authored a set of ***free e-books*** entitled **"Basic Thermodynamics: Software Solutions"**wherein problems are solved using 3 popular software viz. Mathcad, EES, and TEST. This book is presented in 5 parts and all the 5 parts can be downloaded *for free* from www.bookboon.com.

He has also written and published **three book-lets** entitled as follows:

1. Towards Excellence… How to Study (A Guide book to Students)
2. Towards Excellence… How to teach (A guide book to Teachers)
3. Towards Excellence… Seminars, GD's and Personal Interviews (A guide book to Professional and Management students)

Dr. M. Thirumaleshwar has attended several National and International conferences and has more than 50 publications to his credit.

About the Software used

Following three software are used while solving problems in this book:

1. Mathcad 2001 (Ref: www.ptc.com)
2. Engineering Equation Solver (EES) (Ref: www.fchart.com), and
3. The Expert System for Thermodynamics (TEST) (Ref: www.thermofluids.net)

Trial versions of the first two software and detailed Instruction Manuals may be down-loaded from the websites indicated.

TEST is a very versatile and popular Java based software for solving Thermodynamics problems and can be accessed freely on the website indicated. Initially, free registration is required.

Chapter 1 of the free e-book **"Basic Thermodynamics: Software Solutions"**, by this author, published by bookboon.com, gives an introduction to these software as well as some free software available for water/steam properties, humidity calculations and Unit conversions.

To the Student

Dear Student:

Thermodynamics is an important core subject useful in many branches of engineering.

Subject of *Thermodynamics* is generally taught over two semesters: **Basic Thermodynamics** is taught in one semester and **Applied Thermodynamics** is taught in the next semester.

Under the title **'Basic Thermodynamics: Software Solutions'**, you have already studied the topics such as: Units, Pressure, Temperature, Properties of Pure substances, Zeroth Law, Heat and Work, First Law of Thermodynamics for a closed system and for flow processes, Second Law of Thermodynamics, Heat engines, Refrigerators and Heat Pumps, Entropy, Availability and Irreversibility, Real and Ideal gases and Gas mixtures etc.

In this book entitled **'Applied Thermodynamics: Software Solutions'** you will solve problems o application aspects of Thermodynamics, which should be really interesting. Topics included are: Gas power cycles used in I.C. Engines and Turbines, Vapour power cycles used in Power plants, Refrigeration cycles, Air compressors, Thermodynamic relations, Reactive systems (i.e. combustion), Compressible fluid flow etc.

Best way to learn this subject is to work out a large number of problems, particularly of practical applications.

This book contains solutions to problems using three popular software, viz. Mathcad, Engineering Equation Solver (EES), and The Expert System for Thermodynamics (TEST). Trial versions of Mathcad, and EES can be downloaded from the websites indicated. TEST can be accessed directly from the website www.thermofluids.net after an initial, free registration.

Problems in this book are chosen from the University question papers and standard Thermodynamics Text books.

How to use this Book?

You need not worry if you don't know about these software. Since each problem is solved systematically step by step, and is well commented, just reading through the solution will make the logic of the solution clear to you. That is the most important thing in solving the problems. ***Then, you must work out the problem yourself, by hand or using the software***. Of course, use of software has the advantages mentioned in the Preface. *Simply reading the book won't do*. Have your favorite Text book nearby, in case you need to refer to it for any formulas or clarifications. There is no other 'easy method'.

As they say, ***'Success is 1% inspiration plus 99% perspiration!'***

Lastly, I hope that you too will enjoy as much as I did in solving these problems. Good Luck!

Author

1 Gas Power Cycles

Learning objectives:

1. In this chapter, 'Gas Power cycles' are analyzed with 'air standard assumptions'.
2. Cycles analyzed are: (a) Otto cycle (b) Diesel cycle, (c) Dual cycle, and (d) Stirling cycle
3. Otto cycle is used in Spark Ignition (S.I.) engines (i.e. petrol engines) and Diesel cycle and Dual cycle are used in Compression Ignition (C.I.) engines (i.e. Diesel engines)
4. Several Functions are written in Mathcad and EES to determine net work, efficiency and mean effective pressure (MEP) of these cycles.
5. Large number of problems from University question papers and standard Text books are solved with Mathcad, EES and TEST.

1.1 Definitions, Statements and Formulas used [1–6]:

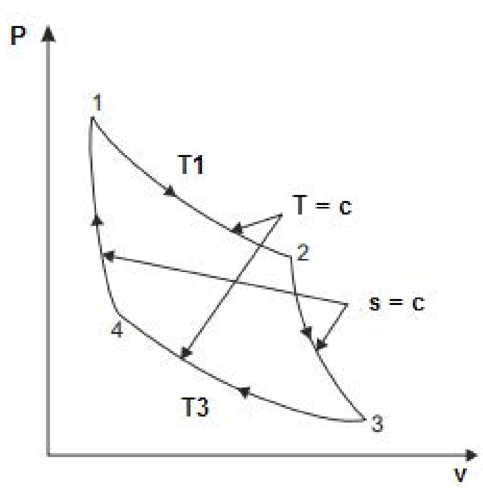
1.1.1 Air standard assumptions:

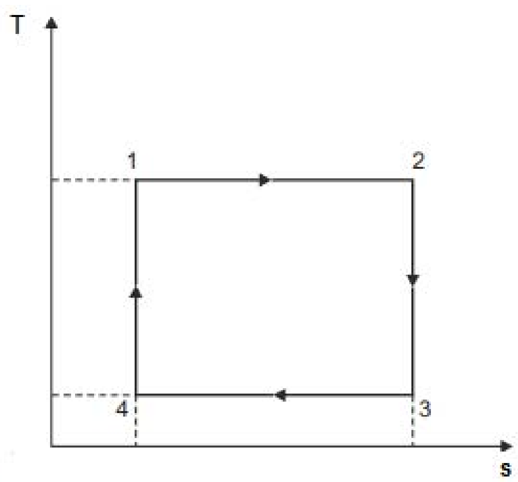
Since the actual Gas power cycles are rather complex, we make following assumptions to simplify the analysis:

1) Working fluid is air circulating continuously in a closed loop, with air behaving as an Ideal gas
2) All processes making up the cycle ate internally reversible
3) The combustion process is replaced by a heat addition process from an external source
4) The exhaust process is replaced by a heat rejection process that restores the working fluid to its initial state

1.1.2 Carnot cycle:

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





For Carnot cycle:

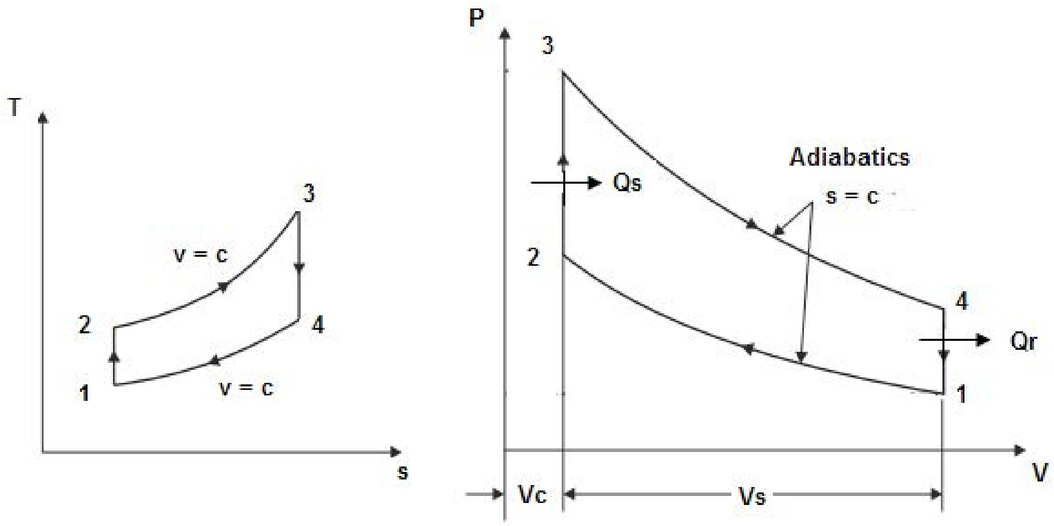
Heat supplied: $Q_s = T1\cdot(s2 - s1) = T1\cdot\Delta s$ J/kg

Heat rejected: $Q_r = T3\cdot(s3 - s4) = T3\cdot\Delta s$ J/kg

Work done: $W = Q_s - Q_r = (T1 - T3)\cdot\Delta s$ J/kg

Thermal efficiency: $\eta_{carnot} = \frac{W}{Q_s} = \frac{T1 - T3}{T1}$

1.1.3 Otto cycle (i.e. const. volume cycle)…. for Petrol engines:



For Otto cycle:

Compression ratio: $r = \frac{v2}{v1}$

$$\frac{T2}{T1} = \left(\frac{v1}{v2}\right)^{\gamma-1} = r^{\gamma-1}$$

Heat supplied: $Q_s = cv\cdot(T3 - T2)$ J/kg

Heat rejected: $Q_r = cv\cdot(T4 - T1)$ J/kg

Work done: $W = Q_s - Q_r$ J/kg

Also: $$W = \frac{p1 \cdot v1}{\gamma - 1} \cdot (rp - 1) \cdot \left(r^{\gamma-1} - 1\right) \quad \text{J/kg}$$

Thermal efficiency: $$\eta_{th} = \frac{W}{Q_s} = \left(1 - \frac{1}{r}\right)^{\gamma-1}$$

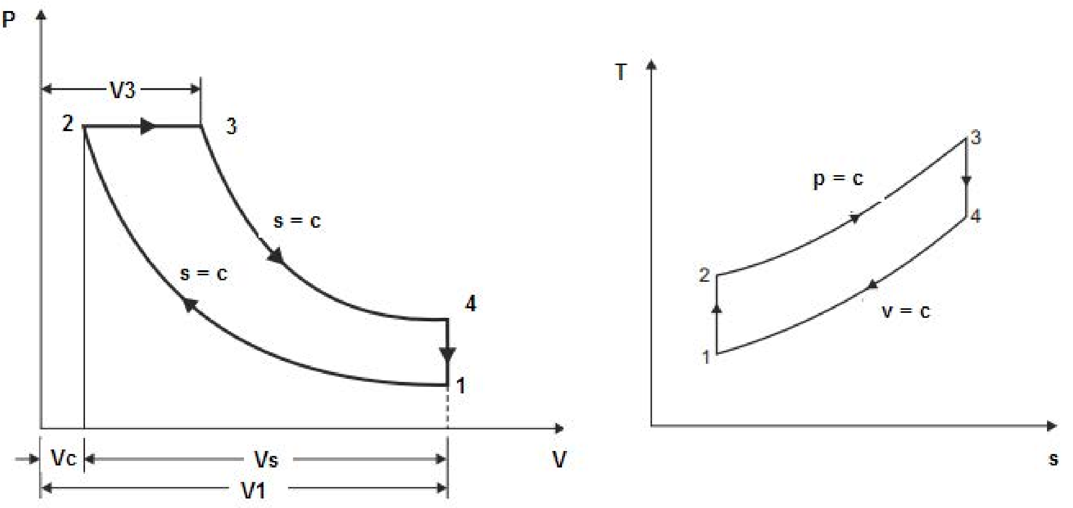
$$\frac{T3}{T4} = \left(\frac{v4}{v3}\right)^{\gamma-1} = \left(\frac{v1}{v2}\right)^{\gamma-1} = r^{\gamma-1}$$

Mean Effective Pressure: $$MEP = \frac{W}{v_s} = \frac{W}{v1 - v2}$$

Also: $$MEP = \frac{p1 \cdot r \cdot (rp - 1) \cdot \left(r^{\gamma-1} - 1\right)}{(\gamma - 1) \cdot (r - 1)} \quad \text{Pa....if p1 is in Pa}$$

where $$rp = \frac{p3}{p2} = \frac{p4}{p1} \quad \text{....pressure ratio}$$

1.1.4 Diesel cycle (i.e. const. pressure cycle)…for Diesel engines:



For Diesel cycle:

Compression ratio: $r = \frac{v1}{v2}$

Cut off ratio: $r_c = \frac{v3}{v2}$

$$\frac{T2}{T1} = \left(\frac{v1}{v2}\right)^{\gamma-1} = r^{\gamma-1}$$

$$\frac{T3}{T4} = \left(\frac{v4}{v3}\right)^{\gamma-1} = \left(\frac{v1}{v3}\right)^{\gamma-1}$$

Heat supplied: $Q_s = cp\cdot(T3 - T2)$ J/kg

Heat rejected: $Q_r = cv\cdot(T4 - T1)$ J/kg

Work done: $W = Q_s - Q_r$ J/kg

Also: $$W = p1\cdot v1\cdot r^{(\gamma-1)}\cdot\left[\frac{\gamma\cdot(rc-1) - r^{1-\gamma}\cdot\left(rc^{\gamma}-1\right)}{\gamma-1}\right] \text{ J/kg}$$

Thermal efficiency: $$\eta_{th} = \frac{W}{Q_s} = \left(1 - \frac{1}{r}\right)^{\gamma-1}$$

Also: $$\eta_{th} = 1 - \frac{1}{r^{\gamma-1}}\cdot\left[\frac{rc^{\gamma}-1}{\gamma\cdot(rc-1)}\right]$$

Mean Effective Pressure: $MEP = \frac{W}{v_s} = \frac{W}{v1 - v2}$

Also: $MEP = p1 \cdot \left[\frac{\gamma \cdot r^{\gamma} \cdot (rc - 1) - r \cdot \left(rc^{\gamma} - 1\right)}{(\gamma - 1) \cdot (r - 1)} \right]$ Pa....if p1 is in Pa

where $rc = \frac{v3}{v2}$ ...cut off ratio

Cut off ratio is normally given as a percentage of stroke volume:

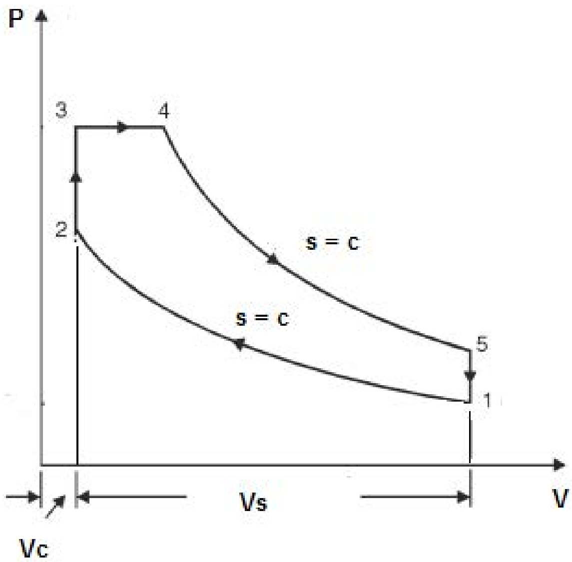
For example, cut off ratio is 8 % of stroke means:

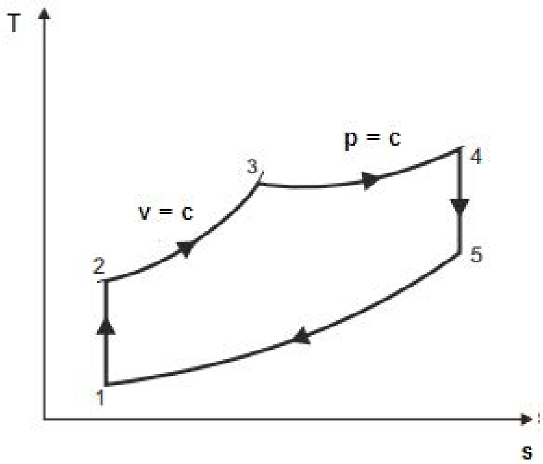
$$\frac{v3 - v2}{v1 - v2} = 0.08$$

But: $\frac{v3 - v2}{v1 - v2} = \frac{v2 \cdot (rc - 1)}{v2 \cdot (r - 1)}$ ...since $r = \frac{v1}{v2}$ and $rc = \frac{v3}{v2}$

Therefore: $\frac{rc - 1}{r - 1} = 0.08$

1.1.5 Dual cycle (or, mixed cycle)…. for Diesel engines:





For Dual cycle:

Compression ratio: $r = \frac{v2}{v1}$

Cut off ratio: $r_c = \frac{v4}{v3}$

Pressure ratio, or explosion ratio: $rp = \frac{p3}{p2}$

$$\frac{T2}{T1} = \left(\frac{v1}{v2}\right)^{\gamma-1} = r^{\gamma-1}$$

$$\frac{T5}{T4} = \left(\frac{v4}{v5}\right)^{\gamma-1}$$

Heat supplied: $Q_s = cv\cdot(T3 - T2) + cp\cdot(T4 - T3)$ J/kg

Heat rejected: $Q_r = cv\cdot(T5 - T1)$ J/kg

Work done: $W = Q_s - Q_r$ J/kg

And: $$W = \left[p3\cdot(v4 - v3) + \frac{(p4\cdot v4 - p5\cdot v5)}{n-1} - \frac{(p2\cdot v2 - p1\cdot v1)}{n-1}\right]$$ J/kg

Also: $$W = \frac{P1\cdot v1\cdot\left[rp\cdot\gamma\cdot(rc - 1)\cdot r^{\gamma-1} + (rp - 1)\cdot r^{\gamma-1} - \left(rp\cdot rc^{\gamma} - 1\right)\right]}{\gamma - 1}$$ J/kg

Thermal efficiency: $$\eta_{th} = \frac{W}{Q_s} = 1 - \frac{(T5 - T1)}{(T3 - T2) + \gamma\cdot(T4 - T3)}$$

Also: $$\eta_{th} = 1 - \frac{1}{r^{\gamma-1}}\cdot\left[\frac{rp\cdot rc^{\gamma} - 1}{(rp - 1) + \gamma\cdot rp\cdot(rc - 1)}\right]$$

Mean Effective Pressure: $$MEP = \frac{W}{v_s} = \frac{W}{v1 - v2}$$

Also:

$$MEP = \frac{p1}{(r-1)\cdot(\gamma-1)}\cdot\left[r^{\gamma}\cdot\left[rp\cdot\gamma\cdot(rc-1)+(rp-1)\right]-r\cdot\left(rp\cdot rc^{\gamma}-1\right)\right]$$ Pa....if p1 is in Pa

where $r = \frac{v1}{v2}$ ...compression ratio

$rc = \frac{v3}{v2}$ ...cut off ratio

$rp = \frac{p3}{p2}$ ..pressure ratio, or explosion ratio

1.1.6 Stirling cycle:

Stirling cycle has two Isothermals and two constant volume processes.

Speciality of Ideal Stirling cycle is that: (i) it has a thermal efficiency equal to that of Ideal Carnot cycle (ii) it makes use of a *'regenerator'* to store heat and to discharge heat during the two constant volume processes.

P-v and T-s diagrams for Ideal Stirling cycle are shown below.

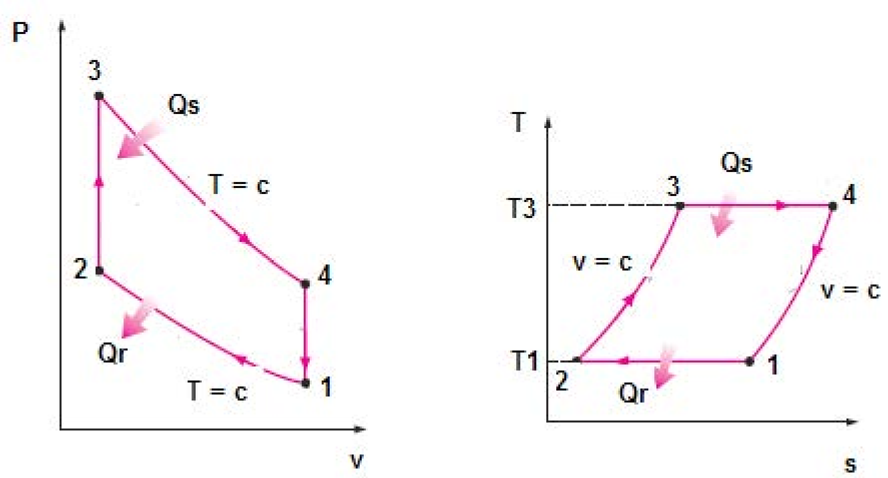
Here, we have:

Process 1-2: Isothermal compression, with heat rejection

Process 2-3: heat absorption by working substance from regenerator during const. vol. process

Process 3-4: Isothermal expansion, with heat absorption

Process 4-1: heat rejection from working substance to regenerator during const. vol. process



In the Ideal Stirling cycle, heat transfers during the two constant volume processes 2-3 and 4-1 are equal.

For Stirling cycle:

Compression ratio: $r = \frac{v1}{v2} = \frac{v4}{v3}$

Heat absorbed by air from regenerator during process 2-3 =
heat rejected by air to regenerator during process 4-1

Regenerator efficiency is assumed to be 100 %.

Heat supplied: $Q_s = p3 \cdot v3 \cdot \ln\left(\frac{v4}{v3}\right) = R \cdot T3 \cdot \ln(r)$ J/kg

Heat rejected: $Q_r = p1 \cdot v1 \cdot \ln\left(\frac{v1}{v2}\right) = R \cdot T1 \cdot \ln(r)$ J/kg

Work done: $W = Q_s - Q_r = R \cdot \ln(r) \cdot (T3 - T1)$ J/kg

Thermal efficiency: $\eta_{th} = \frac{W}{Q_s} = \frac{R \cdot \ln(r) \cdot (T3 - T1)}{R \cdot T3 \cdot \ln(r)}$

i.e. $\eta_{th} = \frac{T3 - T1}{T3}$

Thus, for the same temp limits, efficiency of Stirling cycle is equal to that of Carnot cycle.

(b) When the regenerator efficiency is less than 100 %, say equal to η_{reg}:

Heat supplied: $Q_s = R \cdot T3 \cdot \ln(r) + \left(1 - \eta_{reg}\right) \cdot cv \cdot (T3 - T1)$ J/kg

Heat rejected: $Q_r = R \cdot T1 \cdot \ln(r) + \left(1 - \eta_{reg}\right) \cdot cv \cdot (T3 - T1)$ J/kg

Work done: $W = Q_s - Q_r = R \cdot \ln(r) \cdot (T3 - T1)$ J/kg

Thermal efficiency: $\eta_{th} = \frac{W}{Q_s} = \frac{R \cdot \ln(r) \cdot (T3 - T1)}{R \cdot T3 \cdot \ln(r) + \left(1 - \eta_{reg}\right) \cdot cv \cdot (T3 - T1)}$

Stirling cycle has not become very popular for I.C. engines because the regenerator volume has to be very large compared to the engine size.

However, small liquid nitrogen plants, producing up to 30 l/h of liquid nitrogen, working on reversed Stirling cycle have been produced and marketed very successfully by M/s Philips, Eindhoven.

1.2 Problems on Otto cycle (or, constant volume cycle):

1.2.1 Problems solved with Mathcad:

Prob.1.1. Plot the thermal efficiency of the air standard Otto cycle against the compression ratio.

Mathcad Solution:

Define the Mathcad Functions for Otto Cycle calculations:

r = compression ratio =(Vc+Vs)/Vc   gamma = sp. heat ratio

rp = p3/p2 = p4/p1

$$\mathrm{OTTOEFF}(r,\gamma) := 1 - \frac{1}{r^{\gamma-1}}$$ ...Thermal efficiency

$$\mathrm{OTTOW}(p1, V1, r, rp, \gamma) := \frac{p1\cdot V1}{\gamma - 1}\cdot(rp - 1)\cdot\left(r^{\gamma-1} - 1\right)$$ ...Work output

$$\mathrm{OTTOMEP}(p1, r, rp, \gamma) := \frac{p1\cdot r\cdot(rp - 1)\cdot\left(r^{\gamma-1} - 1\right)}{(\gamma - 1)\cdot(r - 1)}$$ ...Mean effective pressure

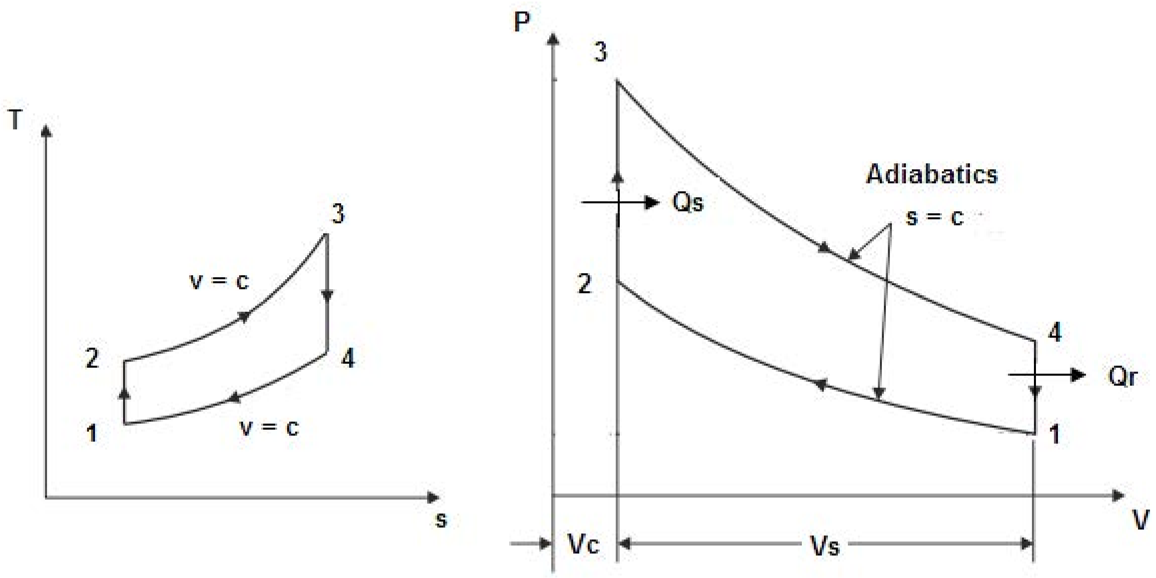


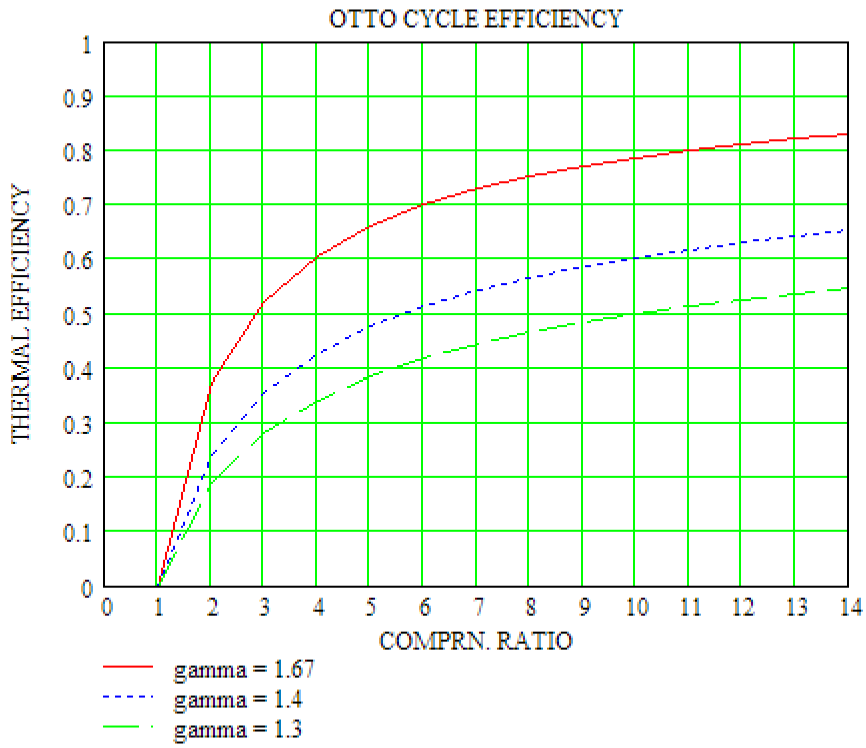
Fig.Prob.1.1

Let us take the range for compression ratio, r as 1 to 14:

r := 1,2.. 14 .... define a range variable for comprn. ratio, from r = 1 to r = 14

r =	OTTOEFF(r,1.67)	OTTOEFF(r,1.4)	OTTOEFF(r,1.3)
1	0	0	0
2	0.371	0.242	0.188
3	0.521	0.356	0.281
4	0.605	0.426	0.34
5	0.66	0.475	0.383
6	0.699	0.512	0.416
7	0.728	0.541	0.442
8	0.752	0.565	0.464
9	0.771	0.585	0.483
10	0.786	0.602	0.499
11	0.799	0.617	0.513
12	0.811	0.63	0.525
13	0.821	0.642	0.537
14	0.829	0.652	0.547

Now, plot the results:



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Prob. 1.2. In an air standard Otto cycle, thermal efficiency is 56%. Heat rejection is 550 kJ/kg. Pressure and Temp at the start of compression are 0.1 MPa and 60 C. Find:

i) compression ratio
ii) P & T at the end of compression
iii) Max. pressure
iv) work done/ kg. [M.U.]

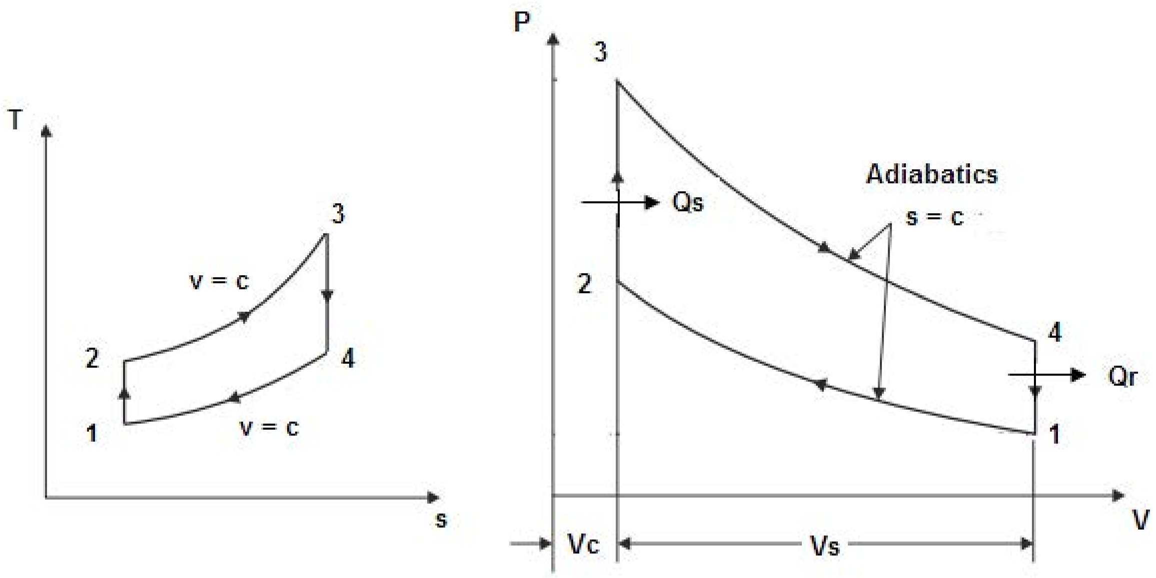


Fig.Prob.1.2

Mathcad Solution:

$\gamma := 1.4$ $P1 := 1$ bar $T1 := 273 + 60$ K

$Q_R := 550$ kJ/kg.... heat rej.

$cv := 0.717$ kJ/kg.K

$r := 5$ Trial value

Given $1 - \frac{1}{r^{\gamma-1}} = 0.56$

$\text{Find}(r) = 7.787$

i.e. $r := 7.787$ **Comprn. ratio....Ans.**

Process 1-2:

$P2 := P1 \cdot r^{\gamma}$ ....for the isentropic compression 1-2

i.e. $P2 = 17.698$ **bar.....Ans.**

And, $T2 := T1 \cdot r^{\gamma-1}$

i.e. $T2 = 756.819$ **K...Ans**

Process 4-1:

We have: $cv \cdot (T4 - T1) = Q_R$

Then: $T4 := \frac{Q_R}{cv} + T1$

i.e. $T4 = 1.1 \times 10^3$ K

Process 4-1:

We have: $cv \cdot (T4 - T1) = Q_R$

Then: $T4 := \frac{Q_R}{cv} + T1$

i.e. $T4 = 1.1 \times 10^3$ K

And,

$T3 := T4 \cdot r^{\gamma-1}$

i.e. $T3 = 2.5 \times 10^{3}$ K

Then:

$\frac{P2}{T2} = \frac{P3}{T3}$ ... for the constant vol. process 2-3

i.e. $P3 := \left(\frac{P2}{T2}\right) \cdot T3$ ...where temps atre in Kelvin

i.e. $P3 = 58.466$ **bar... Max. pressure in the cycle....Ans.**

Now:

$Q_S := cv \cdot (T3 - T2)$

i.e. $Q_S = 1.25 \times 10^{3}$ kJ/kg.... heat supplied

And,

$W := Q_S - Q_R$

i.e. $W = 700.002$ **kJ/kg...Work done per kg ..... Ans.**

==

Prob.1.3. At the beginning of the compression process, in an air standard Otto cycle, p1 = 1 bar, T1 = 300 K. The max. cycle temp is 2000 K. Plot the net work per unit mass in kJ/kg, the thermal efficiency, and the mean effective pressure, in bar, versus the compression ratio ranging from 2 to 14. [Ref: 3]

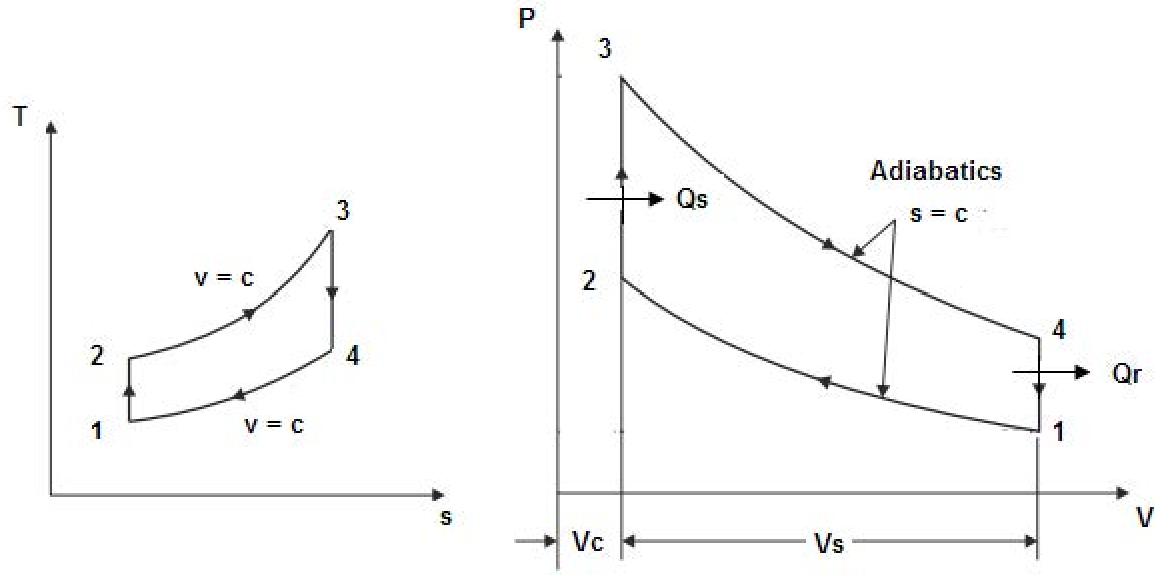


Fig.Prob.1.3

Mathcad Solution:

Data:

$\gamma := 1.4$ $P1 := 1$ bar $T1 := 300$ K $R\_air := 0.287$ kJ/kg.K

$m\_air := 1$ kg

$T3 := 2000$ K.... max. temp.

Let: $r := 2$ ....comprn ratio... to start the calculations.

Calculations:

We have: $\frac{P1 \cdot v1}{R\_air \cdot T1} = m\_air$ ....from Ideal Gas Law

i.e. $v1 := \frac{m\_air \cdot R\_air \cdot T1}{100}$ m^3/kg

i.e. $v1 = 0.861$ m^3/kg

Process 1-2:

$P2(r) := P1 \cdot r^{\gamma}$ ....for the isentropic compression 1-2; P2 as a function of r

i.e. $P2(r) = 2.639$ **bar.....Ans.**

And, $T2(r) := T1 \cdot r^{\gamma-1}$ ...T2 as a function of comprn. ratio, r

i.e. $T2(r) = 395.852$ **K...Ans**

Process 2-3:

$\frac{P2}{T2} = \frac{P3}{T3}$ ... for the constant vol. process 2-3

i.e. $P3(r) := \left(\frac{P2(r)}{T2(r)}\right) \cdot T3$ ...where temps are in Kelvin

i.e. $P3(r) = 13.333$ **bar... Max. pressure in the cycle....Ans.**

Process 3-4:

$$T3 = T4 \cdot r^{\gamma-1}$$

i.e. $T4(r) := \frac{T3}{r^{\gamma-1}}$ K .... T4 as a function of comprn. ratio, r

i.e. $T4(r) = 1.516 \times 10^{3}$ **K .... Ans.**

Also: $\frac{T3}{T4} = \left(\frac{P3}{P4}\right)^{\frac{\gamma-1}{\gamma}}$ ....for isentropic process 3-4

Therefore:

$$P4(r) := \frac{P3(r)}{\left(\frac{T3}{T4(r)}\right)^{\frac{\gamma}{\gamma-1}}}$$ .....P4 as a function of r

i.e. $P4(r) = 5.052$ **bar ... Ans.**

Now that all the four salient temperatures, viz. T1, T2, T3 and T4 are known, the work output, thermal efficiency and the mean effective pressure are easily calculated as follows:

$Q_S = m\_air \cdot cv \cdot (T3 - T2)$ kJ...heat supplied in process 2-3. cv = sp. heat at const. vol. for air = 0.717 kJ/kg.K

$Q_R = m\_air \cdot cv \cdot (T4 - T1)$ kJ...heat rejected in process 4-1.

$W = Q_S - Q_R$ kJ...Work output

$$V_s = Stroke\_volume = V1 - V2 = V1 \cdot \left(1 - \frac{1}{r}\right)$$

$mep = \frac{W}{V_s}$ bar...mean effective pressure

However, to find the thermal efficiency, work done and mean effective pressure, let us use the Mathcad Functions written earlier:

Recollect:

$$\text{OTTOEFF}(r,\gamma) := 1 - \frac{1}{r^{\gamma-1}}$$ ...Thermal efficiency

$$\text{OTTOW}(p1,V1,r,rp,\gamma) := \frac{p1\cdot V1}{\gamma-1}\cdot(rp-1)\cdot\left(r^{\gamma-1}-1\right)$$ ...Work output

$$\text{OTTOMEP}(p1,r,rp,\gamma) := \frac{p1\cdot r\cdot(rp-1)\cdot\left(r^{\gamma-1}-1\right)}{(\gamma-1)\cdot(r-1)}$$ ...Mean effective pressure

We re-write these functions for the present case:

Thermal effcy:

$\eta_{th}(r) := \text{OTTOEFF}(r,\gamma)$ **....Note that η_{th} is written as a function of r.**

i.e. $\eta_{th}(r) = 0.242$ **...thermal effcy when comprn ratio, r = 2 .... Ans.**

Work done per kg of air, W:

Now, pressure ratio = rp = P3/P2:

$rp(r) := \frac{P3(r)}{P2(r)}$ **....Note that rp is written as a function of r.**

i.e. $rp(r) = 5.052$

$W(r) := \text{OTTOW}(P1\cdot 100, v1, r, rp(r), \gamma)$

ie. $W(r) = 278.699$ **kJ/kg .Work output for r = 2... Ans.**

Mean Effective Pressure, MEP:

$mep(r) := \text{OTTOMEP}(P1, r, rp(r), \gamma)$ **....Note that mep is written as a function of r.**

ie. $mep(r) = 6.474$ **bar.......mean effective pressure, for r = 2 ... Ans.**

Now, plot the results for r varying from 2 to 14:

First define a range variable, r from r = 2 to 14:

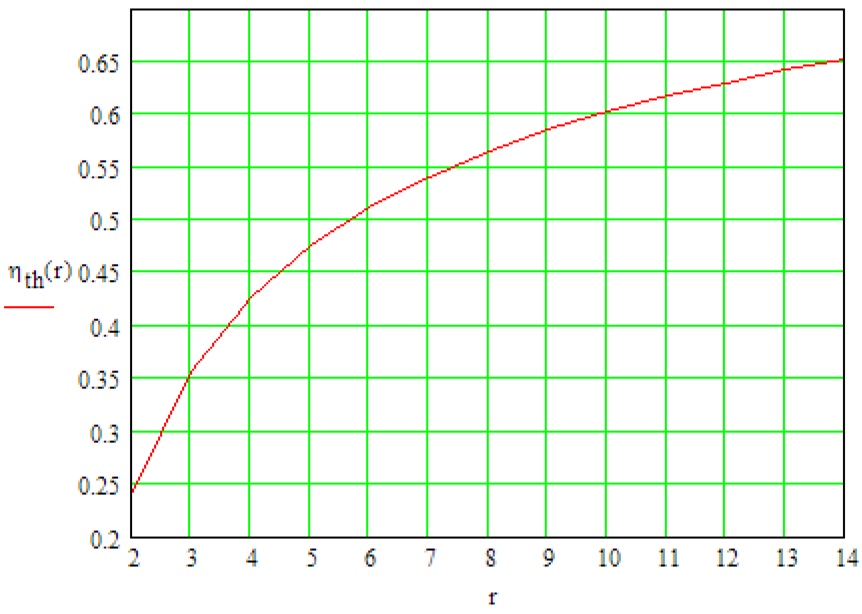
$r := 2, 3 .. 14$ ....range variable defined.

Produce the results in Tabular form:

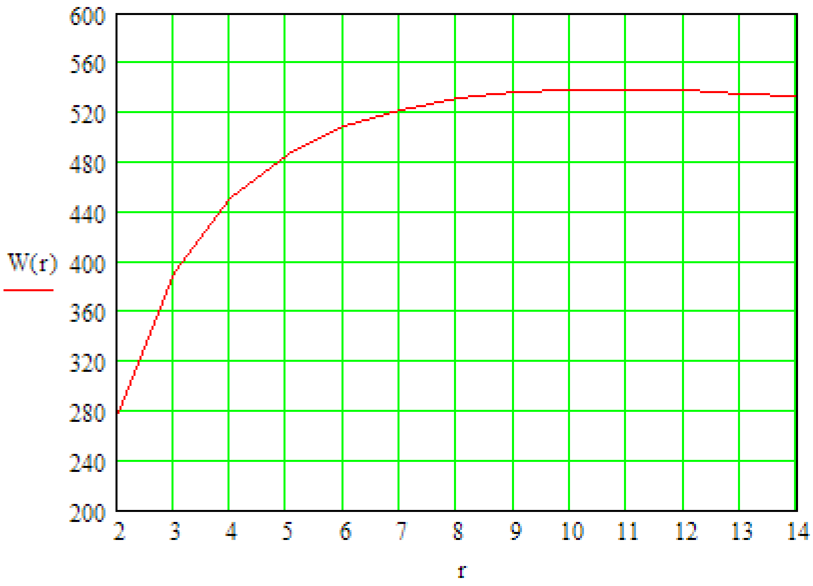
r =	$\eta_{th}(r)$ =	W(r) =	mep(r) =
2	0.242	278.699	6.474
3	0.356	391.51	6.821
4	0.426	451.287	6.989
5	0.475	486.675	7.066
6	0.512	508.693	7.09
7	0.541	522.566	7.081
8	0.565	531.115	7.05
9	0.585	536.005	7.004
10	0.602	538.283	6.946
11	0.617	538.641	6.882
12	0.63	537.558	6.811
13	0.642	535.371	6.736
14	0.652	532.327	6.658

Now, plot the results:

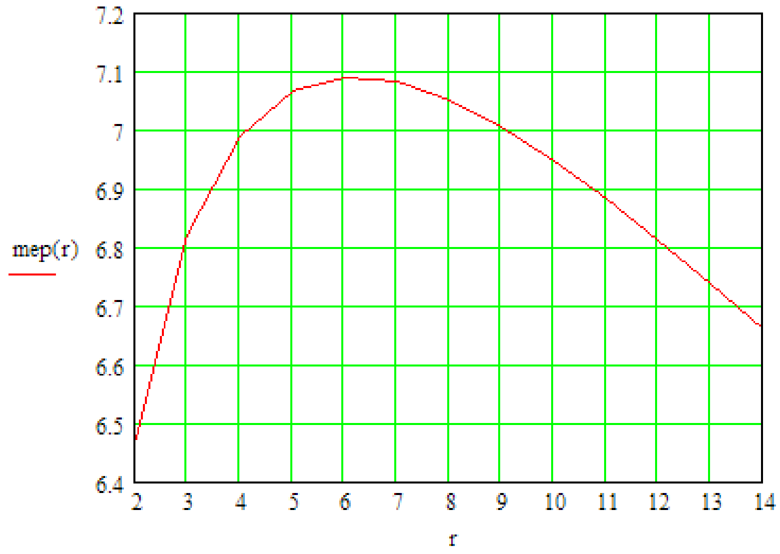
Thermal efficiency versus comprn. ratio, r:



Work output (kJ/kg) versus comprn. ratio, r:



Mean effective pressure (bar) versus comprn. ratio, r:



==

Prob.1.4. An engine working on Otto cycle has its volume 0.5 m^3, pressure = 1bar and temp = 30 C at the beginning of compression stroke. At the end of compression stroke, the pressure is 13.8 bar. If the heat added during const. vol. process is 210 kJ, calculate:

i) the pressures, temp and vol. at salient points
ii) net work done per cycle
iii) m.e.p.

Take cv = 0.714 kJ/kg.K [M.U.]

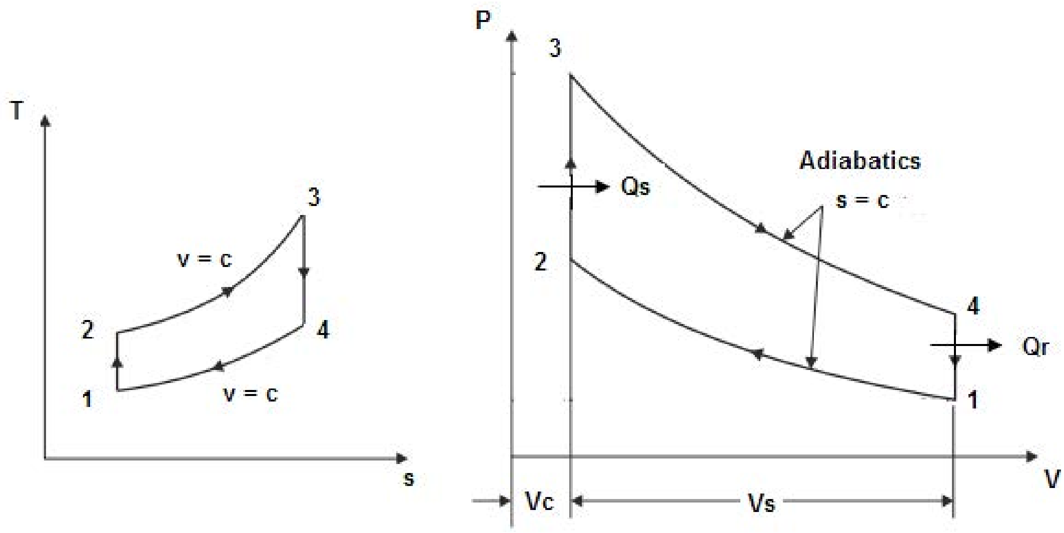


Fig.Prob.1.4

Mathcad Solution:

Data:

$V1 := 0.5$ m^3 $T1 := 30 + 273$ K $P1 := 1$ bar $P2 := 13.8$ bar

$Q_S := 210$ kJ $cv := 0.714$ kJ/kg.K $\gamma := 1.4$

$R := 287$ J/kg.K

Calculations:

Mass of air:

$$m := \frac{P1 \cdot 10^5 \cdot V1}{R \cdot T1}$$ i.e. $m = 0.575$ kg/cycle

Process 1-2:

$$r := \left(\frac{P2}{P1}\right)^{\frac{1}{\gamma}}$$ ...for isentropic process 1-2

i.e. $r = 6.519$ **...comprn. ratio**

Therefore:

$$T2 := r^{\gamma - 1} \cdot T1$$

i.e. $T2 = 641.39$ **K...Ans**

Process 2-3:

We have: $Q_S = m \cdot cv \cdot (T3 - T2)$

Therefore:

$$T3 := \frac{Q_S}{m \cdot cv} + T2$$

i.e. $T3 = 1.153 \times 10^3$ **K...Ans.**

And, $P3 := P2 \cdot \frac{T3}{T2}$

i.e. $P3 = 24.806$ **bar..Ans**

Process 3-4:

$P4 := \frac{P3}{r^{\gamma}}$ ...for isentropic process 3-4

i.e. $P4 = 1.798$ **bar..Ans**

And,

$T4 := \frac{T3}{r^{\gamma-1}}$ ...for isentropic process 3-4

i.e. $T4 = 544.655$ **K...Ans.**

Heat rejected:

$Q_R := m \cdot cv \cdot (T4 - T1)$ i.e. $Q_R = 99.206$ kJ/cycle

Work output:

$W := Q_S - Q_R$

i.e. $W = 110.794$ kJ/cycle...Ans.

Mean eff. pressure:

$$mep := \frac{W \cdot 10^3}{V1 \cdot \left(1 - \frac{1}{r}\right)}$$

i.e. $mep = 2.617 \times 10^5$ Pa...=2.617 bar....Ans.

==

Prob.1.5. An engine operates on air standard Otto cycle. At the start of compression, P1=1bar, T1=27 C. Max temp. in the cycle is 3250 K. Compression ratio is 8 to 1. Determine the pressures and temps. at salient points, thermal efficiency, and the mep. [M.U.]

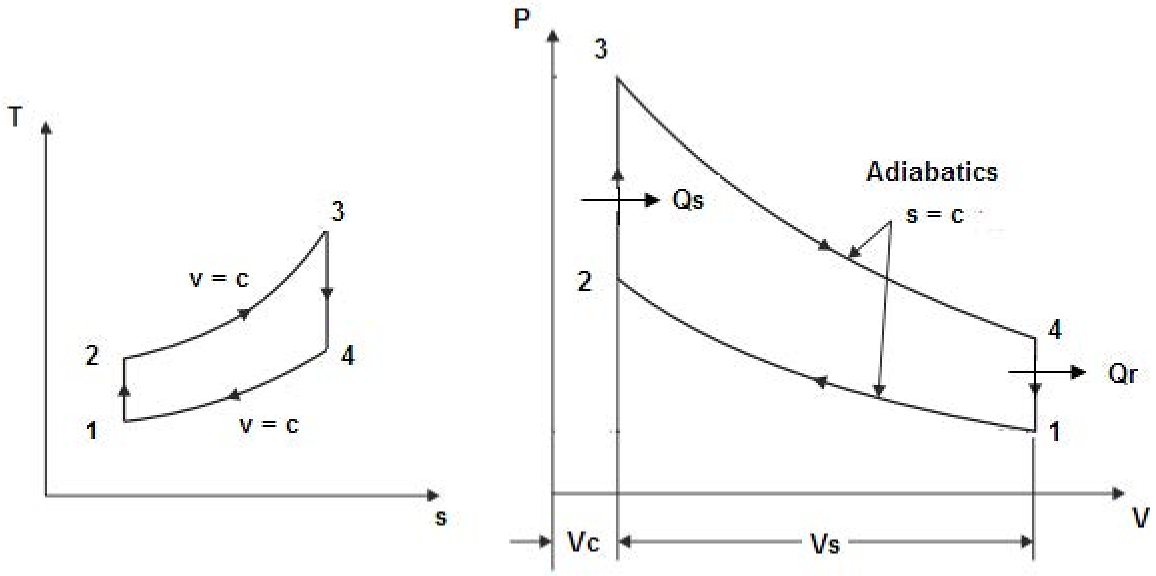


Fig.Prob.1.5

Mathcad Solution:

Data:

$\gamma := 1.4$ $R := 0.287$ kJ/kg.K $P1 := 1$ bar

$T1 := 273 + 27$ K $T3 := 3250$ K

$cv := \frac{R}{\gamma - 1}$ i.e. $cv = 0.718$ kJ/kg.K

$r := 8$ ....comprn. ratio

Calculations:

Process 1-2:

$P2 := P1 \cdot r^{\gamma}$ i.e. $P2 = 18.379$ **bar.....Ans.**

$T2 := T1 \cdot r^{\gamma - 1}$ i.e. $T2 = 689.219$ **K...Ans**

Process 2-3:

$P3 := P2 \cdot \left(\frac{T3}{T2}\right)$ i.e. $P3 = 86.667$ **bar....Ans.**

Process 3-4:

$P4 := \frac{P3}{r^{\gamma}}$ i.e. $P4 = 4.715$ **bar....Ans.**

$T4 := \frac{T3}{r^{\gamma - 1}}$ i.e. $T4 = 1.415 \times 10^{3}$ **K....Ans.**

Heat supplied:

$Q_S := cv \cdot (T3 - T2)$ i.e. $Q_S = 1.837 \times 10^{3}$ kJ/kg

Heat rejected:

$Q_R := cv \cdot (T4 - T1)$ i.e. $Q_R = 799.758$ kJ/kg

Therefore: Work output:

$W := Q_S - Q_R$ i.e. $W = 1.038 \times 10^{3}$ **kJ/kg.... Ans.**

Thermal efficiency:

$\eta := \frac{W}{Q_S} \cdot 100$ i.e. $\eta = 56.472$ **%, thermal effcy...... Ans.**

Mean Effective Pressure:

$$V1 := \frac{R \cdot 10^3 \cdot T1}{P1 \cdot 10^5}$$ i.e. $V1 = 0.861$ **m^3/kg....volume at state 1**

Therefore:

$$mep := \frac{W \cdot 10^3}{V1 \cdot \left(1 - \frac{1}{r}\right)}$$ ....mean effective pressure

i.e. $mep = 1.377 \times 10^6$ **Pa = 13.77 bar....Ans.**

==

Prob.1.6. Find the efficiency of an Otto cycle engine having max. pressure of 21 bar and temp. 1600 C and min. pressure of 1 bar and temp. 38C. What would be the efficiency of a Carnot engine working between the same max. and min. temp.? Assume working fluid as air. [M.U.]

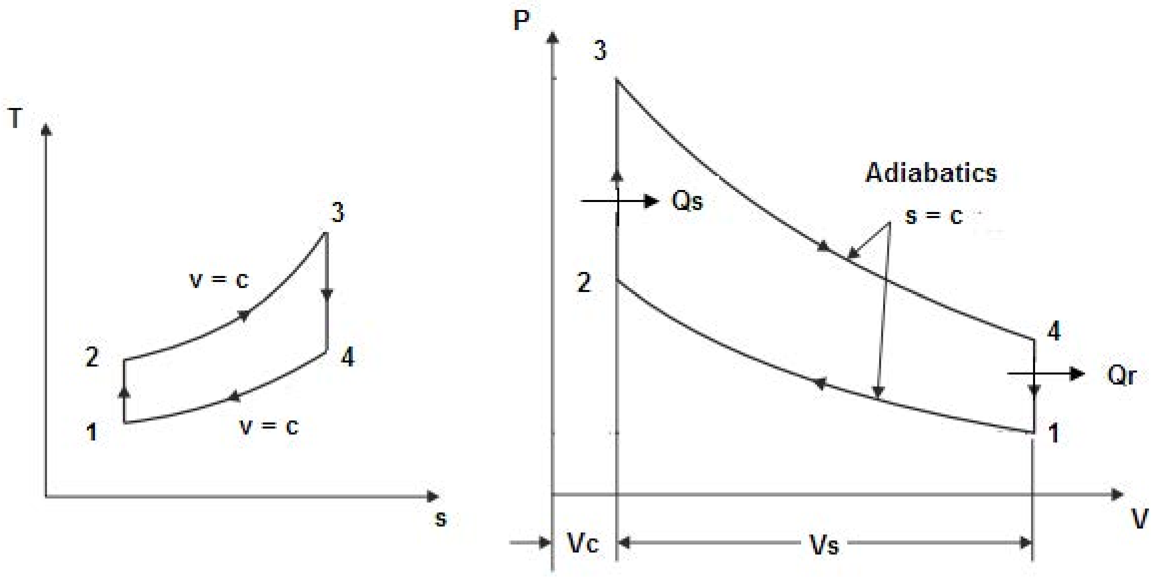


Fig.Prob.1.6

Mathcad Solution:

Data:

$P1 := 1$ bar $\quad T1 := 38 + 273$ i.e. $T1 = 311$ K $\quad cv := 0.717$ kJ/kg.K

$P3 := 21$ bar $\quad T3 := 1600 + 273$ i.e. $T3 = 1.873 \times 10^3$ K

Note that compression ratio, r = v1/v2 = (P2*T1)/(T2*P1) = (P3*T1)/(T3*P1) …. since P2/T2 = P3/T3

Therefore:

$r := \frac{P3 \cdot T1}{T3 \cdot P1}$ i.e. $r = 3.487$ **...comprn. ratio**

Thermal efficiency:

$\eta := 1 - \frac{1}{r^{\gamma-1}}$ i.e. $\eta = 0.393$ **...Air std. effcy. of the Otto cycle....Ans.**

For process 1-2:

$T2 := T1 \cdot r^{\gamma-1}$ ......since 1-2 is isentropic process

i.e. $T2 = 512.551$ K

Heat supplied:

$q1 := cv \cdot (T3 - T2)$ i.e. $q1 = 975.442$ **kJ/kg...heat supplied**

Work output:

$W := \eta \cdot q1$ i.e. $W = 383.574$ **kJ/kg......work done per kg**

Carnot efficiency:

$\eta_{carnot} := \frac{T3 - T1}{T3}$ ...by definition

i.e. $\eta_{carnot} = 0.834$ **...Carnot effcy....Ans.**

==

Prob.1.7. The compression and expansion curves in a petrol engine follow the law PV^1.3 = const. From the indicator diagram it is observed that the pr. at 25% and 75% of the stroke on the comprn. curve are 2 bar and 5.2 bar respectively. If the pressure and temp at the beginning of compression are 1 bar and 300 K, and the max. temp in the cycle is 2000 K, find: (i) the net work done per kg of air, (ii) mean effective pressure, and (iii) thermal efficiency.

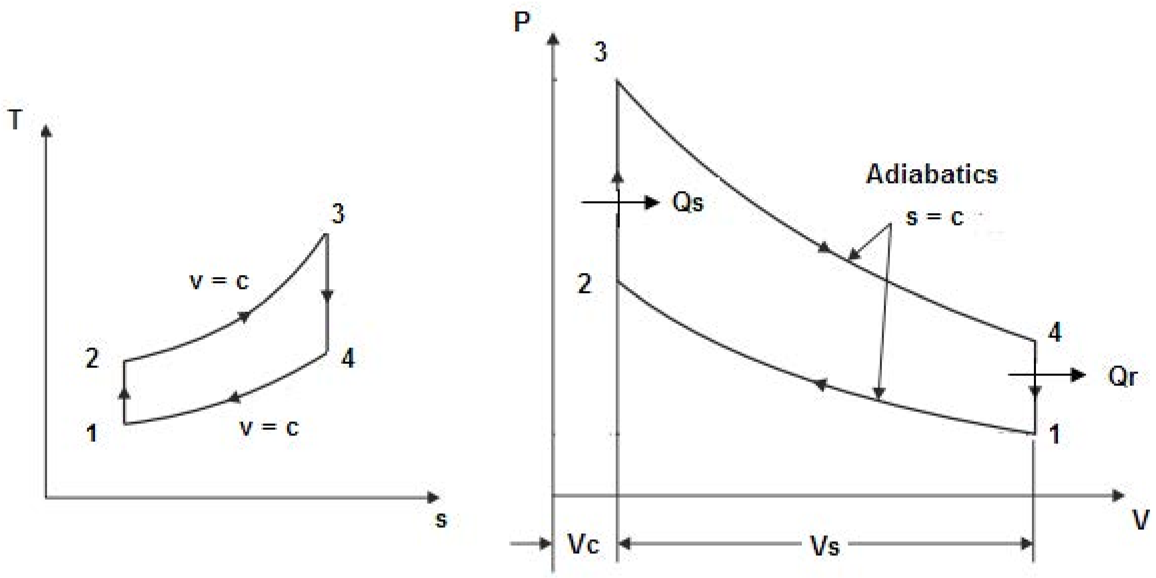


Fig.Prob.1.7

Mathcad Solution:

Data:

$Pa := 2$ bar $\quad Pb := 5.2$ bar $\quad \gamma := 1.4 \quad n := 1.3$ ..polytropic index of compression and expansion

$P1 := 1$ bar $\quad T1 := 300$ K $\quad$ T3:2000 K

$cv := 0.7175$ kJ/kg.K $\quad R := 0.287$ kJ/kg.K

Calculation:

Now, by data:

$$\frac{P_a}{P_b} = \left(\frac{Vc + 0.25 \cdot Vs}{Vc + 0.75 \cdot Vs}\right)^{1.3}$$

From the above, simplify to get Vs/Vc:

i.e. $$\frac{2}{5.2} = \left(\frac{Vc + 0.25 \cdot Vs}{Vc + 0.75 \cdot Vs}\right)^{1.3} = \left(\frac{0.25 \cdot \frac{Vs}{Vc} + 1}{0.75 \cdot \frac{Vs}{Vc} + 1}\right)^{1.3}$$

i.e. $$\left(\frac{2}{5.2}\right)^{\frac{1}{1.3}} = \left(\frac{0.25 \cdot \frac{Vs}{Vc} + 1}{0.75 \cdot \frac{Vs}{Vc} + 1}\right)$$

i.e. $$0.48 = \left(\frac{0.25 \cdot \frac{Vs}{Vc} + 1}{0.75 \cdot \frac{Vs}{Vc} + 1}\right)$$

i.e. $$0.36 \cdot \frac{Vs}{Vc} + 0.48 = 0.25 \cdot \frac{Vs}{Vc} + 1$$

i.e. $$\frac{Vs}{Vc} \cdot (0.36 - 0.25) = 1 - 0.48$$

i.e. $$\frac{Vs}{Vc} \cdot 0.11 = 0.52$$

i.e. $$\frac{Vs}{Vc} = 4.727$$

Therefore:

$$VsbyVc := 4.727$$

And: $r := 1 + VsbyVc$

i.e $r = 5.727$ **...comprn. ratio**

Process 1-2:

$P2 := P1 \cdot r^{n}$ i.e. $P2 = 9.667$ **bar ...Ans.**

$T2 := T1 \cdot r^{n-1}$ i.e. $T2 = 506.407$ **K ... Ans.**

Process 2-3:

T3 is given, T3 = 2000 K.

$P3 := T3 \cdot \frac{P2}{T2}$ ...for const. vol. process 2-3

i.e. $P3 = 35.756$ **bar...Ans.**

Process 3-4:

$P4 := P3 \cdot \left(\frac{1}{r}\right)^{n}$ i.e. $P4 = 3.699$ **bar ... Ans.**

$T4 := T3 \cdot \left(\frac{1}{r}\right)^{n-1}$ i.e. $T4 = 1.11 \times 10^{3}$ **K .... Ans.**

Net work done:

Note: Net work can not be calculated as (Qs-Qr), since there is heat transfer during the two polytropic processes too.

We calculate the net work as the area of the P-v diagram 1-2-3-4:

W_net = (P3.v3 – P4.v4) / (n-1) – (P2.v2- P1.v1) / (n-1)

i.e. $W_{net} := \frac{R \cdot (T3 - T4)}{n - 1} - \frac{R \cdot (T2 - T1)}{n - 1}$ kJ/kg

i.e. $W_{net} = 532.874$ **kJ/kg....Ans.**

Heat supplied, Qs, during process 2-3:

$Q_s := cp \cdot (T3 - T2)$ kJ/kg

i.e. $Q_s = 1.366 \times 10^{3}$ kJ/kg

Thermal efficiency:

$\eta_{th} := \frac{W_{net}}{Q_s}$

i.e $\eta_{th} = 0.39$ **= 39 %...Air standard effcy...Ans.**

Mean effective pressure:

Now, we have: MEP = W_{net} / Stroke volume

i.e. MEP = W_{net} / (v1 - v2)

i.e. $MEP = \frac{W_{net}}{v1 \cdot \left(1 - \frac{1}{r}\right)}$ ....where r = comprn. ratio

For 1 kg of air, v1 is calculated as:

$$\frac{P1 \cdot v1}{R \cdot T1} = 1 \quad \text{...where P1 is in kPa, R in kJ/kg.K}$$

i.e. $$v1 := \frac{R \cdot T1}{P1 \cdot 100}$$

i.e. $v1 = 0.861$ m^3

Therefore:

$$MEP := \frac{W_{net}}{v1 \cdot \left(1 - \frac{1}{r}\right)}$$

i.e. $MEP = 749.83$ kPa = 7.4983 bar .... Ans.

In addition, plot W_{net}, Heat supplied, Q_s and MEP as max. temp. T3 varies from 1500 K to 2300 K:

First, write the related quantities as functions of T3:

$$P3(T3) := T3 \cdot \frac{P2}{T2}$$ bar...for const. vol. process 2-3

$$W_{net}(T3) := \frac{R \cdot (T3 - T4(T3))}{n - 1} - \frac{R \cdot (T2 - T1)}{n - 1}$$ kJ/kg

$$P4(T3) := P3(T3) \cdot \left(\frac{1}{r}\right)^{n}$$ bar

$$T4(T3) := T3 \cdot \left(\frac{1}{r}\right)^{n-1}$$ K

$$W_{net}(T3) := \frac{R \cdot (T3 - T4(T3))}{n - 1} - \frac{R \cdot (T2 - T1)}{n - 1}$$ kJ/kg

$$Q_s(T3) := cp \cdot (T3 - T2)$$ kJ/kg

$$\eta_{th}(T3) := \frac{W_{net}(T3)}{Q_s(T3)}$$

$$MEP(T3) := \frac{W_{net}(T3)}{v1 \cdot \left(1 - \frac{1}{r}\right)}$$

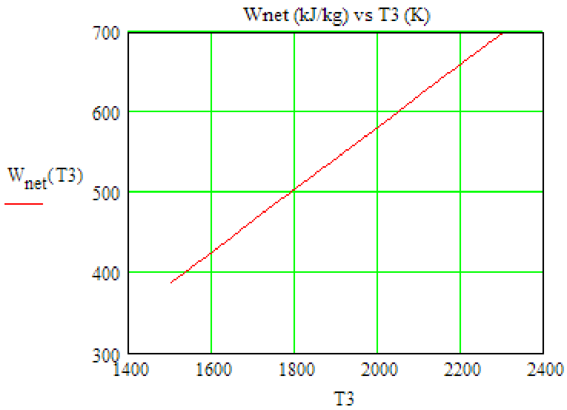
Now, plot the results:

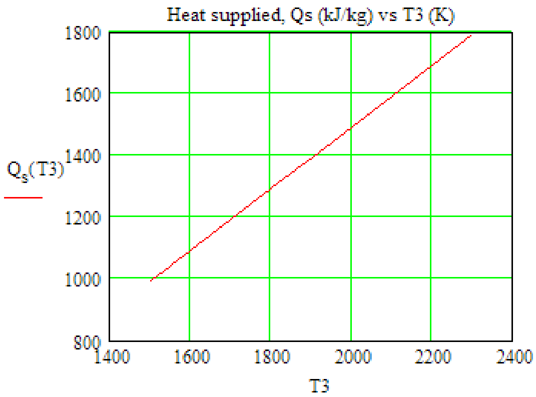
T3 := 1500, 1550.. 2300 K .... define a range variable T3

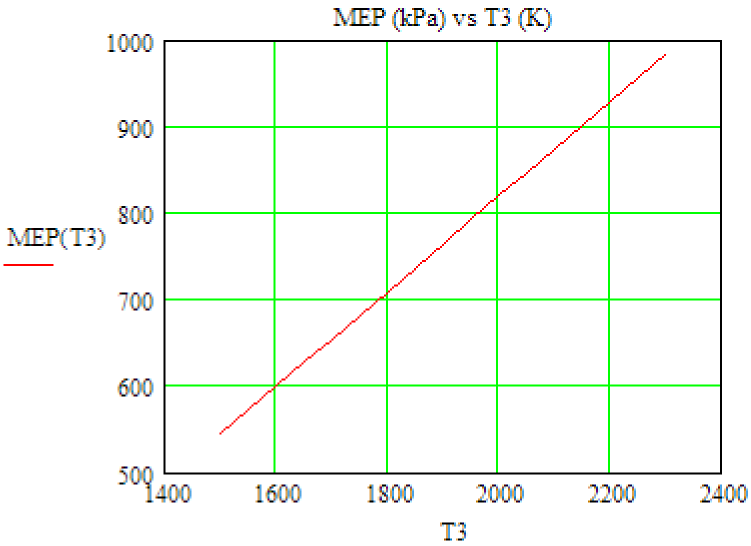
T3 =	$W_{net}(T3)$ =	$\eta_{th}(T3)$ =	MEP(T3) =	$Q_s(T3)$ =
1500	387.43	0.39	545.17	993.196
1550	406.927	0.39	572.604	1043.176
1600	426.423	0.39	600.039	1093.156
1650	445.92	0.39	627.473	1143.136
1700	465.416	0.39	654.907	1193.116
1750	484.912	0.39	682.341	1243.096
1800	504.409	0.39	709.776	1293.076
1850	523.905	0.39	737.21	1343.056
1900	543.402	0.39	764.644	1393.036
1950	562.898	0.39	792.079	1443.016
2000	582.395	0.39	819.513	1492.996
2050	601.891	0.39	846.947	1542.976
2100	621.387	0.39	874.381	1592.956
2150	640.884	0.39	901.816	1642.936
2200	660.38	0.39	929.25	1692.916
2250	679.877	0.39	956.684	1742.896

It is noted that Thermal effcy. does not vary with T3.

Plots:






MEP (kPa) vs T3 (K)
1000
900
800
700
600
500
MEP(T3)
1400
1600
1800
2000
2200
2400
T3

==

1.2.2 Problems solved with EES:

Prob.1.8. Plot the thermal efficiency (η_{th}) vs compression ratio (r_k) for air standard Otto cycle.

EES Solution:

We have the simple EES program:

"Otto Cycle Efficiency:"

gamma=1.4 "ratio of sp. heats for air"

{r_k=7} "comprn. ratio"

eta_th=1-(1/r_k)^(gamma-1) "Air std. effcy."

And, produce the Parametric Table for r_k varying fom 2 to 15:

i) **gamma = 1.4**

gamma = 1.4 | gamma = 1.3 | gamma = 1.667

1..14	1 r_k	2 η_{th}
Run 1	2	0.2421
Run 2	3	0.3556
Run 3	4	0.4257
Run 4	5	0.4747
Run 5	6	0.5116
Run 6	7	0.5408
Run 7	8	0.5647
Run 8	9	0.5848
Run 9	10	0.6019
Run 10	11	0.6168
Run 11	12	0.6299
Run 12	13	0.6416
Run 13	14	0.652
Run 14	15	0.6615

ii) **gamma = 1.3**

gamma = 1.4 | gamma = 1.3 | gamma = 1.667

1..14	r_k	η_{th}
Run 1	2	0.1877
Run 2	3	0.2808
Run 3	4	0.3402
Run 4	5	0.383
Run 5	6	0.4158
Run 6	7	0.4422
Run 7	8	0.4641
Run 8	9	0.4827
Run 9	10	0.4988
Run 10	11	0.5129
Run 11	12	0.5255
Run 12	13	0.5367
Run 13	14	0.5469
Run 14	15	0.5562

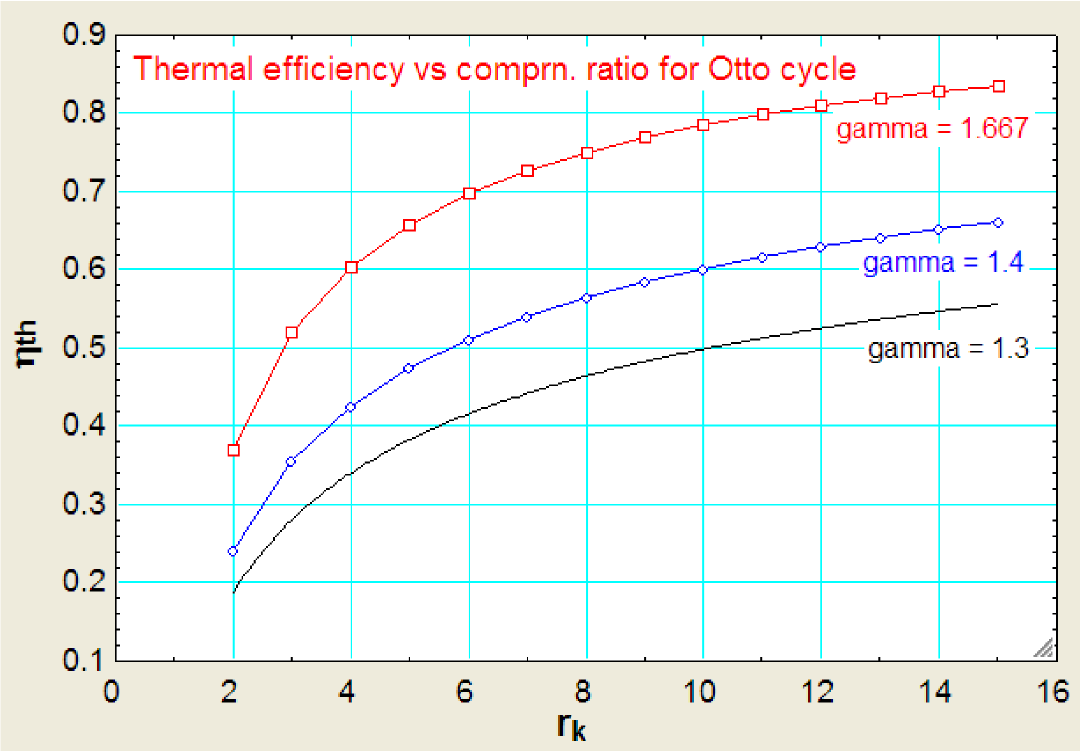
iii) **gamma = 1.667**

Parametric Table

gamma = 1.4 | gamma = 1.3 | gamma = 1.667

1..14	r_k	η_{th}
Run 1	2	0.3702
Run 2	3	0.5194
Run 3	4	0.6033
Run 4	5	0.6582
Run 5	6	0.6973
Run 6	7	0.7269
Run 7	8	0.7502
Run 8	9	0.769
Run 9	10	0.7847
Run 10	11	0.798
Run 11	12	0.8094
Run 12	13	0.8193
Run 13	14	0.828
Run 14	15	0.8357

Now, plot the results:



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"**Prob.1.9.** A petrol engine operates on air standard Otto cycle. The compression ratio is 8. The pressure and temp at the beginning of compression are 100 kPa and 27 C. Heat added to air is 1800 kJ/kg. Determine: (a) pressure and temp at each point in the cycle, (b) thermal efficiency, and (c) m.e.p."

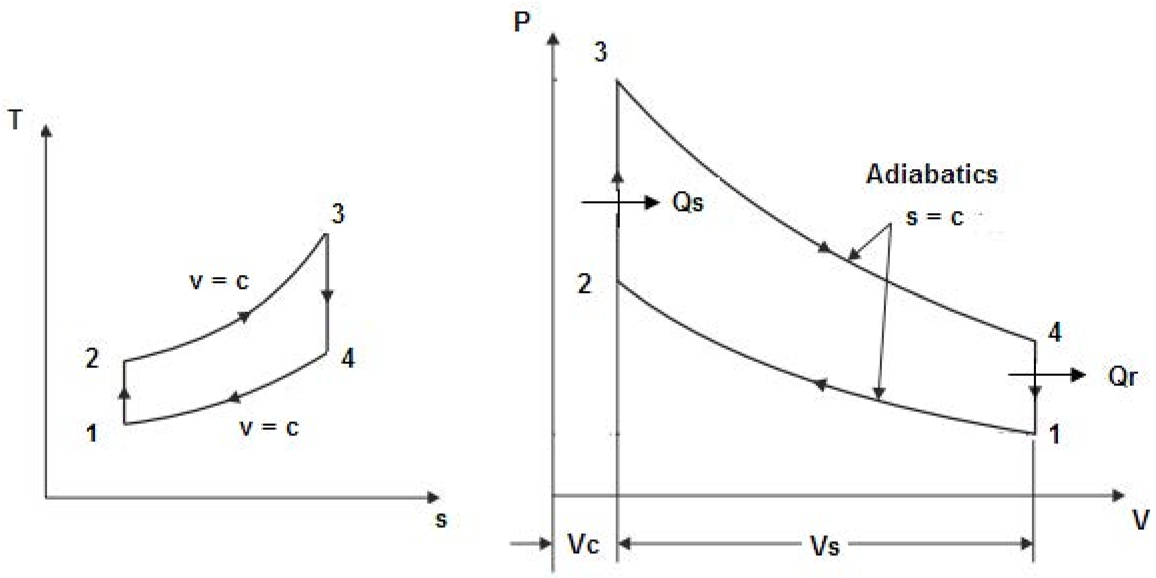


Fig.Prob.1.9

"EES Solution:"

"Data:"

P1=100"kPa"

T1= 27+273"K"

rr_k = 8"comprn. ratio"

Q_in = 1800"kJ/kg"

gamma = 1.4 ".... ratio of sp. heats for air"

cv = 0.717"kJ/kg.K .... for air"

R = 0.287"kJ/kg.K .... for air"

"Calculations:"

T2/T1= rr_k^(gamma-1)"....for isentropic process 1-2 ... finds T2"

P1 * V1= R * T1"...finds V1"

P2 * V2 = R * T2 "...at point 2"

V1/V2=rr_k"...comprn. ratio, by definition"

V3 = V2 "...at point 3"

V4 = V1 "...for process 4-1"

(P3*V3)/T3=(P2*V2)/T2 "…for const. volume process 2-3"

Q_in= cv * (T3-T2)"heat supplied in process 2-3, for 1 kg of air.….kJ/kg"

P4 / P3=(1/rr_k)^gamma "….for isentropic process 3-4"

T3 / T4=rr_k^(gamma-1)"…for process 3-4"

Q_out = cv * (T4-T1)"…heat rejected per kg of air …. kJ/kg"

eta_th = (Q_in-Q_out)/Q_in "….thermal efficiency"

W_net = Q_in-Q_out "kJ/kg …. net work output"

MEP = W_net / (V1-V2)"kPa ….. mean effective pressure.. by definition"

Results:

Unit Settings: SI K kPa kJ mass deg

cv = 0.717 [kJ/kg-K]	η_{th} = 0.5647	γ = 1.4	MEP = 1349 [kPa]
P1 = 100 [kPa]	P2 = 1838 [kPa]	P3 = 8532 [kPa]	P4 = 464.2 [kPa]
Q_{in} = 1800 [kJ/kg]	Q_{out} = 783.5 [kJ/kg]	R = 0.287 [kJ/(kg-K)]	rr_k = 8
T1 = 300 [K]	T2 = 689.2 [K]	T3 = 3200 [K]	T4 = 1393 [K]
V1 = 0.861 [m³]	V2 = 0.1076 [m³]	V3 = 0.1076 [m³]	V4 = 0.861 [m³]
W_{net} = 1017 [kJ/kg]			

Thus:

P1 = 100 kPa, P2 = 1838 kPa, P3 = 8532 kPa, P4 = 464.2 kPa …Ans.

T1 = 300 K, T2 = 689.2 K, T3 = 3200 K, T4 = 1393 K …. Ans.

Thermal efficiency, eta_th = 0.5647 … Ans.

MEP = 1349 kPa … Ans.

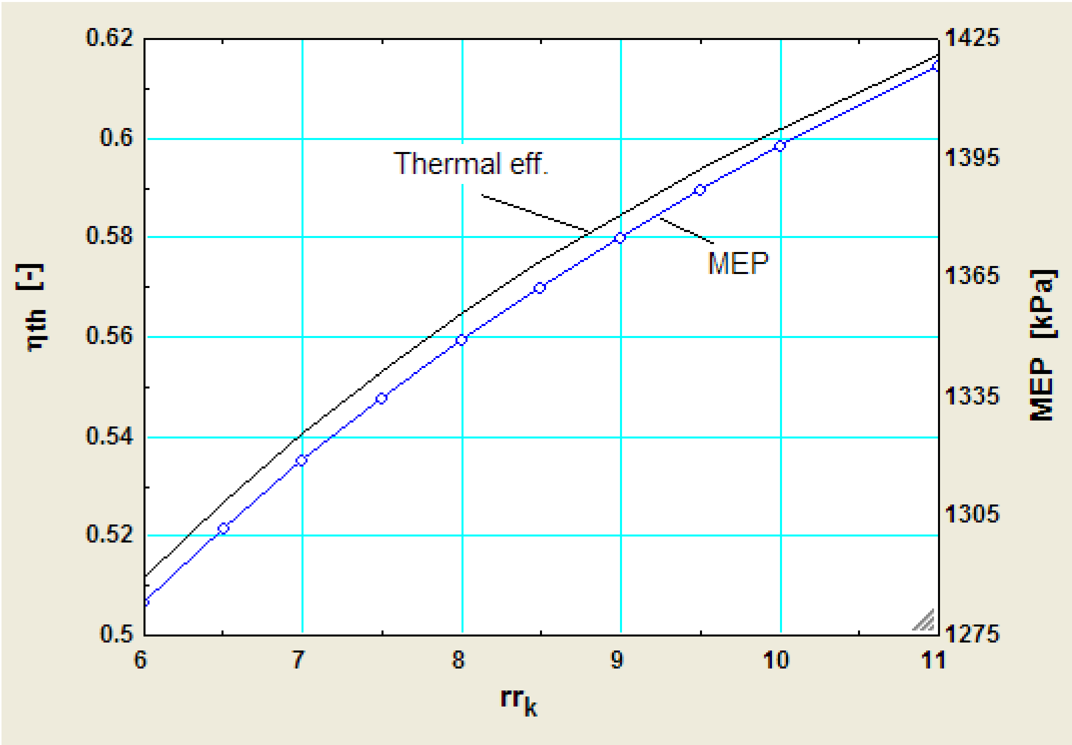
In addition:

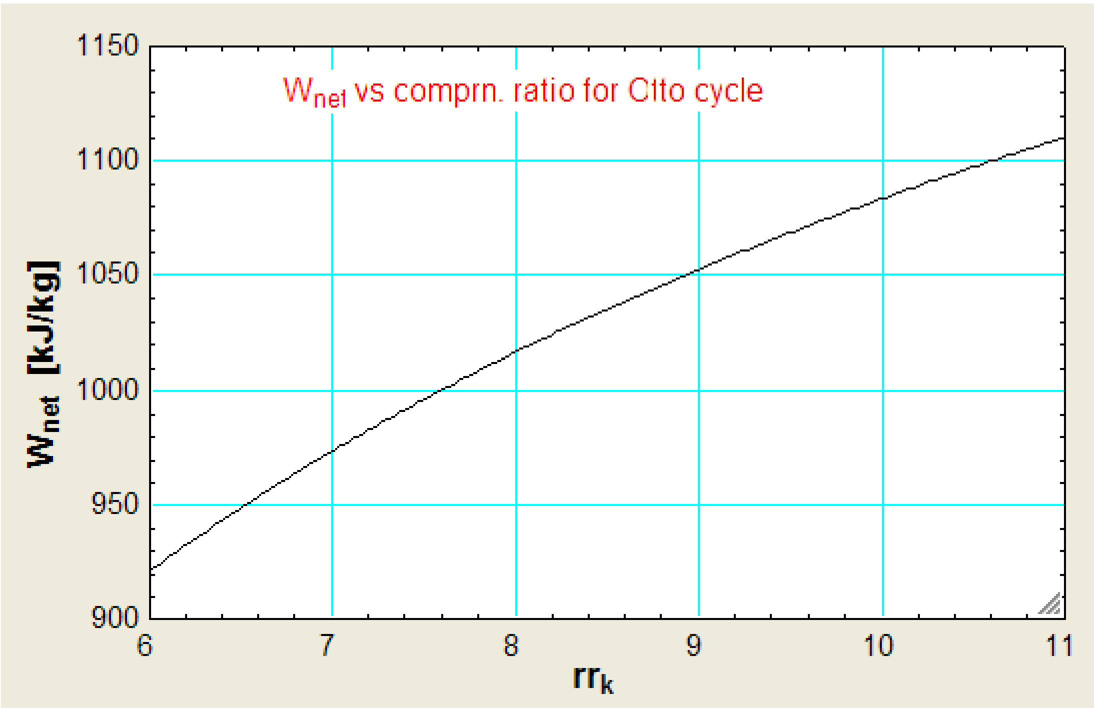
Plot the variation of eta_th, MEP and W_net as comprn. Ratio varies from 6 to 11:

First, compute the Parametric Table:

1..10	η_{th}	MEP [kPa]	W_{net} [kJ/kg]	r_k
Run 1	0.5116	1284	921	6
Run 2	0.527	1302	948.7	6.5
Run 3	0.5408	1319	973.5	7
Run 4	0.5533	1335	996	7.5
Run 5	0.5647	1349	1017	8
Run 6	0.5752	1363	1035	8.5
Run 7	0.5848	1375	1053	9
Run 8	0.5936	1387	1069	9.5
Run 9	0.6019	1398	1083	10
Run 10	0.6168	1418	1110	11

Now, plot the results:





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"**Prob.1.10.** An engine, 250 mm bore, 375 mm stroke, works on Otto cycle. The clearance volume is 0.00263 m^3. Initial pressure and temp are 1 bar and 50 C. If the max. pressure is limited to 25 bar, find: (a) air standard efficiency, (b) MEP of the cycle, (c) If this 4 stroke engine runs at 960 rpm, find the power output."

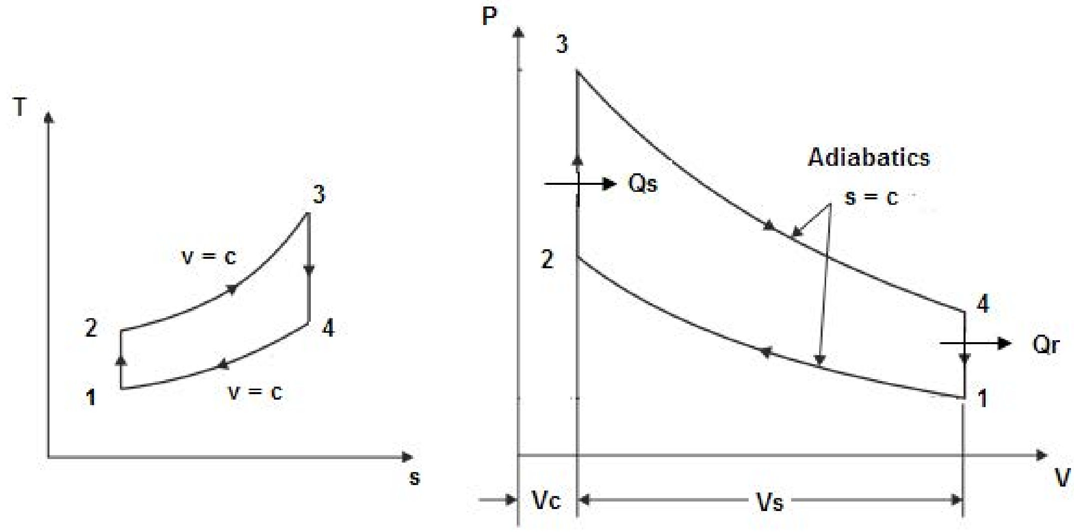


Fig.Prob.1.10

"EES Solution:"

"Data:"

```
D=0.25 "m"

L=0.375 "m"

RPM=960

V2=0.00263 "m3 …. clearance vol."

P1=100 "kPa"

T1=50+273 "K"

P3=2500 "kPa"

R=0.287 "kJ/kg.K …. for air"

gamma=1.4"…for air"

cv=0.718 "kJ/kg.K .. for air"

"Calculations:"

V_s=(PI*(D^2)/4)*L "m3 …. stroke volume"

V1=V_s+V2 "m3 …. vol. at state 1"

m=(P1*V1)/(R*T1) "kg …. mass of air"

rr_k=V1/V2 "comprn. ratio"

T2/T1=(rr_k)^(gamma-1)"… for isentropic process 1-2,,,finds temp T2"

V3=V2 "…process 2-3"

P2/P1=(rr_k)^gamma"…For isentropic process 1-2 … finds P2"

P3/T3=P2/T2 "…for const. vol. process 2-3…finds T3"

V4=V1"…for const. vol. process 4-1"

T3/T4=(rr_k)^(gamma-1)"…for isentropic process 3-4 … finds T4"

P3/P4=(rr_k)^gamma"… for process 3-4…finds P4"

Q_in=m*cv*(T3-T2) "kJ …finds heat supplied"

Q_out=m*cv*(T4-T1) "kJ … heat rejected"

W_net=Q_in-Q_out "kJ …. net work output"

POWER=W_net*(RPM/(2*60)) "kW …. power output …. divided by 2 since for 4 stroke cycle, there
is one power stroke in every two revolutions"

eta_th=W_net/Q_in "Thermal effcy."

MEP=W_net/V_s "kPa …. m.e.p.. by definition"
```

Results:

Unit Settings: SI K kPa kJ mass deg

cv = 0.718 [kj/kg-K]	D = 0.25 [m]	η_{th} = 0.5647	γ = 1.4
L = 0.375 [m]	m = 0.02269 [kg]	MEP = 133.7 [kPa]	P1 = 100 [kPa]
P2 = 1838 [kPa]	P3 = 2500 [kPa]	P4 = 136 [kPa]	POWER = 19.69 [kW]
Q_{in} = 4.358 [kJ]	Q_{out} = 1.897 [kJ]	R = 0.287 [kJ/kg-K]	RPM = 960
rr_k = 7.999	T1 = 323 [K]	T2 = 742 [K]	T3 = 1009 [K]
T4 = 439.4 [K]	V1 = 0.02104 [m^3]	V2 = 0.00263 [m^3]	V3 = 0.00263 [m^3]
V4 = 0.02104 [m^3]	V_s = 0.01841 [m^3]	W_{net} = 2.461 [kJ]	

===

"**Prob.1.11**. The compression ratio of an ideal Otto cycle is 6.2:1. The pressure and temp at the commencement of compression are 1 bar and 28 C. The heat added during the constant volume combustion process is 1205 kJ/kg. Determine the peak pressure and temp, work output per kg of air, and air standard efficiency. Assume cv = 0.717 kJ/kg.K and gamma = 1.4 for air. [VTU-ATD-Jan. 2005]"

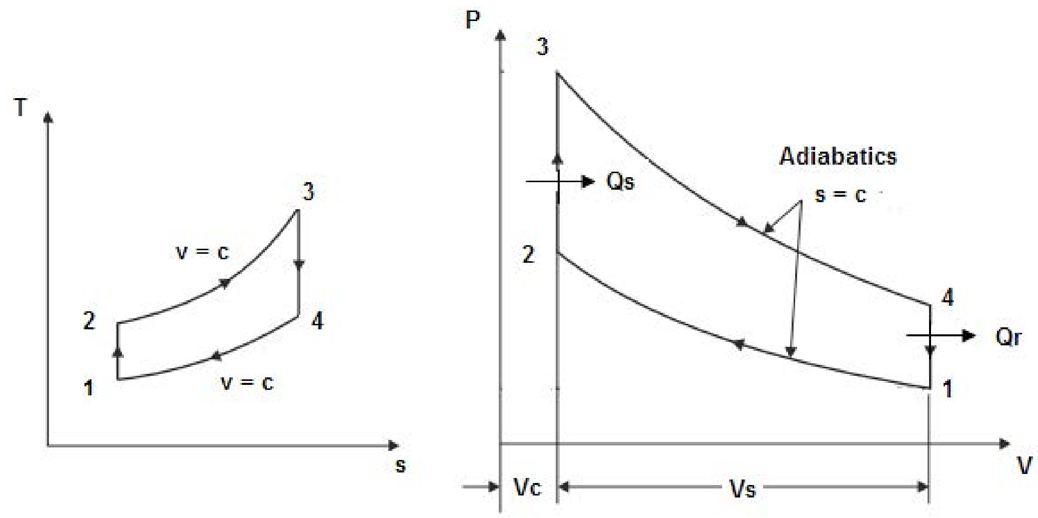


Fig.Prob.1.11

"EES Solution:"

"Data:"

P1=100"kPa"
T1=28+273 "K"
R=0.287 "kJ/kg.K"
gamma=1.4
cv=0.717 "kJ/kg.K"
rr_k=6.2 "comprn. ratio"
Q_in = 1205 "kJ/kg …. heat supplied"

```
"Calculations:"
T2/T1=(rr_k)^(gamma-1)"…for isentropic process 1-2….finds T2"
P1 * V1 / T1= R "…finds V1 for 1 kg of air"
cv * (T3-T2)=Q_in "kJ/kg …. heat supplied …. finds T3"
V3=V2"…for const. vol. process 2-3"
P2 / P1=(rr_k)^gamma "….for process 1-2…finds P2"
P1 * V1 / T1= P2 * V2 / T2 "….finds T2"
P3 / T3=P2 / T2 "….for const. vol. process 2-3…. finds P3"
V4=V1"…for const. vol. process 4-1"
T3 / T4=(rr_k)^(gamma-1)"….for isentropi process 3-4….finds T4"
P3 / P4=(rr_k)^gamma"…for process 3-4…..finds P4"
Q_out=cv*(T4-T1) "kJ/kg …. heat rejected"
W_net=Q_in-Q_out "kJ/kg …. net work output"
eta_th=W_net/Q_in "Thermal effcy."
MEP=W_net/(V1-V2) "kPa … mean effective pressure"
```

Results:

Unit Settings: SI K kPa kJ mass deg

$cv = 0.717$ [kJ/kg-K]	$\eta_{th} = 0.518$	$\gamma = 1.4$	$MEP = 861.5$ [kPa]
$P1 = 100$ [kPa]	$P2 = 1286$ [kPa]	$P3 = 4748$ [kPa]	$P4 = 369.1$ [kPa]
$Q_{in} = 1205$ [kJ]	$Q_{out} = 580.8$ [kJ]	$R = 0.287$ [kJ/kg-K]	$r_k = 6.2$
$T1 = 301$ [K]	$T2 = 624.5$ [K]	$T3 = 2305$ [K]	$T4 = 1111$ [K]
$V1 = 0.8639$ [m^3]	$V2 = 0.1393$ [m^3]	$V3 = 0.1393$ [m^3]	$V4 = 0.8639$ [m^3]
$W_{net} = 624.2$ [kJ]			

Thus:

Peak pressure, P3 = 4748 kPa….Ans.

Peak temp, T3 = 2305 K …. Ans.

Work output, W_net = 624.2 kJ/kg …. Ans.

Air standard efficiency, eta_th = 0.518 …. Ans.

In addition:

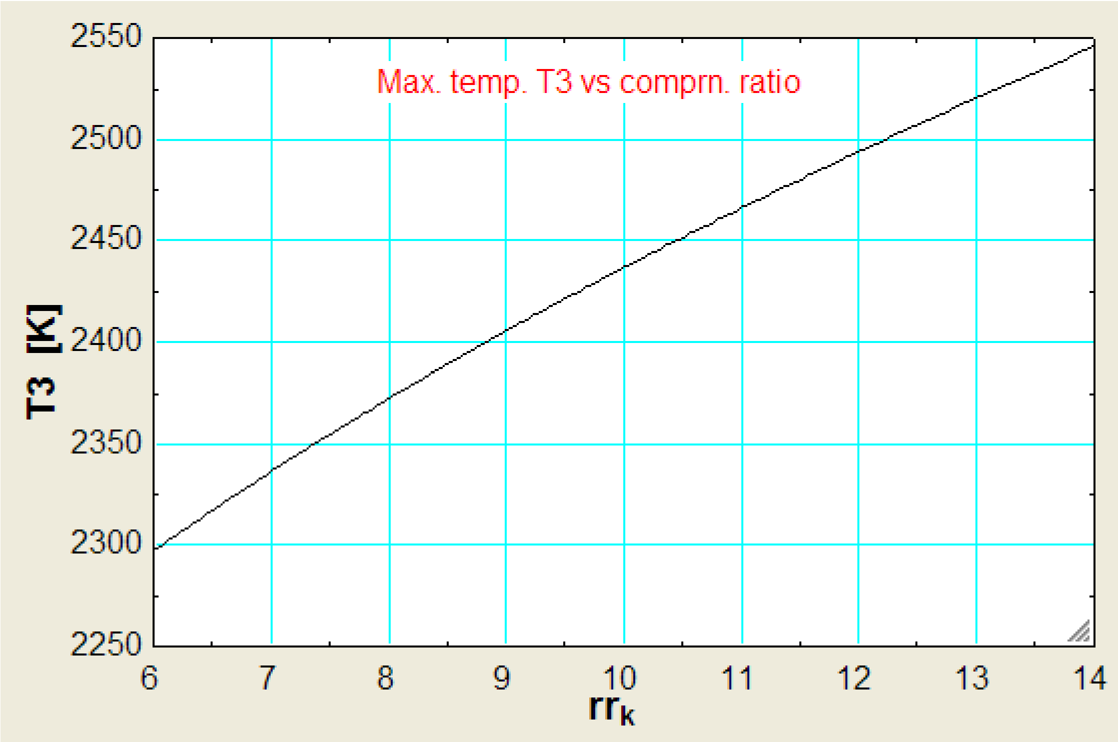
Plot peak temp. T3, eta_th, W_net and MEP as compression ratio varies from 6 to 14, keeping the heat supplied, Q_in un-altered:

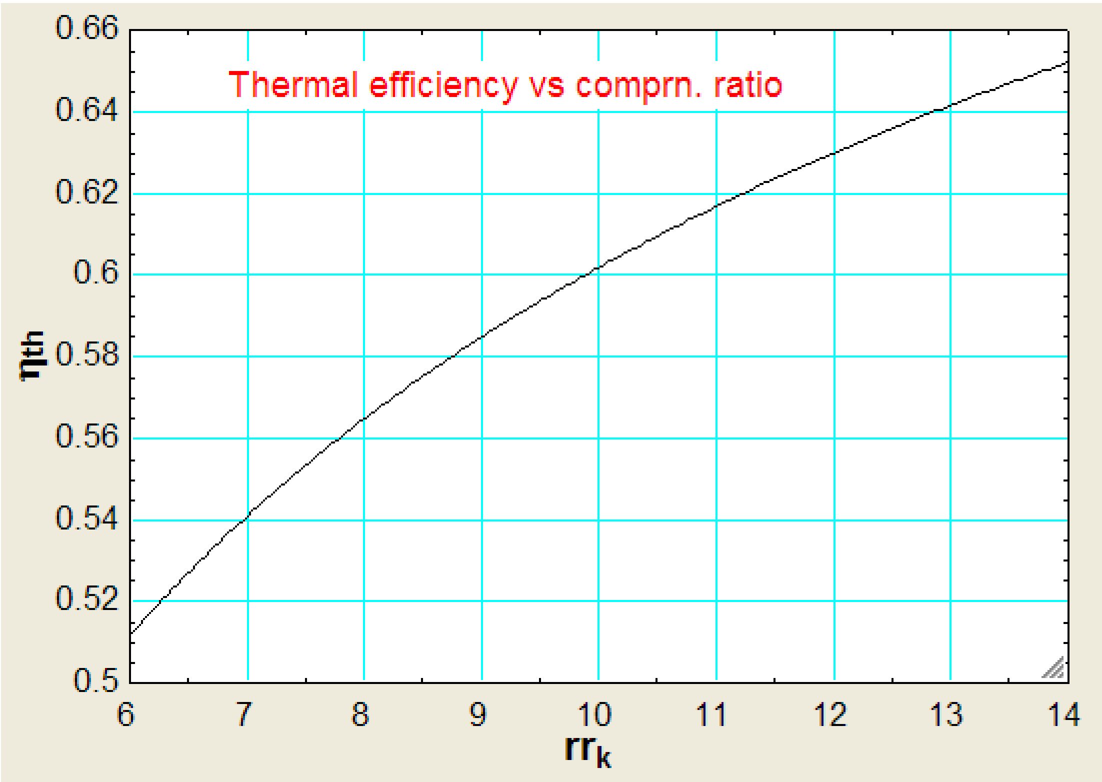
First, compute the Parametric Table:

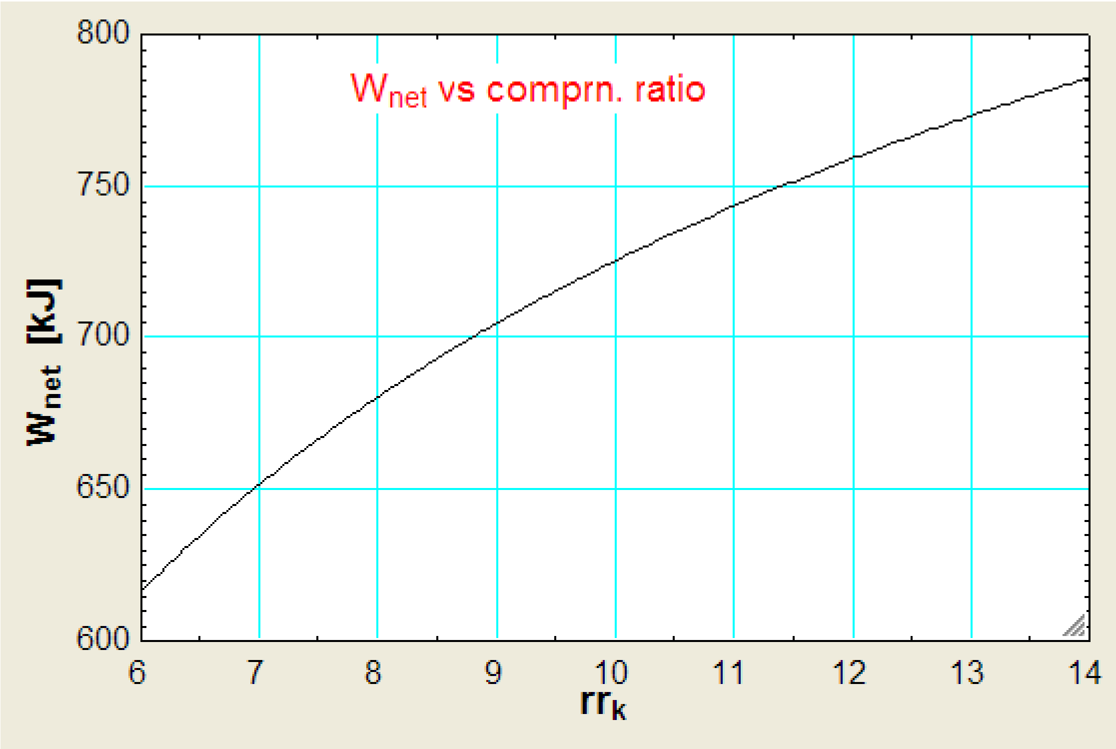
Table 1

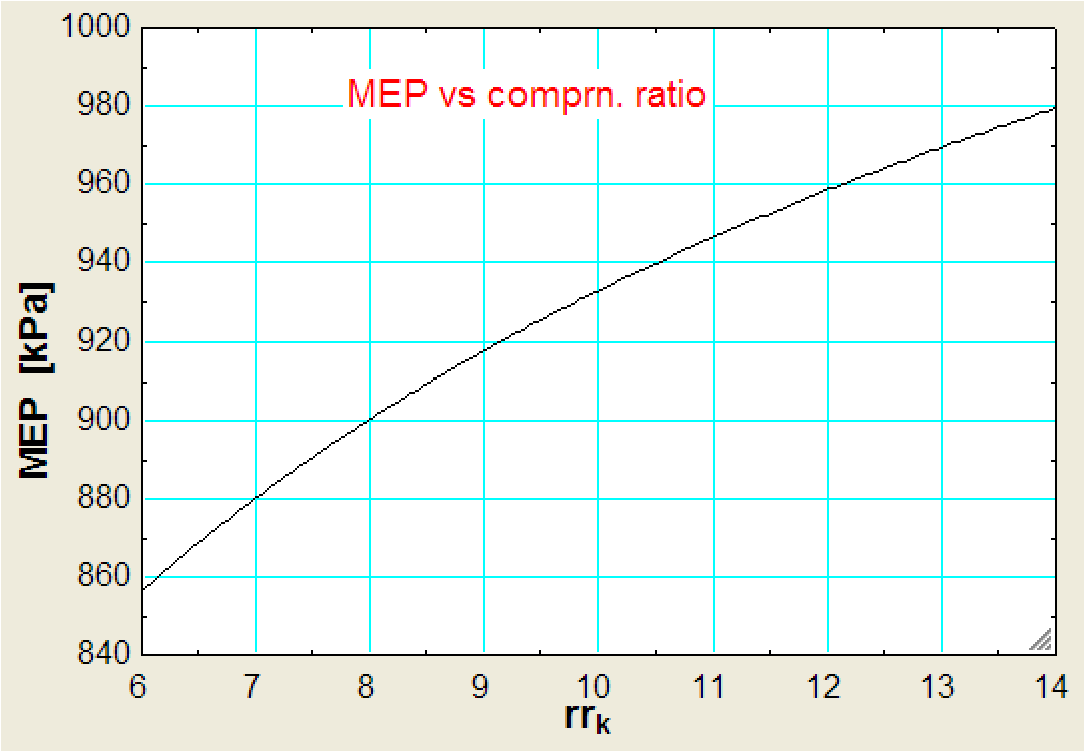
1..9	r_k	T3 [K]	η_{th}	W_{net} [kJ]	MEP [kPa]
Run 1	6	2297	0.5116	616.5	856.4
Run 2	7	2336	0.5408	651.7	880.2
Run 3	8	2372	0.5647	680.5	900.3
Run 4	9	2405	0.5848	704.6	917.6
Run 5	10	2437	0.6019	725.3	932.9
Run 6	11	2466	0.6168	743.2	946.4
Run 7	12	2494	0.6299	759	958.5
Run 8	13	2520	0.6416	773.1	969.5
Run 9	14	2546	0.652	785.7	979.5

Now, plot the results:






Wnet vs comprn. ratio
Wnet [kJ]
rrk
800
750
700
650
600
6
7
8
9
10
11
12
13
14



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"**Prob.1.12.** An ideal Otto cycle has a compression ratio of 8. At the beginning of compression process, air is at 95 kPa and 27 C, and 750 kJ/kg of heat is transferred to air during the const. vol. heat addition process. Using const. sp. heats at room temp, determine: (a) the pressure and temp at the end of heat addition process, (b) the net work output, and (c) the thermal efficiency, and (d) the mean effective pressure. [Ref: 1]"

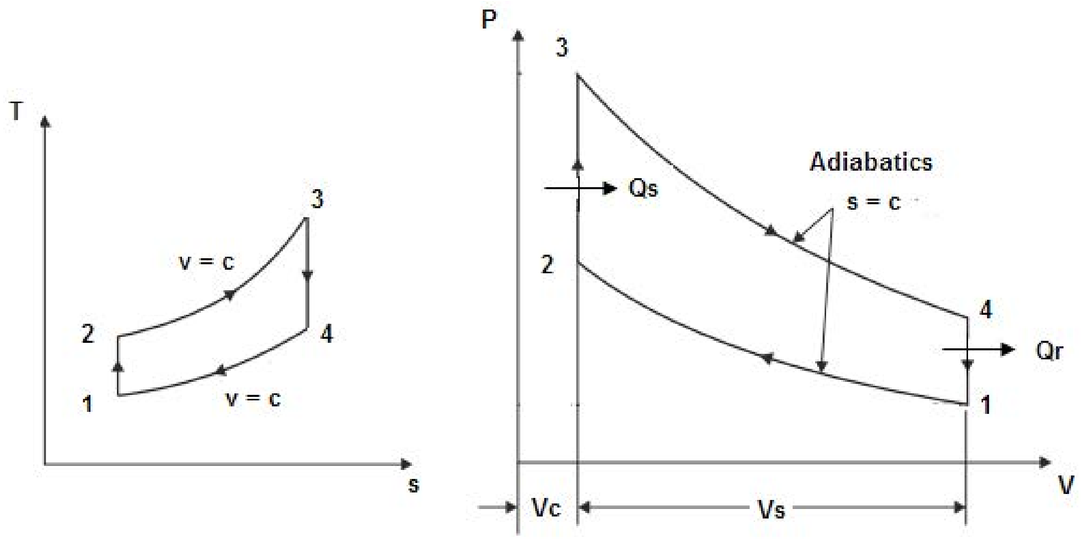


Fig.Prob.1.12

"EES Solution:"

We will use *Array notation* for the properties at the four salient points of the cycle, in order to plot the cycle on a Property plot (i.e. T-s and P-v diagrams) in EES:

"Data:"

P[1]=95"kPa … Pressure at State 1… note that array notation is used by writing P[1]"

T[1]=27+273"K"

rr_k=8"comprn. ratio"

Q_in=750"kJ/kg"

gamma=1.4"….ratio of sp. heats for air"

cv=0.717"kJ/kg.K …. for air"

R=0.287"kJ/kg.K …. for air"

"Calculations:"

T[2]/T[1]=rr_k^(gamma-1)"…for isentropic process 1-2…finds T[2]"

P[1] * V[1]=R * T[1]"…finds V[1]"

P[2] * V[2]=R * T[2]"….for state 2"

V[1] / V[2]=rr_k "… by definition of comprn. ratio"

V[3]=V[2]"…const. vol. process 2-3"

(P[3]*V[3])/T[3]=(P[2]*V[2])/T[2]"…. for process 2-3"

Q_in=cv * (T[3]-T[2]) "kJ….heat supplied"

P[4]/P[3]=(1/rr_k)^gamma "…for isentropic process 3-4"

T[3]/T[4]=rr_k^(gamma-1)"…for process 3-4."

Q_out=cv * (T[4]-T[1]) "kJ…heat rejected"

eta_th=(Q_in-Q_out)/Q_in "…thermal efficiency"

W_net=Q_in-Q_out "kJ….net work output"

MEP=W_net/(V[1]-V[2])"kPa …. mean effective pressure …. by definition"

V[4]=V[1] "..for const. vol. process 4-1"

"For drawing the cycle on a T-s plot:"

s[1]=entropy(Air,P=P[1], T=T[1])"…entropy at state 1"

s[2]=s[1]"…entropy at state 2"

s[3]=entropy(Air,P=P[3], T=T[3])"…entropy at state 3"

s[4]=s[3]"…entropy at state 4"

Results:

Unit Settings: SI K kPa kJ mass deg

cv = 0.717 [kJ/kg-K]

η_{th} = 0.5647

γ = 1.4

MEP = 534.1 [kPa]

Q_{in} = 750 [kJ/kg]

Q_{out} = 326.5 [kJ/kg]

R = 0.287 [kJ/kg-K]

r_k = 8

W_{net} = 423.5 [kJ/kg]

Sort	P_i [kPa]	T_i [K]	V_i [m3]	s_i [kJ/kg-K]
[1]	95	300	0.9063	5.72
[2]	1746	689.2	0.1133	5.72
[3]	4396	1735	0.1133	6.54
[4]	239.2	755.3	0.9063	6.54

Thus:

P and T at the end of heat addition process, i.e. at State 3:

P3 = 4396 kPa, T3 = 1735 K …. Ans.

Thermal efficiency, eta_th = 0.5647 … Ans.

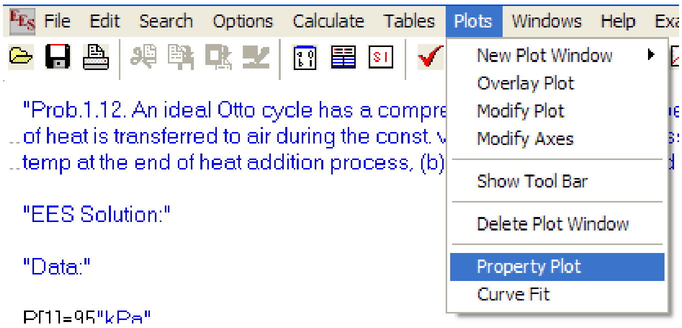
Net work output, W_net = 423.5 kJ/kg … Ans.

MEP = 534.1 kPa … Ans.

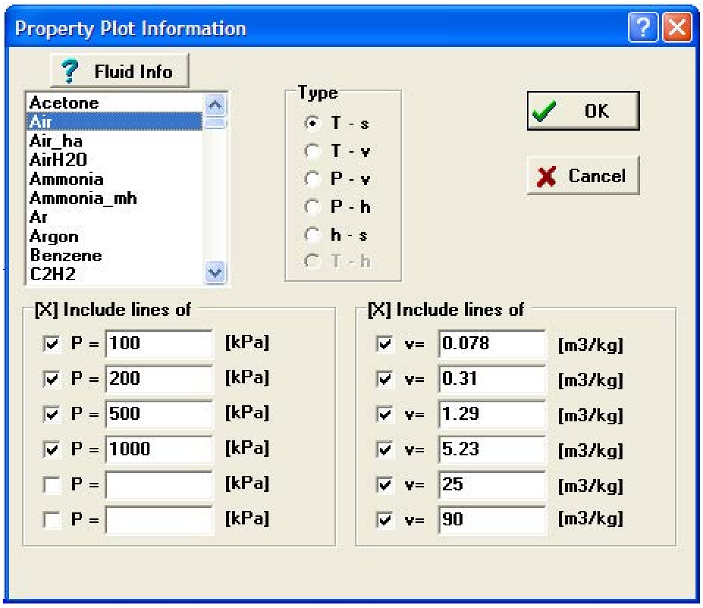
To plot the cycle on T-s and P-v diagrams:

This is very easy in EES:

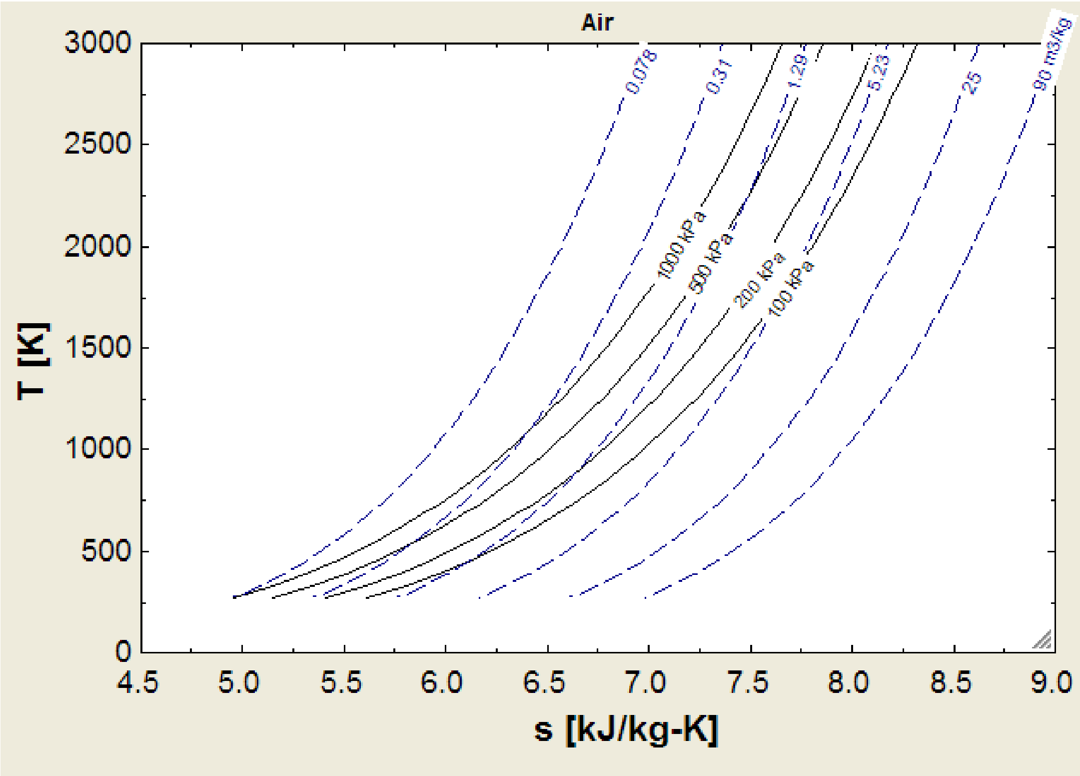
First, in the EES menu: go to Plots – Property Plot:



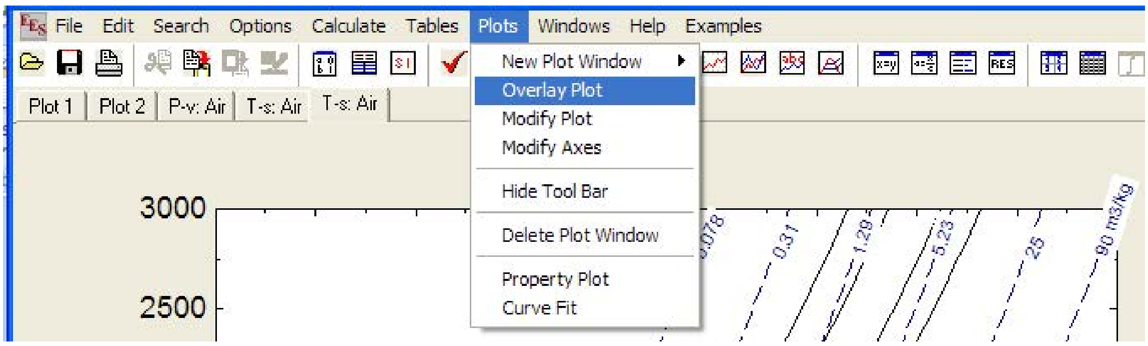
Clicking on Property Plot gives:



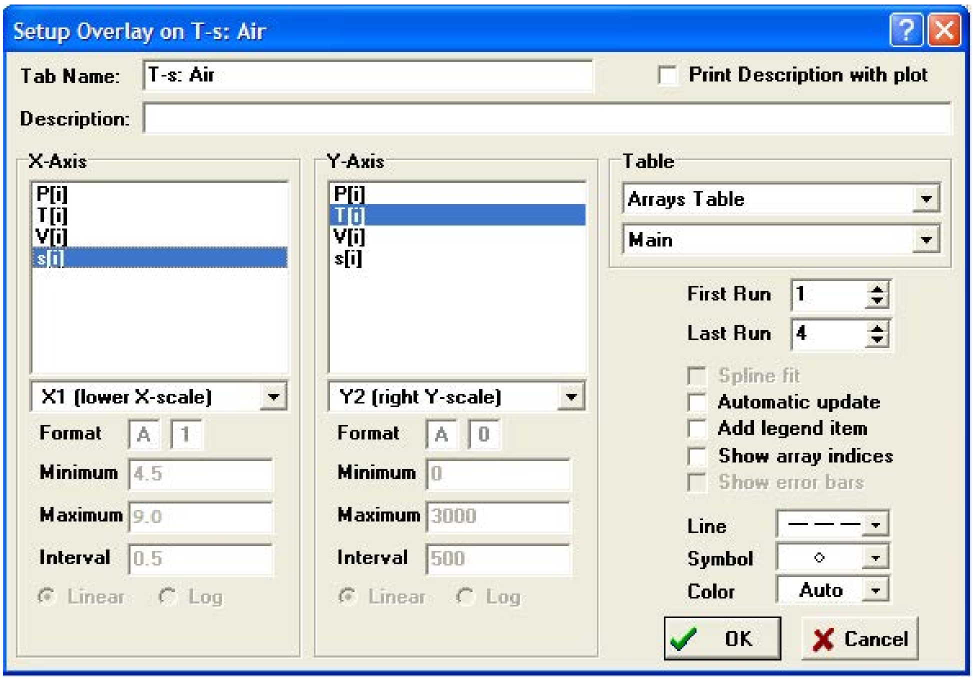
Choose Air for the Fluid, click on T-s radio button for T-s plot, choose the P and v lines desired. Click OK. We get:



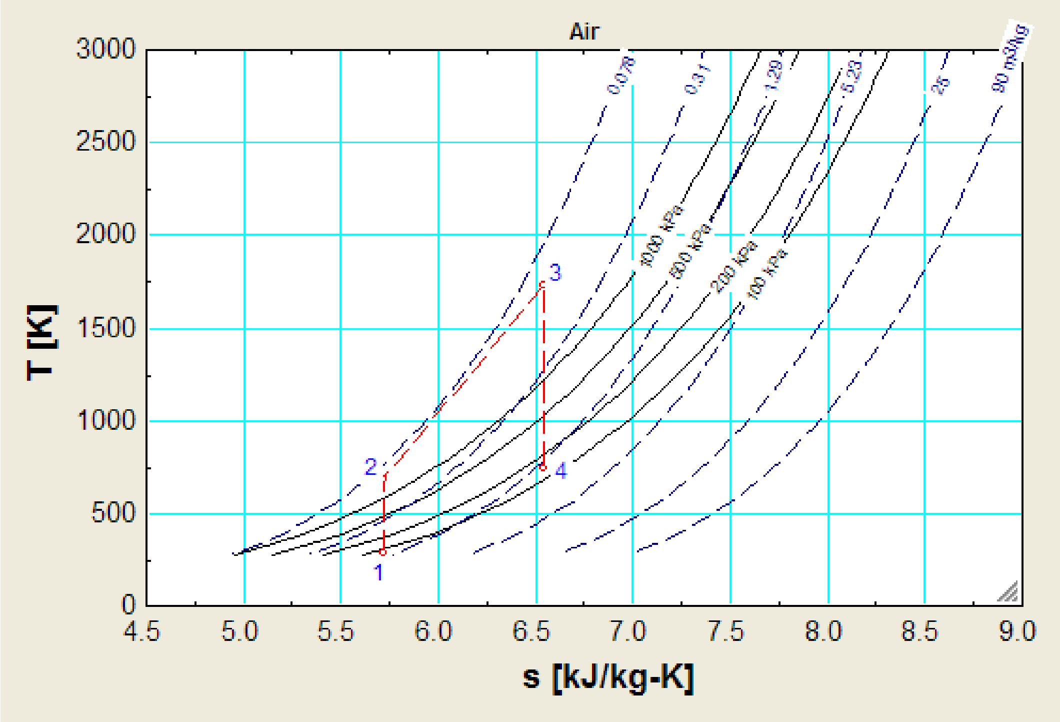
Now, click on Overlay plot under the Plot menu, as shown:



And choose the Arrays Table under the 'Table' tab. And choose T[i] for Y-axis and s[i] for X-axis, as shown below:

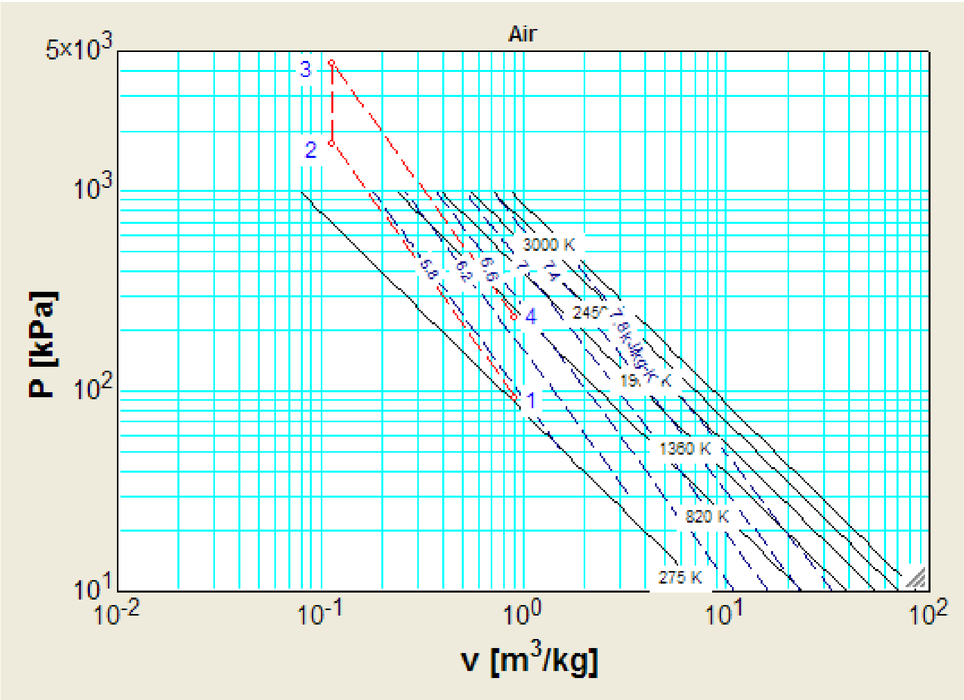


Click OK. Format the plot to get X and Y grid lines. We get:



In the above plot, salient points (i.e. 1, 2, 3 and 4) are shown marked.

Similarly, get the P-v plot:



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Prob.1.13. At the beginning of the compression process, in an air standard Otto cycle, p1 = 1 bar, T1 = 300 K. Compression ratio, rr_k = 6. The max. cycle temp is 2000 K. Find the net work per unit mass in kJ/kg, the thermal efficiency, and the mean effective pressure, in bar. (b) Also plot the variation of net work per unit mass of air and MEP versus the max. cycle temp (T3) for rr_k = 6, 8 and 10. Let T3 vary from1200 K to 2300 K.

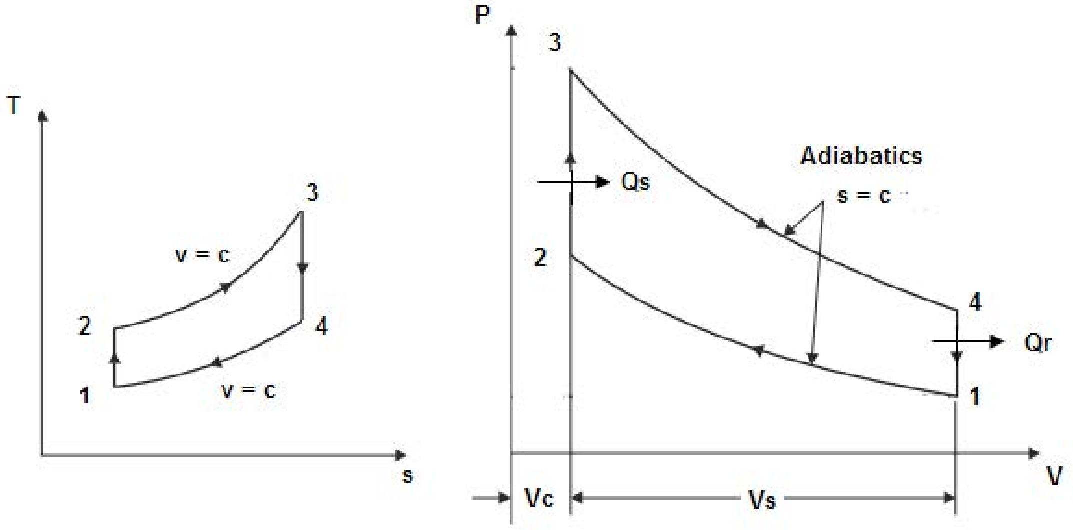


Fig.Prob.1.13

"EES Solution:"

"Data:"

P1=100"kPa"

T1=300 "K"

R=0.287 "kJ/kg.K"

gamma=1.4

cv=0.717 "kJ/kg.K"

rr_k=6 "comprn. ratio"

T3 = 2000 "K….max. cycle temp."

"Calculations:"

T2/T1=(rr_k)^(gamma-1)"…for isentropic process 1-2….finds T2"

P1 * V1 / T1= R "…finds V1 for 1 kg of air"

cv * (T3-T2)=Q_in "kJ/kg …. heat supplied …. finds Q_in"

V3=V2"…for const. vol. process 2-3"

P2 / P1=(rr_k)^gamma "….for process 1-2…finds P2 (kPa)"

P1 * V1 / T1= P2 * V2 / T2 "….finds V2"

P3 / T3=P2 / T2 "….for const. vol. process 2-3…. finds P3"

V4=V1"…for const. vol. process 4-1"

T3 / T4=(rr_k)^(gamma-1)"….for isentropi process 3-4….finds T4"
P3 / P4=(rr_k)^gamma"…for process 3-4…..finds P4"
Q_out=cv*(T4-T1) "kJ/kg …. heat rejected"
W_net=Q_in-Q_out "kJ/kg …. net work output"
eta_th=W_net/Q_in "Thermal effcy."
MEP=W_net/(V1-V2) "kPa … mean effective pressure"

Results:

Unit Settings: SI K kPa kJ mass deg

cv = 0.717 [kJ/kg-K]	η_{th} = 0.5116	γ = 1.4
MEP = 708.5 [kPa]	P1 = 100 [kPa]	P2 = 1229 [kPa]
P3 = 4000 [kPa]	P4 = 325.6 [kPa]	Q_{in} = 993.5 [kJ]
Q_{out} = 485.2 [kJ]	R = 0.287 [kJ/kg-K]	rr_k = 6
T1 = 300 [K]	T2 = 614.3 [K]	T3 = 2000 [K]
T4 = 976.7 [K]	V1 = 0.861 [m^3]	V2 = 0.1435 [m^3]
V3 = 0.1435 [m^3]	V4 = 0.861 [m^3]	W_{net} = 508.3 [kJ]

Thus:

Net work per unit mass of air = W_net = 508.3 kJ/kg …. Ans.

Thermal efficiency = eta_th = 0.5116 …. Ans.

MEP = 708.5 kPa = 7.085 bar …. Ans.

(b) Plot W_net vs T3 for rr_k = 6, 8 and 10:

First, compute the Parametric Tables for compression ratios, rr_k = 6, 8 and 10:

For rr_k = 6:

compprn.ratio = 6

1..12	T3 [K]	W_{net} [kJ]	MEP [kPa]
Run 1	1200	214.9	299.5
Run 2	1300	251.5	350.6
Run 3	1400	288.2	401.7
Run 4	1500	324.9	452.8
Run 5	1600	361.6	504
Run 6	1700	398.3	555.1
Run 7	1800	435	606.2
Run 8	1900	471.7	657.4
Run 9	2000	508.3	708.5
Run 10	2100	545	759.6
Run 11	2200	581.7	810.7
Run 12	2300	618.4	861.9

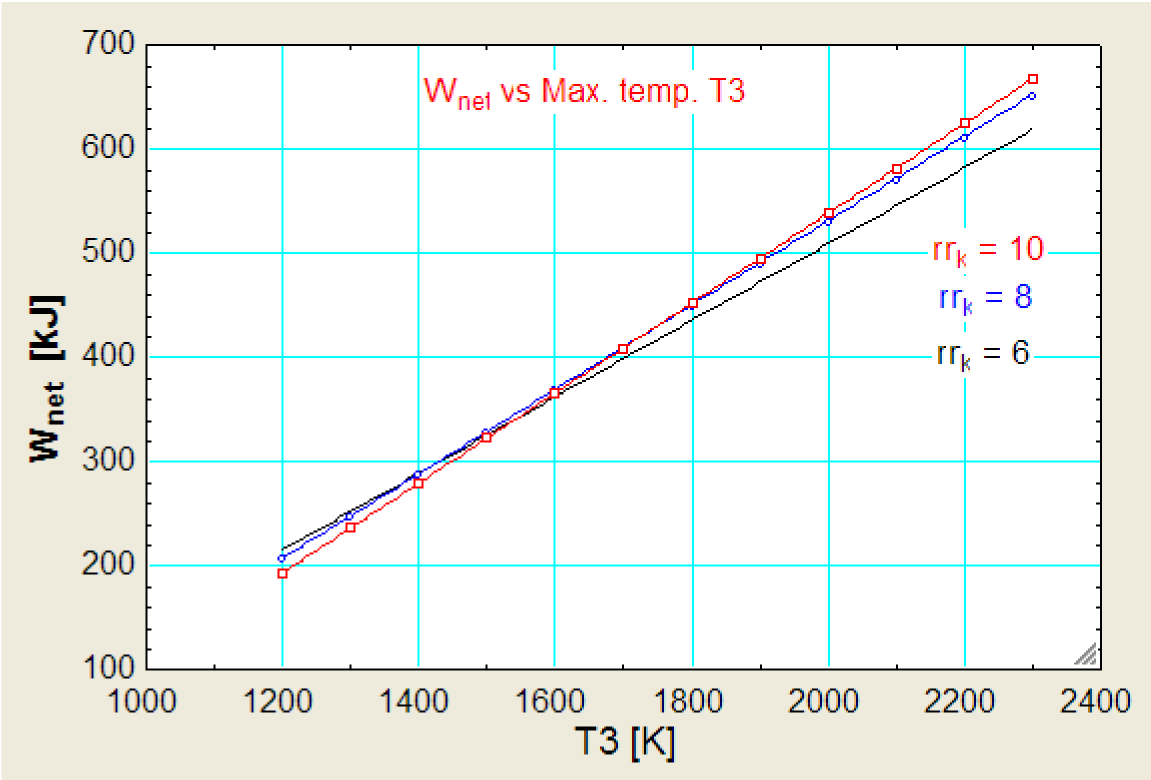
For rr_k = 8:

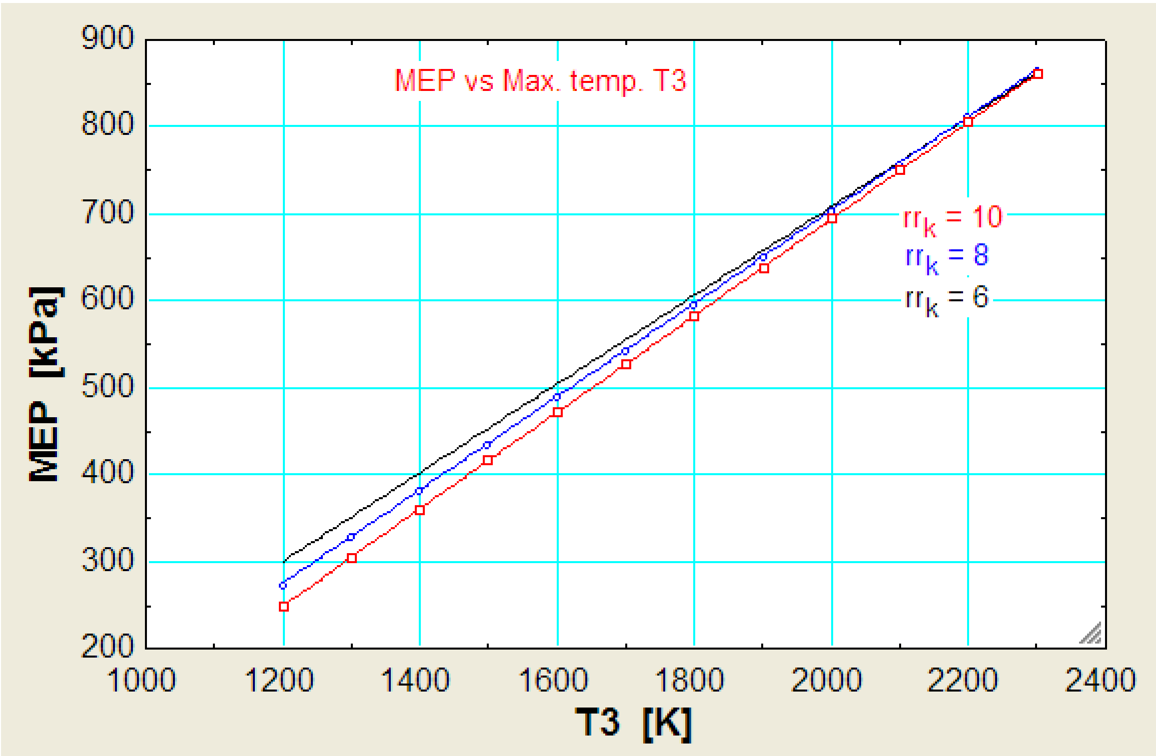
1..12	T3 [K]	W_{net} [kJ]	MEP [kPa]
Run 1	1200	206.8	274.5
Run 2	1300	247.3	328.3
Run 3	1400	287.8	382
Run 4	1500	328.3	435.8
Run 5	1600	368.8	489.5
Run 6	1700	409.3	543.3
Run 7	1800	449.8	597
Run 8	1900	490.3	650.7
Run 9	2000	530.7	704.5
Run 10	2100	571.2	758.2
Run 11	2200	611.7	812
Run 12	2300	652.2	865.7

For rr_k = 10:

1..12	T3 [K]	W_{net} [kJ]	MEP [kPa]
Run 1	1200	192.7	248.6
Run 2	1300	235.8	304.3
Run 3	1400	279	360
Run 4	1500	322.1	415.7
Run 5	1600	365.3	471.4
Run 6	1700	408.4	527.1
Run 7	1800	451.6	582.8
Run 8	1900	494.8	638.5
Run 9	2000	537.9	694.2
Run 10	2100	581.1	749.9
Run 11	2200	624.2	805.5
Run 12	2300	667.4	861.2

Now, plot the results:





==

1.2.3 Problems solved with TEST:

Prob.1.14. A four stroke, 4 cylinder petrol engine of 250 mm bore and 375 mm stroke works on the Otto cycle. The clearance volume is 0.01052 m^3. The initial pressure and temp are 1 bar and 47 C. If the max. pressure is limited to 25 bar, find the following: (a) Air standard efficiency, and (b) mean Effective Pressure. [VTU-ATD-Dec. 2011]

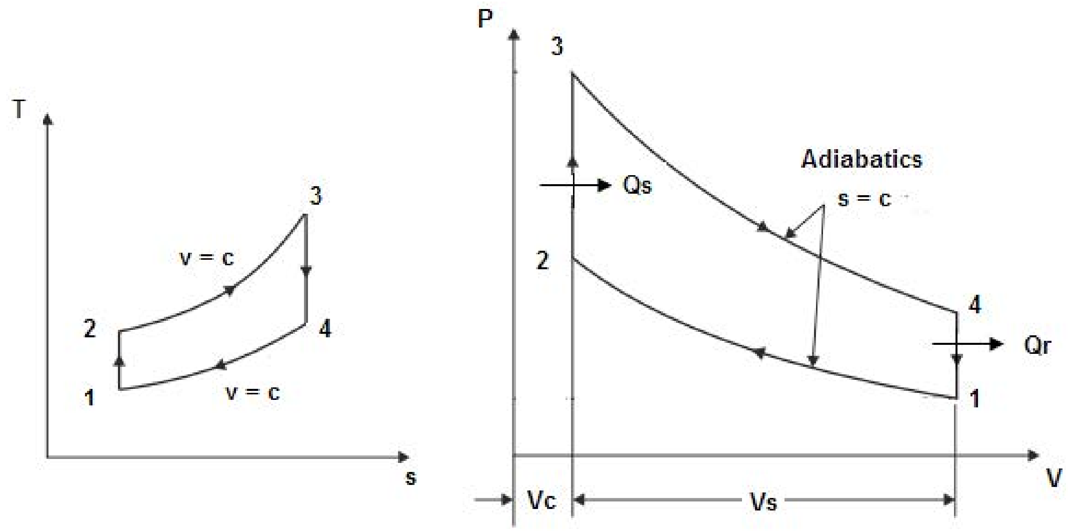


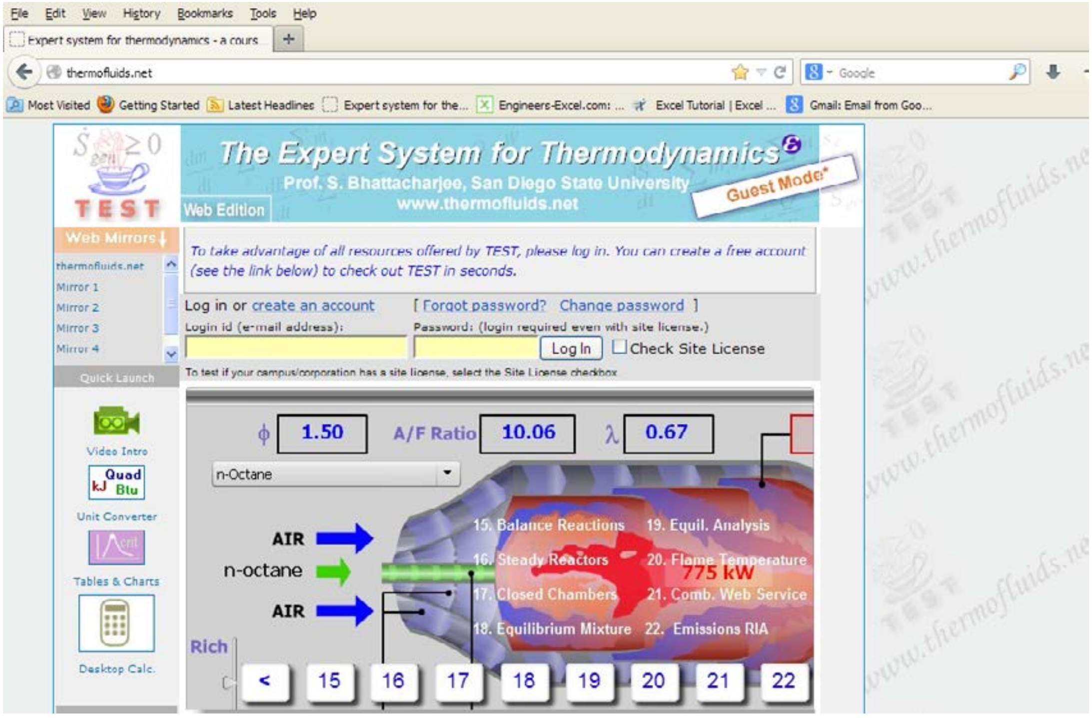
Fig.Prob.1.14

TEST Solution:

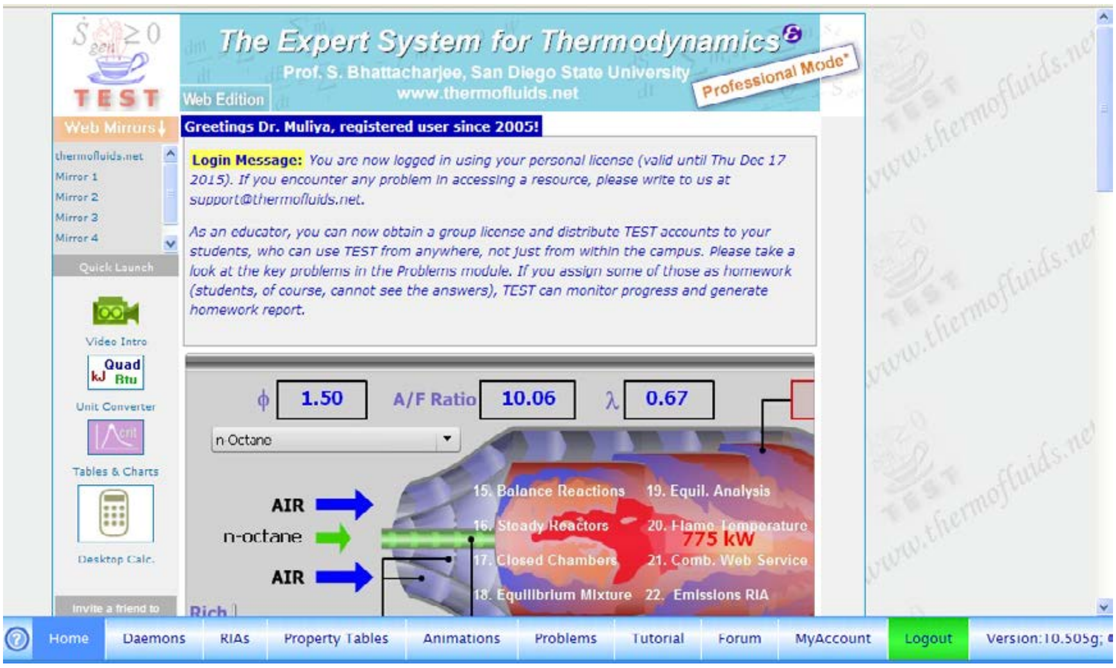
It is assumed that one has already visited www.thermofluids.net and completed the 'free registration'.

Following are the steps:

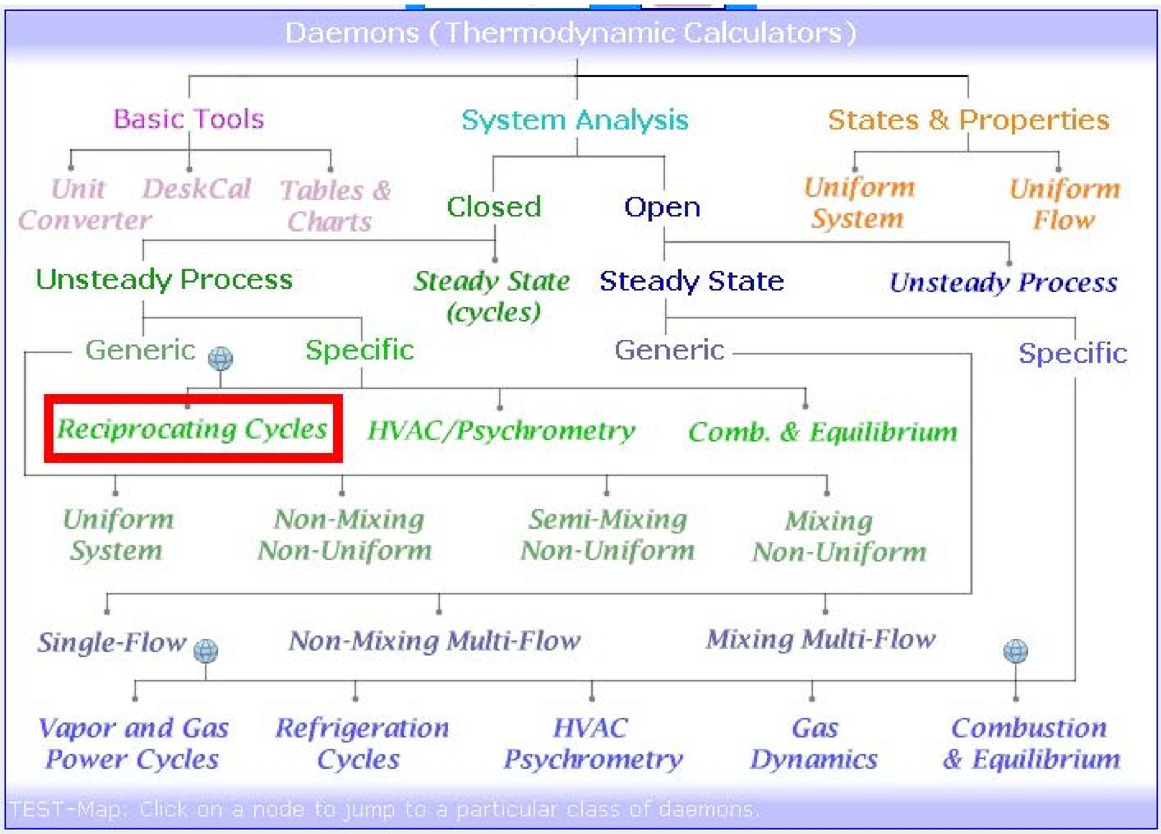
1. Go to www.thermofluids.net:



2. Fill in the e-mail address and password; you get the personalized greeting screen:

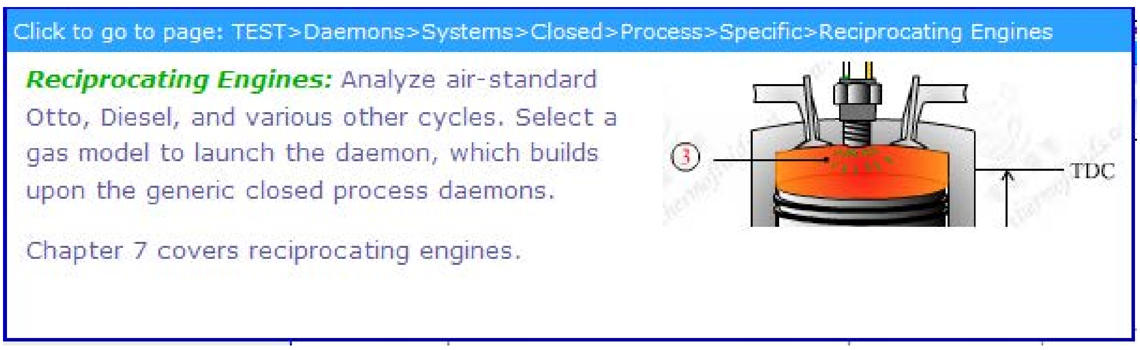


3. Click on Daemons at the bottom of screen above. We get:

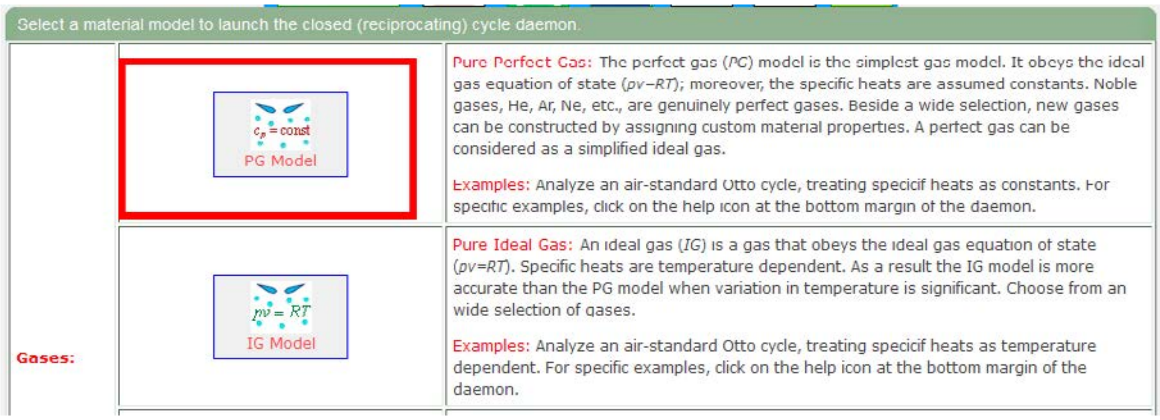


For this chapter, we have to choose System-Closed-Reciprocating Cycles.

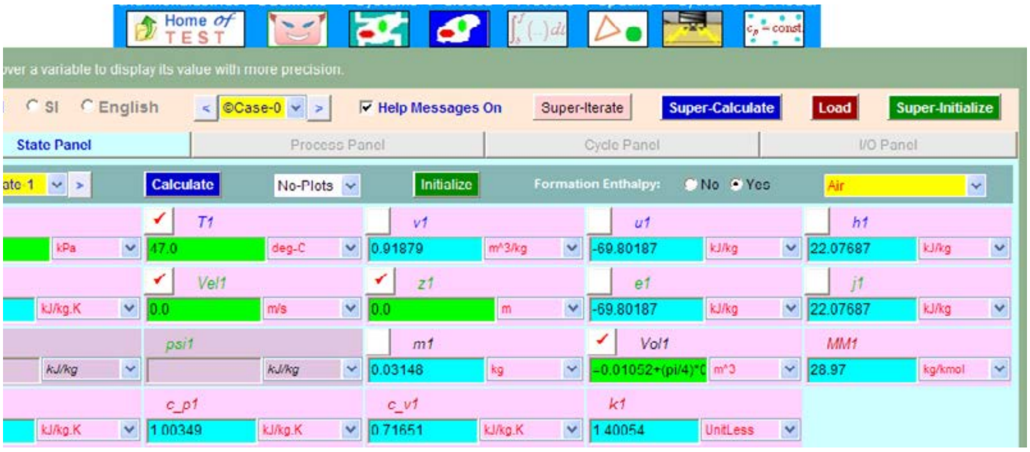
Hovering the mouse pointer over 'Reciprocating Cycles' gives the following pop up:



4. Click on Reciprocating cycles. For Material model, choose Perfect Gas (PG) model, where sp. heat, cp is constant.



5. Select Air as the working substance. For State 1, enter p1, T1 and Vol1 = Vc + Vs = 0.01052 + (pi/4)* 0.375 * (0.25)*0.25. Hit Enter. We get:



Note that all other parameters are immediately calculated. Observe that m1 = 0.03148 kg.

6. For State 2: we have m2 = m1, Vol2 = Vc = 0.01052 m^3, and s2 = s1 since process 1-2 is isentropic. Hit Enter. We get:

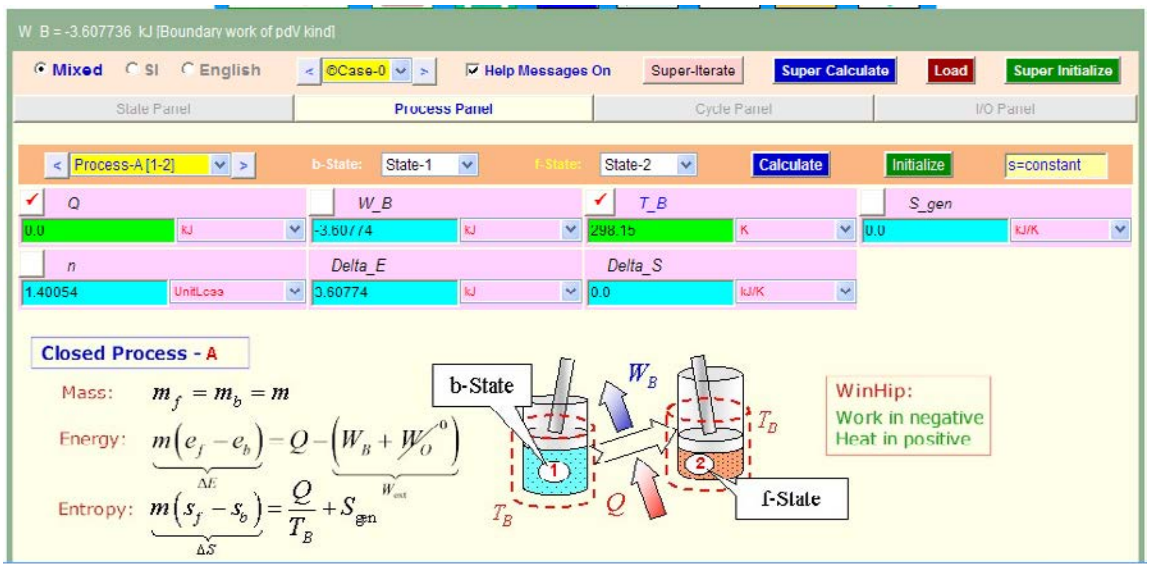
7. For State 3: p3 = 2500 kPa, by data, and, m3 = m1, Vol3 = Vol2, since process 2-3 is at constant volume. Hit Enter. We get:

Note that T3 = 2910.679 K.

8. For State 4: Enter s4 = s3 since process 3-4 is isentropic, and Vol4 = Vol1, m4 = m1. Hit Enter. We get:

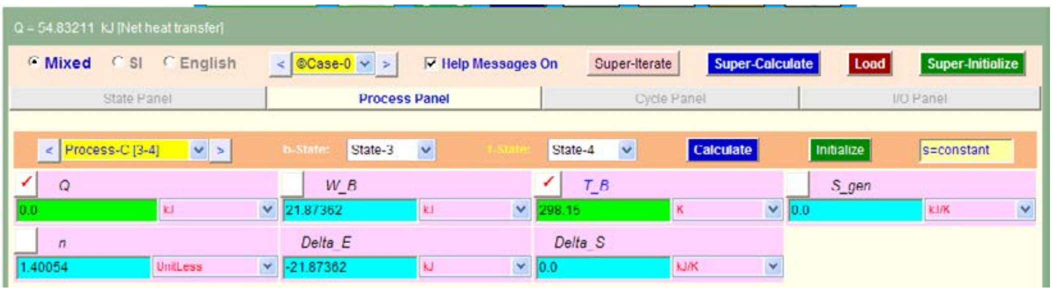
Note that p4, T4 are now calculated.

9. Now, go to Process Panel. For Process-A, choose State 1 for b-state (i.e. begin state) and State 2 for f-state (i.e. finish state). Q = 0, since process 1-2 is adiabatic. Hit Enter. We get:

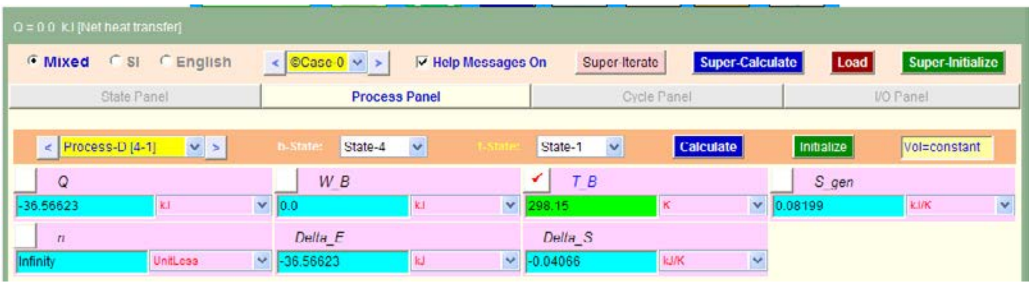


10. Similarly, for Process-B, i.e. process 2-3 in the Otto cycle: Hit Calculate. We get:

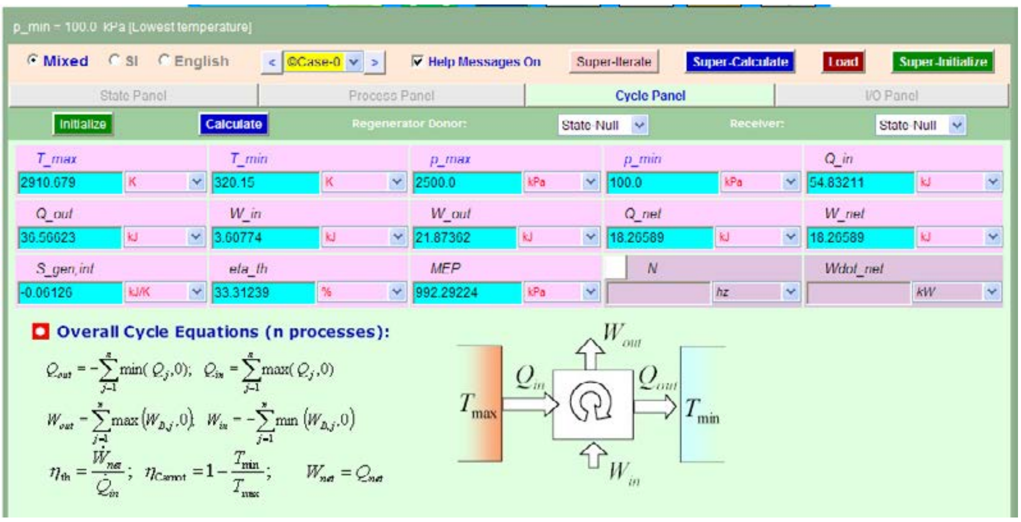
11. Similarly, for Process-C, i.e. process 3-4 in the Otto cycle: Now, Q = 0. Hit Calculate. We get:



12. Similarly, for Process-D, i.e. process 4-1 in the Otto cycle: Hit Calculate. We get:



13. Go to Cycle Panel. Click on Calculate and SuperCalculate. We get:



Here, all cycle calculations are available.

Thus:

Thermal efficiency = eta_th = 33.31% …. Ans.

MEP = 992.29 kPa = 9.923 bar … Ans.

---

14. I/O panel gives the TEST code etc:

```
#~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE
#        Daemon Path: Systems>Closed>Process>Specific>PowerCycle>PG-Model; v-10.ca08
#--------------------Start of TEST-code ------------------------------------------------------------------------
States   {
         State-1: Air;
         Given: { p1= 100.0 kPa; T1= 47.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; Vol1= "0.01052+(pi/4)*0.3
75*0.25*0.25"m^3; }
         State-2: Air;
         Given: { s2= "s1"kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; m2= "m1"kg; Vol2= 0.01052 m^3; }
         State-3: Air;
         Given: { p3= 2500.0 kPa; Vel3= 0.0 m/s; z3= 0.0 m; m3= "m1"kg; Vol3= "Vol2"m^3; }
         State-4: Air;
         Given: { s4= "s3"kJ/kg.K; Vel4= 0.0 m/s; z4= 0.0 m; m4= "m1"kg; Vol4= "Vol1"m^3; }
         }
Analysis {
         Process-A: b-State = State-1; f-State = State-2;
         Given: { Q= 0.0 kJ; T_B= 298.15 K; }
         Process-B: b-State = State-2; f-State = State-3;
         Given: { T_B= 298.15 K; }
         Process-C: b-State = State-3; f-State = State-4;
         Given: { Q= 0.0 kJ; T_B= 298.15 K; }
         Process-D: b-State = State-4; f-State = State-1;
         Given: { T_B= 298.15 K; }
         }
#----------------------End of TEST-code ----------------------------------------------------------------------

#******DETAILED OUTPUT:
# Evaluated States:
#        State-1: Air > PG-Model;
#                 Given: p1= 100.0 kPa; T1= 47.0 deg-C; Vel1= 0.0 m/s;
#                        z1= 0.0 m; Vol1= "0.01052+(pi/4)*0.375*0.25*0.25"m^3;
#                 Calculated: v1= 0.9188 m^3/kg; u1= -69.8019 kJ/kg; h1= 22.0769 kJ/kg;
#                        s1= 6.9581 kJ/kg.K; e1= -69.8019 kJ/kg; j1= 22.0769 kJ/kg;
#                        m1= 0.0315 kg; MM1= 28.97 kg/kmol; R1= 0.287 kJ/kg.K;
#                        c_p1= 1.0035 kJ/kg.K; c_v1= 0.7165 kJ/kg.K; k1= 1.4005 UnitLess;
#        State-2: Air > PG-Model;
#                 Given: s2= "s1"kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m;
```

m2= "m1"kg; Vol2= 0.01052 m^3;
Calculated: p2= 412.3387 kPa; T2= 480.0742 K; v2= 0.3341 m^3/kg;
u2= 44.785 kJ/kg; h2= 182.5598 kJ/kg; e2= 44.785 kJ/kg;
j2= 182.5598 kJ/kg; MM2= 28.97 kg/kmol; R2= 0.287 kJ/kg.K;
c_p2= 1.0035 kJ/kg.K; c_v2= 0.7165 kJ/kg.K; k2= 1.4005 UnitLess;
State-3: Air > PG-Model;
Given: p3= 2500.0 kPa; Vel3= 0.0 m/s; z3= 0.0 m;
m3= "m1"kg; Vol3= "Vol2"m^3;
Calculated: T3= 2910.679 K; v3= 0.3341 m^3/kg; u3= 1786.3315 kJ/kg;
h3= 2621.657 kJ/kg; s3= 8.2494 kJ/kg.K; e3= 1786.3315 kJ/kg;
j3= 2621.657 kJ/kg; MM3= 28.97 kg/kmol; R3= 0.287 kJ/kg.K;
c_p3= 1.0035 kJ/kg.K; c_v3= 0.7165 kJ/kg.K; k3= 1.4005 UnitLess;
State-4: Air > PG-Model;
Given: s4= "s3"kJ/kg.K; Vel4= 0.0 m/s; z4= 0.0 m;
m4= "m1"kg; Vol4= "Vol1"m^3;
Calculated: p4= 606.2977 kPa; T4= 1941.0623 K; v4= 0.9188 m^3/kg;
u4= 1091.5938 kJ/kg; h4= 1648.6526 kJ/kg; e4= 1091.5938 kJ/kg;
j4= 1648.6526 kJ/kg; MM4= 28.97 kg/kmol; R4= 0.287 kJ/kg.K;
c_p4= 1.0035 kJ/kg.K; c_v4= 0.7165 kJ/kg.K; k4= 1.4005 UnitLess;
#--------Property spreadsheet starts: #

#	State	p(kPa)	T(K)	v(m^3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	100.0	320.2	0.9188	-69.8	22.08	6.958
#	2	412.34	480.1	0.3341	44.78	182.56	6.958
#	3	2500.0	2910.7	0.3341	1786.33	2621.66	8.249
#	4	606.3	1941.1	0.9188	1091.59	1648.65	8.249

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

 # Mass, Energy, and Entropy Analysis Results:
Process-A: b-State = State-1; f-State = State-2;
Given: Q= 0.0 kJ; T_B= 298.15 K;
Calculated: W_B= -3.607736 kJ; S_gen= -0.0 kJ/K; n= 1.4005353 UnitLess; Delta_E= 3.607736 kJ;
Delta_S= -0.0 kJ/K;
Process-B: b-State = State-2; f-State = State-3;
Given: T_B= 298.15 K;
Calculated: Q= 54.83211 kJ; W_B= 0.0 kJ; S_gen= -0.14325188 kJ/K; n= Infinity UnitLess;
Delta_E= 5 4.83211 kJ; Delta_S= 0.040655926 kJ/K;
Process-C: b-State = State-3; f-State = State-4;
Given: Q= 0.0 kJ; T_B= 298.15 K;

Calculated: W_B= 21.873623 kJ; S_gen= -0.0 kJ/K; n= 1.4005353 UnitLess; Delta_E= -21.873623 kJ;

Delta_S= -0.0 kJ/K;

Process-D: b-State = State-4; f-State = State-1;

Given: T_B= 298.15 K;

Calculated: Q= -36.566227 kJ; W_B= 0.0 kJ; S_gen= 0.0819878 kJ/K; n= Infinity UnitLess;

Delta_E= -36.566227 kJ; Delta_S= -0.040655926 kJ/K;

Cycle Analysis Results:

Calculated: T_max= 2910.679 K; T_min= 320.15 K; p_max= 2500.0 kPa;

p_min= 100.0 kPa; Q_in= 54.83211 kJ; Q_out= 36.56623 kJ;

W_in= 3.60774 kJ; W_out= 21.87362 kJ; Q_net= 18.26589 kJ;

W_net= 18.26589 kJ; S_gen,int= -0.06126 kJ/K; **eta_th= 33.31239 %;**

MEP= 992.29224 kPa;

==

Prob.1.15. An engine of 250 mm bore and 375 mm stroke works on the Otto cycle. The clearance volume is 0.00263 m^3. The initial pressure and temp are 1 bar and 50 C. If the max. pressure is limited to 25 bar, find the following: (a) Air standard efficiency, and (b) Mean Effective Pressure. [VTU-ATD-July/Aug. 2002]

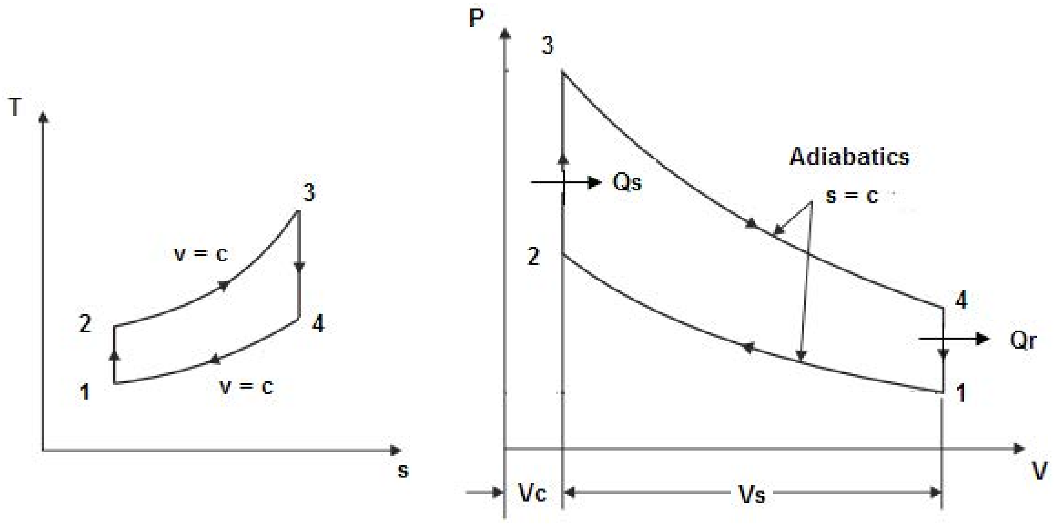
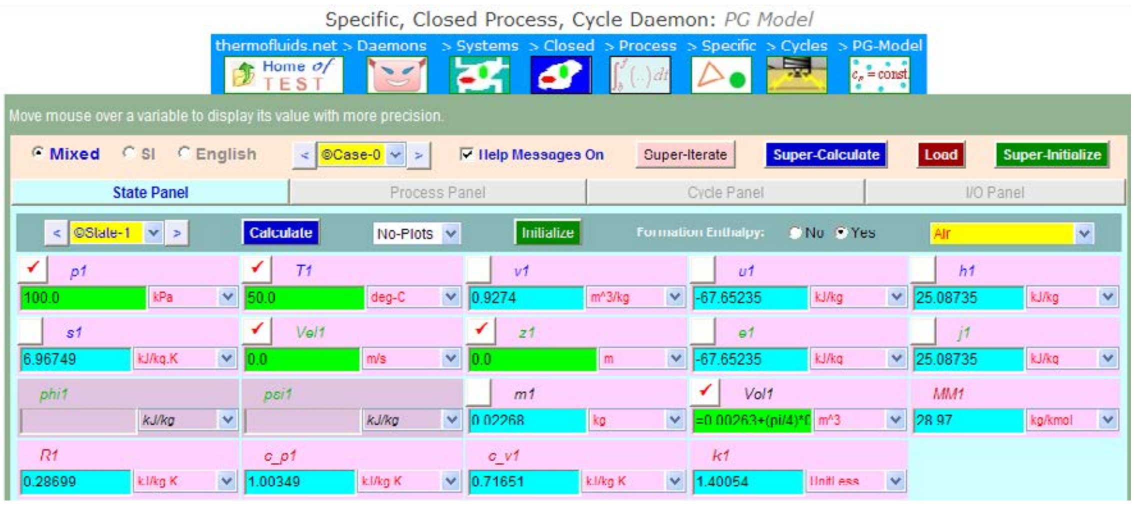


Fig.Prob.1.15

TEST Solution:

Steps 1 to 4 are the same as for the previous problem.

5. Select Air as the working substance. For State 1, enter p1, T1 and Vol1 = Vc + Vs = 0.00263 + (pi/4) 0.375 * 0.25*0.25. Hit Enter. We get:

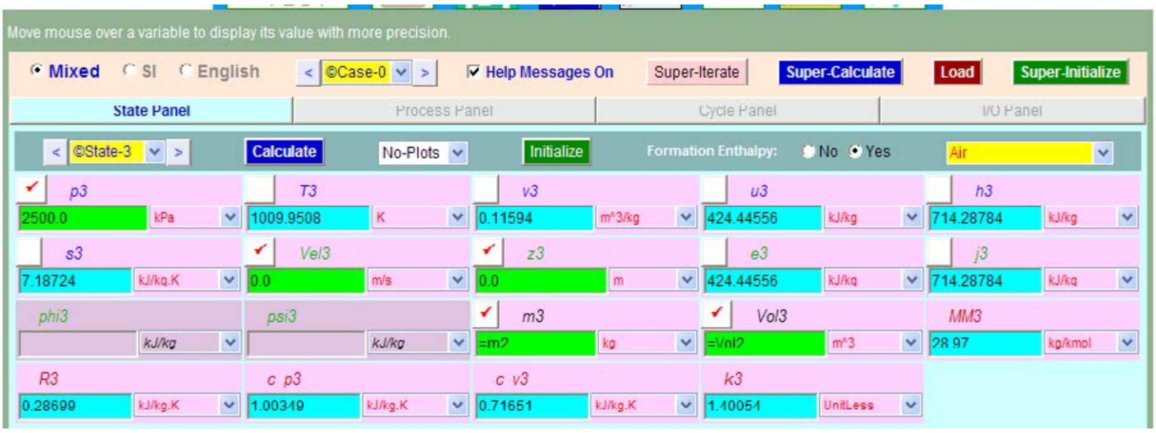


Note that all other parameters are immediately calculated. Observe that m1 = 0.02268 kg.

6. For State 2: we have m2 = m1, Vol2 = Vc = 0.00263 m^3, and s2 = s1 since process 1-2 is isentropic. Hit Enter. We get:

Note that p2 = 839.69 kPa, T2 = 743.2 K.

7. For State 3: p3 = 2500 kPa, by data, and, m3 = m2, Vol3 = Vol2, since process 2-3 is at constant volume. Hit Enter. We get:

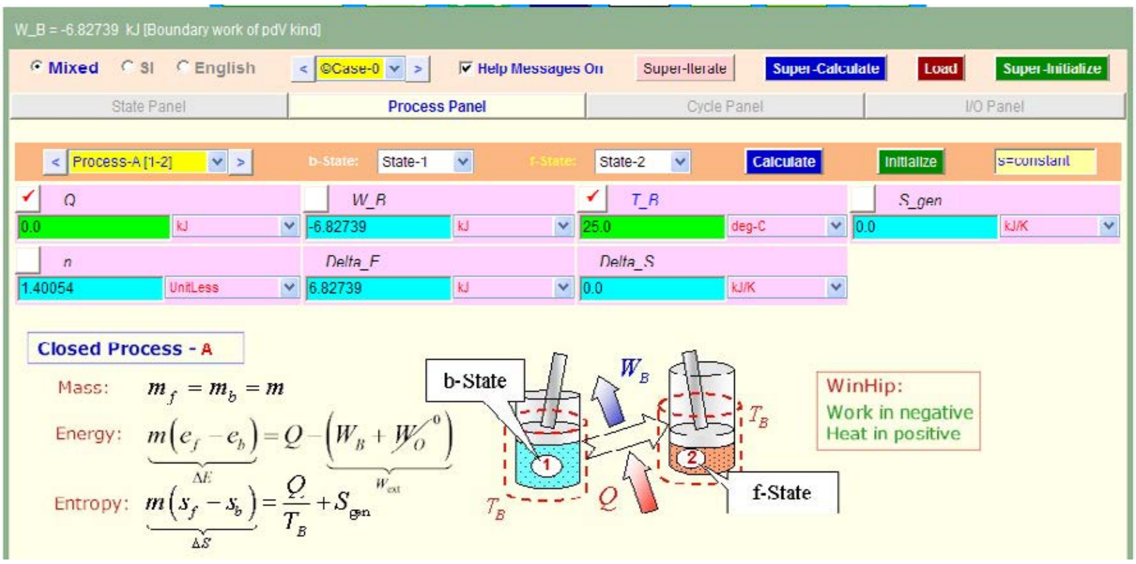


Note that T3 = 1009.95 K.

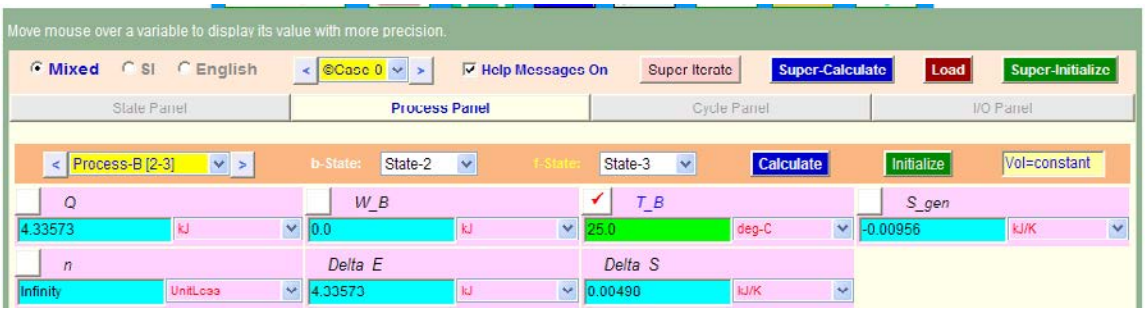
8. For State 4: Enter s4 = s3 since process 3-4 is isentropic, and Vol4 = Vol1, m4 = m3. Hit Enter. We get:

Note that p4, T4 are now calculated.

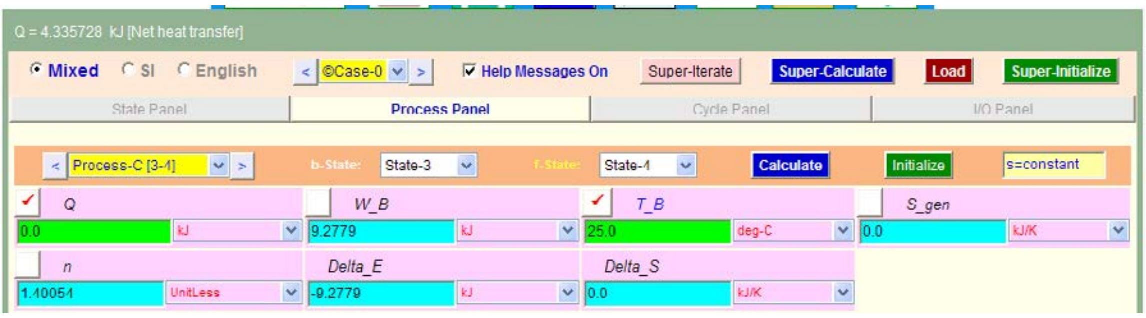
9. Now, go to Process Panel. For Process-A, choose State 1 for b-state (i.e. begin state) and State 2 for f-state (i.e. finish state). Q = 0, since process 1-2 is adiabatic. Hit Enter. We get:



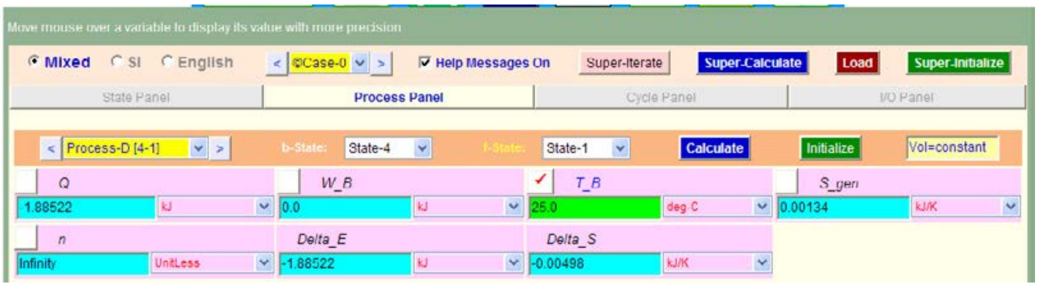
10. Similarly, for Process-B, i.e. process 2-3 in the Otto cycle: Hit Calculate. We get:



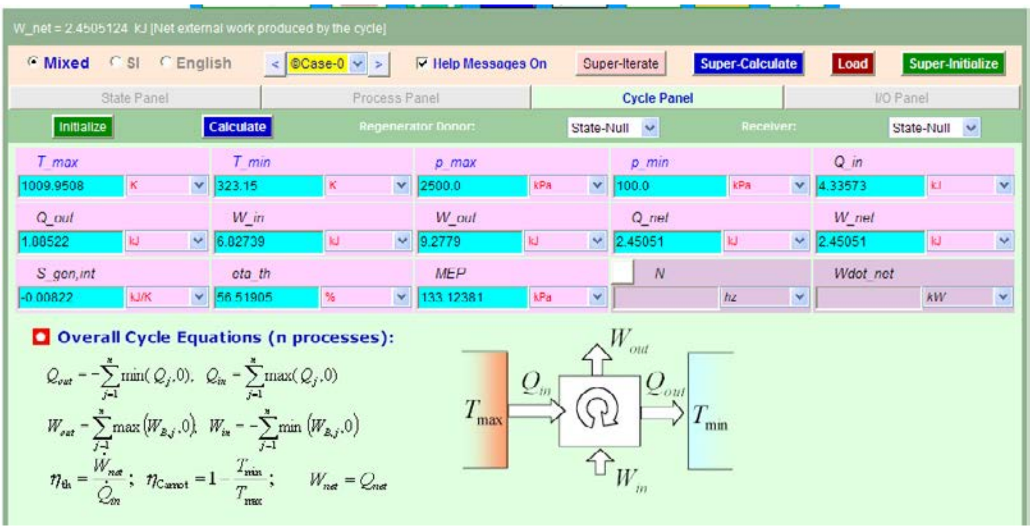
11. Similarly, for Process-C, i.e. process 3-4 in the Otto cycle: Now, Q = 0. Hit Calculate. We get:



12. Similarly, for Process-D, i.e. process 4-1 in the Otto cycle: Hit Calculate. We get:



13. Go to Cycle Panel. Click on Calculate and SuperCalculate. We get:



Here, all cycle calculations are available.

Thus:

Thermal efficiency = eta_th = 56.52% …. Ans.

MEP = 133.124 kPa = 1.33 bar … Ans.

14. I/O panel gives the TEST code etc:

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

Daemon Path: Systems>Closed>Process>Specific>PowerCycle>PG-Model; v-10.ca08

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

States {

State-1: Air;

Given: { p1= 100.0 kPa; T1= 50.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; Vol1= "0.00263+(pi/4)*0.375*0.25*0.25"m^3; }

State-2: Air;
Given: { s2= “s1”kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; m2= “m1”kg; Vol2= 0.00263 m^3; }
State-3: Air;
Given: { p3= 2500.0 kPa; Vel3= 0.0 m/s; z3= 0.0 m; m3= “m2“kg; Vol3= “Vol2”m^3; }
State-4: Air;
Given: { s4= “s3“kJ/kg.K; Vel4= 0.0 m/s; z4= 0.0 m; m4= “m3“kg; Vol4= “Vol1“m^3; }
}
Analysis {
Process-A: b-State = State-1; f-State = State-2;
Given: { Q= 0.0 kJ; T_B= 25.0 deg-C; }
Process-B: b-State = State-2; f-State = State-3;
Given: { T_B= 25.0 deg-C; }
Process-C: b-State = State-3; f-State = State-4;
Given: { Q= 0.0 kJ; T_B= 25.0 deg-C; }
Process-D: b-State = State-4; f-State = State-1;
Given: { 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	323.2	0.9274	-67.65	25.09	6.967
#	2	1839.69	743.2	0.1159	233.32	446.6	6.967
#	3	2500.0	1010.0	0.1159	424.45	714.29	7.187
#	4	135.89	439.1	0.9274	15.45	141.48	7.187

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

 # Mass, Energy, and Entropy Analysis Results:

Process-A: b-State = State-1; f-State = State-2;

Given: Q= 0.0 kJ; T_B= 25.0 deg-C;

Calculated: W_B= -6.82739 kJ; S_gen= -0.0 kJ/K; n= 1.4005353 UnitLess; Delta_E= 6.82739 kJ;

Delta_S= -0.0 kJ/K;

Process-B: b-State = State-2; f-State = State-3;

Given: T_B= 25.0 deg-C;

Calculated: Q= 4.335728 kJ; W_B= 0.0 kJ; S_gen= -0.009557178 kJ/K; n= Infinity UnitLess;

Delta_E= 4.335728 kJ; Delta_S= 0.0049849246 kJ/K;

Process-C: b-State = State-3; f-State = State-4;

Given: Q= 0.0 kJ; T_B= 25.0 deg-C;

Calculated: W_B= 9.277903 kJ; S_gen= -0.0 kJ/K; n= 1.4005353 UnitLess; Delta_E= -9.277903 kJ;

Delta_S= -0.0 kJ/K;

Process-D: b-State = State-4; f-State = State-1;

Given: T_B= 25.0 deg-C;

Calculated: Q= -1.8852158 kJ; W_B= 0.0 kJ; S_gen= 0.0013381199 kJ/K; n= Infinity UnitLess;

Delta_E= -1.8852158 kJ; Delta_S= -0.0049849246 kJ/K;

 # Cycle Analysis Results:

Calculated: T_max= 1009.9508 K; T_min= 323.15 K; p_max= 2500.0 kPa;

p_min= 100.0 kPa; Q_in= 4.33573 kJ; Q_out= 1.88522 kJ;

W_in= 6.82739 kJ; W_out= 9.2779 kJ; Q_net= 2.45051 kJ;

W_net= 2.45051 kJ; S_gen,int= -0.00822 kJ/K; **eta_th= 56.51905 %;**

MEP= 133.12381 kPa;

==

Prob.1.16: In an Otto cycle, temp. before compression = 27 C, temp. after expansion = 627 C, compression ratio = 10. Find Thermal efficiency, net work, and specific air consumption in kg/kWh.

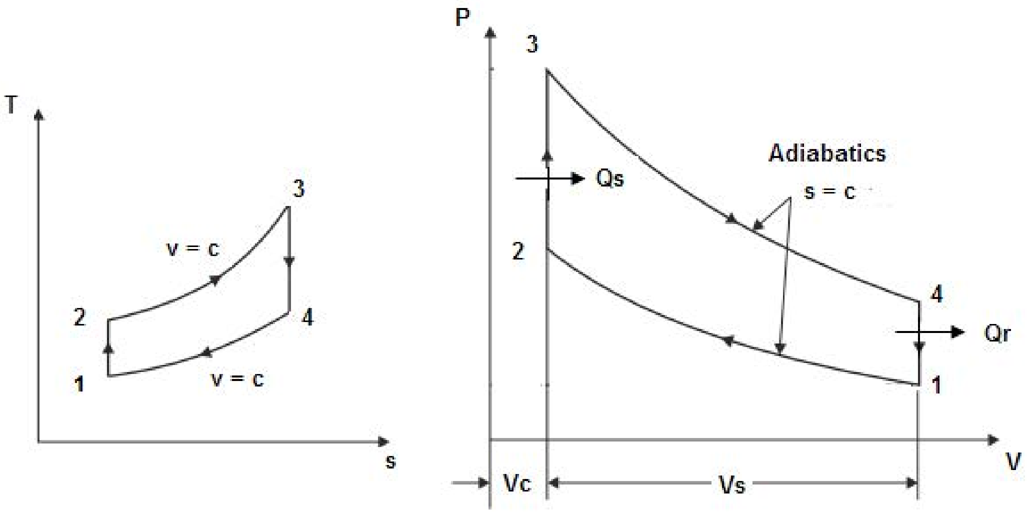
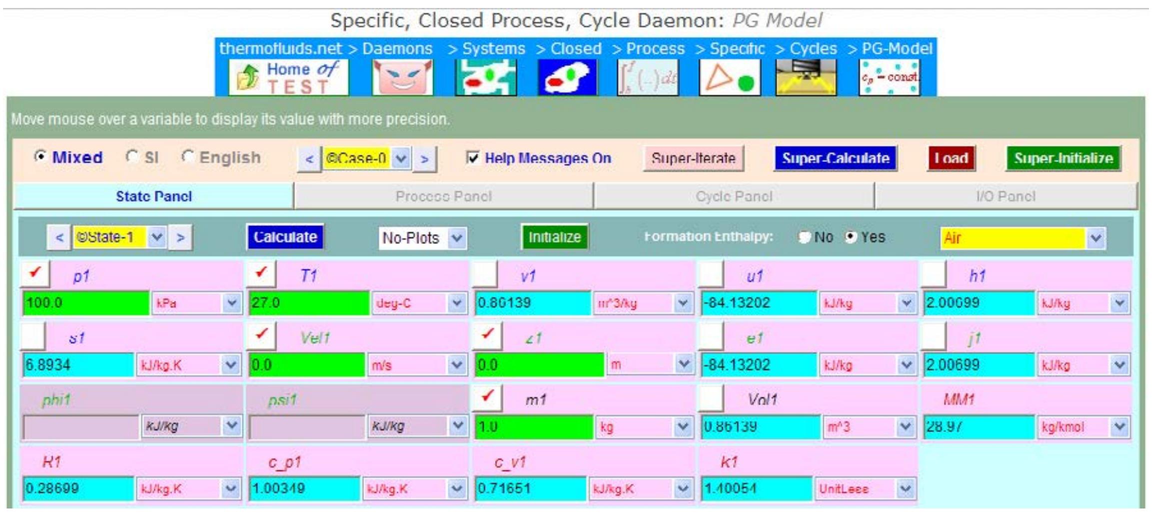


Fig.Prob.1.16

TEST Solution:

Steps 1 to 4 are the same as for the previous problem.

5. Select Air as the working substance. For State 1, enter p1, T1 and m1. Hit Enter. We get:



Note that all other parameters are immediately calculated.

6. For State 2: we have m2 = m1, v2 = vc = v1/10 since comprn. ratio is 10, and s2 = s1 since process 1-2 is isentropic. Hit Enter. We get:

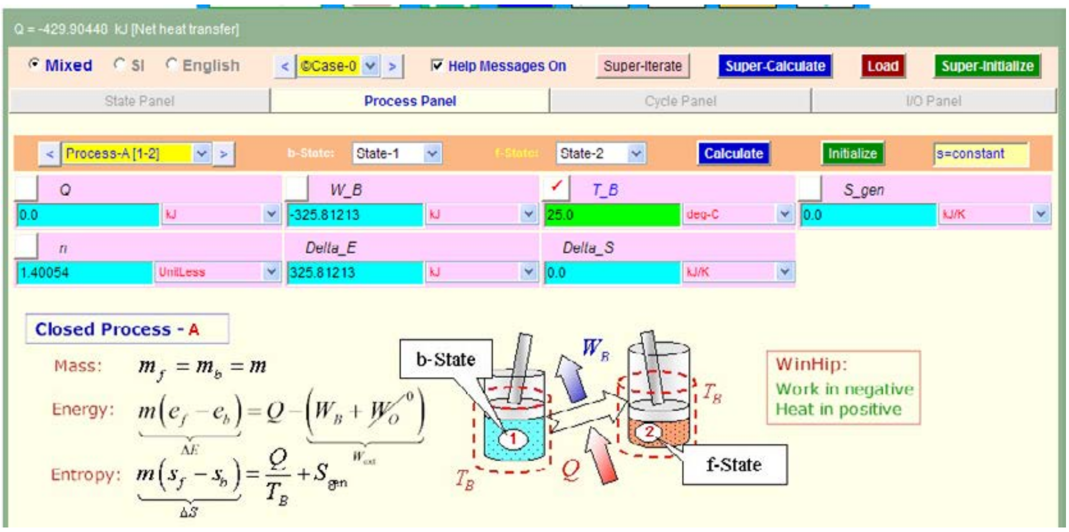
Note that p2 = 2514.98 kPa, T2 = 754.87 K.

7. For State 3: s3=s4 (to be brought in later after SuperCalculate), and, m3 = m1, v3 = v2, since process 2-3 is at constant volume. Hit Enter. We get:

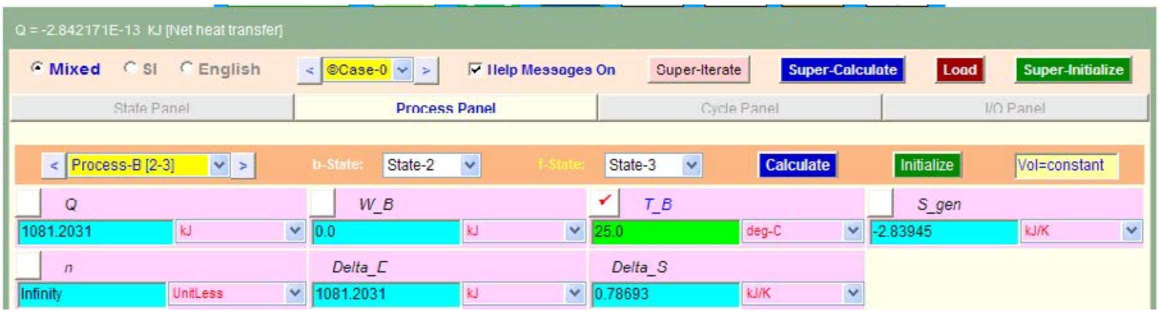
8. For State 4: Enter T4 = 627 C (by data), and v4 = v1, m4 = m1. Hit Enter. We get:

Note that p4, s4 etc are now calculated.

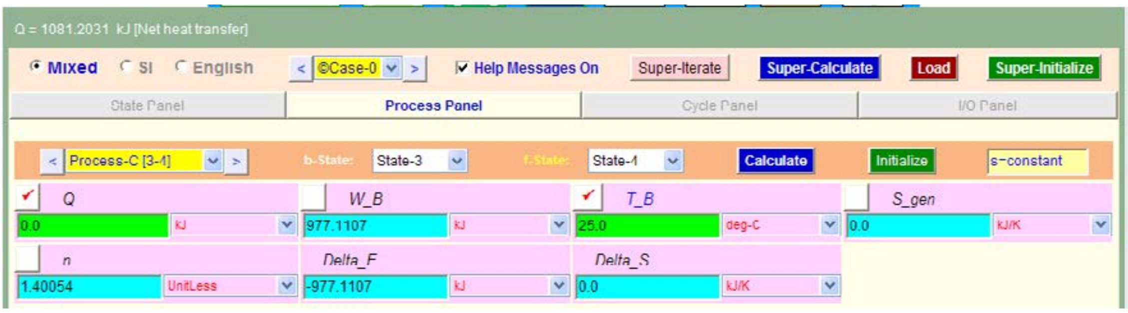
9. Now, go to Process Panel. For Process-A, choose State 1 for b-state (i.e. begin state) and State 2 for f-state (i.e. finish state). Q = 0, since process 1-2 is adiabatic. Hit Enter. We get:



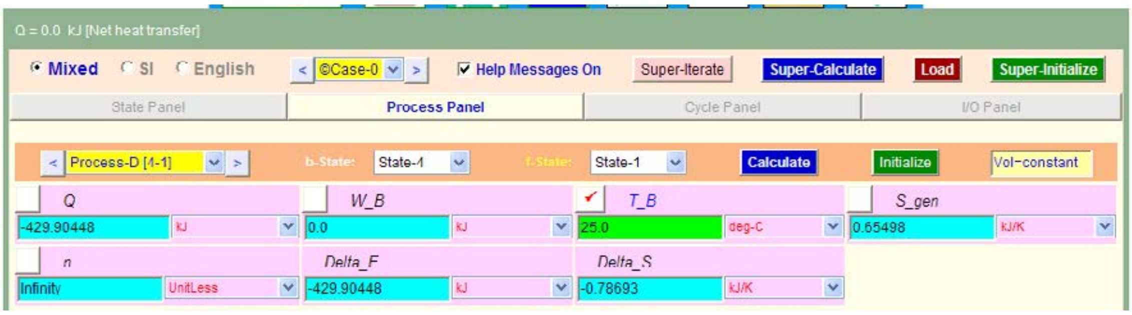
10. Similarly, for Process-B, i.e. process 2-3 in the Otto cycle: Hit Calculate. We get:



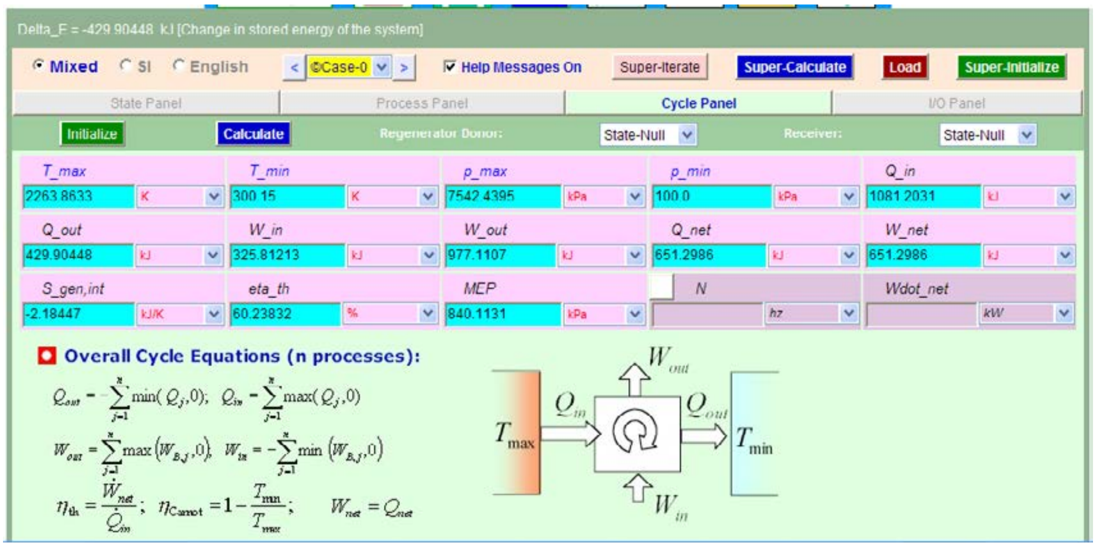
11. Similarly, for Process-C, i.e. process 3-4 in the Otto cycle: Now, Q = 0. Hit Calculate. We get:



12. Similarly, for Process-D, i.e. process 4-1 in the Otto cycle: Hit Calculate. We get:



13. Go to Cycle Panel. Click on Calculate and SuperCalculate. We get:



Here, all cycle calculations are available.

Thus:

Thermal efficiency = eta_th = 60.24% …. Ans.

MEP = 840.11 kPa = 8.4 bar … Ans.

Sp. air consumption in kg/kWh = 3600 / W_net:

=3600/651.2986 = 5.527 kg/kWh … Ans.

I/O panel gives the TEST code etc.

```
#~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE
#       Daemon Path: Systems>Closed>Process>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; m1= 1.0 kg; }
        State-2: Air;
        Given: { v2= "v1/10"m^3/kg; s2= "s1"kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; m2= "m1"kg; }
        State-3: Air;
        Given: { v3= "v2"m^3/kg; s3= "s4"kJ/kg.K; Vel3= 0.0 m/s; z3= 0.0 m; m3= "m1"kg; }
        State-4: Air;
        Given: { T4= 627.0 deg-C; v4= "v1"m^3/kg; Vel4= 0.0 m/s; z4= 0.0 m; m4= "m1"kg; }
        }
Analysis {
        Process-A: b-State = State-1; f-State = State-2;
        Given: { T_B= 25.0 deg-C; }
        Process-B: b-State = State-2; f-State = State-3;
        Given: { T_B= 25.0 deg-C; }
        Process-C: b-State = State-3; f-State = State-4;
        Given: { Q= 0.0 kJ; T_B= 25.0 deg-C; }
        Process-D: b-State = State-4; f-State = State-1;
        Given: { 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       2514.98   754.9    0.0861      241.68     458.32     6.893
#       3       7542.44   2263.9   0.0861      1322.88    1972.58    7.68
#       4       299.9     900.2    0.8614      345.77     604.1      7.68
#--------Property spreadsheet ends-----------------------------------------------------------------------------
# Mass, Energy, and Entropy Analysis Results:
#       Process-A: b-State = State-1; f-State = State-2;
#               Given: T_B= 25.0 deg-C;
#               Calculated: Q= "-2.842171E-13"kJ; W_B= -325.81213 kJ; S_gen= "9.532688E-16"kJ/K;
n= 1.4005353 UnitLess;
#                       Delta_E= 325.81213 kJ; Delta_S= -0.0 kJ/K;
#       Process-B: b-State = State-2; f-State = State-3;
#               Given: T_B= 25.0 deg-C;
```

Calculated: Q= 1081.2031 kJ; W_B= 0.0 kJ; S_gen= -2.8394477 kJ/K; n= Infinity UnitLess;
Delta_E= 1081.2031 kJ; Delta_S= 0.78692514 kJ/K;
Process-C: b-State = State-3; f-State = State-4;
Given: Q= 0.0 kJ; T_B= 25.0 deg-C;
Calculated: W_B= 977.1107 kJ; S_gen= -0.0 kJ/K; n= 1.4005353 UnitLess; Delta_E= -977.1107 kJ;
Delta_S= -0.0 kJ/K;
Process-D: b-State = State-4; f-State = State-1;
Given: T_B= 25.0 deg-C;
Calculated: Q= -429.90448 kJ; W_B= 0.0 kJ; S_gen= 0.65498155 kJ/K; n= Infinity UnitLess;
Delta_E= -429.90448 kJ; Delta_S= -0.78692514 kJ/K;
 # Cycle Analysis Results:
#
Calculated: T_max= 2263.8633 K; T_min= 300.15 K; p_max= 7542.4395 kPa;
p_min= 100.0 kPa; Q_in= 1081.2031 kJ; Q_out= 429.90448 kJ;
W_in= 325.81213 kJ; W_out= 977.1107 kJ; Q_net= 651.2986 kJ;
W_net= 651.2986 kJ; S_gen,int= -2.18447 kJ/K; **eta_th= 60.23832 %;**
MEP= 840.1131 kPa;

#
#******CALCULATE VARIABLES: Type in an expression starting with an '=' sign ('= mdot1*(h2-h1)', '= sqrt(4*A1/PI)', etc.) and press the Enter key)*********
#Sp. air consumption in kg/kWh = 3600 / W_net:
=3600/651.2986

3600/651.2986 = 5.527418606457928 kg/kWh … Ans.

==

"**Prob.1.17.**The compression ratio of an ideal Otto cycle is 6.2:1. The pressure and temp at the commencement of compression are 1 bar and 28 C. The heat added during the constant volume combustion process is 1205 kJ/kg. Determine the peak pressure and temp, work output per kg of air, and air standard efficiency. Assume cv = 0.717 kJ/kg.K and gamma = 1.4 for air. [VTU-ATD-Jan. 2005]"

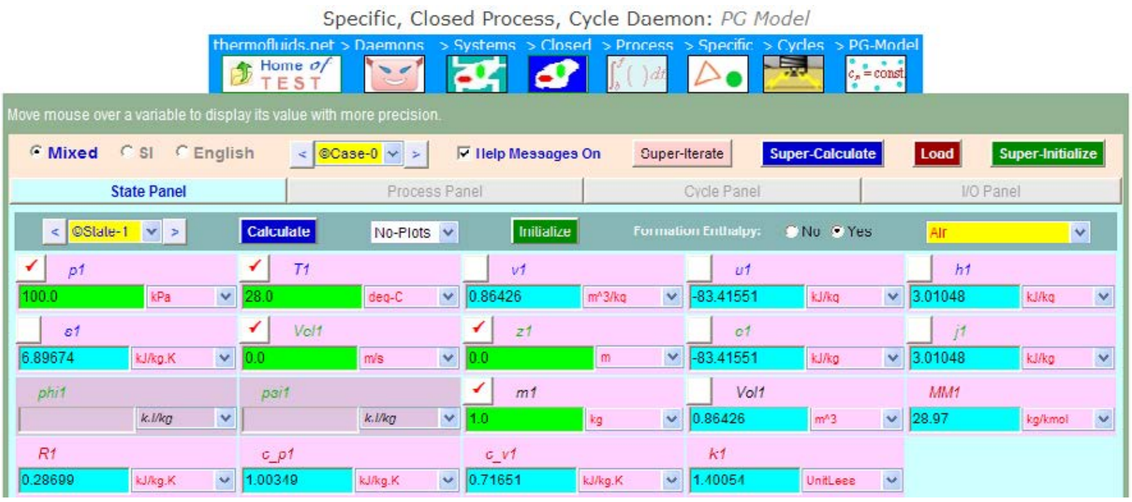
Note: This is the same as Prob.1.11, which was solved with EES.

Now, let us solve it with TEST:

TEST Solution:

Steps 1 to 4 are the same as for the previous problem.

5. Select Air as the working substance. For State 1, enter p1, T1 and m1. Hit Enter. We get:



Note that all other parameters are immediately calculated.

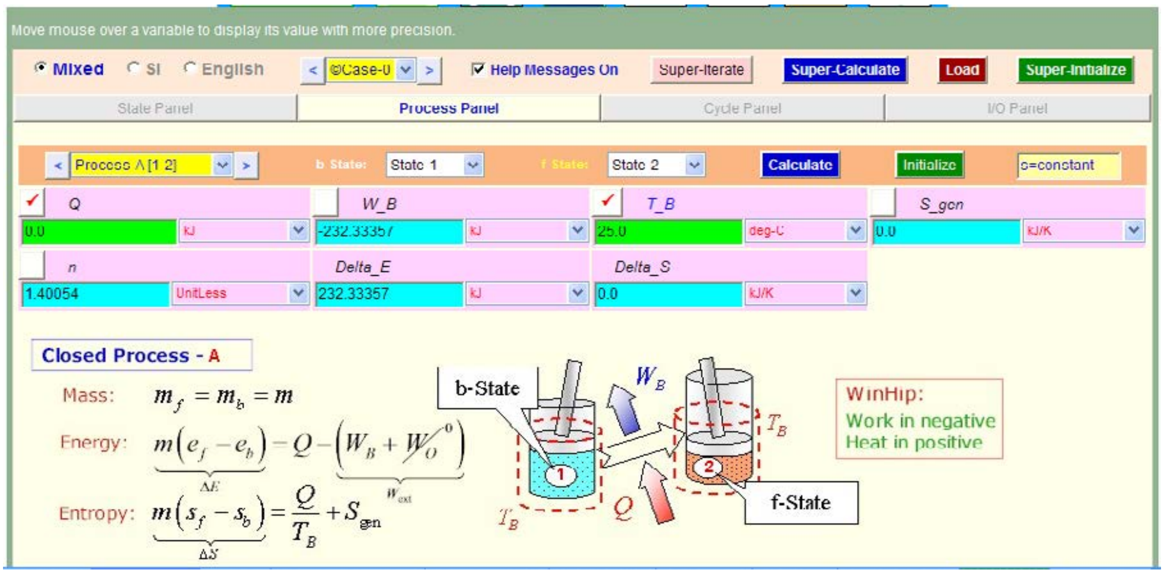
6. For State 2: we have m2 = m1, v2 = vc = v1/6.2 since comprn. ratio is 6.2, and s2 = s1 since process 1-2 is isentropic. Hit Enter. We get:

Note that p2 = 1287.575 kPa, T2 = 625.41 K.

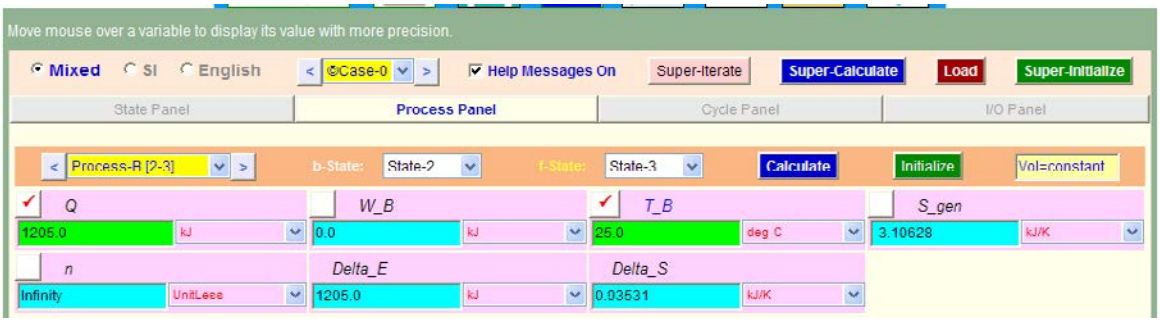
7. For State 3: m3 = m2, v3 = v2, since process 2-3 is at constant volume. Hit Enter. We get (later, after SuperCalculate):

8. For State 4: Enter s4 = s3, and v4 = v1, m4 = m3. Hit Enter. We get (later, after SuperCalculate):

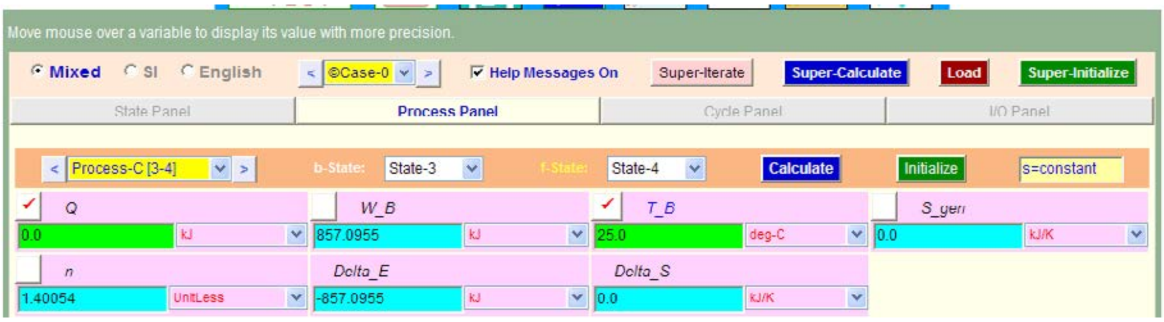
9. Now, go to Process Panel. For Process-A, choose State 1 for b-state (i.e. begin state) and State 2 for f-state (i.e. finish state). Q = 0, since process 1-2 is adiabatic. Hit Enter. We get:



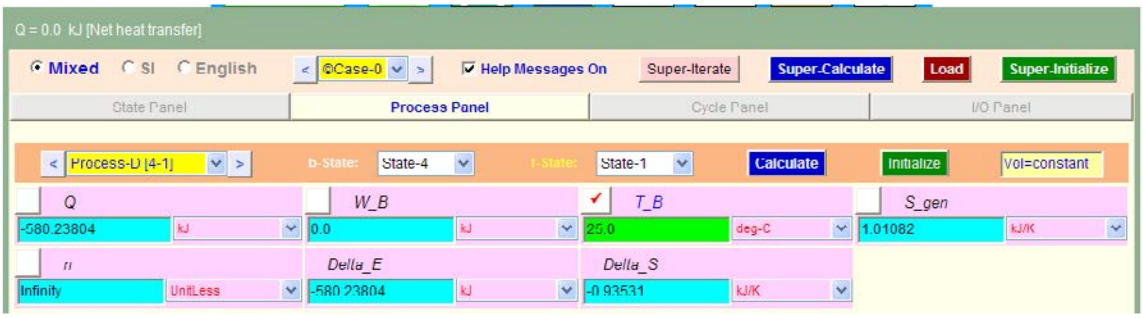
10. Similarly, for Process-B, i.e. process 2-3 in the Otto cycle: Here, enter Q = 1205 kJ, heat added, by data. Hit Calculate. We get:



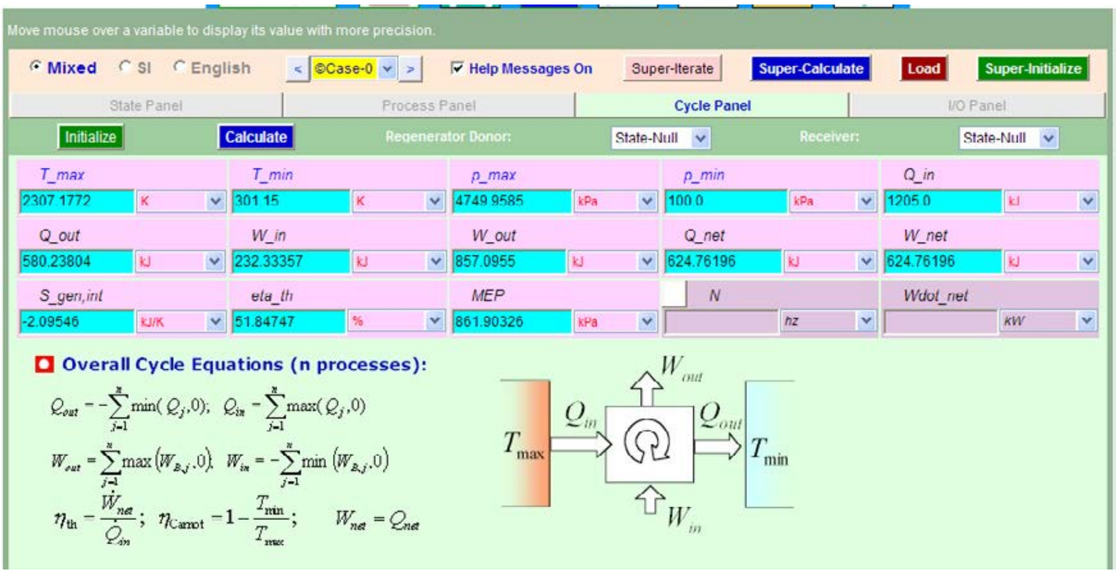
11. Similarly, for Process-C, i.e. process 3-4 in the Otto cycle: Now, Q = 0. Hit Calculate. We get:



12. Similarly, for Process-D, i.e. process 4-1 in the Otto cycle: Hit Calculate. We get:



13. Go to Cycle Panel. Click on Calculate and SuperCalculate. We get:



Here, all cycle calculations are available.

Thus:

Thermal efficiency = eta_th = 51.85% …. Ans.

MEP = 861.9 kPa = 8.619 bar … Ans.

W_net = 624.76 kJ/kg …. Ans.

Peak pressure (P3) and peak temp. (T3) …. From State 3:

P3 = 4749.96 kPa = 47.4996 bar … Ans.

T3 = 2307.18 K …. Ans.

---

14. I/O panel gives TEST code etc:

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

Daemon Path: Systems>Closed>Process>Specific>PowerCycle>PG-Model; v-10.ca08

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

States {

State-1: Air;

```
        Given: { p1= 100.0 kPa; T1= 28.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; m1= 1.0 kg; }
        State-2: Air;
        Given: { v2= "v1/6.2"m^3/kg; s2= "s1"kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; }
        State-3: Air;
        Given: { v3= "v2"m^3/kg; Vel3= 0.0 m/s; z3= 0.0 m; m3= "m2"kg; }
        State-4: Air;
        Given: { v4= "v1"m^3/kg; s4= "s3"kJ/kg.K; Vel4= 0.0 m/s; z4= 0.0 m; m4= "m3"kg; }
        }
Analysis {
        Process-A: b-State = State-1; f-State = State-2;
        Given: { Q= 0.0 kJ; T_B= 25.0 deg-C; }
        Process-B: b-State = State-2; f-State = State-3;
        Given: { Q= 1205.0 kJ; T_B= 25.0 deg-C; }
        Process-C: b-State = State-3; f-State = State-4;
        Given: { Q= 0.0 kJ; T_B= 25.0 deg-C; }
        Process-D: b-State = State-4; f-State = State-1;
        Given: { 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	301.2	0.8643	-83.42	3.01	6.897
#	2	1287.58	625.4	0.1394	148.92	328.4	6.897
#	3	**4749.96**	**2307.2**	0.1394	1353.92	2016.05	7.832
#	4	368.91	1111.0	0.8643	496.82	815.65	7.832

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

 # Mass, Energy, and Entropy Analysis Results:

```
#       Process-A: b-State = State-1; f-State = State-2;
#               Given: Q= 0.0 kJ; T_B= 25.0 deg-C;
#               Calculated: W_B= -232.33357 kJ; S_gen= -0.0 kJ/K; n= 1.4005353 UnitLess; Delta_E=
232.33357 kJ;
#                       Delta_S= -0.0 kJ/K;
#       Process-B: b-State = State-2; f-State = State-3;
#               Given: Q= 1205.0 kJ; T_B= 25.0 deg-C;
#               Calculated: W_B= 0.0 kJ; S_gen= -3.1062787 kJ/K; n= Infinity UnitLess; Delta_E= 1205.0
kJ;
#                       Delta_S= 0.9353111 kJ/K;
#       Process-C: b-State = State-3; f-State = State-4;
#               Given: Q= 0.0 kJ; T_B= 25.0 deg-C;
```

Calculated: W_B= 857.0955 kJ; S_gen= -0.0 kJ/K; n= 1.4005353 UnitLess; Delta_E= -857.0955 kJ;

Delta_S= -0.0 kJ/K;

Process-D: b-State = State-4; f-State = State-1;

Given: T_B= 25.0 deg-C;

Calculated: Q= -580.23804 kJ; W_B= 0.0 kJ; S_gen= 1.0108168 kJ/K; n= Infinity UnitLess;

Delta_E= -580.23804 kJ; Delta_S= -0.9353111 kJ/K;

 # Cycle Analysis Results:

#

Calculated: T_max= 2307.1772 K; T_min= 301.15 K; p_max= 4749.9585 kPa;

p_min= 100.0 kPa; Q_in= 1205.0 kJ; Q_out= 580.23804 kJ;

W_in= 232.33357 kJ; W_out= 857.0955 kJ; Q_net= 624.76196 kJ;

W_net= 624.76196 kJ; S_gen,int= -2.09546 kJ/K; **eta_th= 51.84747 %;**

MEP= 861.90326 kPa;

==

Prob.1.18. In an Otto cycle, compression and expansion processes are modified to be *polytropic with n = 1.3*. Compression ratio is 9. At the beginning of compression, p1 = 1 bar, T1 = 300 K. Max. temp in the cycle = 2000 K. Determine: (a heat transfer and work per unit mass of air for each process, (b) the thermal efficiency, and (c) the MEP. [Ref: 3]

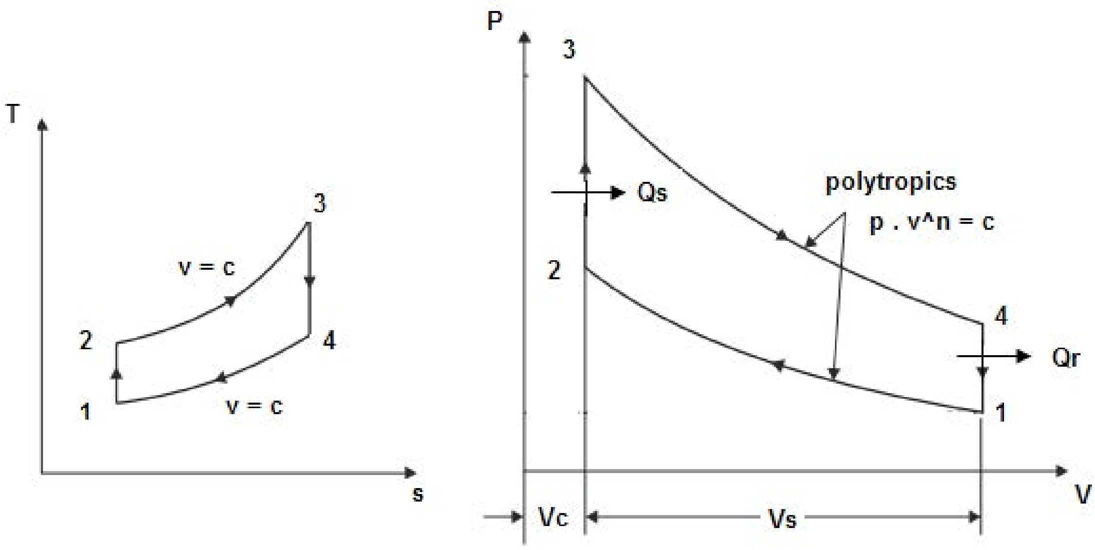


Fig.Prob.1.18

TEST Solution:

Steps 1 to 4 are the same as for the previous problem.

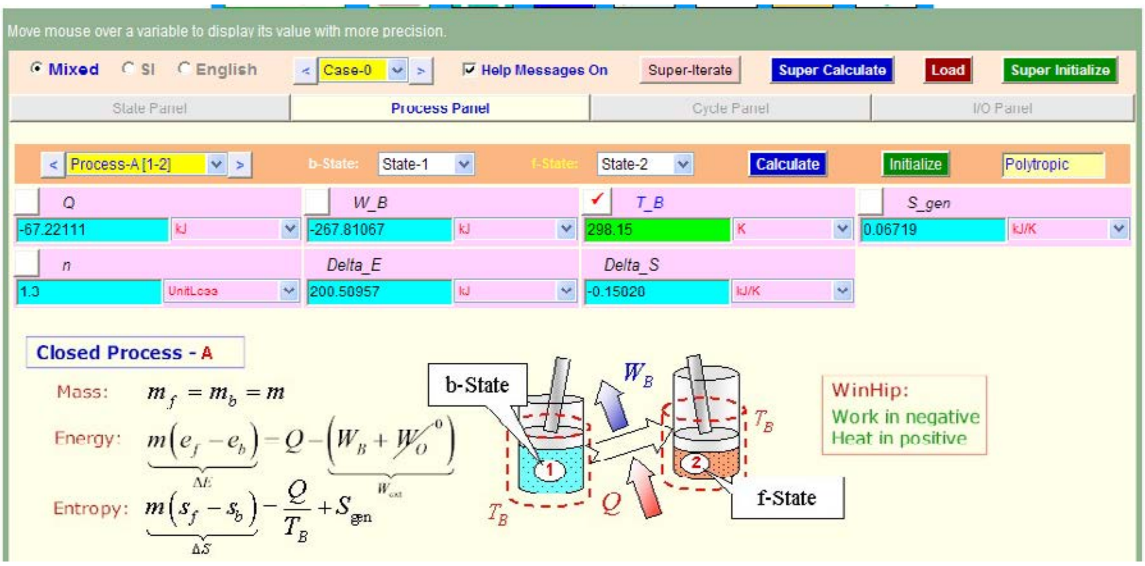
5. Select Air as the working substance. For State 1, enter p1, T1 and m1. Hit Enter. We get:

6. For State 2: enter v2 = v1/9 (since comprn. ratio = 9), m2 = m1, and p2 = p1 * (v1/v2)^1.3 (since process 3-4 is polytropic, with n = 1.3). Hit Enter. We get:

7. For State 3: enter T3 = 2000 K (by data), m3 = m1 and v3 = v2 since process 2-3 is at constant volume. Hit Enter:

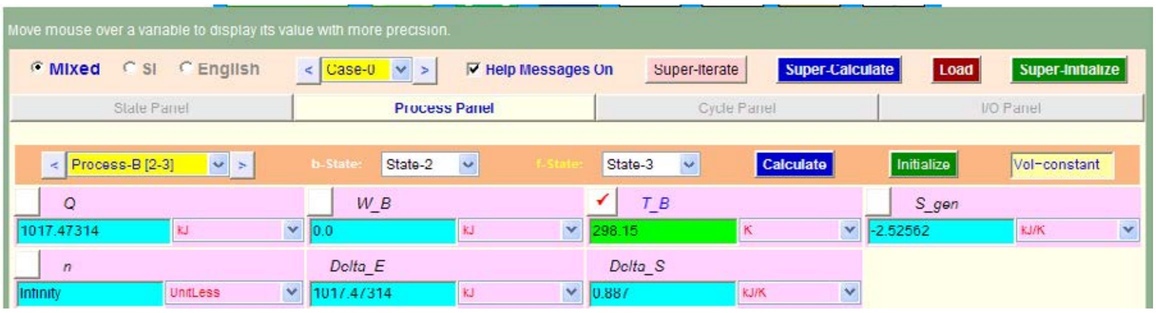
8. For State 4: enter v4 = v1 (since process 4-1 is at constant vol.), m4 = m1, and p4 = p3 * (v3/v4)^1.3 (since process 3-4 is polytropic, with n = 1.3). Hit Enter. We get:

9. Now, go to Process Panel. Process A is for process 1-2. Enter b-state and f-state for this process as shown. Click on Calculate. We get:

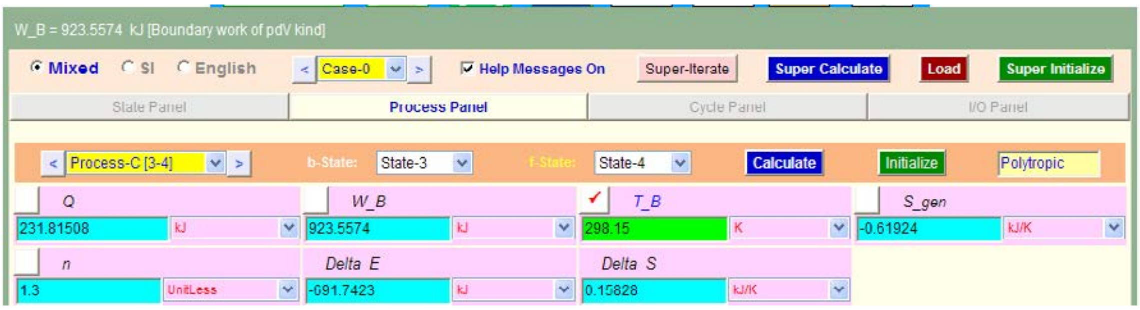


Note from the above screen shot that Q and W for polytropic process 1-2 are immediately calculated.

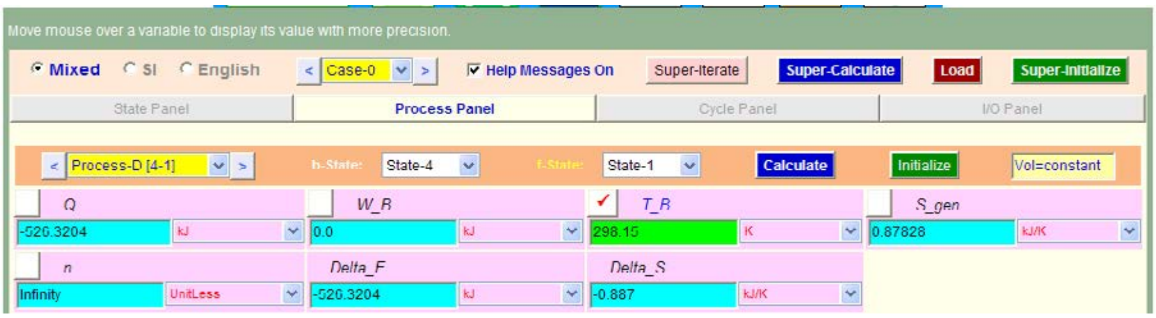
10. Similarly, for Process B (i.e. 2-3). Hit Enter or Calculate. We get:



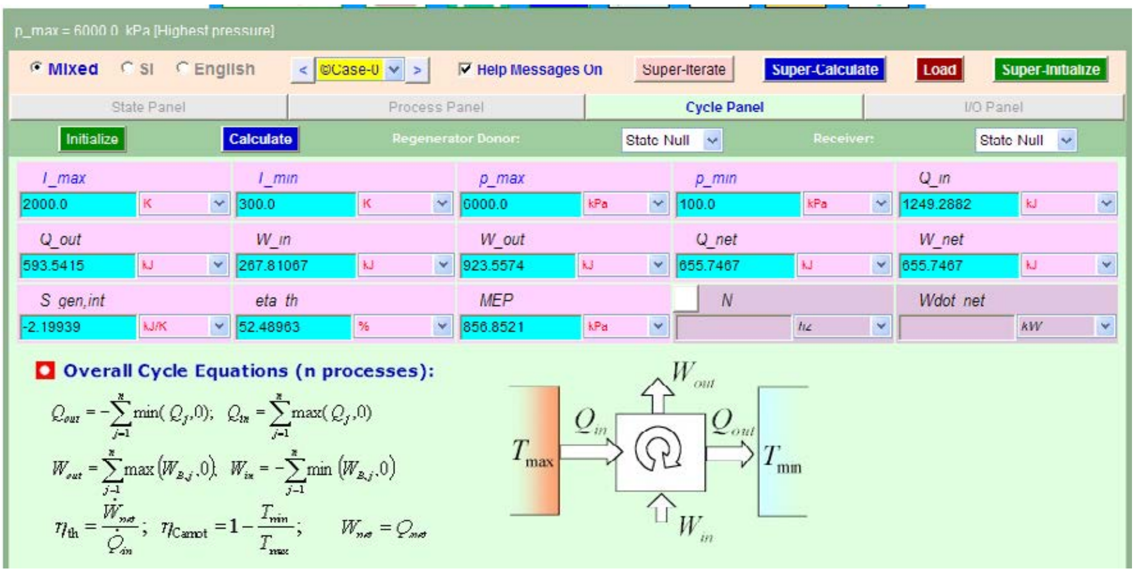
11. And, for process C (3-4): Click on Calculate, and we get:



12. And, for Process D (4-1): Click on Calculate, and we get:



13. Now, go to Cycle Panel. Click on Calculate, and SuperCalculate. We get:



Here, all calculations for cycle are available.

Thus:

Q and W for each process are:

Process	Q (kJ/kg)	W (kJ/kg)
1-2	-67.22	-267.81
2-3	1017.47	0
3-4	231.82	923.06
4-1	-526.32	0

Thermal efficiency = eta_th = 52.49% …. Ans.

MEP = 856.85 kPa = 8.5685 bar …. Ans.

14. **I/O panel gives TEST code etc:**

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

Daemon Path: Systems>Closed>Process>Specific>PowerCycle>PG-Model; v-10.ca08

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

States {

State-1: Air;

Given: { p1= 100.0 kPa; T1= 300.0 K; Vel1= 0.0 m/s; z1= 0.0 m; m1= 1.0 kg; }
State-2: Air;
Given: { p2= "p1 * (v1/v2)^1.3"kPa; v2= "v1/9"m^3/kg; Vel2= 0.0 m/s; z2= 0.0 m; m2= "m1"kg;
}
State-3: Air;
Given: { T3= 2000.0 K; v3= "v2"m^3/kg; Vel3= 0.0 m/s; z3= 0.0 m; m3= "m1"kg; }
State-4: Air;
Given: { p4= "p3*(v3/v4)^1.3"kPa; v4= "v1"m^3/kg; Vel4= 0.0 m/s; z4= 0.0 m; m4= "m1"kg; }
}
Analysis {
Process-A: b-State = State-1; f-State = State-2;
Given: { T_B= 298.15 K; }
Process-B: b-State = State-2; f-State = State-3;
Given: { T_B= 298.15 K; }
Process-C: b-State = State-3; f-State = State-4;
Given: { T_B= 298.15 K; }
Process-D: b-State = State-4; f-State = State-1;
Given: { 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	300.0	0.861	-84.24	1.86	6.893
#	2	1739.86	580.0	0.0957	116.35	282.79	6.735
#	3	6000.0	2000.0	0.0957	1133.82	1707.8	7.622
#	4	344.85	1034.6	0.861	442.08	738.99	7.78

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

 # Mass, Energy, and Entropy Analysis Results:

Process-A: b-State = State-1; f-State = State-2;

Given: T_B= 298.15 K;

Calculated: Q= -67.221115 kJ; W_B= -267.8107 kJ; S_gen= 0.06718519 kJ/K; n= 1.3 UnitLess;

Delta_E= 200.58957 kJ; Delta_S= -0.15827553 kJ/K;

Process-B: b-State = State-2; f-State = State-3;

Given: T_B= 298.15 K;

Calculated: Q= 1017.47314 kJ; W_B= 0.0 kJ; S_gen= -2.5256193 kJ/K; n= Infinity UnitLess;

Delta_E= 1017.47314 kJ; Delta_S= 0.8870023 kJ/K;

Process-C: b-State = State-3; f-State = State-4;

Given: T_B= 298.15 K;

Calculated: Q= 231.81508 kJ; W_B= 923.5574 kJ; S_gen= -0.61923605 kJ/K; n= 1.3 UnitLess;

Delta_E= -691.7423 kJ; Delta_S= 0.15827553 kJ/K;

Process-D: b-State = State-4; f-State = State-1;

Given: T_B= 298.15 K;

Calculated: Q= -526.3204 kJ; W_B= 0.0 kJ; S_gen= 0.87828493 kJ/K; n= Infinity UnitLess;

Delta_E= -526.3204 kJ; Delta_S= -0.8870023 kJ/K;

 # Cycle Analysis Results:

Calculated: T_max= 2000.0 K; T_min= 300.0 K; p_max= 6000.0 kPa;

p_min= 100.0 kPa; Q_in= 1249.2882 kJ; Q_out= 593.5415 kJ;

W_in= 267.81067 kJ; W_out= 923.5574 kJ; Q_net= 655.7467 kJ;

W_net= 655.7467 kJ; S_gen,int= -2.19939 kJ/K; **eta_th= 52.48963 %;**

MEP= 856.8521 kPa;

===

1.3 Problems on Diesel cycle (or, constant pressure cycle):

1.3.1 Problems solved with Mathcad:

Prob.1.19. Plot the thermal efficiency and mean effective pressure (MEP) of the air standard Diesel cycle against the compression ratio.

Mathcad Solution:

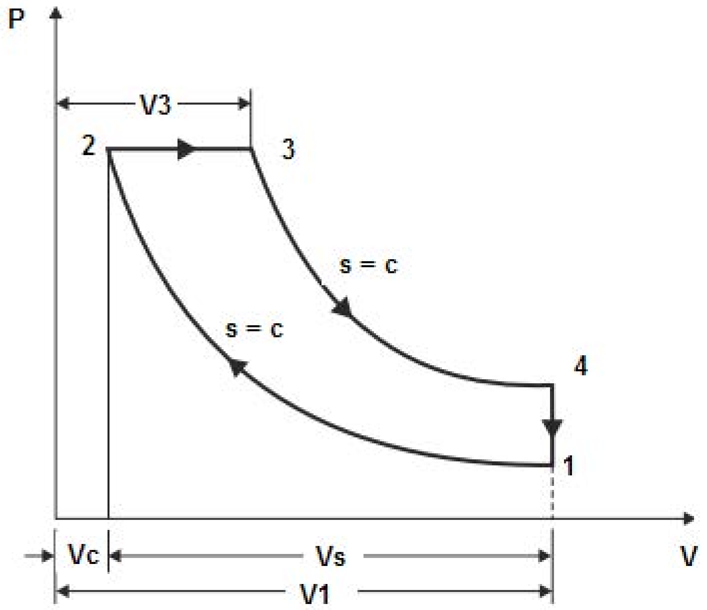


Fig.Prob.1.19

We have:

r = compression ratio =(Vc+Vs)/Vc   gamma = sp. heat ratio
rc = cut off ratio = V3/Vc

Define Mathcad Functions:

$$EFF(rc, r, \gamma) := 1 - \frac{1}{r^{\gamma-1}} \cdot \left[\frac{rc^{\gamma} - 1}{\gamma \cdot (rc - 1)} \right]$$ ...Thermal efficiency

$$W(p1, V1, r, rc, \gamma) := p1 \cdot V1 \cdot r^{(\gamma-1)} \cdot \left[\frac{\gamma \cdot (rc - 1) - r^{1-\gamma} \cdot \left(rc^{\gamma} - 1\right)}{\gamma - 1} \right]$$ ...Work output

$$MEP(p1, r, rc, \gamma) := p1 \cdot \left[\frac{\gamma \cdot r^{\gamma} \cdot (rc - 1) - r \cdot \left(rc^{\gamma} - 1\right)}{(\gamma - 1) \cdot (r - 1)} \right]$$ ...Mean effective pressure

---

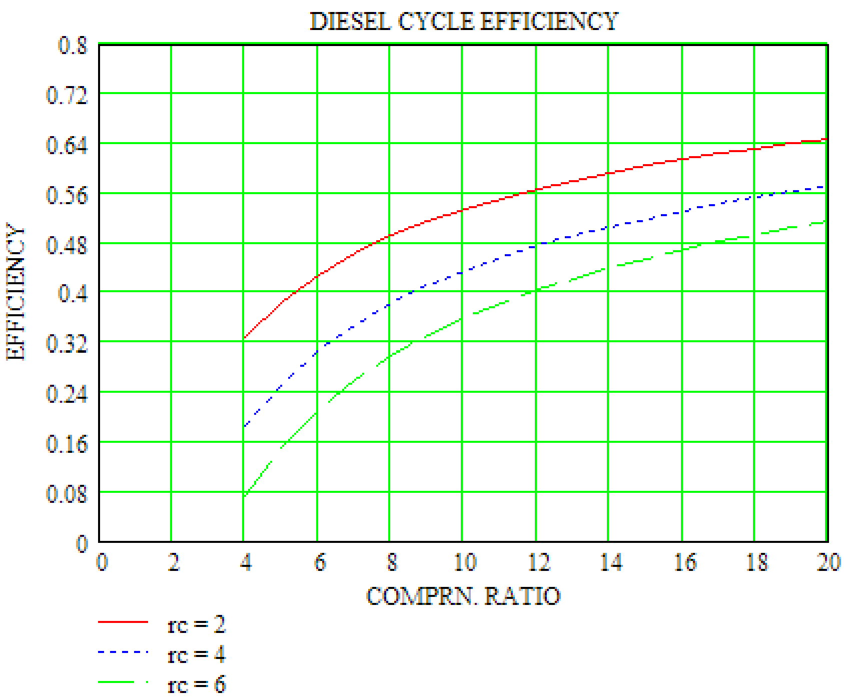
Now, use the above Functions to draw the graphs:

1) **Thermal efficiency:**

$\gamma := 1.4$ $\quad r := 4, 5 .. 20$ $\quad$ comprn. ratio .... defined as range variable

For cut off ratios of 2, 4, 6:

r =	EFF(2, r, γ) =
4	0.328
5	0.385
6	0.428
7	0.462
8	0.49
9	0.514
10	0.534
11	0.551
12	0.567
13	0.58
14	0.593
15	0.604
16	0.614
17	0.623
18	0.632
19	0.639
20	0.647

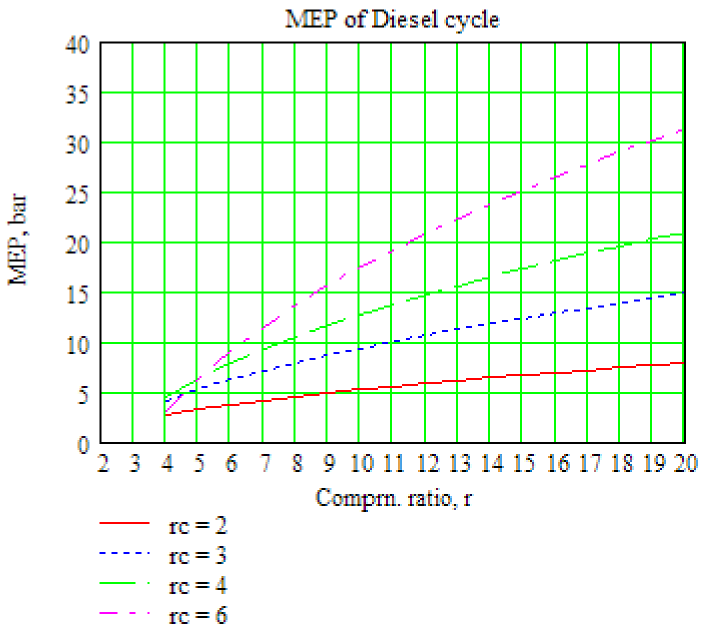


2) **Mean Effective Pressure (MEP) vs compression ratio:**

$r := 4, 5 .. 20$ ...comprn. ratio .... defined as a range variable

$\gamma := 1.4$ $p1 := 1$ bar

$r =$	$MEP(p1, r, 2, \gamma)$	$MEP(p1, r, 3, \gamma)$	$MEP(p1, r, 4, \gamma)$	$MEP(p1, r, 6, \gamma)$
4	2.662	4.065	4.494	3.006
5	3.207	5.233	6.347	6.374
6	3.683	6.234	7.907	9.143
7	4.113	7.124	9.283	11.548
8	4.507	7.935	10.528	13.702
9	4.873	8.684	11.672	15.67
10	5.216	9.383	12.738	17.492
11	5.539	10.04	13.738	19.196
12	5.846	10.663	14.683	20.802
13	6.139	11.256	15.581	22.324
14	6.419	11.822	16.438	23.774
15	6.688	12.365	17.258	25.16
16	6.947	12.887	18.047	26.491
17	7.196	13.39	18.807	27.771
18	7.438	13.876	19.54	29.006
19	7.671	14.346	20.25	30.199



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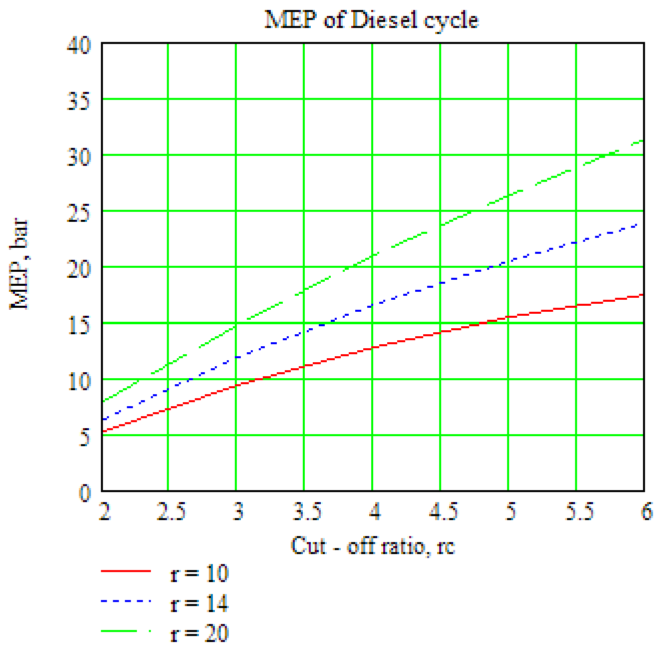
3) **Mean Effective Pressure (MEP) vs cut-off ratio:**

rc := 2,3..6 ...cut off ratio .... defined as a range variable

γ := 1.4 p1 := 1 bar

rc =	MEP(p1, 10, rc, γ)	MEP(p1, 14, rc, γ)	MEP(p1, 20, rc, γ)
2	5.216	6.419	7.898
3	9.383	11.822	14.802
4	12.738	16.438	20.938
5	15.412	20.394	26.428
6	17.492	23.774	31.356



==

Prob.1.20. If the MEP of a Diesel cycle is 7.5 bar and the compression ratio is 14, find the percentage cut off of the cycle if the initial pressure is 1 bar.

Mathcad Solution:

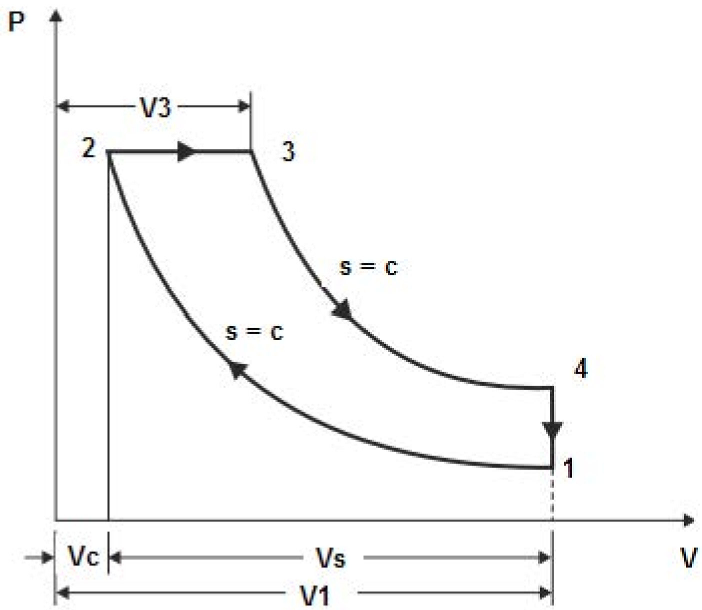


Fig.Prob.1.20

We shall use the Mathcad Function for m.e.p., written earlier, along with the 'Solve block' of Mathcad:

$\gamma := 1.4$ $r := 14$ $mep := 7.5$ $p1 := 1$ bar

$rc := 6$ ... Trial value

Given

$mep = MEP(p1, r, rc, \gamma)$ ...using the Mathcad Function for m.e.p.

$Find(rc) = 2.187$

Therefore, $rc := 2.187$ **...cut off ratio,   Ans.**

Alternatively:

$\gamma := 1.4 \quad r := 14 \quad mep := 7.5 \quad p1 := 1$ bar

$rc := 6$ Trial value

Given

$$mep = \frac{p1}{r-1}\cdot\left[r^{\gamma}\cdot(rc-1)+\frac{r^{\gamma}\cdot rc - rc^{\gamma}\cdot r}{\gamma-1}-\frac{r^{\gamma}-r}{\gamma-1}\right]$$

$Find(rc) = 2.187$

Therefore, $rc := 2.187$ **...cut off ratio, Ans.**

Cut off as a percentage of stroke volume:

Now, we have:

$$\frac{V3-Vc}{Vs} = \frac{V3-Vc}{V1-Vc} = \frac{\frac{V3}{Vc}-1}{\frac{V1}{Vc}-1} = \frac{rc-1}{r-1}$$

where rc = cut off ratio, and r = compression ratio

Therefore:

$\frac{rc-1}{r-1}\cdot 100 = 9.131$ %

i.e. cut off is 9.131% of stroke volume …. Ans.

==

Prob.1.21. In an air standard Diesel cycle, piston stroke is 30 cm and cylinder dia is 20 cm. P and T at the start of compression process are 1 bar and 27 C. cut off takes place at 10 % of stroke and compression ratio is 16. Find:

1) P and T at all points
2) heat added, heat rejected and net work done
3) air standard efficiency and m.e.p. [M.U.]

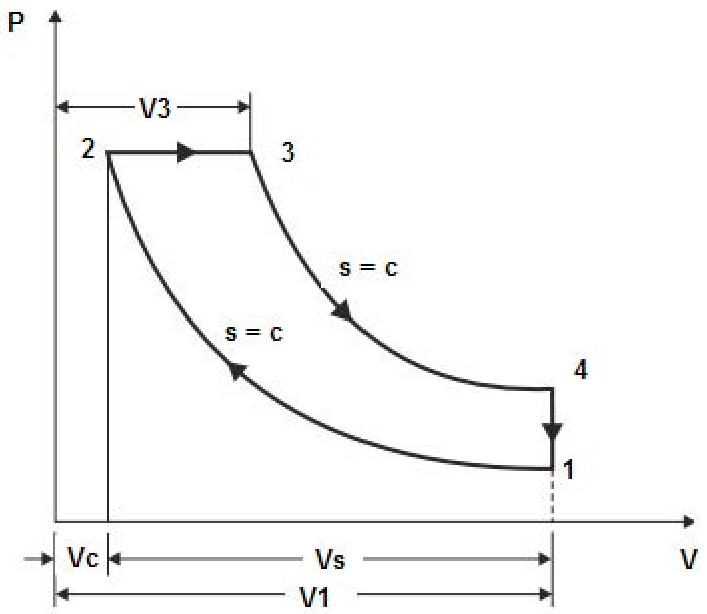


Fig.Prob.1.21

Mathcad Solution:

Data:

$L := 0.3$ m $D := 0.2$ m $P1 := 1$ bar $T1 := 300$ K

$r := 16$ ....comprn. ratio

$\gamma := 1.4$ $R := 287$ J/kg.K

Calculations:

$V_s := \frac{\pi \cdot D^2}{4} \cdot L$ i.e. $V_s = 9.425 \times 10^{-3}$ m^3... stroke vol.

$V2 := \frac{V_s}{r-1}$ i.e. $V2 = 6.283 \times 10^{-4}$ m^3....clearance vol.

$V1 := V_s + V2$ i.e. $V1 = 0.01$ m^3

Process 1-2:

$T2 := T1 \cdot r^{\gamma - 1}$ i.e. $T2 = 909.43$ K...Ans

$P2 := P1 \cdot r^{\gamma}$ i.e. $P2 = 48.503$ bar...Ans.

Process 2-3:

We have: V3-V2 =0.1*(V1-V2)

Therefore, V3/V2 = 1 + 0.1*16-0.1 = 2.5 .... cut off ratio i.e. $r_c := 2.5$ ....cut off ratio

$T3 := r_c \cdot T2$ i.e. $T3 = 2.274 \times 10^3$ **K...Ans.**

Also: $P3 := P2$ i.e. $P3 = 48.503$ **bar...Ans.**

Process 3-4:

$T4 := T3 \cdot \left(r_c \cdot \frac{1}{r} \right)^{\gamma - 1}$ i.e. $T4 = 1.082 \times 10^3$ **K...Ans.**

$P4 := P3 \cdot \left(\frac{r_c}{r} \right)^{\gamma}$ i.e. $P4 = 3.607$ **bar...Ans.**

Heat added, Qs:

Now: $m := \frac{P1 \cdot 10^5 \cdot V1}{R \cdot T1}$ i.e. $m = 0.012$ kg/cycle .... mass of air

$cp := \frac{R \cdot \gamma}{\gamma - 1}$ i.e. $cp = 1.005 \times 10^3$ J/kg.K .... sp. heat at const. pressure

$Q_s := m \cdot cp \cdot (T3 - T2)$ i.e. $Q_s = 1.6 \times 10^4$ **Joules..Heat addded .... Ans.**

Heat rejected, Qr:

$cv := \frac{R}{\gamma - 1}$ i.e. $cv = 717.5$ J/kg.K.... sp. heat at const. volume.

$Q_r := m \cdot cv \cdot (T4 - T1)$ i.e. $Q_r = 6.551 \times 10^3$ **Joules.. Heat rejected ...Ans.**

Net work done:

$W := Q_s - Q_r$ i.e. $W = 9.448 \times 10^3$ **Joules ..... Neat work .... Ans.**

Thermal effcy.:

$\eta := \frac{W}{Q_s} \cdot 100$ i.e. $\eta = 59.052$ **%....Ans.**

Mean Effective Pressure:

$$mep := \frac{W}{V1 - V2}$$ ...by definition

i.e. $mep = 1.0025 \times 10^{6}$ **Pa = 10.025 bar .... Ans.**

Alternatively: Using the Mathcad Functions for Diesel cycle, already written:

$$EFF(rc, r, \gamma) := 1 - \frac{1}{r^{\gamma-1}} \cdot \left[\frac{rc^{\gamma} - 1}{\gamma \cdot (rc - 1)}\right]$$ ...Thermal efficiency

$$W(P1, V1, r, rc, \gamma) := P1 \cdot V1 \cdot r^{(\gamma-1)} \cdot \left[\frac{\gamma \cdot (rc - 1) - r^{1-\gamma} \cdot \left(rc^{\gamma} - 1\right)}{\gamma - 1}\right]$$ ...Work output

$$MEP(P1, r, rc, \gamma) := P1 \cdot \left[\frac{\gamma \cdot r^{\gamma} \cdot (rc - 1) - r \cdot \left(rc^{\gamma} - 1\right)}{(\gamma - 1) \cdot (r - 1)}\right]$$ ...Mean effective pressure

We get:

$EFF\left(r_c, r, \gamma\right) = 0.591$ **= 59.1 % .... Ans.**

$W\left(P1 \cdot 10^{5}, V1, r, r_c, \gamma\right) = 9.448 \times 10^{3}$ **J/cycle ... Ans.**

$MEP\left(P1, r, r_c, \gamma\right) = 10.025$ **bar.... Ans.**

Note that all the answers are the same as obtained earlier.

===

Prob.1.22. The inlet air temp and pressure at the beginning of compression in a Diesel cycle are 303 K and 100 kPa respectively. Pressure at the end of compression is 4500 kPa. If heat supplied to the system is at the rate of 750 J/g of air, calculate; (i) the work done per cycle, and (ii) the air standard effcy. [M.U.]

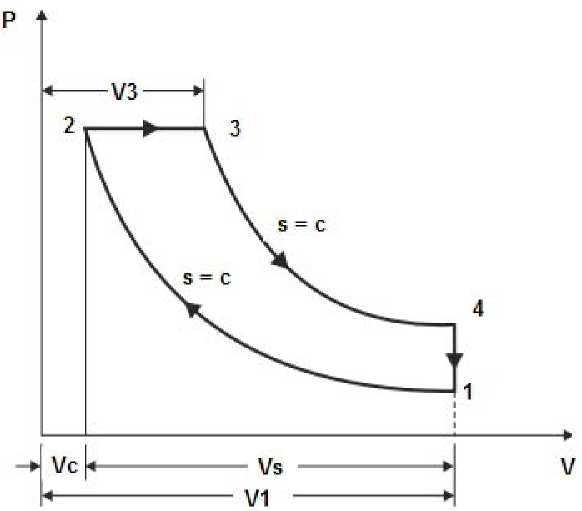


Fig.Prob.1.22

Mathcad Solution:

Data:

$P1 := 1$ bar $T1 := 303$ K $P2 := 45$ bar

$Q_S := 750$ kJ/kg $P3 := P2$

$\gamma := 1.4$ $R := 0.287$ kJ/kg.K

$cp := \frac{R \cdot \gamma}{\gamma - 1}$ i.e. $cp = 1.005$ kJ/kg.K..sp.heat at const. pressure, for air

Calculations:

Find temps. at all the four salient points:

Process 1-2:

$r := \left(\frac{P2}{P1}\right)^{\frac{1}{\gamma}}$ i.e. $r = 15.166$ ....comprn. ratio

Then:

$T2 := T1 \cdot r^{\gamma - 1}$ i.e. $T2 = 899.061$ **K.**

Process 2-3:

$T3 := \frac{Q_S}{cp} + T2$ i.e. $T3 = 1.646 \times 10^3$ **K.**

Process 3-4:

$P4 := P3 \cdot \left(\frac{1}{r} \cdot \frac{T3}{T2}\right)^{\gamma}$ i.e. $P4 = 2.331$ **bar..**

$T4 := T3 \cdot \left(\frac{P4}{P3}\right)^{\frac{\gamma-1}{\gamma}}$ i.e. $T4 = 706.365$ **K.**

Heat rejected, QR:

$cv := \frac{R}{\gamma - 1}$ i.e. $cv = 0.718$ J/kg.K... sp. heat at const. vol. for air

Therefore:

$Q_R := cv \cdot (T4 - T1)$ i.e. $Q_R = 289.414$ kJ/kg.... heat rej.

Work done, W:

$W := Q_S - Q_R$ i.e. $W = 460.586$ **kJ/kg.....Ans.**

Thermal effcy.:

$\eta := \frac{W}{Q_S} \cdot 100$ i.e. $\eta = 61.411$ **%....Ans.**

==

Prob.1.23. A 4 stroke Diesel engine has 4 cylinders of 10 cm dia and 12 cm stroke. The engine runs at 2200 rpm. The pressure and temp. at the beginning of compression stroke are 1 bar and 30 C respectively. If the clearance vol. is 6.5% of stroke vol. and max. cycle temp. is 1850 K, find:

i) compression ratio
ii) P & T at the end of compression
iii) Thermal effcy.
iv) Power output. [M.U.]

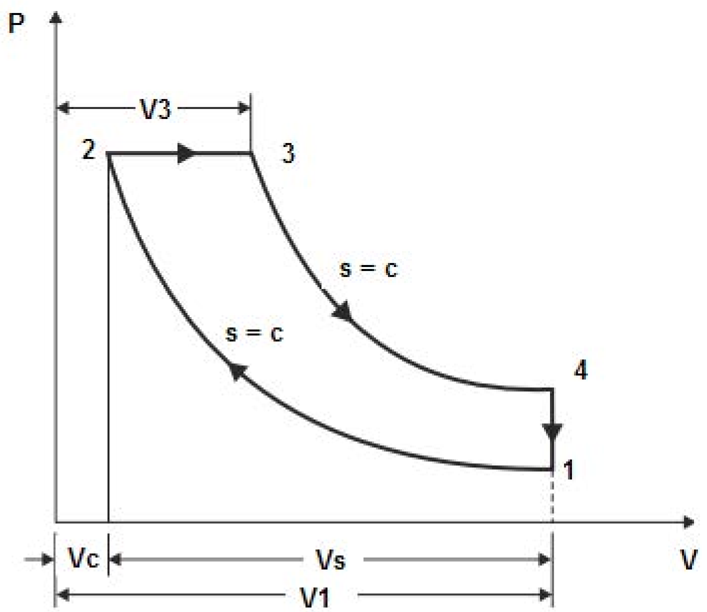


Fig.Prob.1.23

Mathcad Solution:

Data:

$L := 0.12$ m $D := 0.1$ m $P1 := 1$ bar $T1 := 303$ K $T3 := 1850$ K

$\gamma := 1.4$ $R := 287$ J/kg.K $n := 4$ ...no. of cyl. $N := 2200$ rpm

Calculations:

Now: Vc/Vs = 0.065; r = (Vc + Vs)/Vc;

$r := 1 + \frac{1}{0.065}$ i.e. $r = 16.385$ **...compr. ratio.....Ans.**

$V_s := \frac{\pi \cdot D^2}{4} \cdot L$ i.e. $V_s = 9.425 \times 10^{-4}$ m^3... stroke vol.

$V2 := \frac{V_s}{r - 1}$ i.e. $V2 = 6.126 \times 10^{-5}$ m^3.... clearance vol.

$V1 := V_s + V2$ i.e. $V1 = 1.004 \times 10^{-3}$ m^3

Process 1-2:

$T2 := T1 \cdot r^{\gamma - 1}$ i.e. $T2 = 927.293$ **K...Ans**

$P2 := P1 \cdot r^{\gamma}$ i.e. $P2 = 50.143$ **bar...Ans.**

Process 2-3:

$P3 := P2$ i.e. $P3 = 50.143$ **bar...Ans.**

$r_c := \frac{T3}{T2}$ i.e. $r_c = 1.995$ ....cut off ratio, since V3/V2 = T3/T2 when P3 = P2

Therefore:

$T4 := T3 \cdot \left(r_c \cdot \frac{1}{r}\right)^{\gamma - 1}$ .....since $\frac{T4}{T3} = \left(\frac{V3}{V4}\right)^{\gamma - 1} = \left(\frac{\frac{V3}{V2}}{\frac{V4}{V2}}\right)^{\gamma - 1} = \left(\frac{rc}{r}\right)^{\gamma - 1}$ ..remember: V4 = V1

i.e. $T4 = 796.855$ **K...Ans.**

And,

$P4 := P3 \cdot \left(\frac{r_c}{r}\right)^{\gamma}$ i.e. $P4 = 2.63$ **bar...Ans.**

Heat added, Qs:

$m := \frac{P1 \cdot 10^5 \cdot V1}{R \cdot T1}$ i.e. $m = 1.154 \times 10^{-3}$ kg/cycle

$cp := \frac{R \cdot \gamma}{\gamma - 1}$ i.e. $cp = 1.005 \times 10^3$ J/kg.K.... sp. heat at const. pressure for air

Then: $Q_s := m \cdot cp \cdot (T3 - T2)$ i.e. $Q_s = 1.07 \times 10^3$ Joules/cyle... heat supplied

Heat rejected, Qr:

$cv := \frac{R}{\gamma - 1}$ i.e. $cv = 717.5$ J/kg.K... sp. heat at const. volume for air

Then: $Q_r := m \cdot cv \cdot (T4 - T1)$ i.e. $Q_r = 408.994$ Joules/cycle....heat rej.

Net work done, W:

$W := Q_s - Q_r$ i.e. $W = 660.824$ Joules/cycle

Power developed, P:

$P := W \cdot \frac{N}{2 \cdot 60} \cdot n$ i.e. $P = 4.846 \times 10^4$ **W, for 4 cyl....Ans.**

Thermal effcy.:

$\eta := \frac{W}{Q_s} \cdot 100$ i.e. $\eta = 61.77$ **%....Ans.**

Mean Effective Pressure:

$$mep := \frac{W}{V1 - V2}$$

i.e. $mep = 7.012 \times 10^5$ **Pa = 7.012 bar ..mean effective pressure .... Ans.**

==

Prob.1.24. A 4 stroke C.I. engine works on Diesel cycle. The engine bore is 20 cm and stroke is 25 cm. Clearance volume is 500 cm^3 and the fuel injection takes place at const. pressure for 5% of stroke. P and T at beginning of compression are 1.05 bar and 350 K. Determine: (i) Air standard efficiency (ii) compression ratio (iii) heat added and work output. [M.U.]

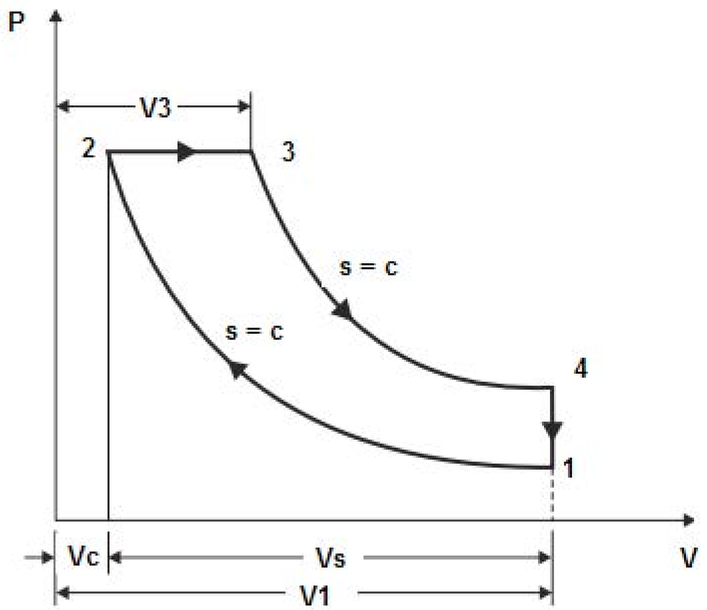


Fig.Prob.1.24

Mathcad Solution:

Data:

$L := 0.25$ m $D := 0.2$ m $P1 := 1.05$ bar $T1 := 350$ K

$\gamma := 1.4$ $R := 287$ J/kg.K $V2 := 500\cdot 10^{-6}$ m^3 ... clearance vol.

Calculations:

$V_s := \frac{\pi \cdot D^2}{4} \cdot L$ i.e. $V_s = 7.854 \times 10^{-3}$ m^3... stroke vol.

$V1 := V_s + V2$ i.e. $V1 = 8.354 \times 10^{-3}$ m^3

$r := \frac{V1}{V2}$ i.e. $r = 16.708$ **...comprn. ratio...Ans.**

Process 1-2:

$T2 := T1 \cdot r^{\gamma - 1}$ i.e. $T2 = 1.08 \times 10^3$ **K...Ans**

$P2 := P1 \cdot r^{\gamma}$ i.e. $P2 = 54.111$ **bar...Ans.**

Process 2-3:

$P3 := P2$ i.e. $P3 = 54.111$ **bar...Ans.**

By data, cut off at 5 % of stroke; i.e.

$$\frac{V3 - V2}{V1 - V2} = \frac{V2 \cdot (rc - 1)}{V2 \cdot (r - 1)} = 0.05$$

i.e. $\frac{rc - 1}{r - 1} = 0.05$

i.e. $r_c := 1 + (r - 1) \cdot 0.05$

i.e. $r_c = 1.785$ **...cut off ratio**

Therefore:

$T3 := T2 \cdot r_c$ i.e. $T3 = 1.927 \times 10^3$ K

$T4 := T3 \cdot \left(r_c \cdot \frac{1}{r}\right)^{\gamma-1}$ i.e. $T4 = 787.947$ **K...Ans.**

And,

$P4 := P3 \cdot \left(\frac{r_c}{r}\right)^{\gamma}$ i.e. $P4 = 2.364$ **bar...Ans.**

Heat added, Qs:

$m := \frac{P1 \cdot 10^5 \cdot V1}{R \cdot T1}$ i.e. $m = 8.732 \times 10^{-3}$ kg/cycle

$cp := \frac{R \cdot \gamma}{\gamma - 1}$ i.e. $cp = 1.005 \times 10^3$ J/kg.K

$Q_s := m \cdot cp \cdot (T3 - T2)$ i.e. $Q_s = 7.437 \times 10^3$ Joules/cyle

Heat rejected, Qr:

$cv := \frac{R}{\gamma - 1}$ i.e. $cv = 717.5$ J/kg.K

$Q_r := m \cdot cv \cdot (T4 - T1)$ i.e. $Q_r = 2.744 \times 10^3$ Joules/cycle.

Net work done:

$W := Q_s - Q_r$ i.e. $W = 4.693 \times 10^3$ **Joules/cycle....Ans.**

Thermal effcy.:

$\eta := \frac{W}{Q_s} \cdot 100$ i.e. $\eta = 63.105$ **%....Ans.**

Alternatively:

$$EFF(r_c, r, \gamma) := 1 - \frac{1}{r^{\gamma-1}} \cdot \left[\frac{r_c^{\gamma} - 1}{\gamma \cdot (r_c - 1)}\right]$$ **...Thermal efficiency of Diesel cycle**

$\eta := EFF(r_c, r, \gamma)$ i.e. $\eta = 0.631$ **= 63.1 %....Ans.**

===

1.3.2 Problems solved with EES:

"**Prob.1.25.** Write EES Functions for Thermal efficiency, Work output and Mean Effective Pressure (MEP) of an Air standard Diesel cycle.

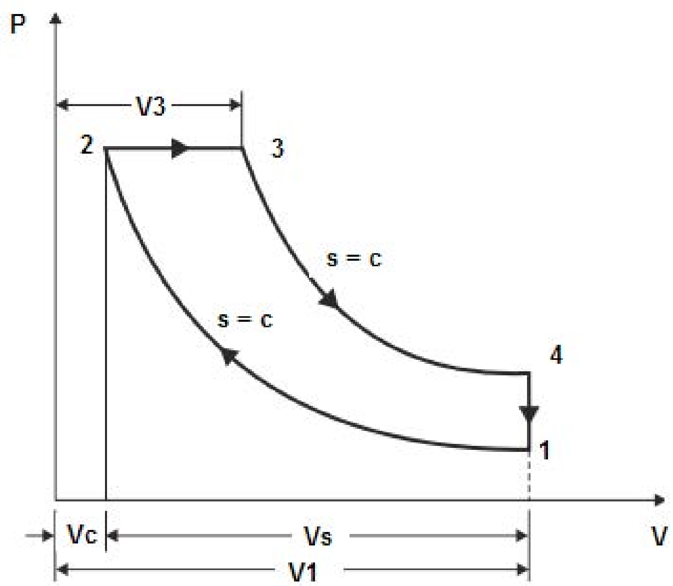


Fig.Prob.1.25

"Diesel cycle-EES Functions:"

FUNCTION EFFCY_Diesel(rc,rr,gamma)

"Thermal effcy. of Air standard Diesel cycle"

"Inputs: rc = cut off ratio = V3/V2,

rr = comprn. ratio = V1/V2,

gamma = sp. heat ratio = 1.4 for air"

"Outputs: EFFCY_Diesel = Thermal effcy. of Diesel cycle"

EFFCY_Diesel := 1 – (1/rr^(gamma-1))* (rc^gamma – 1)/(gamma * (rc – 1))

END

"=="

FUNCTION W_net_Diesel(P1, V1, rc, rr, gamma)

"W_net of Air standard Diesel cycle"

"Inputs: P1 = Pressure at State 1 (Pa), V1 = Vol. at State 1 (m^3),
rc = cut off ratio = V3/V2,
rr = comprn. ratio = V1/V2,
gamma = sp. heat ratio = 1.67 for air"

"Outputs: W_net_Diesel = Net work output of Diesel cycle"

A := P1 * V1 * rr^(gamma – 1)
B := gamma * (rc – 1) – rr^(1 – gamma) * (rc^gamma – 1)
C := gamma -1

W_net_Diesel := A * B / C

END

"=="

```
FUNCTION MEP_Diesel(P1, rc, rr, gamma)

"MEP of Air standard Diesel cycle"

"Inputs: P1 = Pressure at State 1 (Pa),
rc = cut off ratio = V3/V2,
rr = comprn. ratio = V1/V2,
gamma = sp. heat ratio = 1.67 for air"

"Outputs: MEP_Diesel = MEP of Diesel cycle"

A := P1/((gamma – 1) * (rr – 1))
B := gamma * rr^gamma *(rc – 1)
C := rr * (rc^gamma – 1)

MEP_Diesel := A * (B – C)

END

"===================================================================="
```

Prob.1.26. Plot Thermal effcy. vs compression ratio for a Diesel cycle, for cut off ratio, rc = 2, 4 and 6.

EES Solution:

"To plot Thermal effcy. vs comprn. ratio for rc = 2, 4 and 6:"

"Following is the simple EES program:"

rc = 6 "cut off ratio"

{rr = 12 "..comprn. ratio"}

gamma = 1.4 "..for air"

eta_th = EFFCY_Diesel(rc, rr, gamma)

To plot the graphs, first, compute the Parametric Table:

For rc = 2

1..16	rr	η_{th}
Run 1	5	0.385
Run 2	6	0.4283
Run 3	7	0.4625
Run 4	8	0.4904
Run 5	9	0.5139
Run 6	10	0.5339
Run 7	11	0.5514
Run 8	12	0.5667
Run 9	13	0.5804
Run 10	14	0.5926
Run 11	15	0.6037
Run 12	16	0.6138
Run 13	17	0.6231
Run 14	18	0.6316
Run 15	19	0.6395
Run 16	20	0.6468

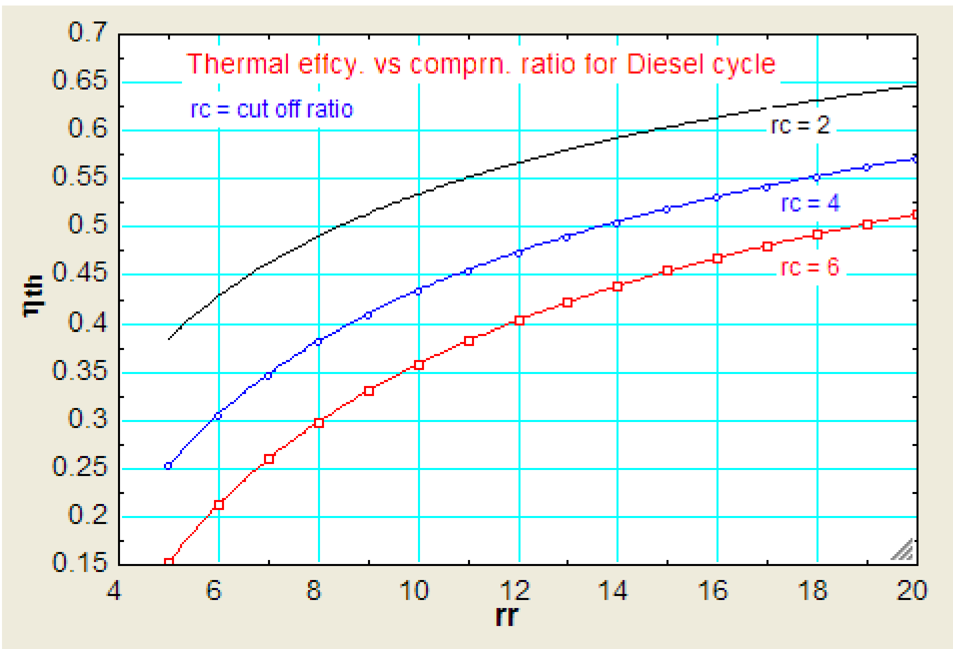
For rc = 4

1..16	rr	η_{th}
Run 1	5	0.254
Run 2	6	0.3065
Run 3	7	0.348
Run 4	8	0.3819
Run 5	9	0.4103
Run 6	10	0.4346
Run 7	11	0.4558
Run 8	12	0.4744
Run 9	13	0.491
Run 10	14	0.5058
Run 11	15	0.5193
Run 12	16	0.5315
Run 13	17	0.5428
Run 14	18	0.5531
Run 15	19	0.5627
Run 16	20	0.5715

For rc = 6:

1..16	rr	η_{th}
Run 1	5	0.1531
Run 2	6	0.2126
Run 3	7	0.2597
Run 4	8	0.2982
Run 5	9	0.3305
Run 6	10	0.3581
Run 7	11	0.3821
Run 8	12	0.4033
Run 9	13	0.4221
Run 10	14	0.439
Run 11	15	0.4542
Run 12	16	0.4681
Run 13	17	0.4809
Run 14	18	0.4926
Run 15	19	0.5035
Run 16	20	0.5136

Now, plot the graphs:



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"**Prob.1.27.** An air standard Diesel cycle has a compression ratio of 16 and a cut off ratio of 2.5. At the beginning of compression, P1 = 1 bar, V1 = 0.01415 m^3, T1 = 300 K. Calculate: (i) heat added in kJ (ii) max. temp. in the cycle (iii) thermal efficiency, and (iv) mean effective pressure in kPa.

(b) Also, plot each of the above quantities for compression ratios ranging from 5 to 18 and for cut off ratios of 1.5, 2 and 2.5. [Ref: 3]"

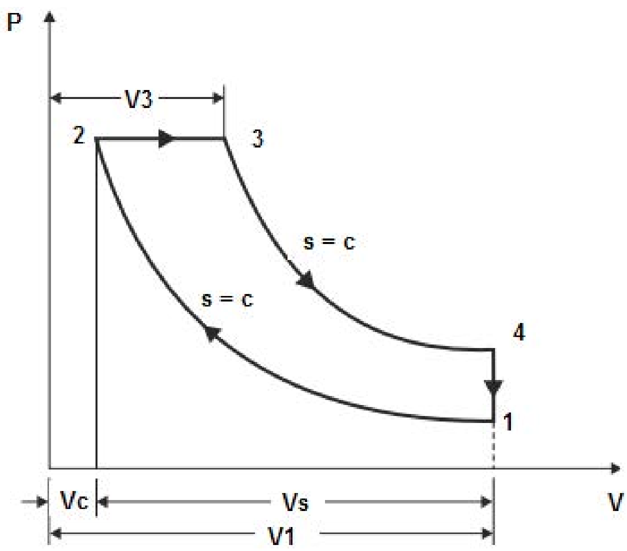


Fig.Prob.1.27

EES Solution:

```
"Data:"
rc = 2.5 "cut off ratio"
rr = 16 "..comprn. ratio"
gamma = 1.4 "..for air"
R = 0.287 "kJ/kg.K"
cp = gamma * R / (gamma – 1) "kJ/g.K … sp. heat at const. pressure"
cp – cv = R "… finds cv, sp. heat at const. volume….kJ/kg.K"
V1 = 0.01415 "m^3"
P1 = 100"kPa"
T1 = 300 "K"
"Calculations:"
"Find all the four temperatures:"
m = P1* V1 / ( R * T1) "kg…. mass of air per cycle"
"Process 1-2:"
V1/V2 = rr "…finds V2, m^3"
P1 * V1^gamma = P2 * V2^gamma "…finds P2, kPa"
m = P2 * V2 / (R * T2) "…finds T2, K"
"Process 2-3:"
P3 = P2 "…since Process 2-3 is at const. pressure"
V3/V2 = rc "…finds V3, m^3"
V2/T2 = V3/T3 "…finds the max. temp. T3, K"
"Process 3-4:"
V4 = V1 "…for const. vol. process 4-1"
P3 * V3^gamma = P4 * V4^gamma "…finds P4, kPa"
P4 / T4 = P1 / T1 "…finds T4, K … since V4 = V1"
"Process 4-1:"
Q_r = m * cv * (T4 – T1) "kJ/cycle …. heat rejected"
Q_s = m * cp * (T3 – T2) "kJ/cycle …. heat supplied"
W_net = Q_s – Q_r "kJ…net work output"
eta_th = W_net / Q_s "..thermal efficiency"
MEP = W_net / (V1 – V2) "kPa … mean effective pressure"

"Verify these values using the EES Functions already written:"

eta_th_2 = EFFCY_Diesel(rc, rr, gamma)
W_net_2 = W_net_Diesel(P1, V1, rc, rr, gamma)
MEP_2 = MEP_Diesel(P1,rc, rr, gamma)
"-----------------------------------------------------------------------"
```

Results:

Unit Settings: SI C Pa J mass deg

cp = 1.005 [kJ/kg.K]	cv = 0.7175 [kJ/kg.K]	η_{th} = 0.5905
$\eta_{th,2}$ = 0.5905	γ = 1.4	m = 0.01643 [kg/cycle]
MEP = 1002 [kPa]	MEP_2 = 1002 [kPa]	P1 = 100 [kPa]
P2 = 4850 [kPa]	P3 = 4850 [kPa]	P4 = 360.7 [kPa]
Q_r = 9.221 [kJ/cycle]	Q_s = 22.52 [kJ/cycle]	R = 0.287 [kJ/kg.K]
rc = 2.5	rr = 16	T1 = 300 [K]
T2 = 909.4 [K]	T3 = 2274 [K]	T4 = 1082 [K]
V1 = 0.01415 [m^3]	V2 = 0.0008844 [m^3]	V3 = 0.002211 [m^3]
V4 = 0.01415 [m^3]	W_{net} = 13.3 [kJ/cycle]	$W_{net,2}$ = 13.3 [kJ/cycle]

Thus:

Heat added = Q_s = 22.52 kJ/cycle …Ans.

Max. temp. in cycle = T3 = 2274 K .. Ans.

Thermal efficiency = eta_th = 0.5905 = 59.05% … Ans.

Mean Effective Pressure = MEP = 1002 kPa = 10.02 bar … Ans.

Also, note that, using the EES Functions, we get the same results for Thermal effcy., Net work and MEP:

i.e. eta_th_2 = 0.5905, W_net_2 = 13.3 kJ/cycle, and MEP_2 = 1002 kPa.

(b) To plot the variation of Q_s, T3, eta_th and MEP with comprn. ratio, rr for different values of cut off ratio, rc:

First, compute the Parametric Tables:

For rc = 1.5:

1..14	rr	Q_s [kJ/cycle]	T3 [K]	η_{th}	MEP [kPa]
Run 1	5	4.714	856.6	0.4266	177.6
Run 2	6	5.071	921.5	0.4669	200.8
Run 3	7	5.393	980.1	0.4988	221.8
Run 4	8	5.689	1034	0.5249	241.2
Run 5	9	5.963	1084	0.5467	259.2
Run 6	10	6.22	1130	0.5654	276.2
Run 7	11	6.462	1174	0.5817	292.2
Run 8	12	6.691	1216	0.596	307.4
Run 9	13	6.908	1255	0.6087	322
Run 10	14	7.116	1293	0.6202	335.9
Run 11	15	7.315	1329	0.6305	349.2
Run 12	16	7.507	1364	0.6399	362.1
Run 13	17	7.691	1398	0.6485	374.5
Run 14	18	7.869	1430	0.6565	386.5

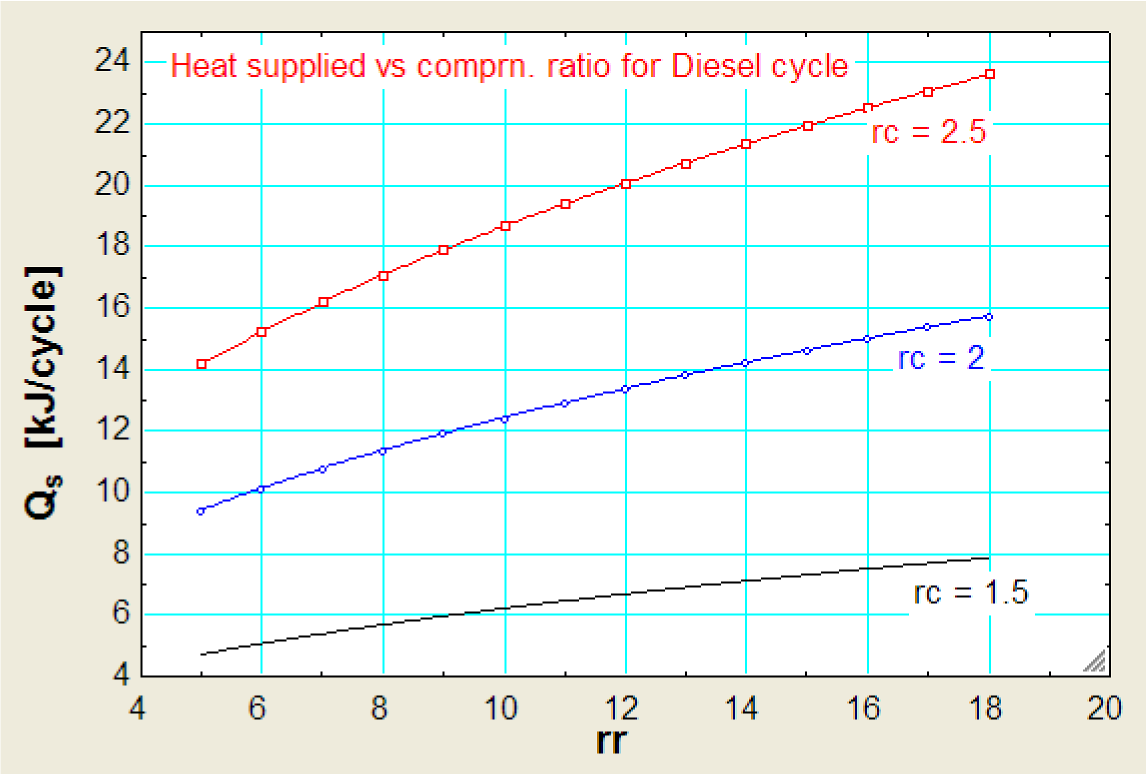
For rc = 2:

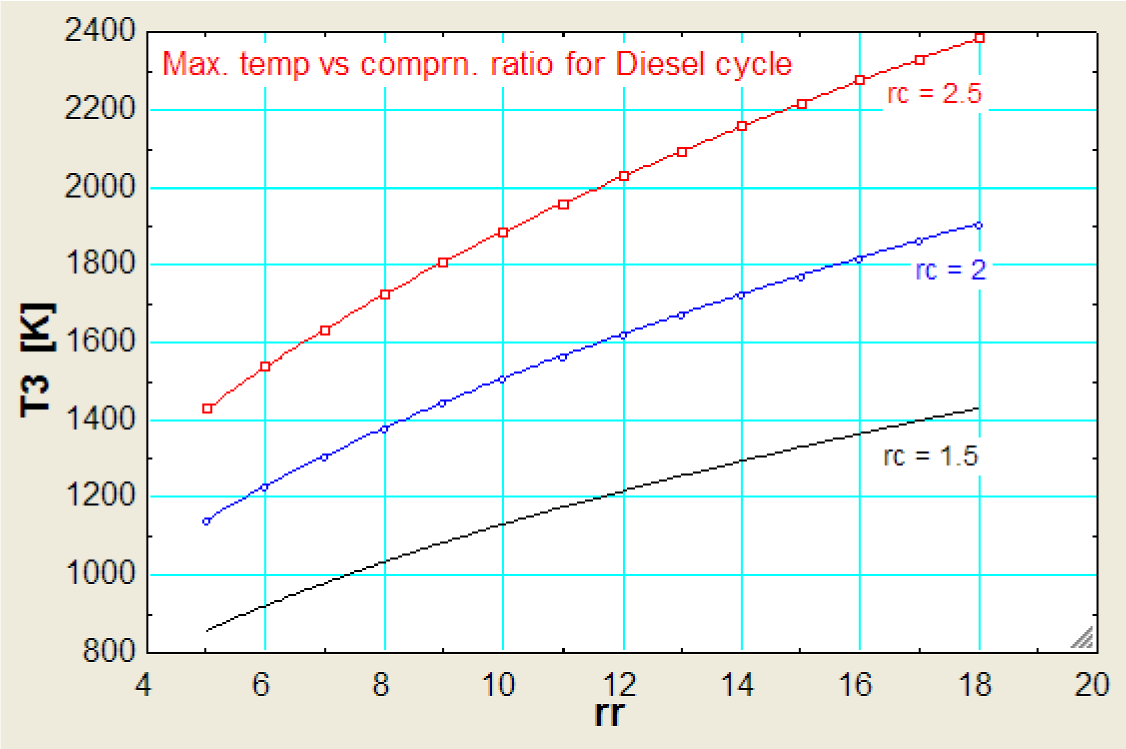
1..14	rr	Q_s [kJ/cycle]	T3 [K]	η_{th}	MEP [kPa]
Run 1	5	9.428	1142	0.385	320.7
Run 2	6	10.14	1229	0.4283	368.3
Run 3	7	10.79	1307	0.4625	411.3
Run 4	8	11.38	1378	0.4904	450.7
Run 5	9	11.93	1445	0.5139	487.3
Run 6	10	12.44	1507	0.5339	521.6
Run 7	11	12.92	1566	0.5514	553.9
Run 8	12	13.38	1621	0.5667	584.6
Run 9	13	13.82	1674	0.5804	613.9
Run 10	14	14.23	1724	0.5926	641.9
Run 11	15	14.63	1773	0.6037	668.8
Run 12	16	15.01	1819	0.6138	694.7
Run 13	17	15.38	1864	0.6231	719.6
Run 14	18	15.74	1907	0.6316	743.8

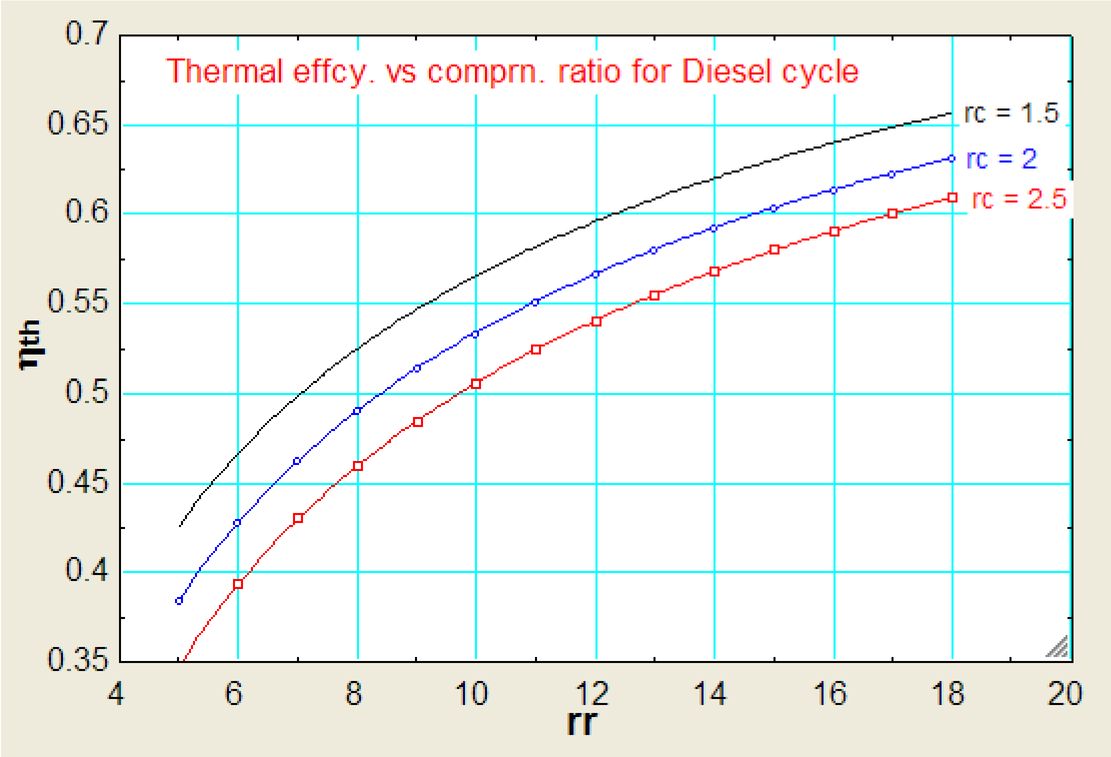
For rc = 2.5:

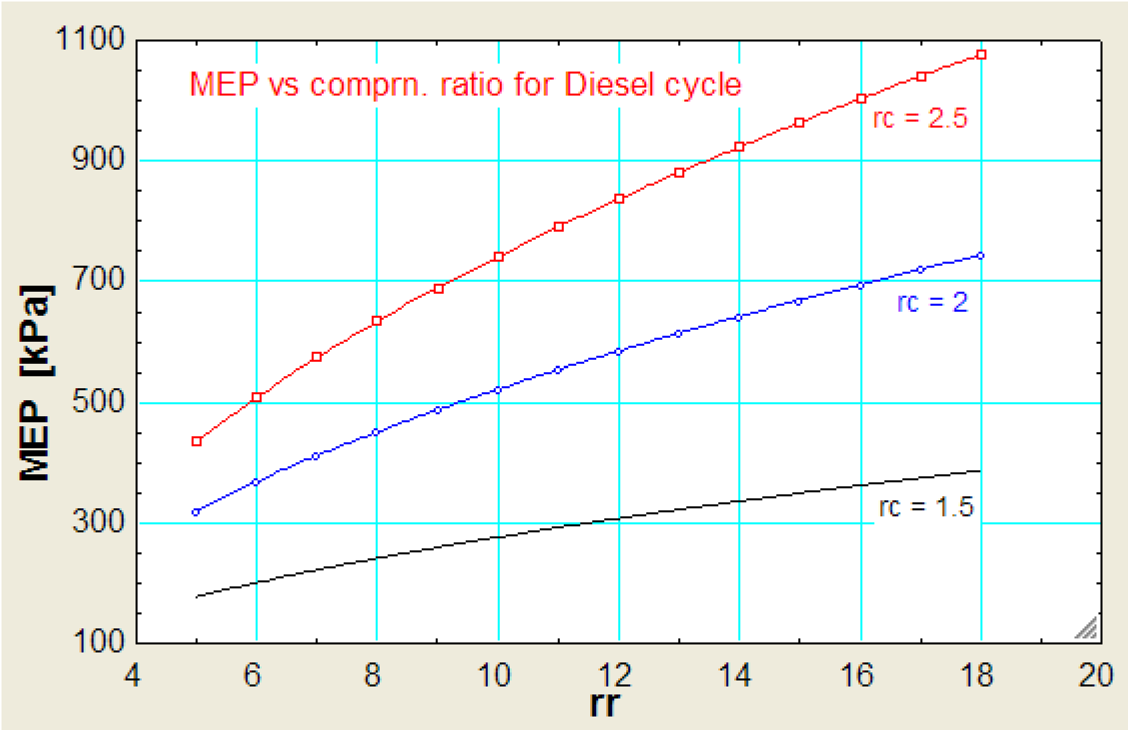
1..14	rr	Q_s [kJ/cycle]	T3 [K]	η_{th}	MEP [kPa]
Run 1	5	14.14	1428	0.3479	434.7
Run 2	6	15.21	1536	0.3938	508
Run 3	7	16.18	1633	0.43	573.7
Run 4	8	17.07	1723	0.4597	633.7
Run 5	9	17.89	1806	0.4846	689.2
Run 6	10	18.66	1884	0.5058	741.2
Run 7	11	19.39	1957	0.5243	790.1
Run 8	12	20.07	2026	0.5406	836.5
Run 9	13	20.72	2092	0.5551	880.7
Run 10	14	21.35	2155	0.5681	923
Run 11	15	21.95	2216	0.5798	963.5
Run 12	16	22.52	2274	0.5905	1002
Run 13	17	23.07	2329	0.6003	1040
Run 14	18	23.61	2383	0.6094	1076

Now, plot the results:






Thermal effcy. vs comprn. ratio for Diesel cycle
ηth
rr
rc = 1.5
rc = 2
rc = 2.5
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
4
6
8
10
12
14
16
18
20



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"**Prob.1.28.** Air in a piston – cylinder device of bore = 200 mm, stroke = 300 mm and a clearance volume = 7% of stroke volume, undergoes a Diesel cycle. The P and T of air at the beginning of compression are 1 bar and 27 C. The max. temp. in the cycle is 1900 K. Calculate the following: (i) compression ratio (ii) Cut – off ratio (iii) heat transferred to air in kJ/kg (iv) heat transferred from air in kJ/kg (v) cycle efficiency, and (vi) MEP. [VTU-ATD-July-Aug. 2003]"

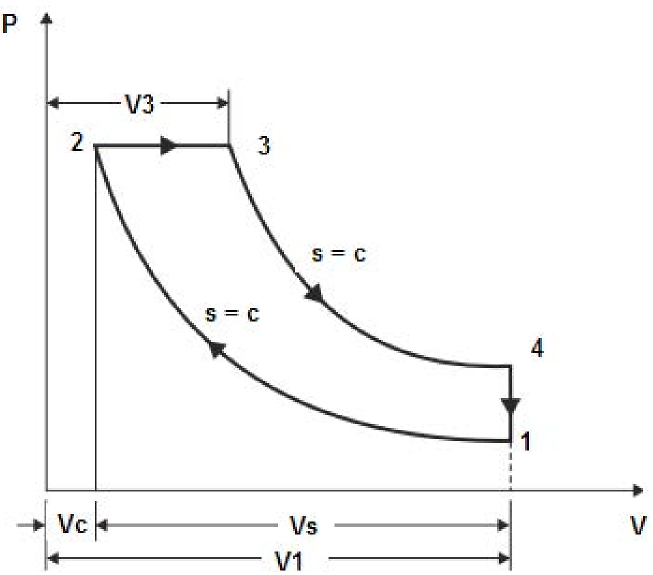


Fig.Prob.1.28

EES Solution:

"Data:"

```
d=0.2"m"
L=0.3"m"
p1=100"kPa"
T1=27+273"K"
T3=1900"k … Max. temp."
R= 0.287"kJ/kg.K"
gamma=1.4
cp = gamma * R / (gamma – 1) "kJ/g.K … sp. heat at const. pressure"
cp – cv = R "… finds cv, sp. heat at const. volume….kJ/kg.K"
"Calculations:"
V_s = PI * d^2 * L/4"m3…stroke vol."
V_c = 0.07 * V_s"m3…clearance vol."
V1=V_s+V_c"m3 … volume at the beginning of compression"
V2=V_c "…vol. at point 2"
"Process 1-2:"
rr=V1/V2"..comprn. ratio"
p1 * V1=m * R * T1"…calculates mass, m in kg"
p2 / p1=rr^gamma"….finds p2, kPa"
T2/T1=rr^(gamma-1)"…. finds T2"
"Process 2-3:"
p2=p3 "….const. pressure heat addition"
p3 * V3=m * R * T3 "…finds V3, m^3"
"Process 3-4:"
V4=V1"…const. vol. process 4-1"
p3 * V3^gamma=p4 * V4^gamma"….finds p4, kPa"
T4 / T3 = (V3 / V4)^(gamma-1) "..finds T4.. for isentropic process 3-4"
"Cut off ratio, rc:"
rc = V3/V2"…. cut-off ratio"
"Heat added:"
Q_in=m * cp * (T3-T2)"kJ/cycle"
"Heat rejected:"
Q_out=m * cv * (T4-T1)"kJ/cycle"
"Work output:"
W=Q_in-Q_out"kJ/cycle"
"Thermal efficiency:"
eta_th = W / Q_in
"Mean Effective Pressure:"
mep=(W/V_s)"kPa"
```

Results:

Unit Settings: SI C Pa J mass deg

cp = 1.005 [kJ/kg-K]	cv = 0.7175 [kJ/kg-K]	d = 0.2 [m]
η_{th} = 0.6004	γ = 1.4	L = 0.3 [m]
m = 0.01171 [kg/cycle]	mep = 754.8 [kPa]	p1 = 100 [kPa]
p2 = 4550 [kPa]	p3 = 4550 [kPa]	p4 = 287.8 [kPa]
Q_{in} = 11.85 [kJ/cycle]	Q_{out} = 4.735 [kJ/cycle]	R = 0.287 [kJ/kg-K]
rc = 2.128	rr = 15.29	T1 = 300 [K]
T2 = 893 [K]	T3 = 1900 [K]	T4 = 863.4 [K]
V1 = 0.01008 [m^3]	V2 = 0.0006597 [m^3]	V3 = 0.001404 [m^3]
V4 = 0.01008 [m^3]	V_c = 0.0006597 [m^3]	V_s = 0.009425 [m^3]
W = 7.113 [kJ/cycle]		

Thus:

Comprn. ratio = rr = 15.29 …. Ans.

Cut-off ratio = rc = 2.128 …. Ans.

Heat supplied to air = Q_in = 11.85 kJ …. Ans.

Heat rejected = Q_out = 4.735 kJ …. Ans.

Cycle efficiency = eta_th = 0.6004 = 60.04 %… Ans.

MEP = 754.8 kPa = 7.548 bar … Ans.

==

"**Prob.1.29.** An air standard Diesel cycle has a compression ratio of 16. The temp before compression is 27 C and the temp after expansion is 627 C. Determine: (i) net work output per unit mass of air (ii) thermal efficiency, (iii) specific air consumption, in kg/kWh. (iv) cut off ratio (v) expansion ratio. [VTU-ATD-July 2005 & Jan. 2006]"

EES solution:

```
"Data:"
rr =16 "….comprn. ratio"
P1=100 "kPa"
T1=27+273 "K…. temp. before compression"
R=0.287 "kJ/kg.K"
cp=1.005 "kJ/kg.K"
cv = 0.7175 "kJ/kg.K"
gamma=1.4
T4 = 627+273 "K … temp. after expansion"
"Calculations:"
"Process 1-2:"
P1* V1= R * T1 "…finds V1 for mass = 1 kg"
rr = V1/V2 "…finds V2"
P1* V1^gamma=P2 * V2^gamma "..finds P2, kPa"
T2/T1=(rr)^(gamma-1) "… finds T2, K"
"Process 2-3:"
P3 = P2 "..const. pressure heat addition in 2-3"
"Proces 4-1:"
V4=V1 "…for process 4-1"
P4/T4 = P1/T1 "…finds P4, kPa"
"Process 3-4:"
P4 * V4^gamma=P3 * V3^gamma "…finds V3, m^3"
T4 / T3 = (V3 / V4)^(gamma-1) "…finds T3 , K"
"Cut off ratio, rc:"
```

rc = V3/V2 "….cut off ratio"

"Expansion ratio, re:"

re = V4/V3 "….expansion ratio"

"Heat supplied:"

Q_in=cp*(T3-T2) "kJ/kg"

"Heat rejected:"

Q_out=cv*(T4-T1) "kJ/kg"

"Net work output:"

W_net=Q_in-Q_out "kJ/kg"

"Thermal efficiency:"

eta_th=W_net/Q_in "thermal effcy."

"Specific Air Consumption:"

SAC=3600/W_net "Specific Air Cons. in kg/kWh"

"Mean Effective Pressure:"

MEP=W_net/(V1-V2) "Mean Effective Pressure, kPa"

Results:

Unit Settings: SI K kPa kJ mass deg

cp = 1.005 [kJ/kg-K]	cv = 0.7175 [kJ/kg-K]	η_{th} = 0.6048
γ = 1.4	MEP = 816.1 [kPa]	P1 = 100 [kPa]
P2 = 4850 [kPa]	P3 = 4850 [kPa]	P4 = 300 [kPa]
Q_{in} = 1089 [kJ/kg]	Q_{out} = 430.5 [kJ/kg]	R = 0.287 [kJ/kg-K]
rc = 2.192	re = 7.3	rr = 16
SAC = 5.465 [kg/kWh]	T1 = 300 [K]	T2 = 909.4 [K]
T3 = 1993 [K]	T4 = 900 [K]	V1 = 0.861 [m^3/kg]
V2 = 0.05381 [m^3/kg]	V3 = 0.1179 [m^3/kg]	V4 = 0.861 [m^3/kg]
W_{net} = 658.8 [kJ/kg]		

Thus:

Net work output = W_net = 658.8 kJ/kg …. Ans.

Thermal efficiency = eta_th = 0.6048 = 60.48% … Ans.

Sp. Air Consumption = SAC = 5.465 kg/kWh … Ans.

Cut off ratio = rc = 2.192 …. Ans.

Expansion ratio = re = 7.3 … Ans.

==

"**Prob.1.30.** Conditions at the beginning of compression in an air standard Diesel cycle are: P = 200 kPa, T1 = 380 K. The compression ratio is 20 and heat addition per unit mass is 900 kJ/kg. Determine: (i) the max. temp (ii) cut off ratio, (iii) net work per unit mass of air in kJ/kg, (iv) thermal efficiency, and (v) the mean effective pressure.

Also, plot the variation of these quantities as compression ratio varies from 5 to 25. [Ref: 3]"

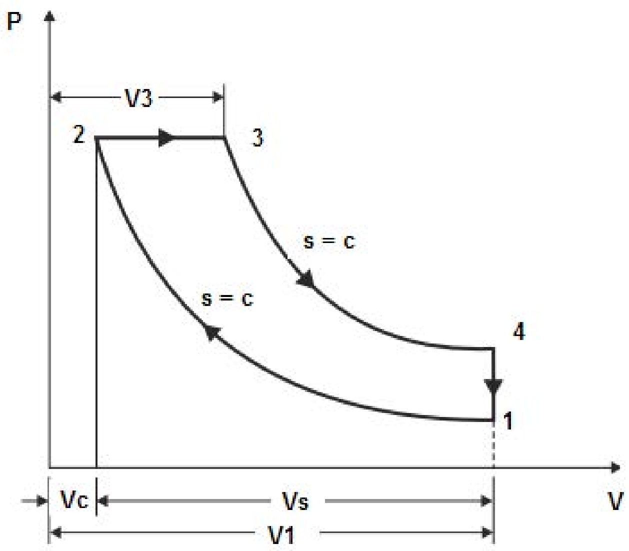


Fig.Prob.1.27

EES Solution:

"Data:"

rr = 20 "..comprn. ratio"

gamma = 1.4 "..for air"

R = 0.287 "kJ/kg.K"

cp = gamma * R / (gamma – 1) "kJ/g.K … sp. heat at const. pressure"

cp – cv = R "… finds cv, sp. heat at const. volume….kJ/kg.K"

P1 = 200"kPa"

T1 = 380 "K"

Q_s = 900 "kJ/kg … heat supplied"

m = 1 "kg"

"Calculations:"

"Find all the four temperatures:"

m = P1* V1 / (R * T1) "finds volume of air at beginning of compression, m^3"

"Process 1-2:"

V1/V2 = rr "…finds V2, m^3"

P1 * V1^gamma = P2 * V2^gamma "…finds P2, kPa"

```
m = P2 * V2 / (R * T2) "…finds T2, K"
"Process 2-3:"
P3 = P2 "…since Process 2-3 is at const. pressure"
Q_s = m * cp * (T3 – T2) "….finds T3, K"
P3 * V3/ T3 = m * R "…finds V3, m^3"
V3/V2 = rc "…finds cut off ratio, rc"
"Process 3-4:"
V4 = V1 "…for const. vol. process 4-1"
P3 * V3^gamma = P4 * V4^gamma "…finds P4, kPa"
P4 / T4 = P1 / T1 "…finds T4, K … since V4 = V1"
"Process 4-1:"
Q_r = m * cv * (T4 – T1) "kJ/kg …. heat rejected"
"Therefore: Net work:"
W_net = Q_s – Q_r "kJ/kg…net work output"
"Thermal efficiency:"
eta_th = W_net / Q_s "..thermal efficiency"
"Mean Effective Pressure:"
MEP = W_net / (V1 – V2) "kPa … mean effective pressure"
"-------------------------------------------------------------------------------"
```

"Verify these values using the EES Functions already written:"

eta_th_2 = EFFCY_Diesel(rc, rr, gamma)

W_net_2 = W_net_Diesel(P1, V1, rc, rr, gamma)

MEP_2 = MEP_Diesel(P1,rc, rr, gamma)

Results:

Unit Settings: SI C Pa J mass deg

cp = 1.005 [kJ/kg-K]	cv = 0.7175 [kJ/kg-K]	η_{th} = 0.6602
$\eta_{th,2}$ = 0.6602	γ = 1.4	m = 1 [kg/cycle]
MEP = 1147 [kPa]	MEP_2 = 1147 [kPa]	P1 = 200 [kPa]
P2 = 13258 [kPa]	P3 = 13258 [kPa]	P4 = 424.3 [kPa]
Q_r = 305.8 [kJ/kg]	Q_s = 900 [kJ/kg]	R = 0.287 [kJ/kg-K]
rc = 1.711	rr = 20	T1 = 380 [K]
T2 = 1259 [K]	T3 = 2155 [K]	T4 = 806.2 [K]
V1 = 0.5453 [m^3]	V2 = 0.02727 [m^3]	V3 = 0.04666 [m^3]
V4 = 0.5453 [m^3]	W_{net} = 594.2 [kJ/kg]	$W_{net,2}$ = 594.2 [kJ/kg]

Thus:

Max. temp. = T3 = 2155 K …Ans.

Cut off ratio = rc = 1.711 .. Ans.

Net work per unit mass of air = W_net = 594.2 kJ/kg …. Ans.

Thermal efficiency = eta_th = 0.6602 = 66.02% … Ans.

Mean Effective Pressure = MEP = 1147 kPa = 11.47 bar … Ans.

Also, note that, using the EES Functions, we get the same results for Thermal effcy., Net work and MEP:

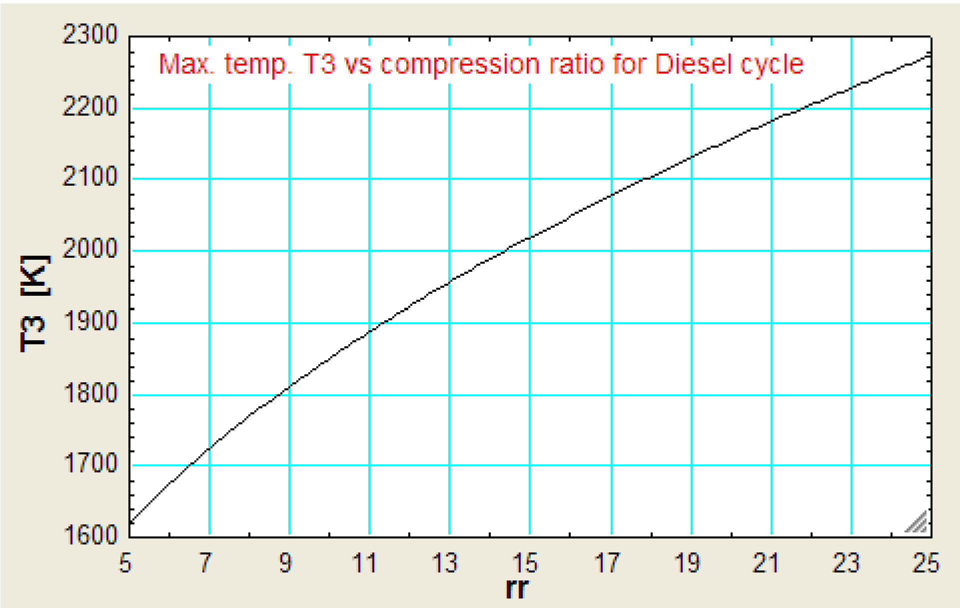
i.e. eta_th_2 = 0.6602, W_net_2 = 594.2 kJ/kg, and MEP_2 = 1147 kPa.

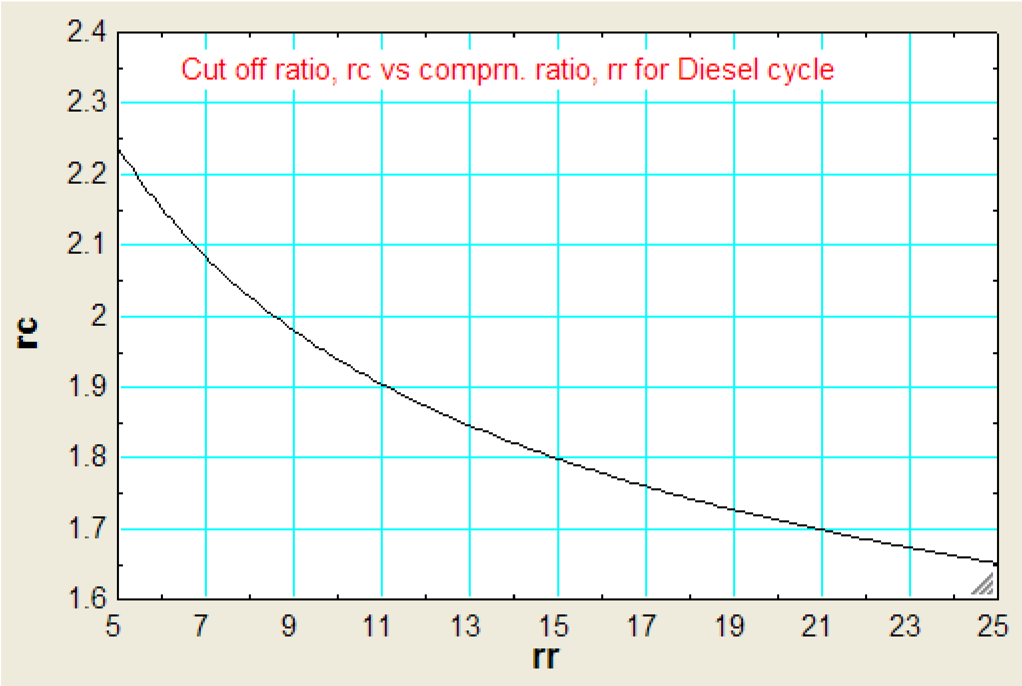
(b) To plot the variation of T3, rc, W_net, eta_th and MEP as compression ratio, rr varies from 5 to 25:

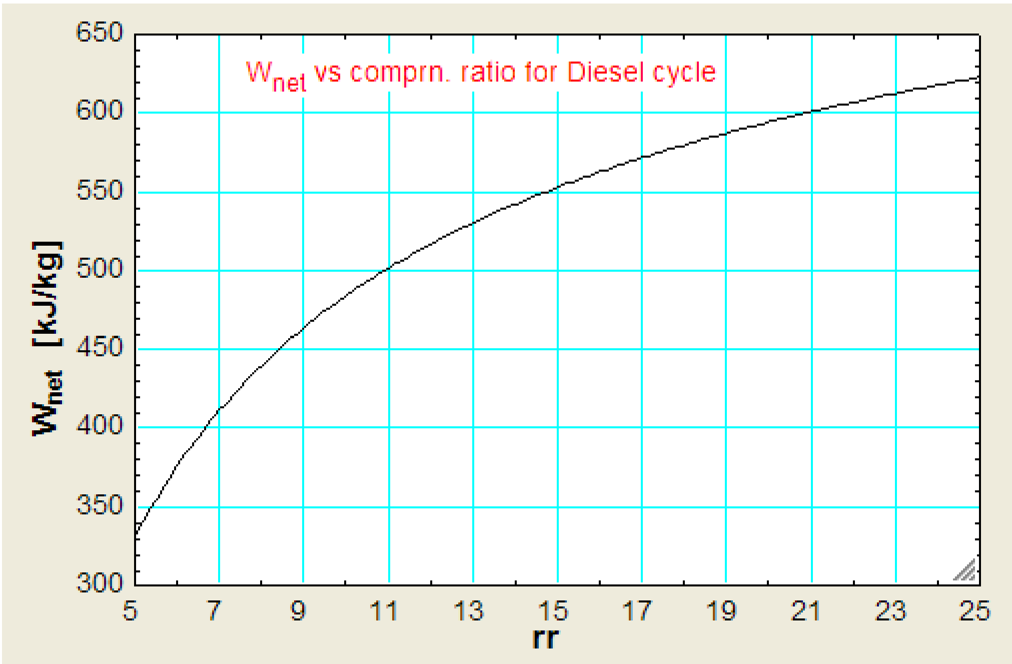
First, compute the Parametric Table:

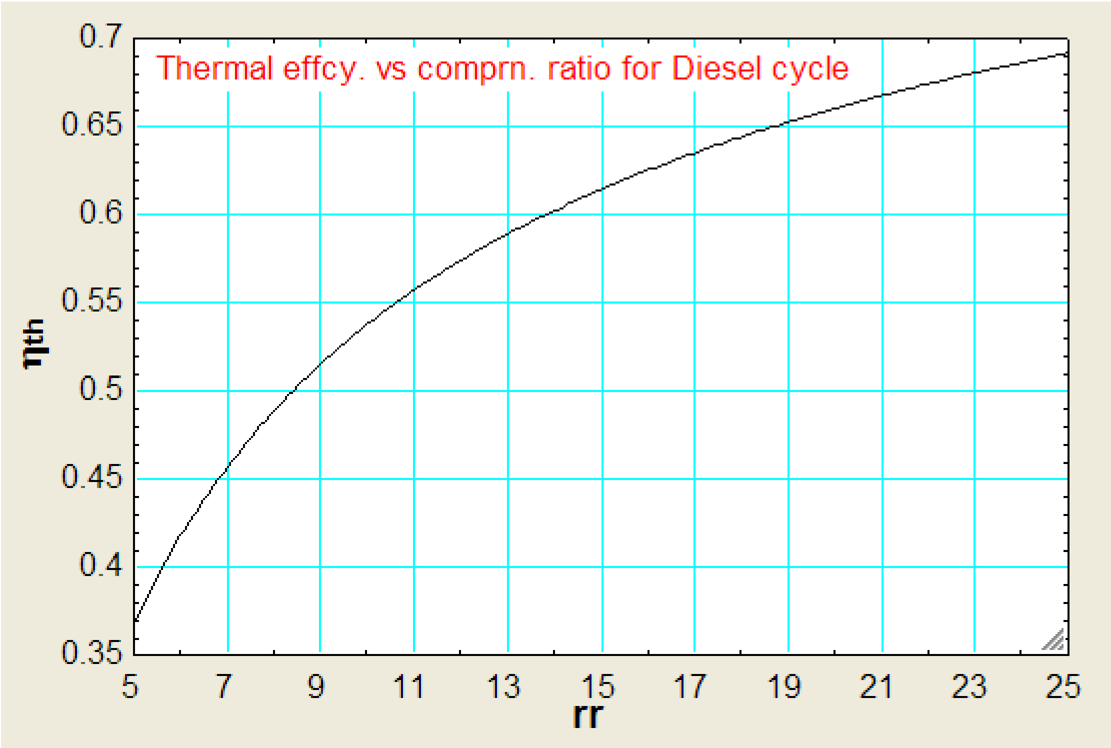
1..21	rr	T3 [K]	rc	W_{net} [kJ/kg]	η_{th}	MEP [kPa]
Run 1	5	1619	2.239	330.2	0.3668	756.8
Run 2	6	1674	2.151	375.7	0.4174	826.8
Run 3	7	1724	2.083	411.2	0.4569	879.7
Run 4	8	1769	2.026	439.8	0.4887	921.8
Run 5	9	1811	1.979	463.6	0.5152	956.5
Run 6	10	1850	1.939	483.8	0.5376	985.9
Run 7	11	1888	1.904	501.2	0.5569	1011
Run 8	12	1923	1.873	516.4	0.5738	1033
Run 9	13	1956	1.845	529.9	0.5888	1053
Run 10	14	1988	1.82	541.9	0.6021	1070
Run 11	15	2019	1.798	552.7	0.6141	1086
Run 12	16	2048	1.778	562.5	0.625	1100
Run 13	17	2076	1.759	571.4	0.6349	1113
Run 14	18	2103	1.742	579.6	0.644	1125
Run 15	19	2130	1.726	587.2	0.6524	1137
Run 16	20	2155	1.711	594.2	0.6602	1147
Run 17	21	2180	1.698	600.7	0.6674	1157
Run 18	22	2204	1.685	606.7	0.6741	1166
Run 19	23	2228	1.673	612.4	0.6804	1174
Run 20	24	2251	1.661	617.7	0.6863	1182
Run 21	25	2273	1.651	622.7	0.6919	1190

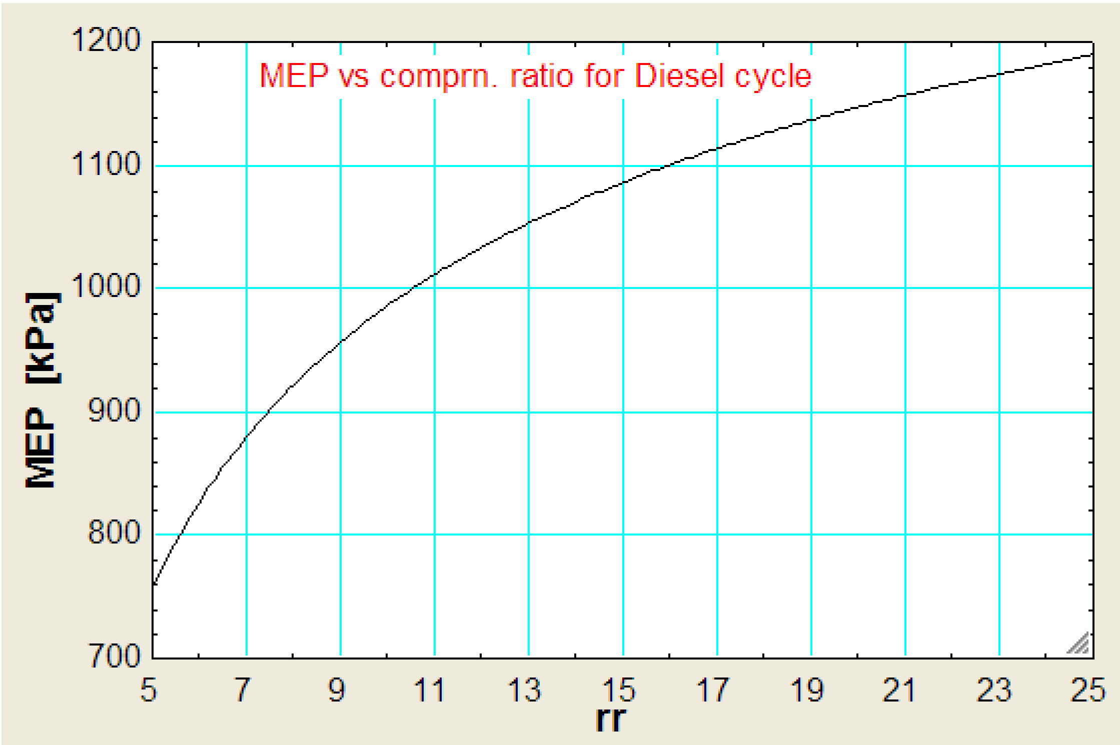
Now, plot the results:




Cut off ratio, rc vs comprn. ratio, rr for Diesel cycle
rc
rr
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
5
7
9
11
13
15
17
19
21
23
25


Wnet vs comprn. ratio for Diesel cycle
Wnet [kJ/kg]
rr
650
600
550
500
450
400
350
300
5
7
9
11
13
15
17
19
21
23
25


Thermal effcy. vs comprn. ratio for Diesel cycle
ηth
rr
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
5
7
9
11
13
15
17
19
21
23
25


MEP vs comprn. ratio for Diesel cycle
MEP [kPa]
rr
1200
1100
1000
900
800
700
5
7
9
11
13
15
17
19
21
23
25

==

“**Prob.1.31.**An oil engine works on ideal Diesel cycle, with a compression ratio of 20. Heat addition at constant pressure takes place up to 10% of stroke. Initial pressure and temp are 1 bar and 67 C. Compression and expansion follow the law P. v^1.3 = constant. Find the following: (i) temps and pressures at all salient points (ii) mean effective pressure of the cycle, (iii) net work done per kg of air, and (iii) the thermal efficiency. Also, plot the variation of W_net, MEP and eta_th as compression ratio varies from 5 to 25.”

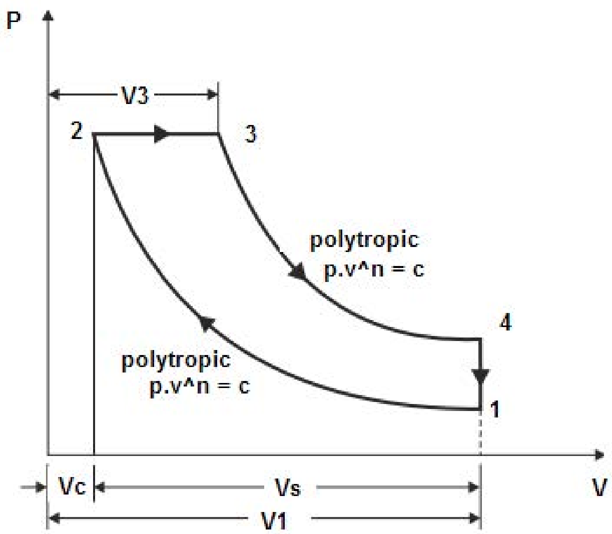


Fig.Prob.1.31

EES Solution:

Note that here, the compression and expansion are *not* isentropic, but polytropic.
Therefore, Net work should be calculated as area of P-v diagram, and not as (Qs – Qr).

"Data:"

rr = 20 "..comprn. ratio"

gamma = 1.4 "..for air"

n = 1.3 "…polytropic index of compression and expansion"

R = 0.287 "kJ/kg.K"

cp = gamma * R / (gamma – 1) "kJ/g.K … sp. heat at const. pressure"

cp – cv = R "… finds cv, sp. heat at const. volume….kJ/kg.K"

P1 = 100"kPa"

T1 = 67 + 273 "K"

m = 1 "kg"

"Calculations:"

"Find all the four temperatures:"

m = P1* V1 / (R * T1) "finds volume of air at beginning of compression, m^3"

"Process 1-2:"

V1/V2 = rr "…finds V2, m^3"

P1 * V1^n = P2 * V2^n "…finds P2, kPa"

m = P2 * V2 / (R * T2) "…finds T2, K"

"Process 2-3:"

P3 = P2 "…since Process 2-3 is at const. pressure"

(V3 – V2) / (V1 – V2) = 0.1 **"…since, by data, cut off occurs at 10 % of stroke …. finds V3, m^3"**

P3 * V3 = m * R * T3 "…finds T3, K"

Q_s = m * cp * (T3 – T2) "….finds heat supplied in Process 2-3 = Q_s, kJ/kg"

V3/V2 = rc "…finds cut off ratio, rc"

"Process 3-4:"

V4 = V1 "…for const. vol. process 4-1"

P3 * V3^n = P4 * V4^n "…finds P4, kPa"

P4 / T4 = P1 / T1 "…finds T4, K … since V4 = V1"

"Process 4-1:"

Q_r = m * cv * (T4 – T1) "kJ/kg …. heat rejected in Process 4-1"

"Net work: should be calculated as area of P-v diagram, and not as (Qs – Qr), since compression and expansion are polytropic and there is heat transfer during these processes too"

"W_net =P2 * (V3 – V2) + (P3. V3 – P4. V4) / (n -1) – (P2. V2 – P1. V1) / (n-1)
i.e. W_net = P2 * (V3 – V2) +R * (T3 – T4) / (n-1) – R * (T2 – T1) / (n – 1) …kJ/kg…net work output"

W_net = P2 * (V3 – V2) + R * (T3 – T4) / (n-1) – R * (T2 – T1) / (n – 1) "..kJ/kg"

"Thermal efficiency:"

eta_th = W_net / Q_s "..thermal efficiency"

"Mean Effective Pressure:"

MEP = W_net / (V1 – V2) "kPa … mean effective pressure"

Results:

Unit Settings: SI C Pa J mass deg

cp = 1.005 [kJ/kg-K]	cv = 0.7175 [kJ/kg-K]	η_{th} = 0.6277
γ = 1.4	m = 1 [kg]	MEP = 1079 [kPa]
n = 1.3	P1 = 100 [kPa]	P2 = 4913 [kPa]
P3 = 4913 [kPa]	P4 = 399.1 [kPa]	Q_r = 729.7 [kJ/kg]
Q_s = 1594 [kJ/kg]	R = 0.287 [kJ/kg-K]	rc = 2.9
rr = 20	T1 = 340 [K]	T2 = 835.2 [K]
T3 = 2422 [K]	T4 = 1357 [K]	V1 = 0.9758 [m^3]
V2 = 0.04879 [m^3]	V3 = 0.1415 [m^3]	V4 = 0.9758 [m^3]
W_{net} = 1001 [kJ/kg]		

Thus:

P1 = 100 kPa, P2 = 4913 kPa, , P3 = 4913 kPa, P4 = 399.1 kPa …. Ans.

T1 = 340 K, T2 = 835.2 K, T3 = 2422 K, T4 = 1357 K …. Ans.

MEP = 1079 kPa = 10.79 bar … Ans.

Net work output = W_net = 1001 kJ/kg …. Ans.

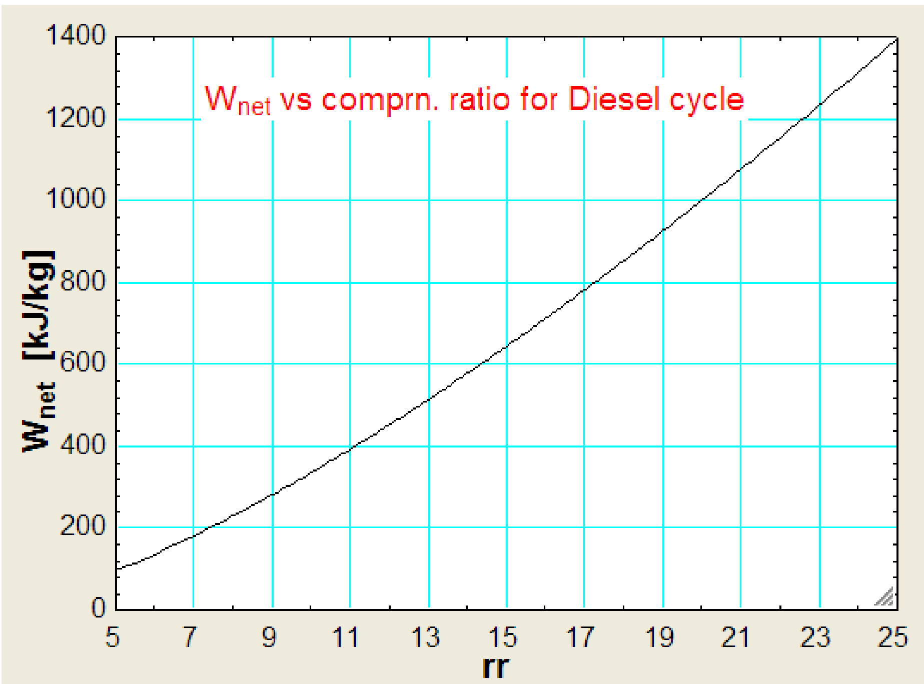
Thermal efficiency = eta_th = 0.6277 = 62.77% … Ans.

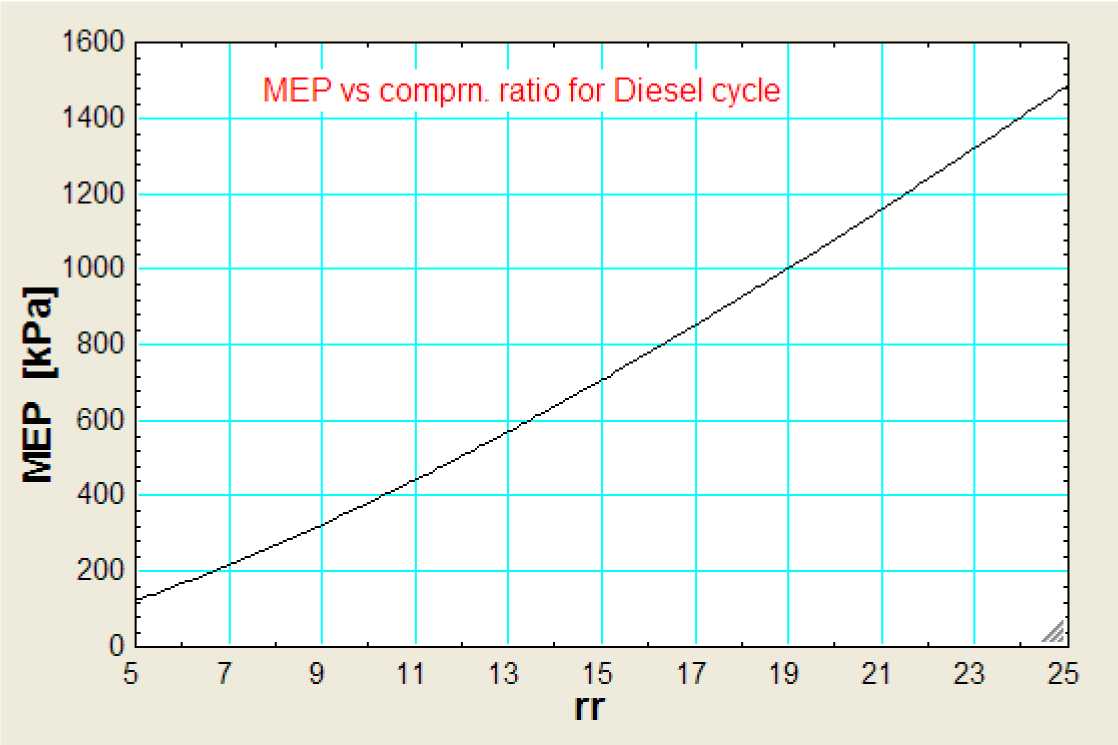
(b) Also, plot the variation of W_net , MEP and eta_th as compression ratio varies from 5 to 25:

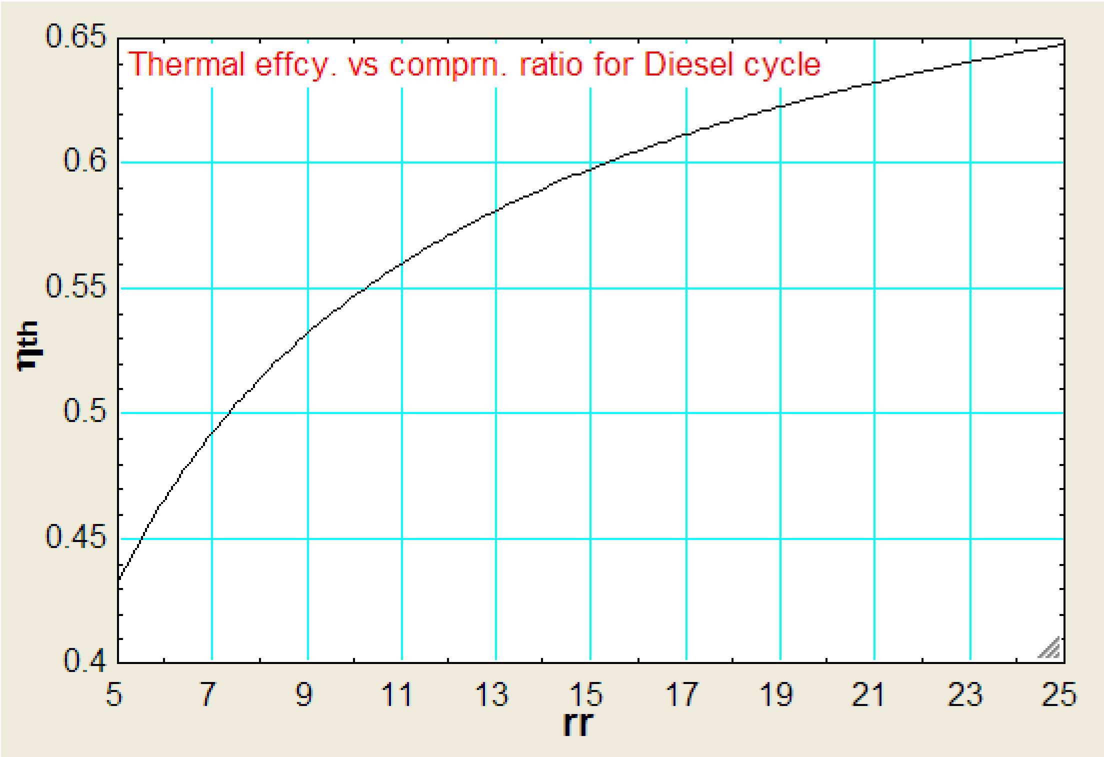
First, compute the Parametric Table:

1..21	rr	W_{net} [kJ/kg]	MEP [kPa]	η_{th}
Run 1	5	95.64	122.5	0.432
Run 2	6	136.2	167.5	0.4658
Run 3	7	180.9	216.3	0.4924
Run 4	8	229.2	268.5	0.5138
Run 5	9	280.8	323.8	0.5317
Run 6	10	335.4	381.9	0.5468
Run 7	11	392.5	442.5	0.5598
Run 8	12	452.2	505.5	0.5711
Run 9	13	514.1	570.7	0.5811
Run 10	14	578.1	638	0.5899
Run 11	15	644.1	707.2	0.5978
Run 12	16	712	778.3	0.605
Run 13	17	781.7	851.1	0.6114
Run 14	18	853	925.6	0.6173
Run 15	19	926	1002	0.6227
Run 16	20	1001	1079	0.6277
Run 17	21	1077	1158	0.6323
Run 18	22	1154	1239	0.6365
Run 19	23	1233	1321	0.6405
Run 20	24	1313	1404	0.6442
Run 21	25	1394	1488	0.6476

Now, plot the results:




MEP vs comprn. ratio for Diesel cycle
MEP [kPa]
rr
0
200
400
600
800
1000
1200
1400
1600
5
7
9
11
13
15
17
19
21
23
25



===

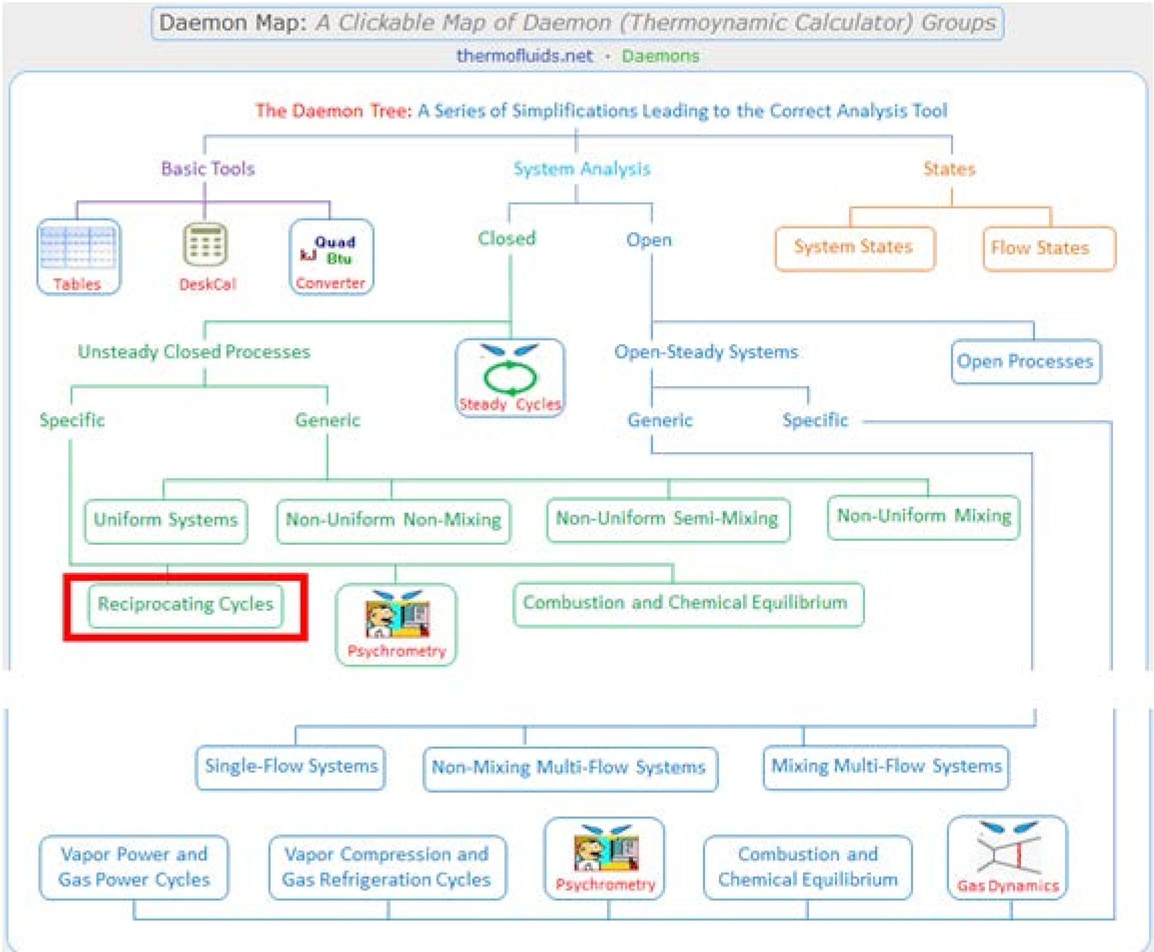
1.3.3 Problems solved with TEST:

Prob.1.32. The compression ratio of a Diesel cycle is 14 and the cut off ratio is 2.2. At the beginning of the cycle, air is at 0.98 bar and 100 C. Find: (i) Temps and pressures at salient points, (ii) Air standard efficiency, and (iii) the MEP. [VTU]

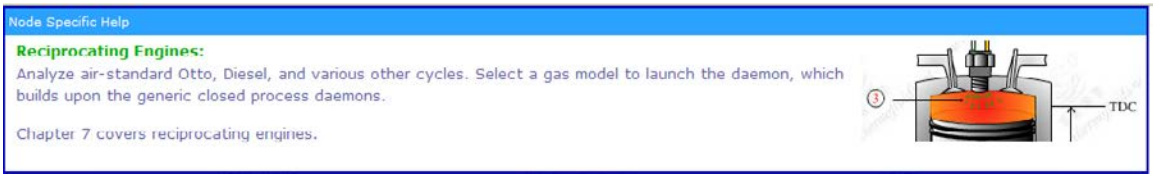
TEST Solution:

Following are the steps:

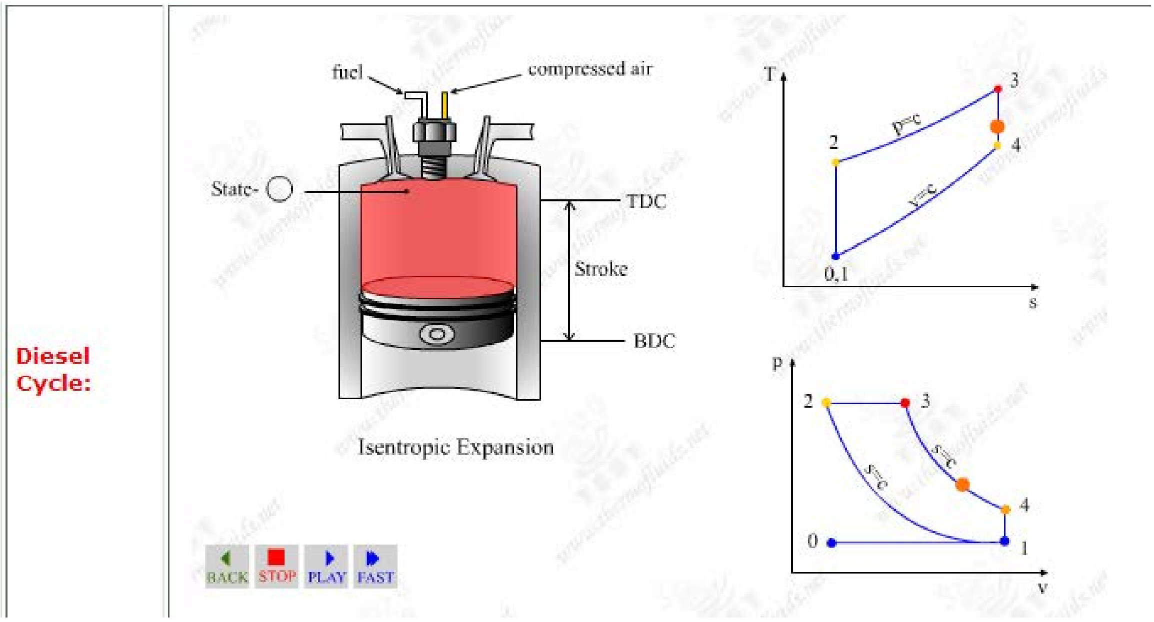
1. From the TEST daemon tree, select the 'Reciprocating cycles' daemon:



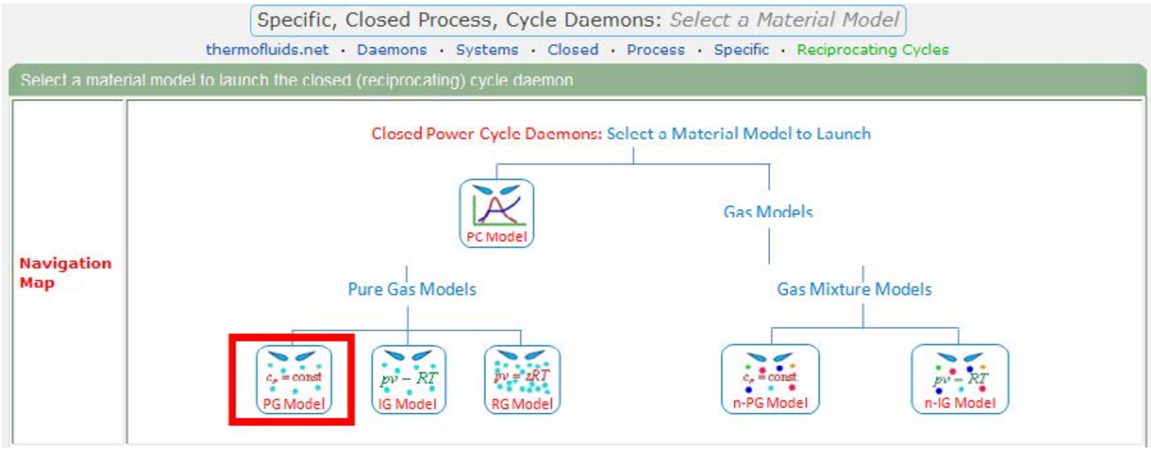
2. Hovering the mouse pointer over 'Reciprocating cycles' brings up the following pop up:



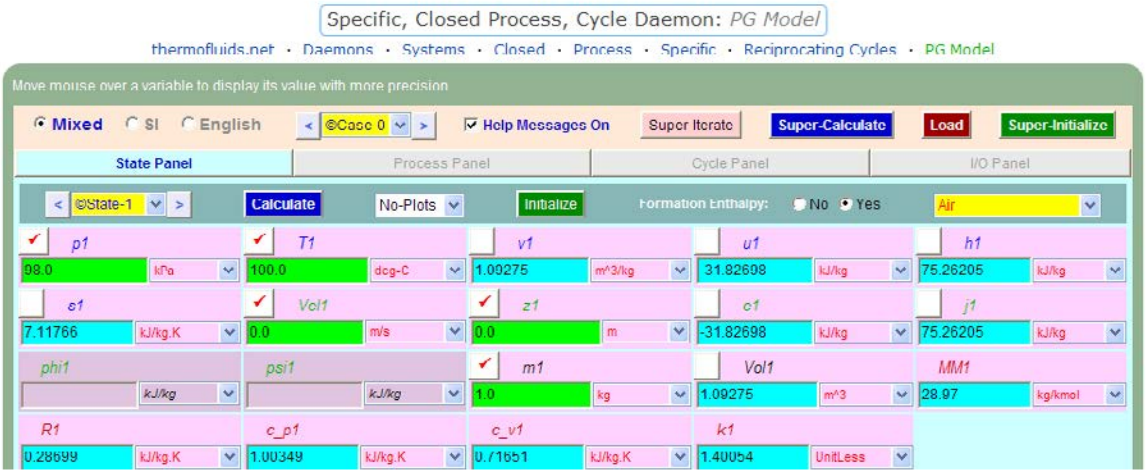
3. Clicking on 'Reciprocating cycles' brings up the window for material selection. There is also a schematic diagram and animation of Diesel cycle:



4. For Materials model, choose Perfect Gas (PG) model, where cp is constant:



5. Select Air as the working substance and fill in data for p1, T1 and m1= 1 kg for State 1, i.e. at beginning of compression, and hit Enter. We get::



Note that properties for State 1 are calculated. Here, p1 = 98 kPa, T1 = 100 C.

6. For State 2: Enter v2 = v1/14 (since compression ratio is 14), s2 = s1 (since Process 1-2 is isentropic) and m2 = m1. Hit Enter:

Here, p2 = 3948.38 kPa, T2 = 1073.86 K ….Ans.

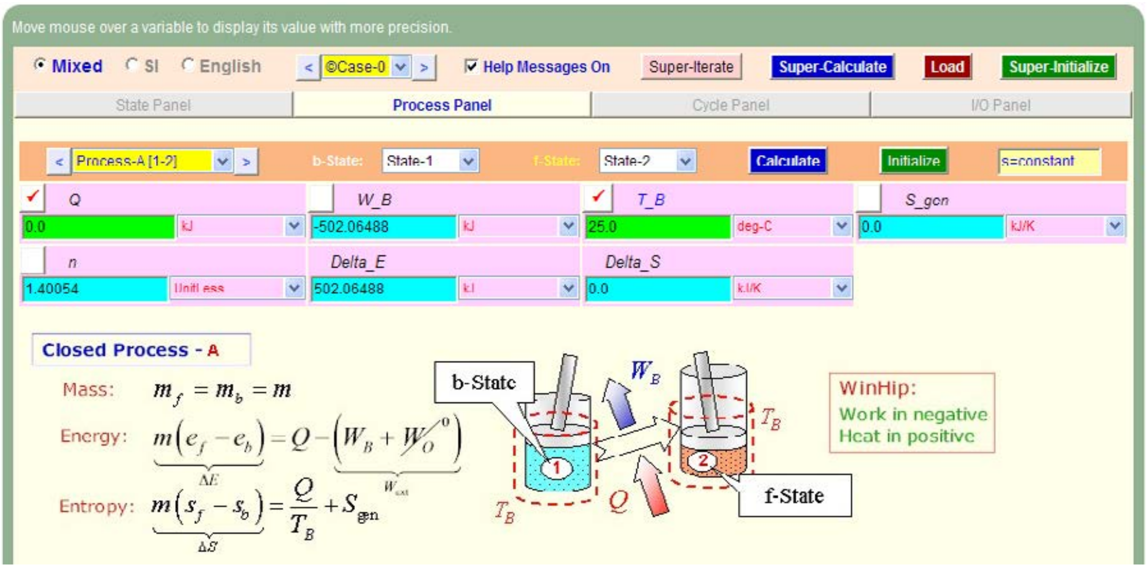
7. Similarly, for State 3: Enter p3 = p2 (since Process 2-3 is a const. pressure process), v3 = v2 * 2.2 (since cut off ratio is 2.2), and m3 = m1. Hit Enter, and we get:

Here, p3 = p2 = 3948.38 kPa, T3 = 2362.49 K ….Ans.

8. And for State 4, enter: v4 = v1 (since Process 4-1 is a const. volume process), s4 = s3 (since process 3-4 is isentropic), and m4 = m1. Hit Enter:

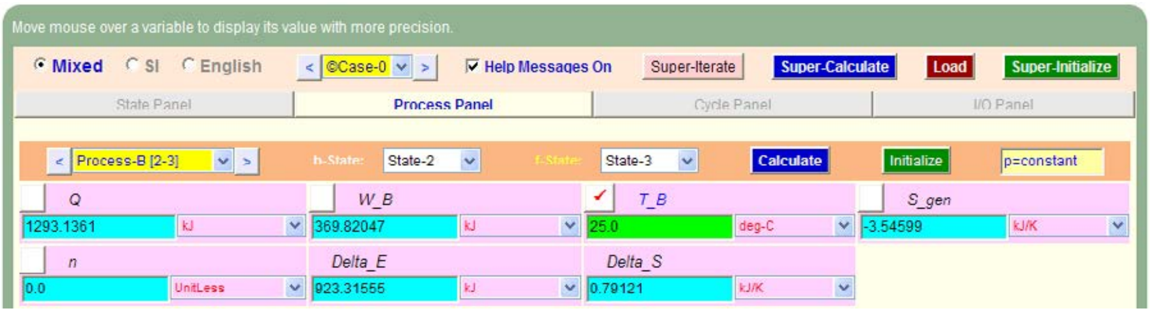
Here, p4 = 295.67 kPa, T1 = 1125.79 K ….Ans.

9. Now, go to the Process Panel. For Process A (i.e. process 1-2), enter State 1 and State 2 for b-state and f-state respectively, and Q = 0 since process 1-2 is adiabatic. Hit Enter, and we get:



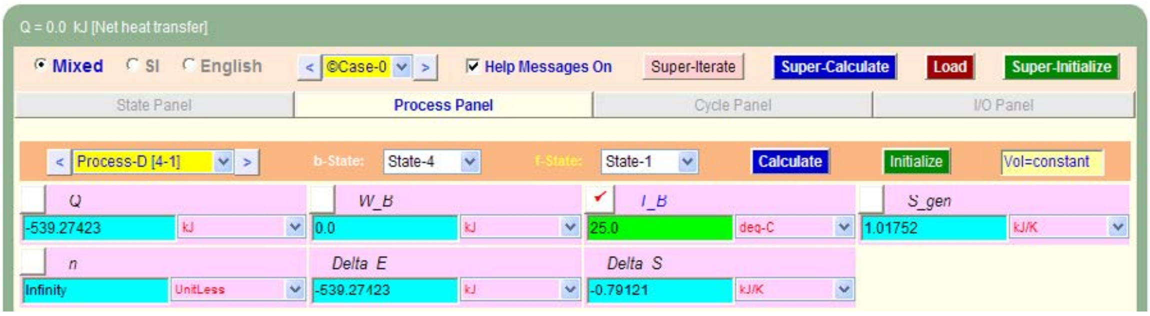
Note that the boundary work, W_B etc for this process are immediately calculated.

10. Similarly, for Process B (i.e. process 2-3): enter b-state and f-state, hit Enter:

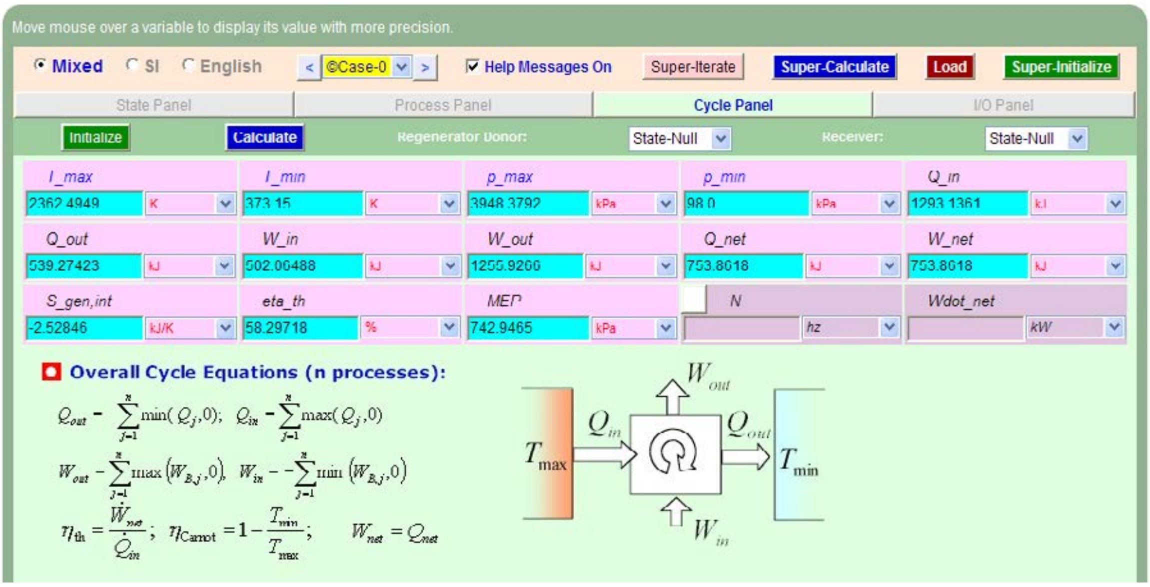


11. And, similarly for Process 3-4:

12. Again, for Process 4-1:



13. Now, go to Cycle Panel, click on Calculate and SuperCalculate. All calculations are available here:



Note that:

Air standard efficiency = eta_th = 50.297% …. Ans.

MEP = 742.945 kPa = 7.43 bar … Ans.

14. Get the TEST code etc from the I/O panel:

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

Daemon Path: Systems>Closed>Process>Specific>PowerCycle>PG-Model; v-10.ca08

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

States {

State-1: Air;

Given: { p1= 98.0 kPa; T1= 100.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; m1= 1.0 kg; }

State-2: Air;

Given: { v2= “v1/14“m^3/kg; s2= “s1”kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; m2= “m1”kg; }

State-3: Air;

Given: { p3= “p2“kPa; v3= “v2*2.2“m^3/kg; Vel3= 0.0 m/s; z3= 0.0 m; m3= “m1”kg; }

State-4: Air;

Given: { v4= “v1”m^3/kg; s4= “s3“kJ/kg.K; Vel4= 0.0 m/s; z4= 0.0 m; m4= “m1”kg; }

}

```
Analysis {
        Process-A: b-State = State-1; f-State = State-2;
        Given: { Q= 0.0 kJ; T_B= 25.0 deg-C; }
        Process-B: b-State = State-2; f-State = State-3;
        Given: { T_B= 25.0 deg-C; }
        Process-C: b-State = State-3; f-State = State-4;
        Given: { Q= 0.0 kJ; T_B= 25.0 deg-C; }
        Process-D: b-State = State-4; f-State = State-1;
        Given: { 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       98.0      373.2    1.0927     -31.83    75.26     7.118
#       2       3948.38   1073.9   0.0781     470.24    778.42    7.118
#       3       3948.38   2362.5   0.1717     1393.55   2071.56   7.909
#       4       295.67    1125.8   1.0927     507.45    830.53    7.909
#--------Property spreadsheet ends------------------------------------------------------------------
```

 # Mass, Energy, and Entropy Analysis Results:
Process-A: b-State = State-1; f-State = State-2;
Given: Q= 0.0 kJ; T_B= 25.0 deg-C;
Calculated: W_B= -502.06488 kJ; S_gen= -0.0 kJ/K; n= 1.4005353 UnitLess; Delta_E= 502.06488 kJ;
Delta_S= -0.0 kJ/K;
Process-B: b-State = State-2; f-State = State-3;
Given: T_B= 25.0 deg-C;
Calculated: Q= 1293.1361 kJ; W_B= 369.8205 kJ; S_gen= -3.5459874 kJ/K; n= 0.0 UnitLess;
Delta_E= 923.31555 kJ; Delta_S= 0.79121226 kJ/K;
Process-C: b-State = State-3; f-State = State-4;
Given: Q= 0.0 kJ; T_B= 25.0 deg-C;
Calculated: W_B= 886.1062 kJ; S_gen= -0.0 kJ/K; n= 1.4005353 UnitLess; Delta_E= -886.1062 kJ;
Delta_S= -0.0 kJ/K;
Process-D: b-State = State-4; f-State = State-1;
Given: T_B= 25.0 deg-C;
Calculated: Q= -539.27423 kJ; W_B= 0.0 kJ; S_gen= 1.0175225 kJ/K; n= Infinity UnitLess;
Delta_E= -539.27423 kJ; Delta_S= -0.79121226 kJ/K;
 # Cycle Analysis Results:
Calculated: T_max= 2362.4949 K; T_min= 373.15 K; p_max= 3948.3792 kPa;
p_min= 98.0 kPa; Q_in= 1293.1361 kJ; Q_out= 539.27423 kJ;
W_in= 502.06488 kJ; W_out= 1255.9266 kJ; Q_net= 753.8618 kJ;
W_net= 753.8618 kJ; S_gen,int= -2.52846 kJ/K; **eta_th= 58.29718 %;**
MEP= 742.9465 kPa;

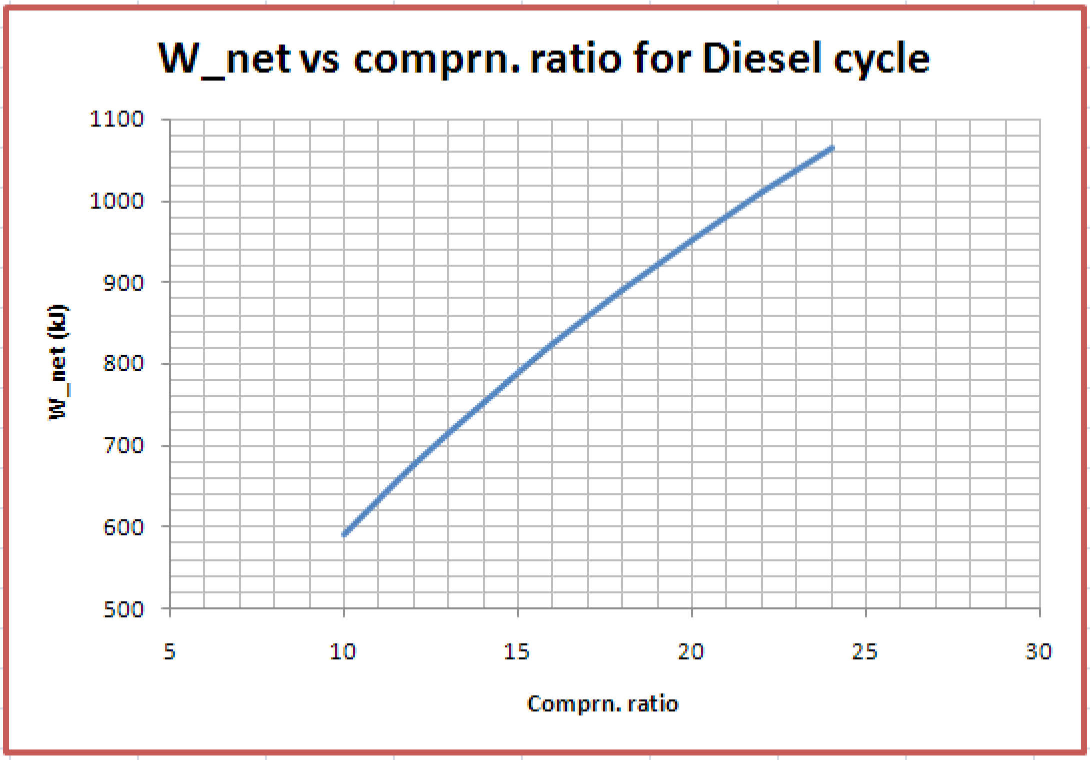
In addition:

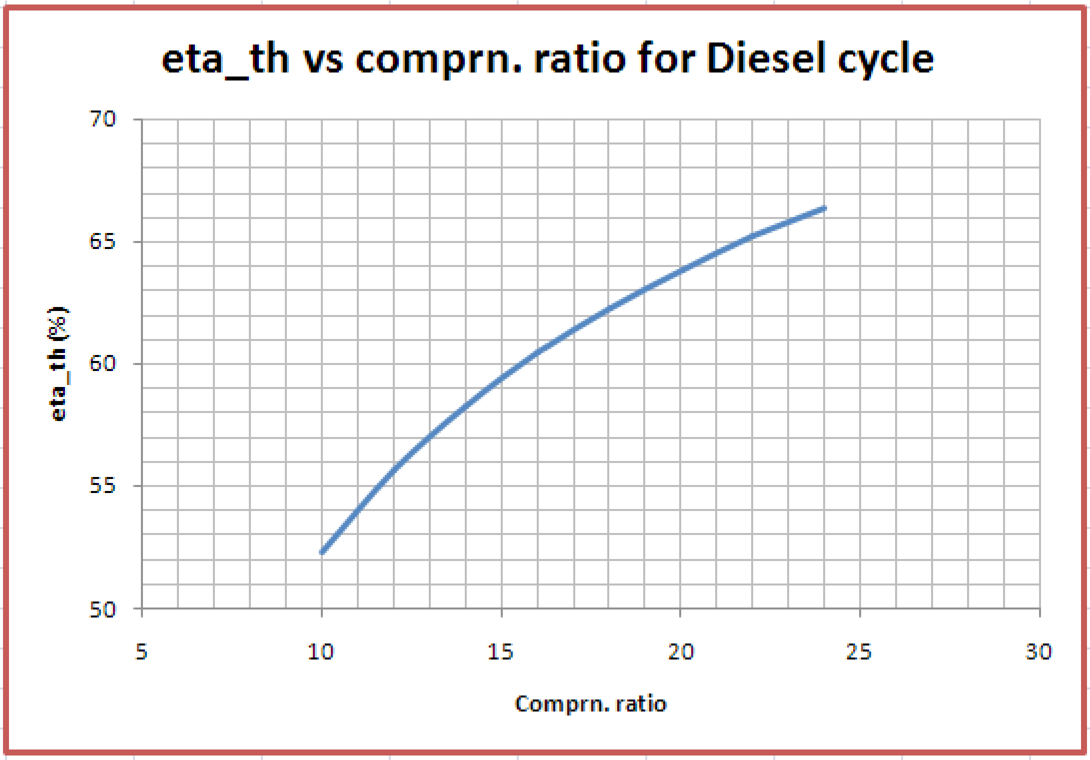
To plot the variation of W_net, eta_th and MEP with compression ratio varying from 10 to 24, following are the steps:

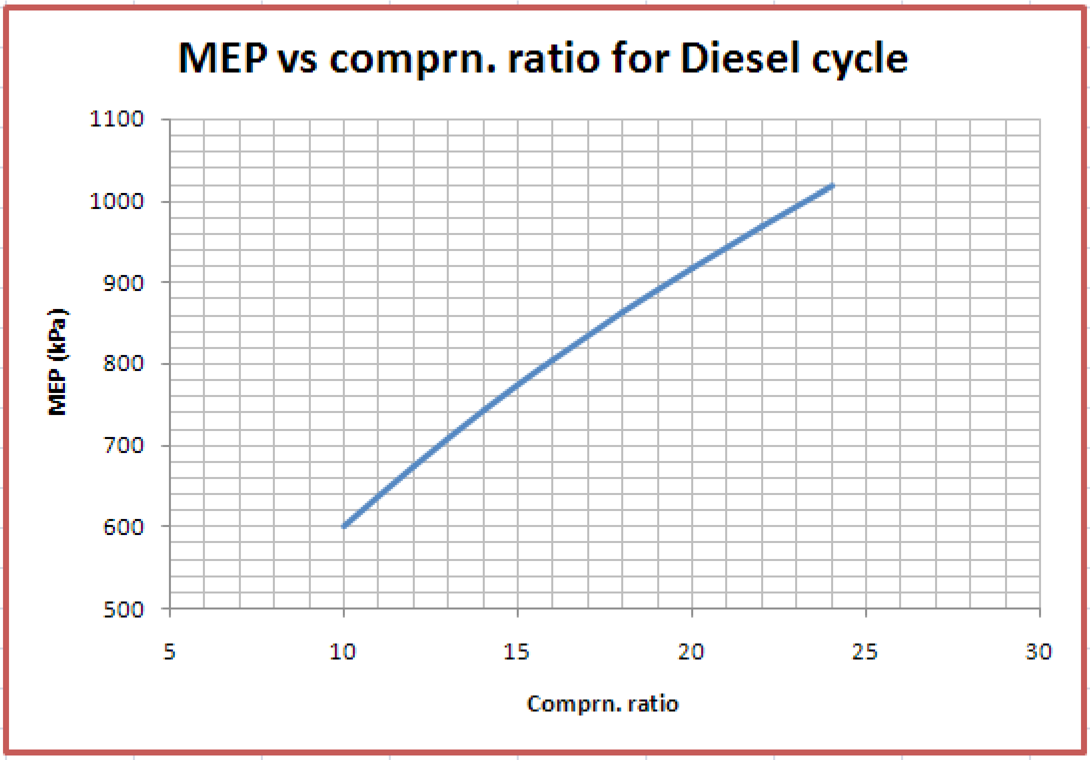
1. Go to State 2, enter for v2 as: v2 = v1 / 10, for compression ratio of 10. Hit Enter.
2. Click on SuperCalculate.
3. Go to Cycle Panel and read out the values for W_net, eta_th and MEP.
4. Repeat steps 1 to 3 for next value of compression ratio in State 2, and tabulate the results in EXCEL.
5. Plot the graphs in EXCEL:

Comprn. ratio	W_net (kJ)	Eta_th (%)	MEP (kPa)
10	590.82	52.28	600.75
12	676.43	55.64	675.30
14	753.86	58.30	742.95
16	824.91	60.47	805.22
18	890.81	62.29	863.15
20	952.45	63.85	917.48
22	1010.5	65.20	968.77
24	1065.46	66.39	1017.42

Plots:




eta_th vs comprn. ratio for Diesel cycle
eta_th (%)
70
65
60
55
50
5
10
15
20
25
30
Comprn. ratio



==

Prob.1.33. The compression ratio of a Compression Ignition engine working on Diesel cycle is 16. Temp and pressure of air at the beginning of compression is 300 K and 1 bar, and the temp of air at the end of expansion is 900 K. Determine: (i) cut off ratio (ii) expansion ratio, and (iii) the cycle efficiency.

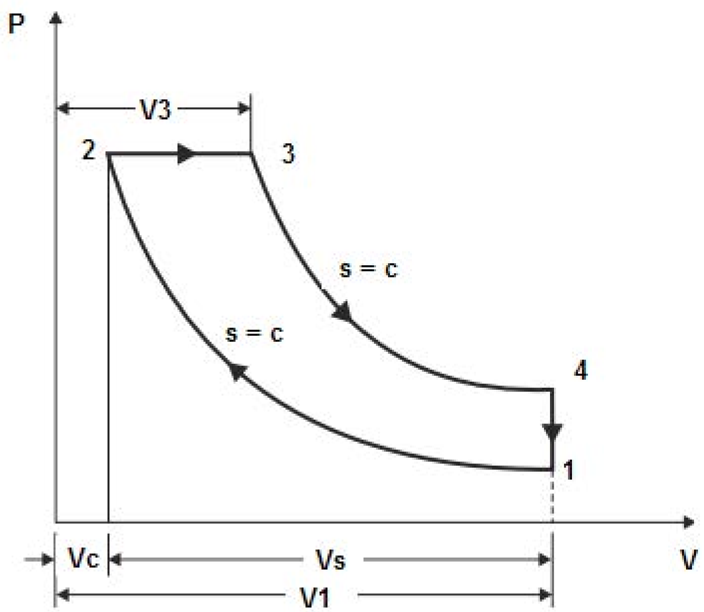


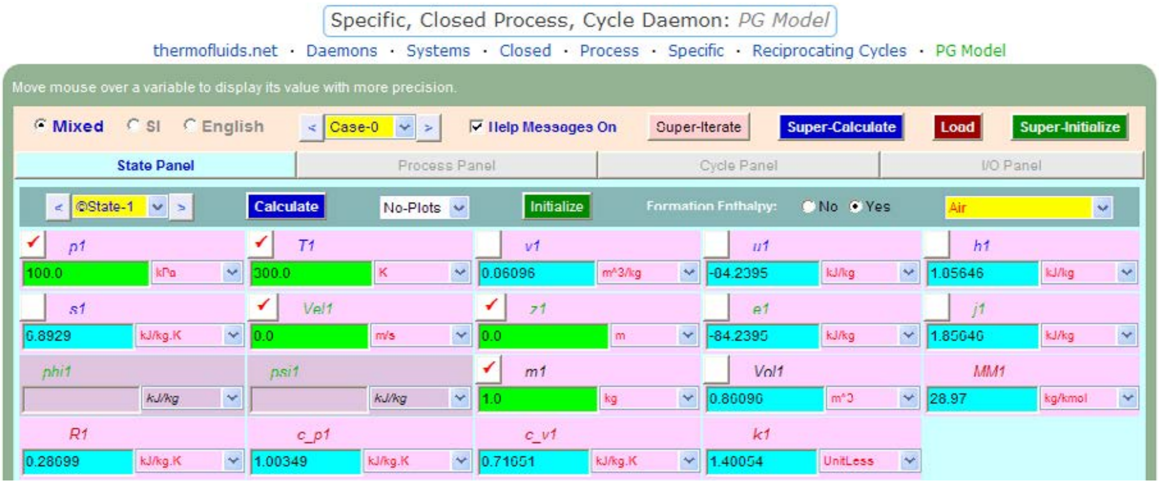
Fig.Prob.1.33

TEST Solution:

Following are the steps:

Steps 1 to 4 are the same as for the previous problem.

5. Select Air as the working substance and fill in data for p1 = 100 kPa, T1 and m1 = 1 kg for State 1, i.e. at beginning of compression, and hit Enter. We get:

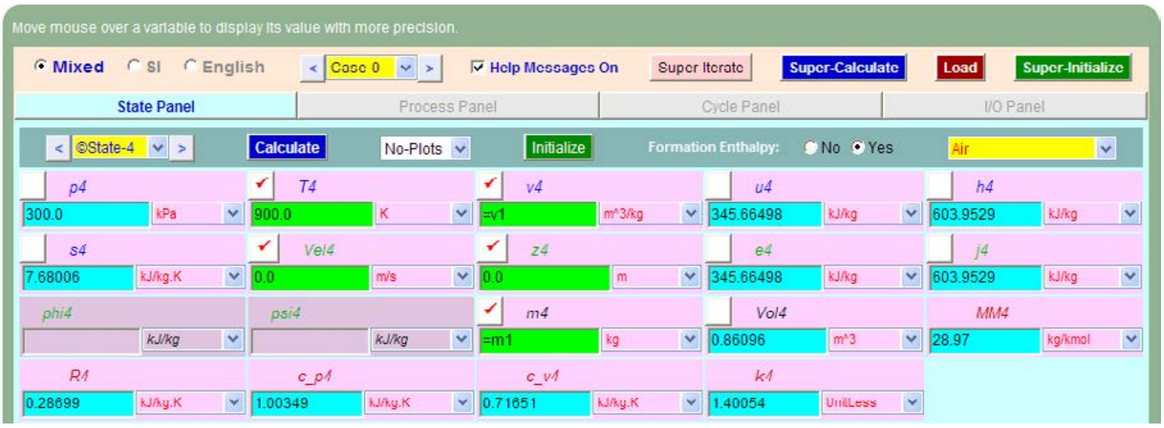


Note that properties for State 1 are calculated.

6. For State 2: Enter v2 = v1/16 (since compression ratio is 16), s2 = s1 (since Process 1-2 is isentropic) and m2 = m1. Hit Enter:

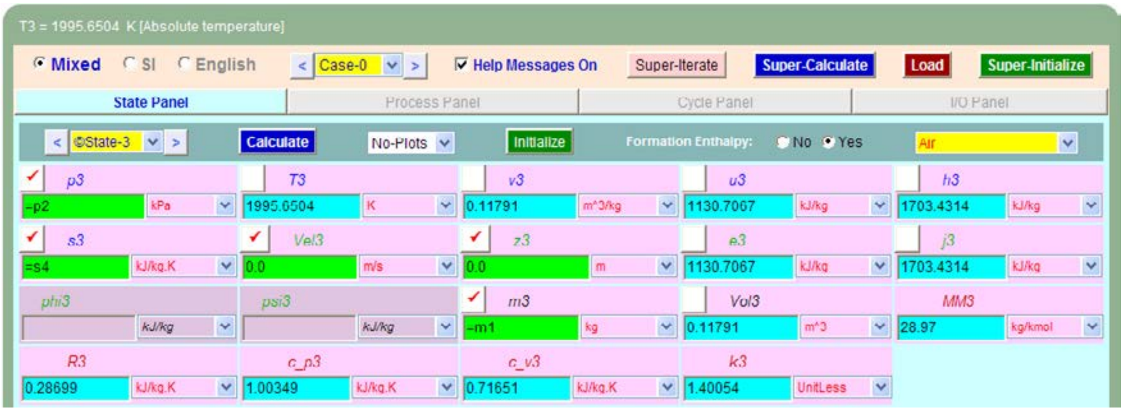
Here, p2 = 4857.497 kPa, T2 = 910.78 K ….Ans.

7. Similarly, for State 3: Enter p3 = p2 (since Process 2-3 is a const. pressure process), s3 = s4, and m3 = m1.. Hit Enter, and then go to State 4, and enter: T4 = 900 K (by data), v4 = v1 (since Process 4-1 is at const. volume), m4 = m1, and hit Enter. We get:



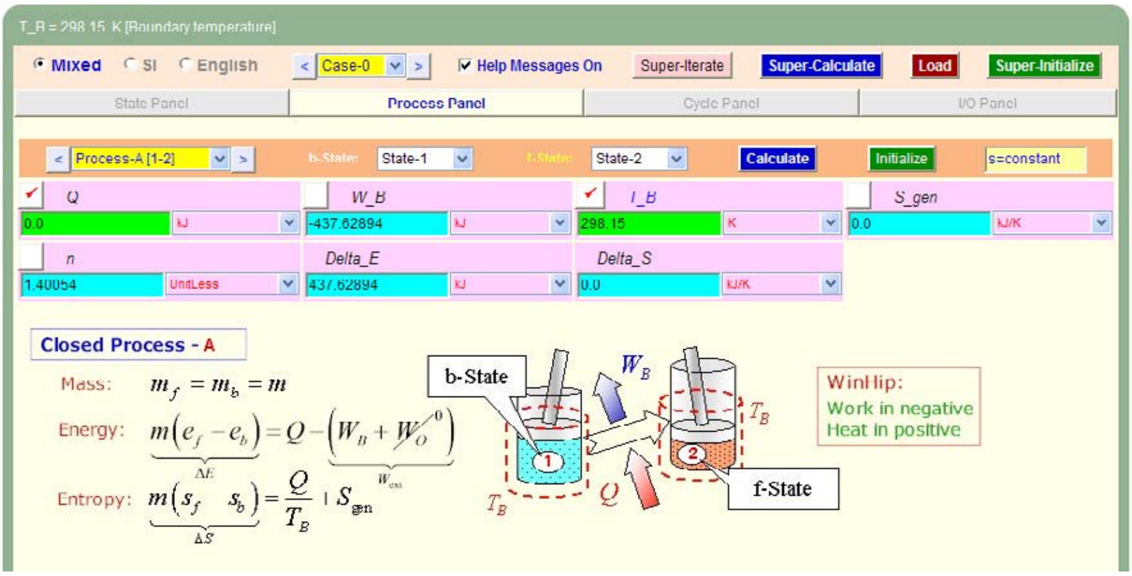
Note that p4 = 300 kPa, T4 = 900 K. And, s4 is also calculated as s4 = 7.68006 kJ/kg.K

8. Then, go back to State 3. Remember that now s3 = s4. Click on Calculate. We get:



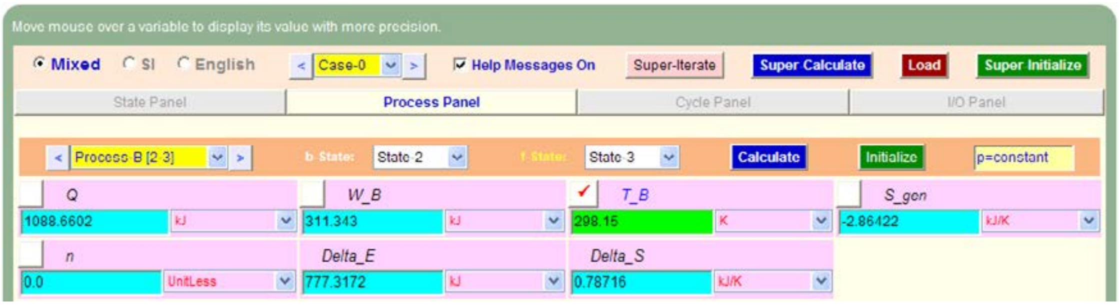
Here, p3 = p2 = 4857.497 kPa, T3 = 1995.65 K ….Ans.

9. Now, go to the Process Panel. For Process A (i.e. process 1-2), enter State 1 and State 2 for b-state and f-state respectively, and Q = 0 since process 1-2 is adiabatic. Hit Enter, and we get:

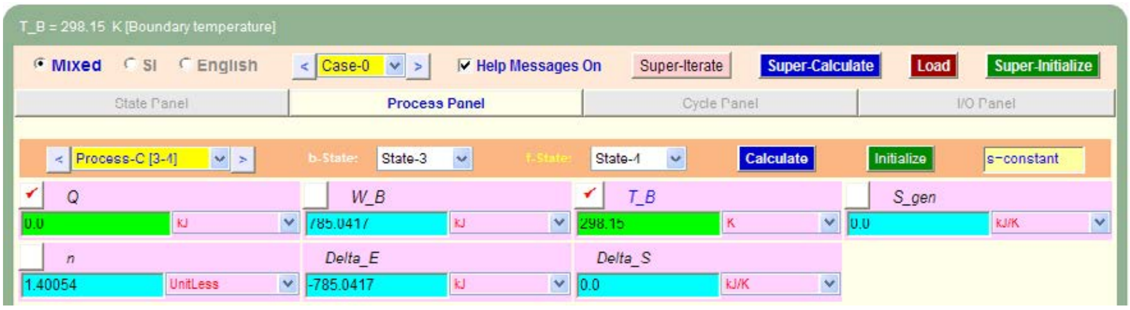


Note that the boundary work, W_B etc for this process are immediately calculated.

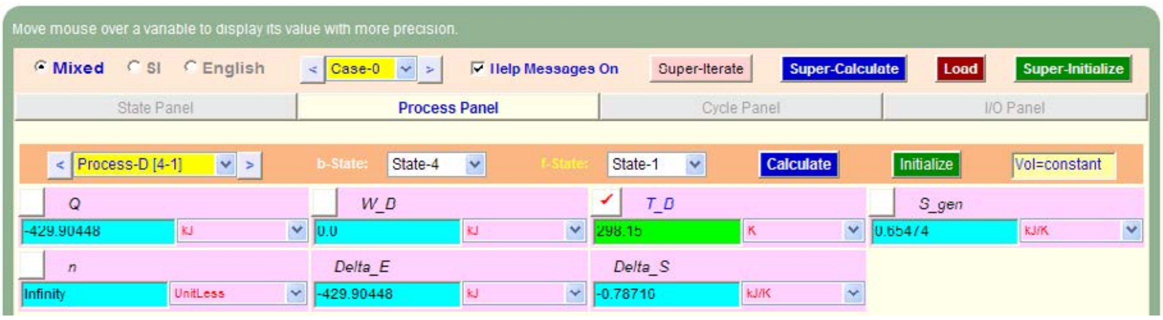
10. Similarly, for Process B (i.e. process 2-3): enter b-state and f-state, hit Enter:



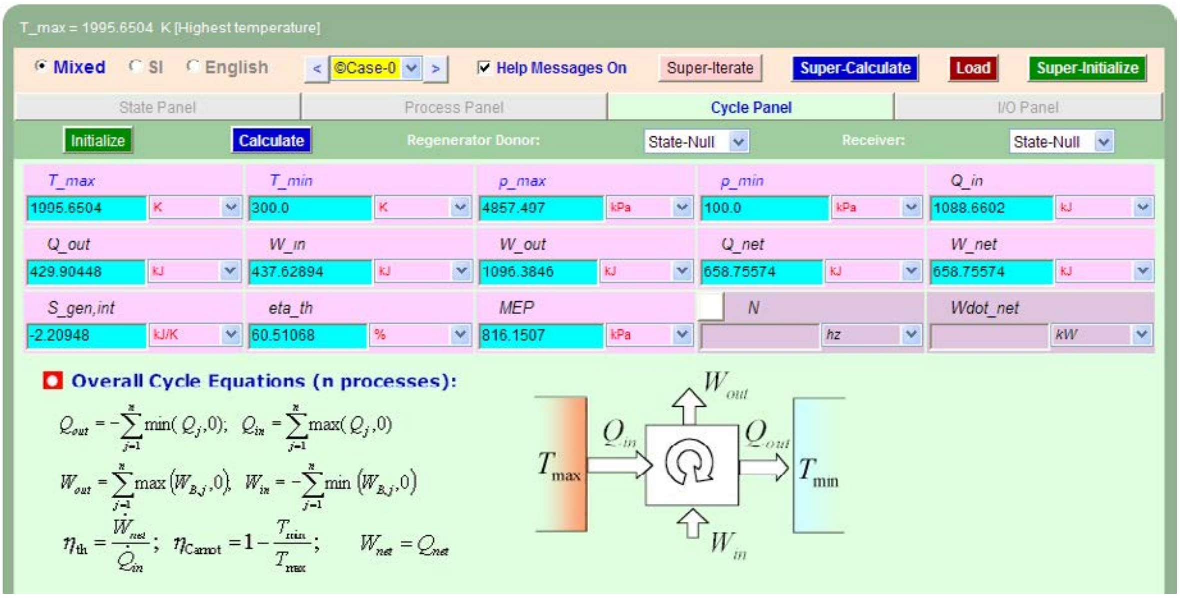
11. And, similarly for Process 3-4:



12. Again, for Process 4-1:



13. Now, go to Cycle Panel, Click on Calculate and SuperCalculate. All calculations are available here:



Note that:

Air standard efficiency = eta_th = 60.51% …. Ans.

MEP = 816.15 kPa = 8.16 bar … Ans.

Cut off ratio = v3/v2 = 2.1911 …. Ans.

Expansion ratio = v4/v3 = 7.3 … Ans.

14. Get the TEST code etc from the I/O panel:

```
#~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE
#        Daemon Path: Systems>Closed>Process>Specific>PowerCycle>PG-Model; v-10.ca08
#--------------------Start of TEST-code -----------------------------------------------------------------------
States   {
         State-1: Air;
         Given: { p1= 100.0 kPa; T1= 300.0 K; Vel1= 0.0 m/s; z1= 0.0 m; m1= 1.0 kg; }
         State-2: Air;
         Given: { v2= "v1/16"m^3/kg; s2= "s1"kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; m2= "m1"kg; }
         State-3: Air;
         Given: { p3= "p2"kPa; s3= "s4"kJ/kg.K; Vel3= 0.0 m/s; z3= 0.0 m; m3= "m1"kg; }
         State-4: Air;
         Given: { T4= 900.0 K; v4= "v1"m^3/kg; Vel4= 0.0 m/s; z4= 0.0 m; m4= "m1"kg; }
         }
Analysis {
         Process-A: b-State = State-1; f-State = State-2;
         Given: { Q= 0.0 kJ; T_B= 298.15 K; }
         Process-B: b-State = State-2; f-State = State-3;
         Given: { T_B= 298.15 K; }
         Process-C: b-State = State-3; f-State = State-4;
         Given: { Q= 0.0 kJ; T_B= 298.15 K; }
         Process-D: b-State = State-4; f-State = State-1;
         Given: { 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     300.0    0.861       -84.24     1.86        6.893
```

#	2	4857.5	910.8	**0.0538**	353.39	614.77	6.893
#	3	4857.5	1995.7	**0.1179**	1130.71	1703.43	7.68
#	4	300.0	900.0	**0.861**	345.66	603.95	7.68

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

 # Mass, Energy, and Entropy Analysis Results:

Process-A: b-State = State-1; f-State = State-2;

Given: Q= 0.0 kJ; T_B= 298.15 K;

Calculated: W_B= -437.62894 kJ; S_gen= -0.0 kJ/K; n= 1.4005353 UnitLess; Delta_E= 437.62894 kJ;

Delta_S= -0.0 kJ/K;

Process-B: b-State = State-2; f-State = State-3;

Given: T_B= 298.15 K;

Calculated: Q= 1088.6602 kJ; W_B= 311.343 kJ; S_gen= -2.8642204 kJ/K; n= 0.0 UnitLess;

Delta_E= 777.3172 kJ; Delta_S= 0.7871639 kJ/K;

Process-C: b-State = State-3; f-State = State-4;

Given: Q= 0.0 kJ; T_B= 298.15 K;

Calculated: W_B= 785.0417 kJ; S_gen= -0.0 kJ/K; n= 1.4005353 UnitLess; Delta_E= -785.0417 kJ;

Delta_S= -0.0 kJ/K;

Process-D: b-State = State-4; f-State = State-1;

Given: T_B= 298.15 K;

Calculated: Q= -429.90448 kJ; W_B= 0.0 kJ; S_gen= 0.6547428 kJ/K; n= Infinity UnitLess;

Delta_E= -429.90448 kJ; Delta_S= -0.7871639 kJ/K;

 # Cycle Analysis Results:

Calculated: T_max= 1995.6504 K; T_min= 300.0 K; p_max= 4857.497 kPa;

p_min= 100.0 kPa; Q_in= 1088.6602 kJ; Q_out= 429.90448 kJ;

W_in= 437.62894 kJ; W_out= 1096.3846 kJ; Q_net= 658.75574 kJ;

W_net= 658.75574 kJ; S_gen,int= -2.20948 kJ/K; **eta_th= 60.51068 %;**

MEP= 816.1507 kPa;

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

=v3/v2

v3/v2 = 2.191142569735077 = 2.1911 …cut off ratio…Ans.

=v4/v3

v4/v3 = 7.302126397888614 = 7.302 … expansion ratio….Ans.

===

Prob.1.34. One kg of air undergoes a Diesel cycle commencing from 15 C and 1 bar. The compression ratio is 15. The heat transfer to the cycle is at constant pressure and is equal to 1850 kJ. Calculate: (i) the cycle efficiency, and (ii) the MEP. [VTU]

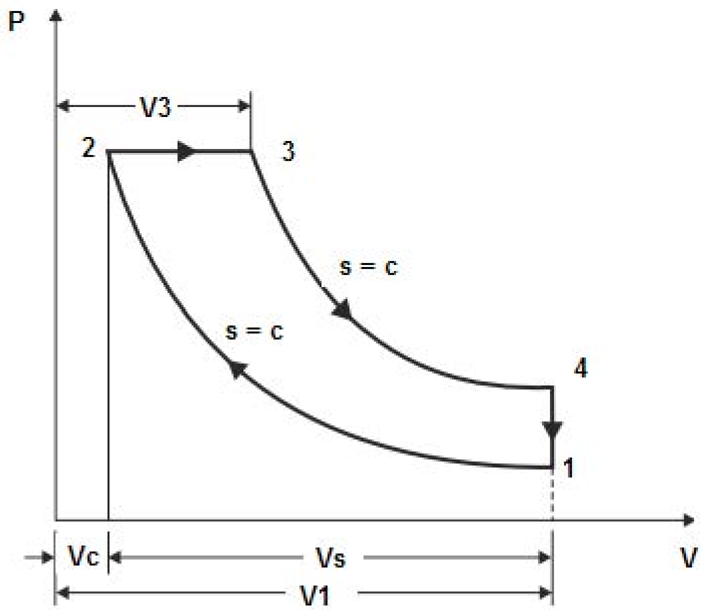


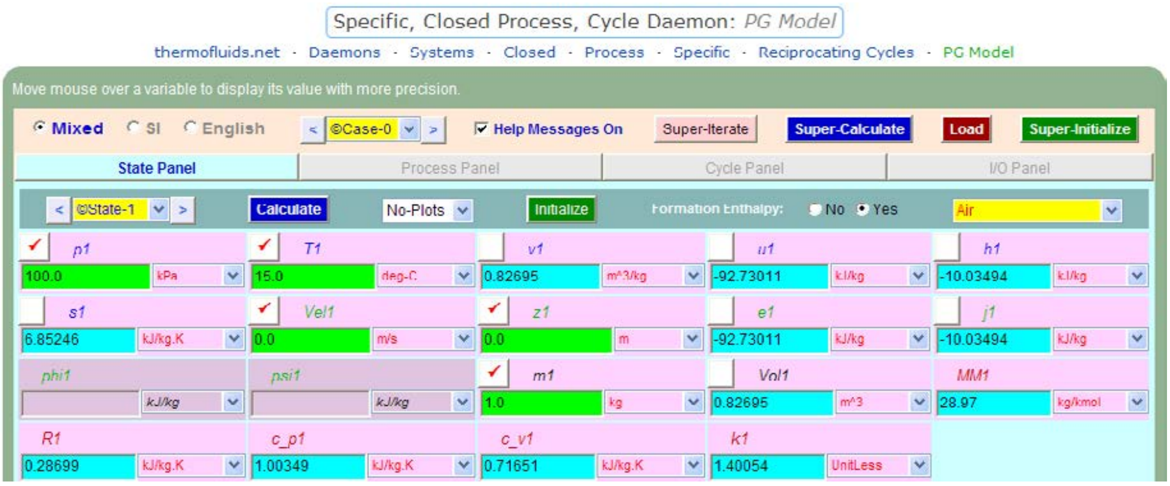
Fig.Prob.1.34

TEST Solution:

Following are the steps:

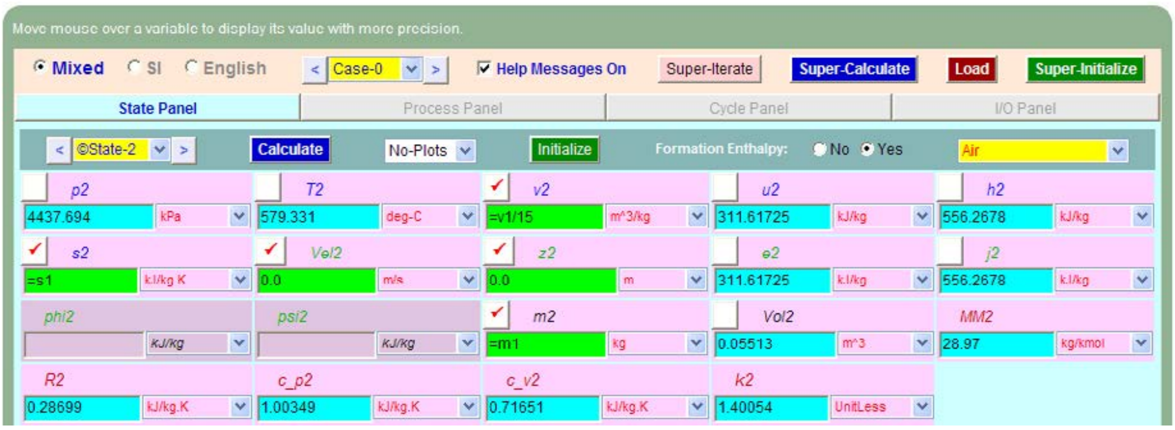
Steps 1 to 4 are the same as for the previous problem.

5. Select Air as the working substance and fill in data for p1= 100 kPa, T1= 15 C, and m1= 1 kg for State 1, i.e. at beginning of compression, and hit Enter. We get:



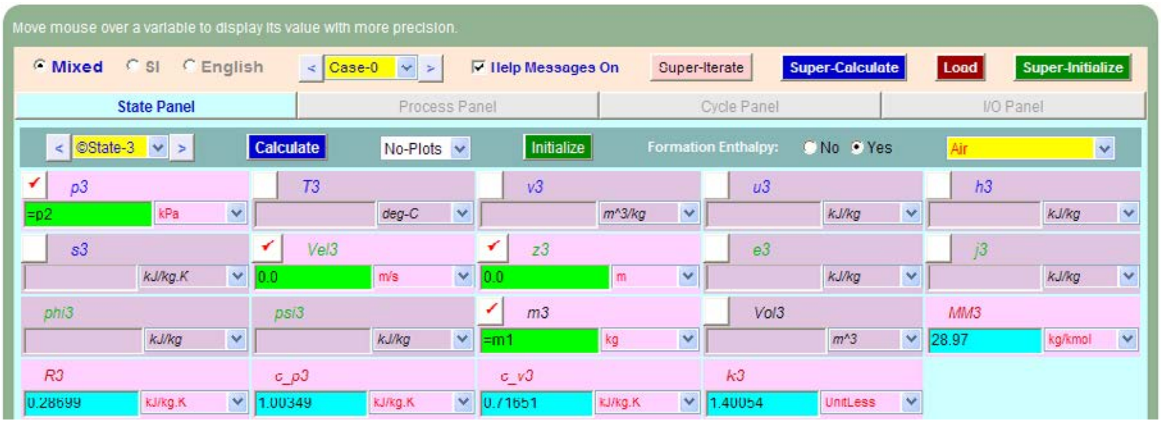
Note that properties for State 1 are calculated.

6. For State 2: Enter v2 = v1/15 (since compression ratio is 15), s2 = s1 (since Process 1-2 is isentropic) and m2 = m1. Hit Enter:

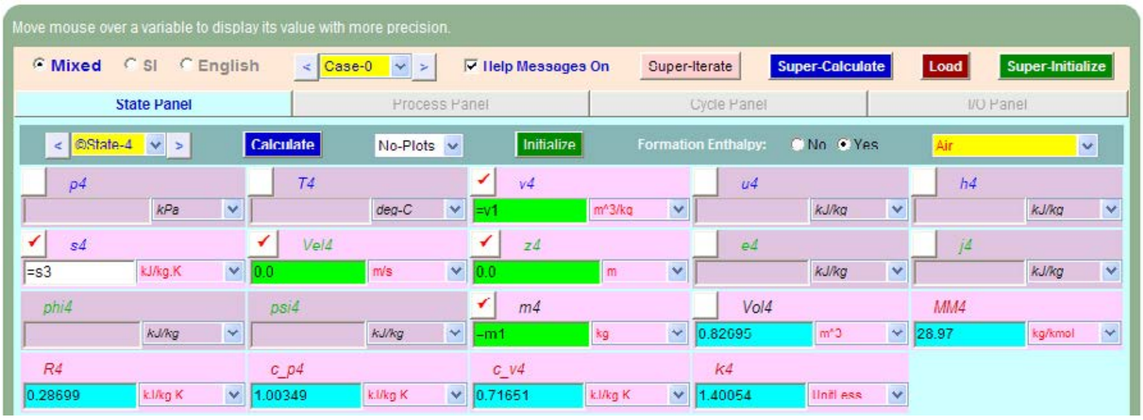


Here, p2 = 4437.694 kPa, T2 = 579.331 C.

7. Similarly, for State 3: Enter p3 = p2 (since Process 2-3 is a const. pressure process), and m3 = m1. Hit Enter. Not all calculations are completed, since data is not enough:

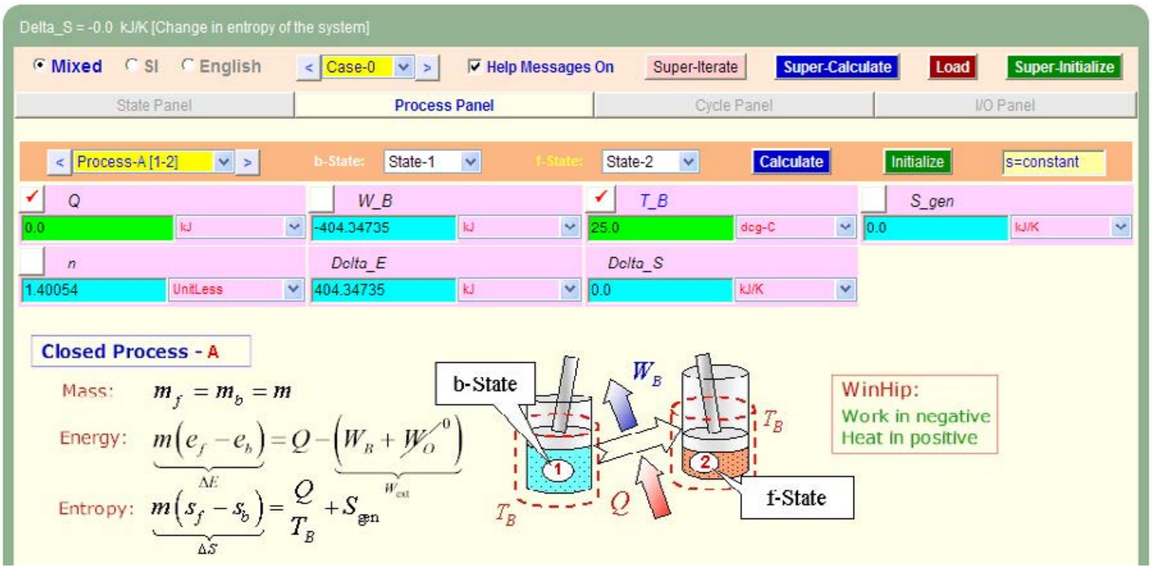


8. Now, go to State 4, and enter: s4 = s3 (for isentropic process 3-4), v4 = v1 (since Process 4-1 is at const. volume), m4 = m1, and hit Enter. We get:



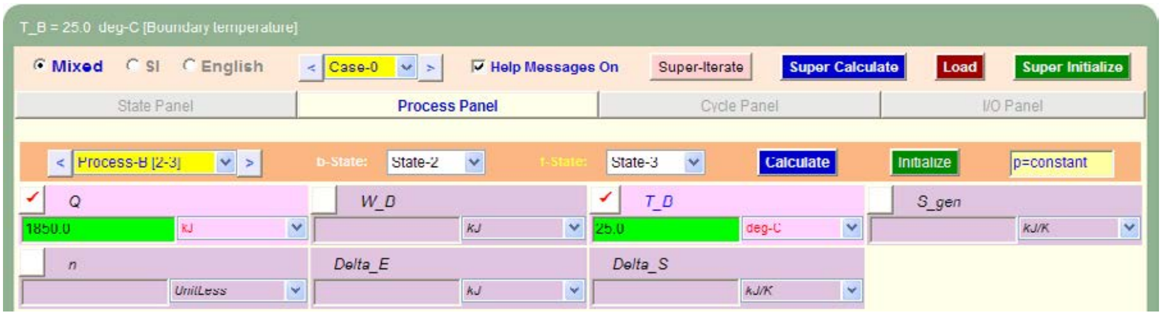
Again, data is not enough (i.e. at least two independent properties must be known to make all calculations). However, these calculations will be made automatically later with SuperCalculate.

9. Now, go to the Process Panel. For Process A (i.e. process 1-2), enter State 1 and State 2 for b-state and f-state respectively, and Q = 0 since process 1-2 is adiabatic. Hit Enter, and we get:



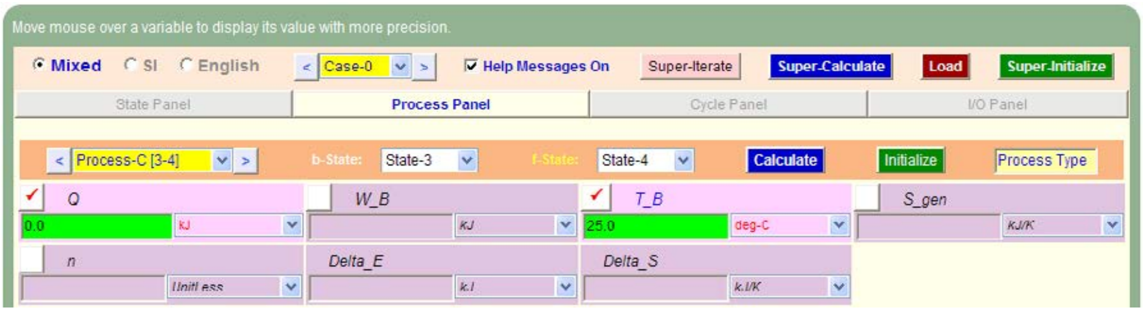
Note that the boundary work, W_B etc for this process are immediately calculated.

10. Similarly, for Process B (i.e. process 2-3): enter b-state and f-state, hit Enter:



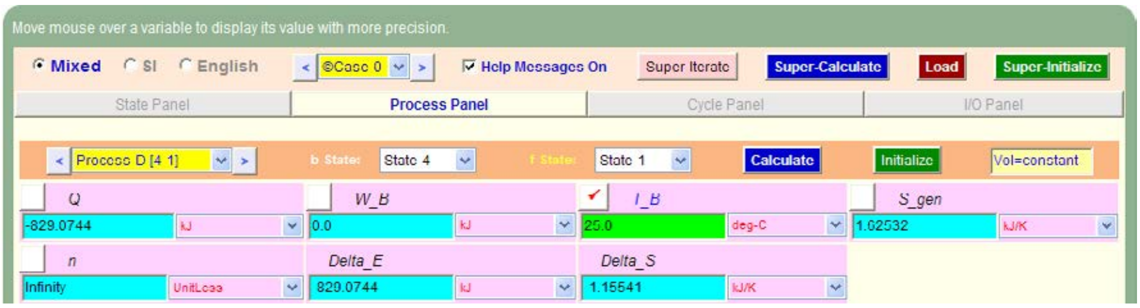
Again, data is not enough to make all calculations.

11. And, similarly for Process 3-4:

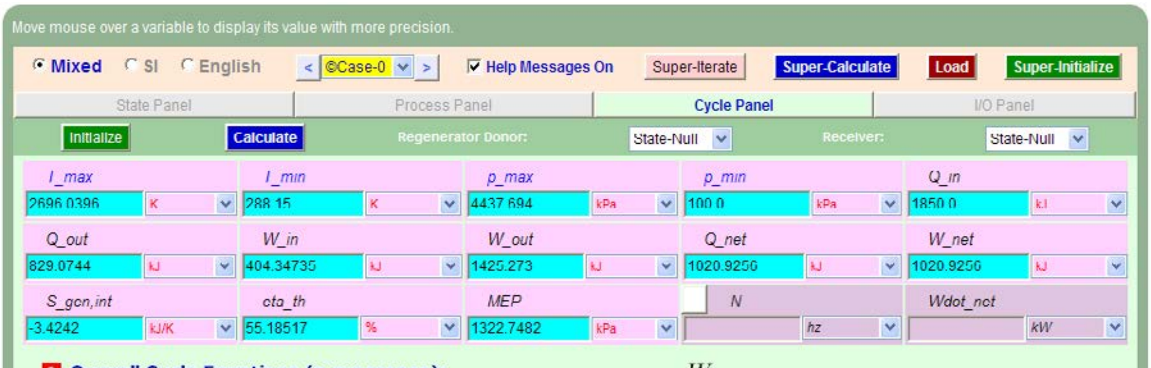


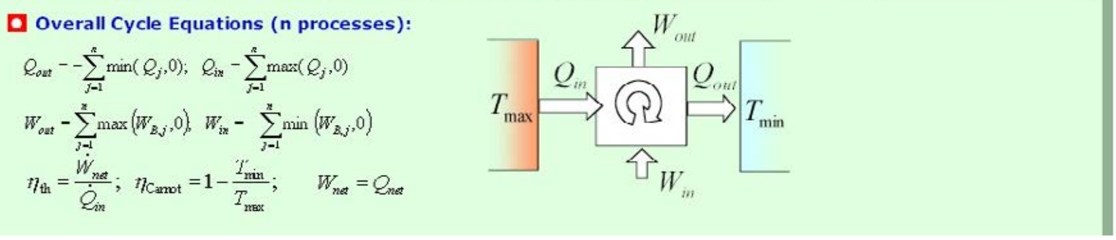
Again, data is not enough to make all calculations.

12. Now, for Process 4-1: Enter for b-state and f-state as shown, and click on SuperCalculate. Immediately, all calculations, including for the previous States, are made. We get:



13. Now, go to Cycle Panel. All calculations are available here:





Thus:

Cycle efficiency = eta_th = 55.185% … Ans.

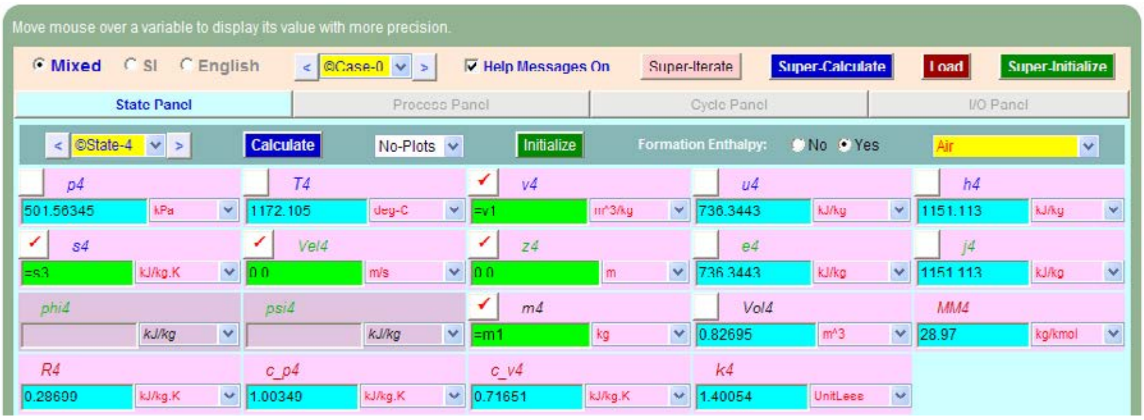
Net work output = W_net = 1020.93 kJ …. Ans.

MEP = 1322.75 kPa = 13.2275 bar …. Ans.

14. Now, go back to States Panel and see State 3 and 4:

Note that T3 = 2422.8896 C …. Max. temp in cycle.

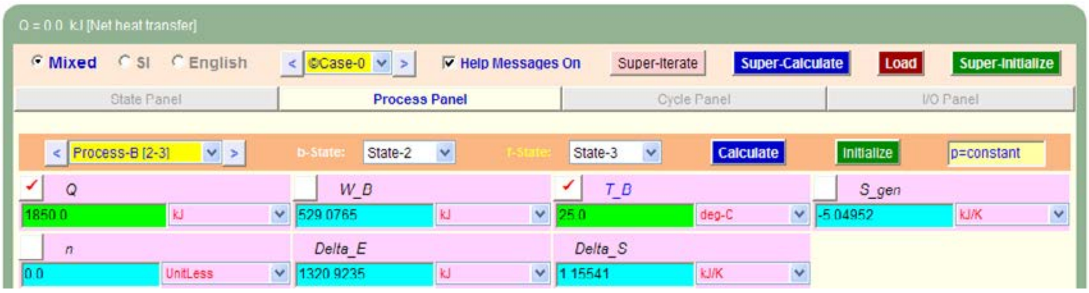
And, State 4:



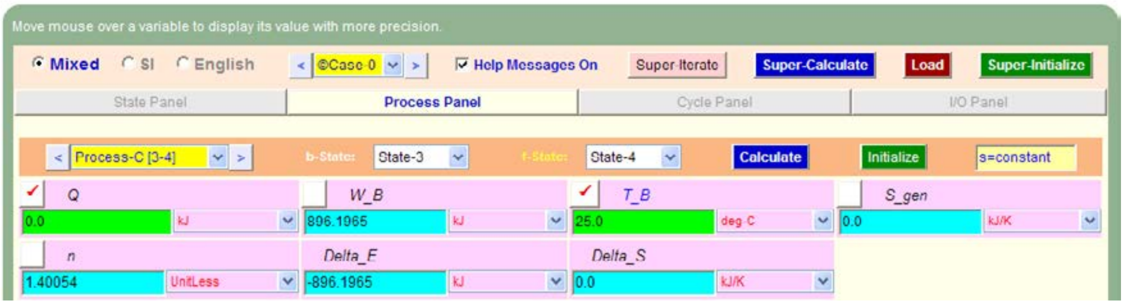
Note that T4 = 1172.105 C , p4 = 501.56 kPa.

15. Also see Processes B, C and D in the Process Panel:

Process B (2-3):



Process C (3-4):



Process D (4-1):

16. Get the TEST code etc from the I/O panel:

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

Daemon Path: Systems>Closed>Process>Specific>PowerCycle>PG-Model; v-10.ca08

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

States {

State-1: Air;

Given: { p1= 100.0 kPa; T1= 15.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; m1= 1.0 kg; }

State-2: Air;

Given: { v2= "v1/15"m^3/kg; s2= "s1"kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; m2= "m1"kg; }

State-3: Air;

```
        Given: { p3= "p2"kPa; Vel3= 0.0 m/s; z3= 0.0 m; m3= "m1"kg; }
        State-4: Air;
        Given: { v4= "v1"m^3/kg; s4= "s3"kJ/kg.K; Vel4= 0.0 m/s; z4= 0.0 m; m4= "m1"kg; }
        }
Analysis {
        Process-A: b-State = State-1; f-State = State-2;
        Given: { Q= 0.0 kJ; T_B= 25.0 deg-C; }
        Process-B: b-State = State-2; f-State = State-3;
        Given: { Q= 1850.0 kJ; T_B= 25.0 deg-C; }
        Process-C: b-State = State-3; f-State = State-4;
        Given: { Q= 0.0 kJ; T_B= 25.0 deg-C; }
        Process-D: b-State = State-4; f-State = State-1;
        Given: { 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       288.2   0.827       -92.73      -10.03      6.852
#       2       4437.69     852.5   0.0551      311.62      556.27      6.852
#       3       4437.69     2696.0  0.1744      1632.54     2406.27     8.008
#       4       501.56      1445.3  0.827       736.34      1151.11     8.008
#--------Property spreadsheet ends--------------------------------------------------------------------
# Mass, Energy, and Entropy Analysis Results:
#       Process-A: b-State = State-1; f-State = State-2;
#               Given: Q= 0.0 kJ; T_B= 25.0 deg-C;
#               Calculated: W_B= -404.34735 kJ; S_gen= -0.0 kJ/K; n= 1.4005353 UnitLess; Delta_E=
404.34735 kJ;
#                       Delta_S= -0.0 kJ/K;
#       Process-B: b-State = State-2; f-State = State-3;
#               Given: Q= 1850.0 kJ; T_B= 25.0 deg-C;
#               Calculated: W_B= 529.0765 kJ; S_gen= -5.049519 kJ/K; n= 0.0 UnitLess; Delta_E=
1320.9235 kJ;
#                       Delta_S= 1.1554112 kJ/K;
#       Process-C: b-State = State-3; f-State = State-4;
#               Given: Q= 0.0 kJ; T_B= 25.0 deg-C;
#               Calculated: W_B= 896.1965 kJ; S_gen= -0.0 kJ/K; n= 1.4005353 UnitLess; Delta_E=
-896.1965 kJ;
#                       Delta_S= -0.0 kJ/K;
#       Process-D: b-State = State-4; f-State = State-1;
```

\#   Given: T_B= 25.0 deg-C;
\#   Calculated: Q= -829.0744 kJ; W_B= 0.0 kJ; S_gen= 1.6253179 kJ/K; n= Infinity UnitLess;
\#   Delta_E= -829.0744 kJ; Delta_S= -1.1554112 kJ/K;

 # Cycle Analysis Results:

\#   Calculated: T_max= 2696.0396 K; T_min= 288.15 K; p_max= 4437.694 kPa;
\#   p_min= 100.0 kPa; Q_in= 1850.0 kJ; Q_out= 829.0744 kJ;
\#   W_in= 404.34735 kJ; W_out= 1425.273 kJ; Q_net= 1020.9256 kJ;
\#   **W_net= 1020.9256 kJ;** S_gen,int= -3.4242 kJ/K; **eta_th= 55.18517 %;**
\#   **MEP= 1322.7482 kPa;**

==

Prob.1.35. An oil engine works on ideal Diesel cycle, with a compression ratio of 20. Heat addition at constant pressure takes place up to 10% of stroke. Initial pressure and temp are 1 bar and 67 C. Compression and expansion follow the law P. v^1.3 = constant. Find the following: (i) temps and pressures at all salient points (ii) mean effective pressure of the cycle, (iii) net work done per kg of air, and (iii) the thermal efficiency.

Note: This is the same as Prob.1.31, which was solved with EES.

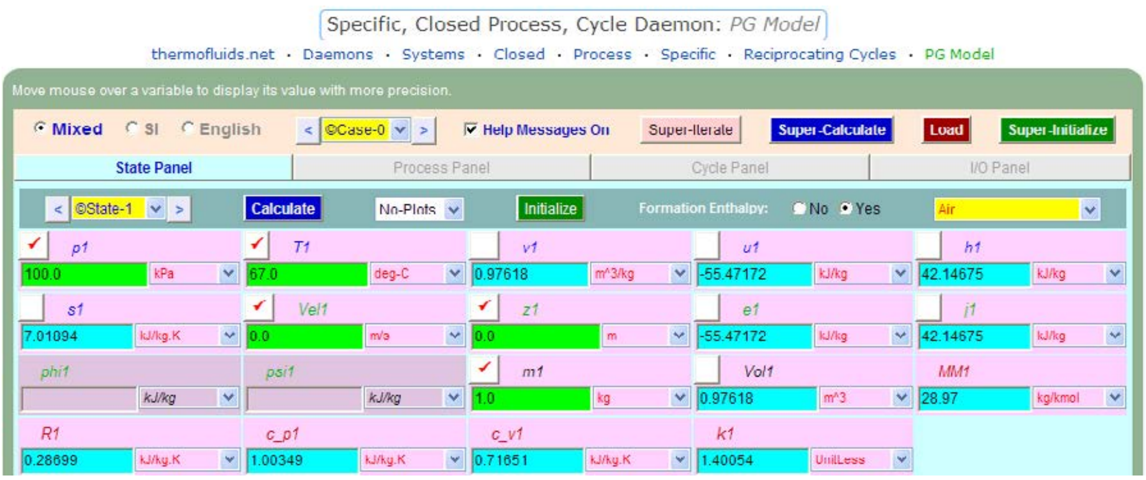
Now, we shall solve it with TEST:

TEST Solution:

Following are the steps:

Steps 1 to 4 are the same as for the previous problem.

5. Select Air as the working substance and fill in data for p1= 100 kPa, T1=67 C, and m1= 1 kg for State 1, i.e. at beginning of compression, and hit Enter. We get:



Note that properties for State 1 are calculated.

6. For State 2: Enter v2 = v1/20 (since compression ratio is 20), p2 = p1 * (v1/v2)^1.3 (since Process 1-2 is polytropic, with n = 1.3) and m2 = m1. Hit Enter:

Here, p2 = 4912.91 kPa, T2 = 562.4135 C ….Ans.

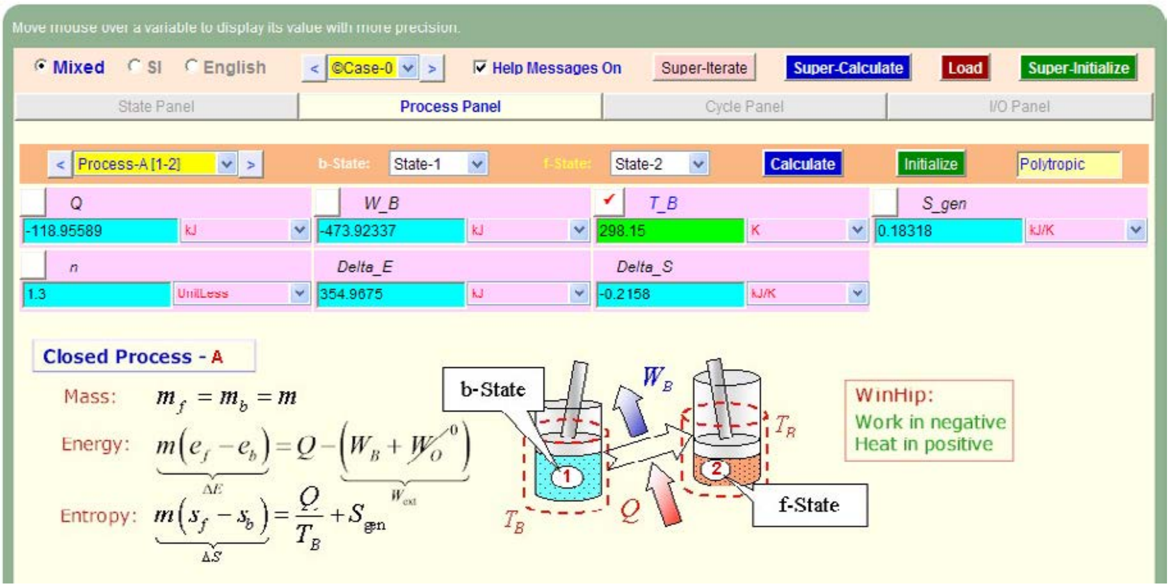
7. Similarly, for State 3: Enter p3 = p2 (since Process 2-3 is a const. pressure process), m3 = m1, and v3 = v2 + (v1 – v2) * 0.1 (since by data, (v3 – v2) / (v1 – v2) = 0.1). Hit Enter. We get:

Note that p3 = 4912.91 kPa, T3 = 2149.9841 C.

8. Now, for to State 4. And, p4 = p3 * (v3/v4)^1.3 (since Process 3-4 is polytropic with n = 1.3). Also, m3 = m1. Click on Calculate. We get:

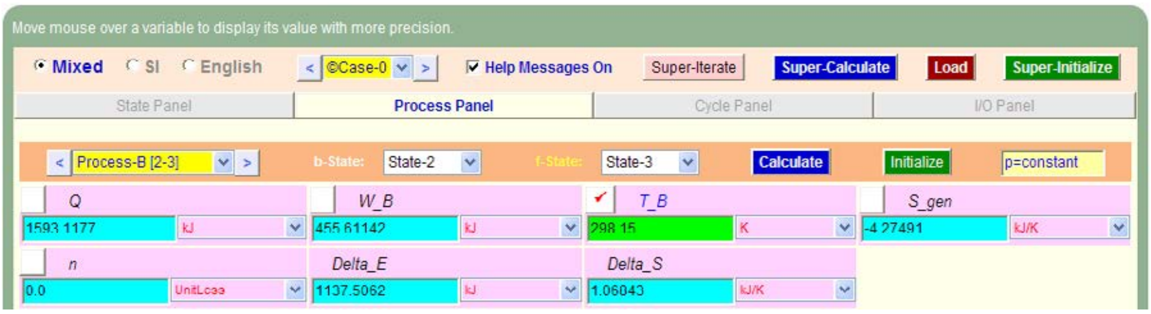
Here, p4 = 399.13 kPa, T4 = 1357.65 K ….Ans.

9. Now, go to the Process Panel. For Process A (i.e. process 1-2), enter State 1 and State 2 for b-state and f-state respectively, and hit Enter, and we get:

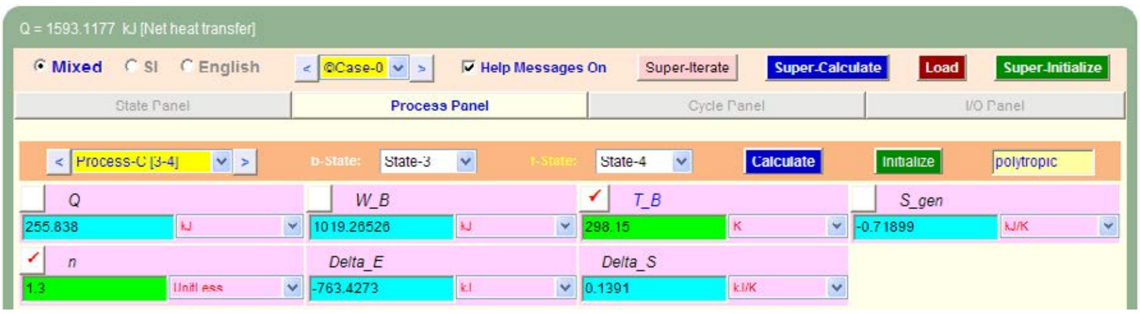


Note that the heat transfer Q and the boundary work, W_B etc for this process are immediately calculated.

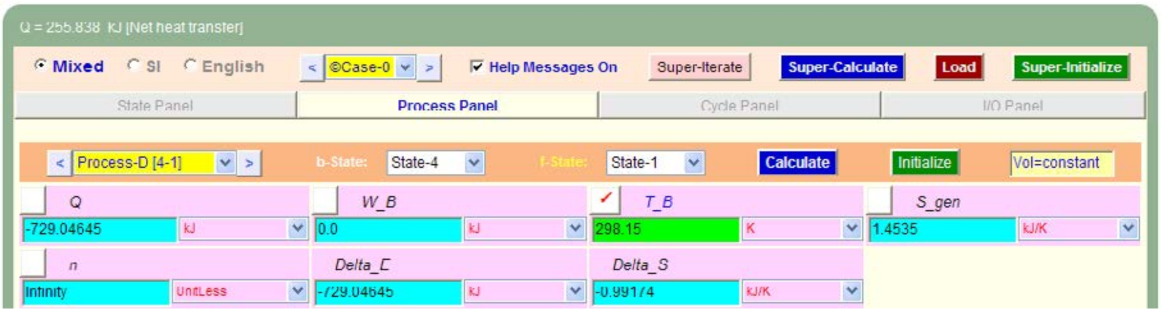
10. Similarly, for Process B (i.e. process 2-3): enter b-state and f-state, hit Enter:



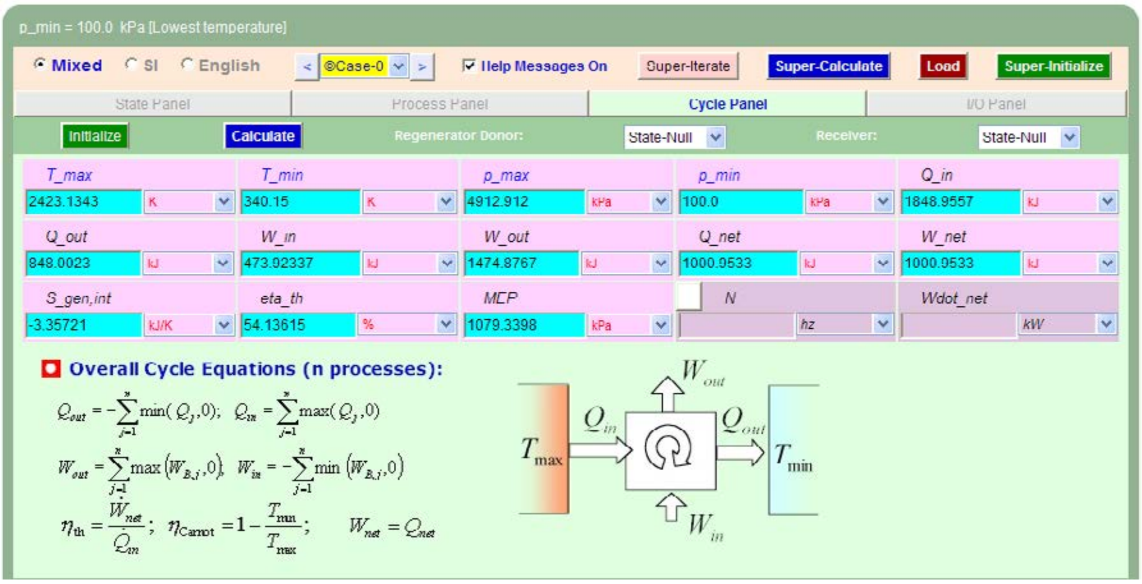
11. And, for Process 3-4:



12. Again, for Process 4-1:



13. And, now go to Cycle Panel. SuperCalculate. All calculations are available here:



Note that:

Cycle efficiency = eta_th = 54.14% % …. Ans.

(Note: With EES, we obtained eta_th = 62.77% since we took Q_s as only the external heat supplied during const. pressure process 2-3. But, with TEST, Q_s is automatically taken as *total heat supplied* in process 2-3 and process 4-1)

W_net = 1009.95 kJ … Ans.

MEP = 1079.34 kPa = 10.79 bar … Ans.

14. Get the TEST code etc from the I/O panel:

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

Daemon Path: Systems>Closed>Process>Specific>PowerCycle>PG-Model; v-10.ca08

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

States {

State-1: Air;

Given: { p1= 100.0 kPa; T1= 67.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; m1= 1.0 kg; }

State-2: Air;

Given: { p2= "p1*(v1/v2)^1.3"kPa; v2= "v1/20"m^3/kg; Vel2= 0.0 m/s; z2= 0.0 m; m2= "m1"kg; }

State-3: Air;

Given: { p3= “p2“kPa; v3= “v2+(v1-v2)*0.1“m^3/kg; Vel3= 0.0 m/s; z3= 0.0 m; m3= “m1”kg; }
State-4: Air;
Given: { p4= “p3*(v3/v4)^1.3“kPa; v4= “v1”m^3/kg; Vel4= 0.0 m/s; z4= 0.0 m; m4= “m1”kg; }
}
Analysis {
Process-A: b-State = State-1; f-State = State-2;
Given: { T_B= 298.15 K; }
Process-B: b-State = State-2; f-State = State-3;
Given: { T_B= 298.15 K; }
Process-C: b-State = State-3; f-State = State-4;
Given: { T_B= 298.15 K; n= 1.3 UnitLess; }
Process-D: b-State = State-4; f-State = State-1;
Given: { 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	340.2	0.9762	-55.47	42.15	7.019
#	2	4912.91	835.6	0.0488	299.5	539.29	6.803
#	3	4912.91	2423.1	0.1415	1437.0	2132.41	7.872
#	4	399.13	1357.7	0.9762	673.57	1063.2	8.011

#--------Property spreadsheet ends---
 # Mass, Energy, and Entropy Analysis Results:
Process-A: b-State = State-1; f-State = State-2;
Given: T_B= 298.15 K;
Calculated: Q= -118.95589 kJ; W_B= -473.92337 kJ; S_gen= 0.18318452 kJ/K; n= 1.3 UnitLess;
Delta_E= 354.9675 kJ; Delta_S= -0.21579547 kJ/K;
Process-B: b-State = State-2; f-State = State-3;
Given: T_B= 298.15 K;
Calculated: Q= 1593.1177 kJ; W_B= 455.61142 kJ; S_gen= -4.274912 kJ/K; n= 0.0 UnitLess;
Delta_E= 1137.5062 kJ; Delta_S= 1.0684308 kJ/K;
Process-C: b-State = State-3; f-State = State-4;
Given: T_B= 298.15 K; n= 1.3 UnitLess;
Calculated: Q= 255.838 kJ; W_B= 1019.26526 kJ; S_gen= -0.718985 kJ/K; Delta_E= -763.4273 kJ;
Delta_S= 0.13909978 kJ/K;
Process-D: b-State = State-4; f-State = State-1;

Given: T_B= 298.15 K;
Calculated: Q= -729.04645 kJ; W_B= 0.0 kJ; S_gen= 1.4534986 kJ/K; n= Infinity UnitLess;
Delta_E= -729.04645 kJ; Delta_S= -0.99173516 kJ/K;
Cycle Analysis Results:
Calculated: T_max= 2423.1343 K; T_min= 340.15 K; p_max= 4912.912 kPa;
p_min= 100.0 kPa; Q_in= 1848.9557 kJ; Q_out= 848.0023 kJ;
W_in= 473.92337 kJ; W_out= 1474.8767 kJ; Q_net= 1000.9533 kJ;
W_net= 1000.9533 kJ; S_gen,int= -3.35721 kJ/K; **eta_th= 54.13615 %;**
MEP= 1079.3398 kPa;

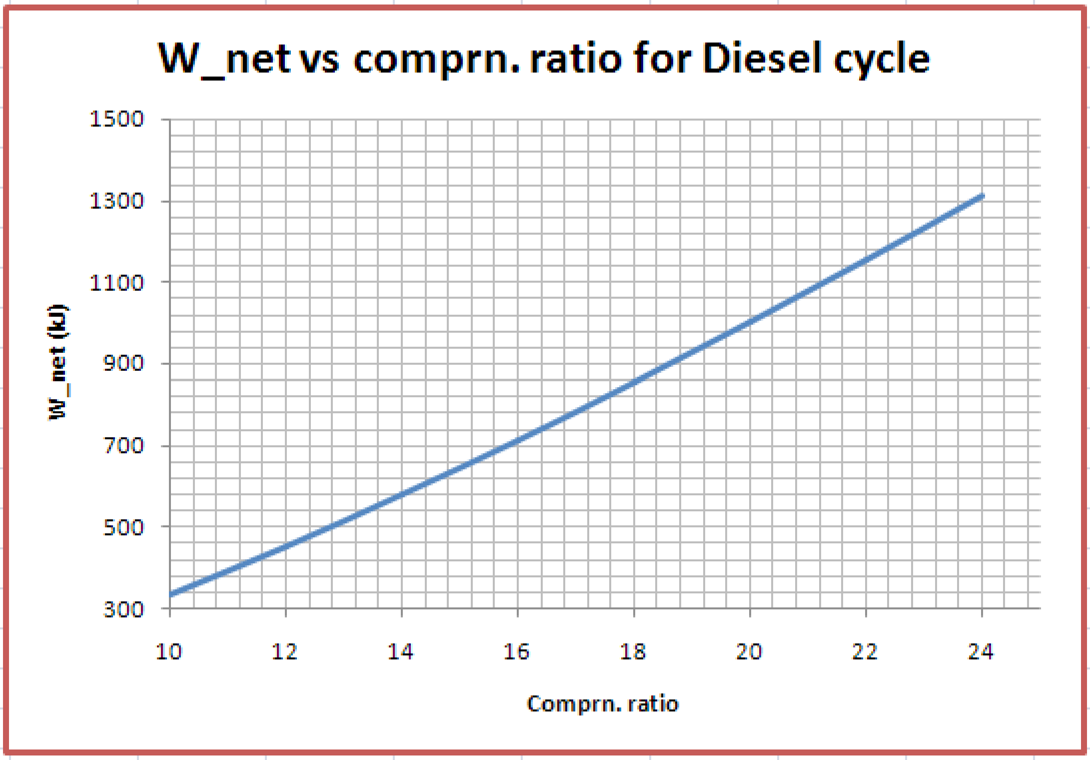
(b) To plot the variation of W_net, eta_th and MEP with compression ratio varying from 10 to 24:

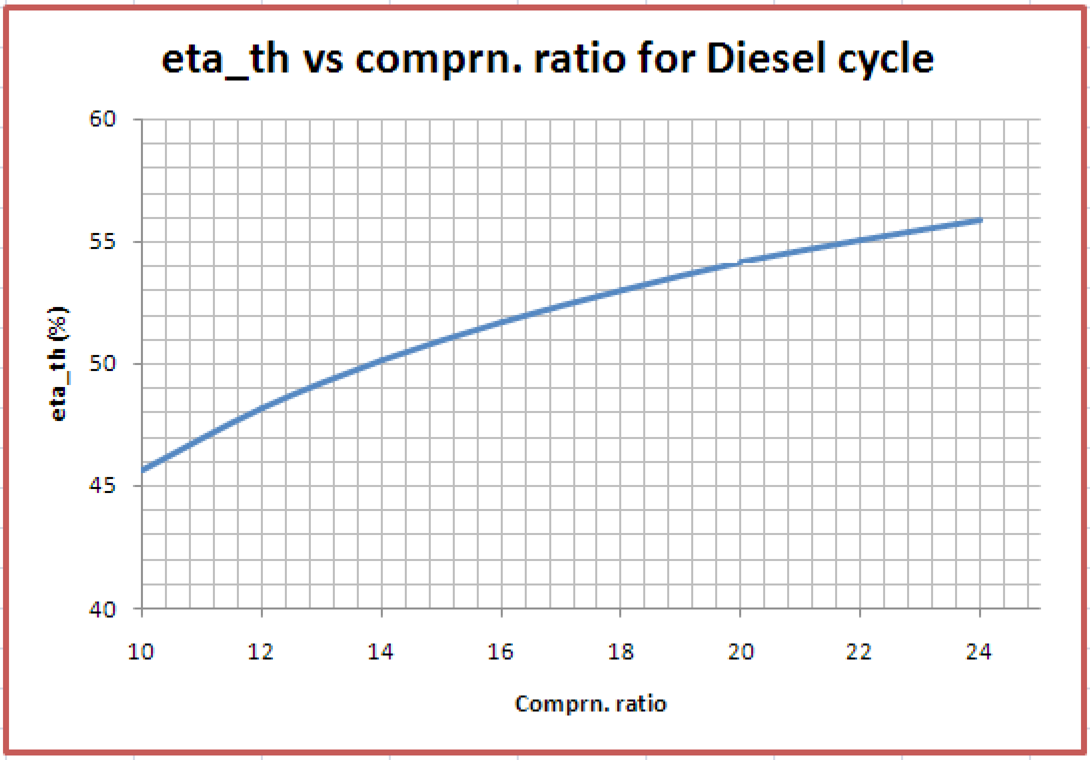
Following are the steps:

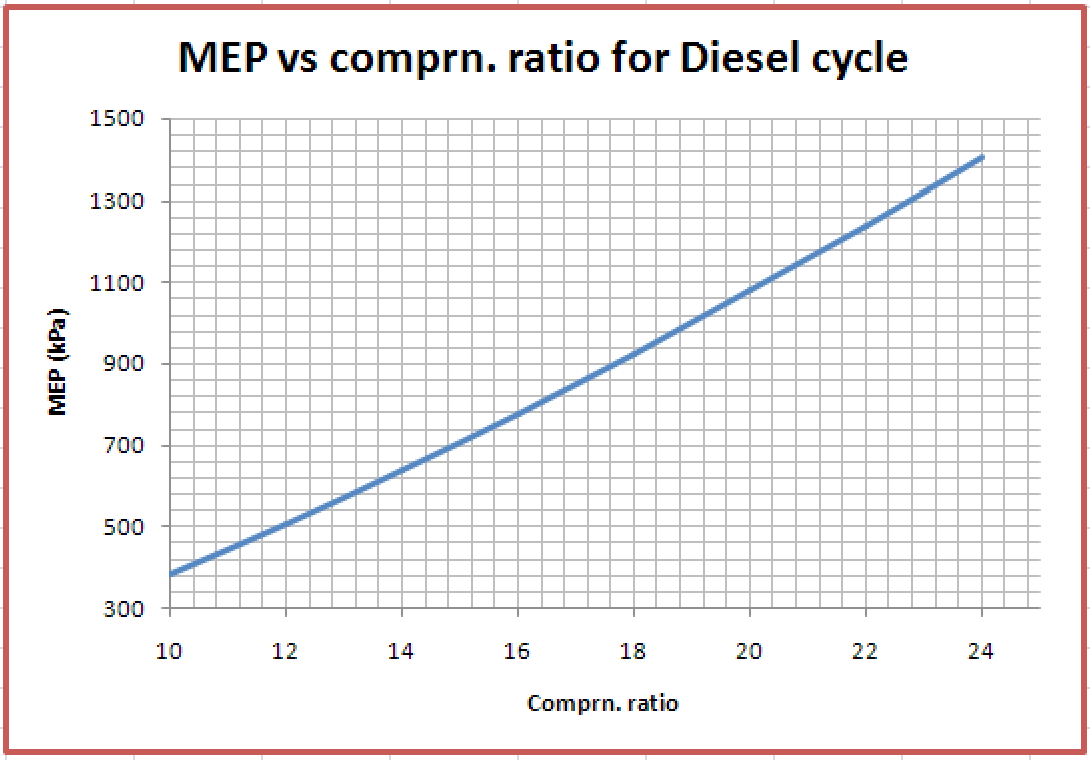
1. Go to State 2, enter for v2 as: v2 = v1 / 10, for compression ratio of 10. Hit Enter.
2. Click on SuperCalculate.
3. Go to Cycle Panel and read out the values for W_net, eta_th and MEP.
4. Repeat steps 1 to 3 for next value of compression ratio in State 2, and tabulate the results in EXCEL.
5. Plot the graphs in EXCEL:

Comprn. ratio	W_net (kJ)	eta_th (%)	MEP (kPa)
10	335.48	45.68	381.85
12	452.33	48.20	505.49
14	578.31	50.16	637.99
16	712.28	51.74	778.30
18	853.38	53.04	925.63
20	1000.95	54.14	1079.34
22	1154.44	55.07	1238.92
24	1313.41	55.88	1403.95

Plot the results in EXCEL:




eta_th vs comprn. ratio for Diesel cycle
60
55
50
45
40
eta_th (%)
10
12
14
16
18
20
22
24
Comprn. ratio



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1.4 Problems on Dual cycle (or, limited pressure cycle):

1.4.1 Problems solved with Mathcad:

Prob.1.36. An air standard dual cycle has a compression ratio of 9. At the beginning of compression, P and T are 1 bar and 300 K respectively. The heat addition per unit mass of air is 1400 kJ/kg, with one-half added at constant volume and one-half added at constant pressure. Determine: (i) the temps at the end of each heat addition process (ii) net work per unit mass (iii) thermal efficiency (iv) the mep. [VTU]

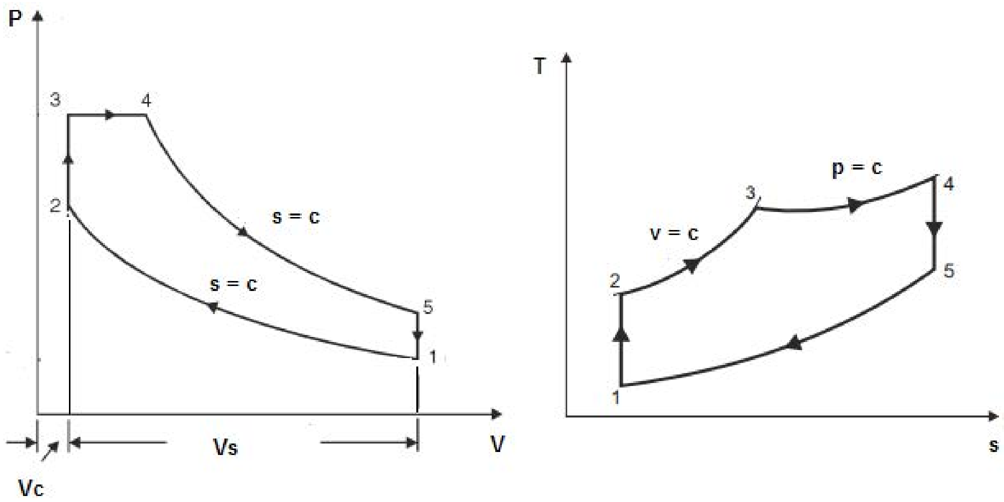


Fig.Prob.1.36

Mathcad Solution:

Data:

$r := 9$ ....compression ratio $R := 0.287$ kJ/kg.K .... Gas const. for air

$P1 := 100$ kPa $T1 := 300$ K $\gamma := 1.4$ $cv := 0.718$ kJ/kg.K $cp := 1.005$ kJ/kg.K

$Q_v := 700$ kJ/kg ... heat supplied at const. vol.

$Q_p := 700$ kJ/kg ... heat supplied at const. pressure

Calculations:

Process 1-2:

$T2 := T1 \cdot r^{\gamma-1}$ i.e. $T2 = 722.467$ **K....Ans.**

$P2 := P1 \cdot r^{\gamma}$ i.e. $P2 = 2.167 \times 10^3$ **kPa....Ans.**

Process 2-3:

cp*(T4-T3) = cv*(T3-T2) = 700 kJ/kg .... heat supplied in two processes

Therefore:

$T3 := \frac{Q_v}{cv} + T2$ i.e. $T3 = 1.697 \times 10^3$ **K......Ans**

And, for Process 3-4::

$T4 := \frac{Q_p}{cp} + T3$ i.e. $T4 = 2.394 \times 10^3$ **K......Ans**

Process 4-5:

Now, we have:

$$\frac{T4}{T5} = \left(\frac{v5}{v4}\right)^{\gamma-1} = \left(\frac{v5}{v2} \cdot \frac{v2}{v4}\right)^{\gamma-1} = \left(\frac{v1}{v2} \cdot \frac{v3}{v4}\right)^{\gamma-1} = \left(r \cdot \frac{T3}{T4}\right)^{\gamma-1}$$ ...since v5 = v1, v3 = v2

Therefore:

$T4byT5 := \left(r \cdot \frac{T3}{T4}\right)^{\gamma-1}$ i.e. $T4byT5 = 2.099$

So: $T5 := \frac{T4}{T4byT5}$ i.e. $T5 = 1.141 \times 10^3$ **K.... Ans.**

Heat rejected, Qr:

$Q_r := cv \cdot (T5 - T1)$ i.e. $Q_r = 603.567$ kJ/kg

Heat supplied, Qs:

$Q_s := Q_v + Q_p$ i.e. $Q_s = 1.4 \times 10^3$ kJ/kg

Net work done:

$W_{net} := Q_s - Q_r$ i.e. $W_{net} = 796.433$ **kJ/kg….Ans.**

Thermal efficiency:

$\eta := \frac{W_{net}}{Q_s}$ i.e. $\eta = 0.569$ **…Ans**

Mean Effective Pressure:

$v1 := \frac{R \cdot T1}{P1}$ i.e. $v1 = 0.861$ m^3/kg.... volume of 1 kg at state 1

$v2 := \frac{R \cdot T2}{P2}$ i.e. $v2 = 0.096$ m^3/kg .... vol. at state 2

Therefore:

$$mep := \frac{W_{net} \cdot 10^3}{v1 - v2}$$

i.e. $mep = 1.0406 \times 10^6$ **Pa = 10.406 bar ... Ans.**

Verify the above results for thermal efficiency, Work done and MEP with Mathcad Functions for the same:

Following are the Mathcad Functions: (see the formulas given at the beginning of this chapter)

$$\eta_{th}(r, rc, rp, \gamma) := 1 - \frac{1}{r^{\gamma-1}} \cdot \left[\frac{rp \cdot rc^{\gamma} - 1}{(rp - 1) + \gamma \cdot rp \cdot (rc - 1)} \right]$$ ...Thermal effcy.

Work output: P1 in kPa, v1 in m^3/kg:

$$W(r, rc, rp, P1, v1, \gamma) := \frac{P1 \cdot v1 \cdot \left[rp \cdot \gamma \cdot (rc - 1) \cdot r^{\gamma-1} + (rp - 1) \cdot r^{\gamma-1} - \left(rp \cdot rc^{\gamma} - 1 \right) \right]}{\gamma - 1}$$ kJ/kg

Mean Effective Pressure: p1 in kpa

$$MEP(r, rc, rp, \gamma, p1) := \frac{p1}{(r - 1) \cdot (\gamma - 1)} \cdot \left[r^{\gamma} \cdot [rp \cdot \gamma \cdot (rc - 1) + (rp - 1)] - r \cdot \left(rp \cdot rc^{\gamma} - 1 \right) \right]$$ kPa

Remember:

$r = \frac{v1}{v2}$ ...compression ratio

$rc = \frac{v3}{v2}$ ...cut off ratio

$rp = \frac{p3}{p2}$ ..pressure ratio, or explosion ratio

Now, for the above problem:

$P1 = 100$ kPa $v1 = 0.861$ m^3/kg

$r = \frac{v1}{v2} = 9$ $r = 9$

$rc = \frac{v3}{v2} = \frac{T4}{T3}$ i.e. $rc := \frac{T4}{T3}$ i.e. $rc = 1.41$

$rp = \frac{p3}{p2} = \frac{T3}{T2}$ i.e. $rp := \frac{T3}{T2}$ i.e. $rp = 2.349$

Applying the above Mathcad Functions:

$\eta_{th}(r, rc, rp, \gamma) = 0.569$ **= 56.9 % .... Ans.**

$W(r, rc, rp, P1, v1, \gamma) = 796.018$ **kJ/kg... Ans.**

$MEP(r, rc, rp, \gamma, P1) = 1.0401 \times 10^3$ **kPa = 10.401 bar ...Ans.**

Note that the results obtained with Mathcad Functions match very well with those obtained earlier.

==

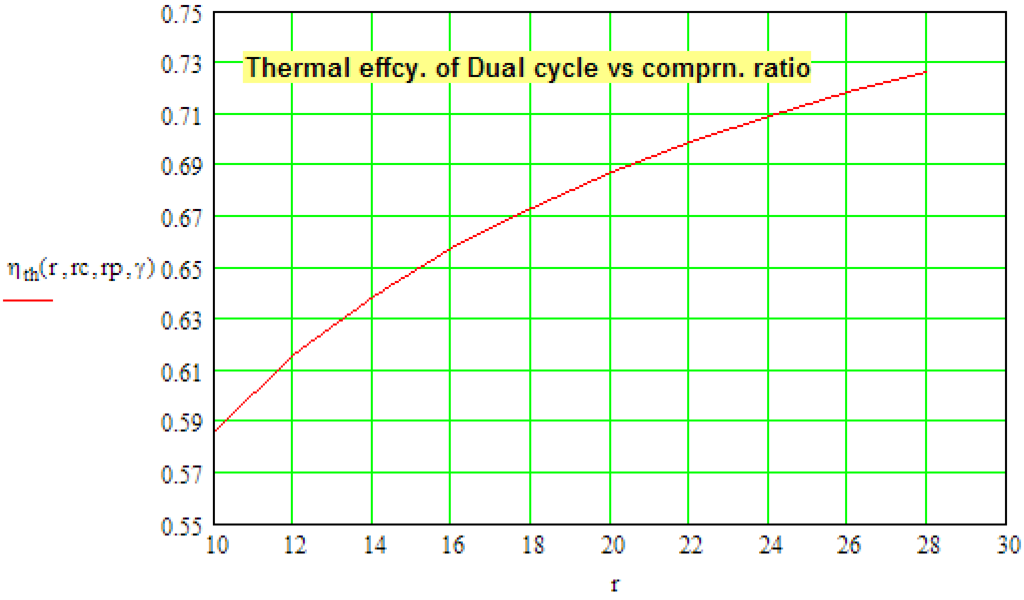
(b) Now, for the above problem, plot the Efficiency, Work output and MEP as the compression ratio varies from 10 to 28:

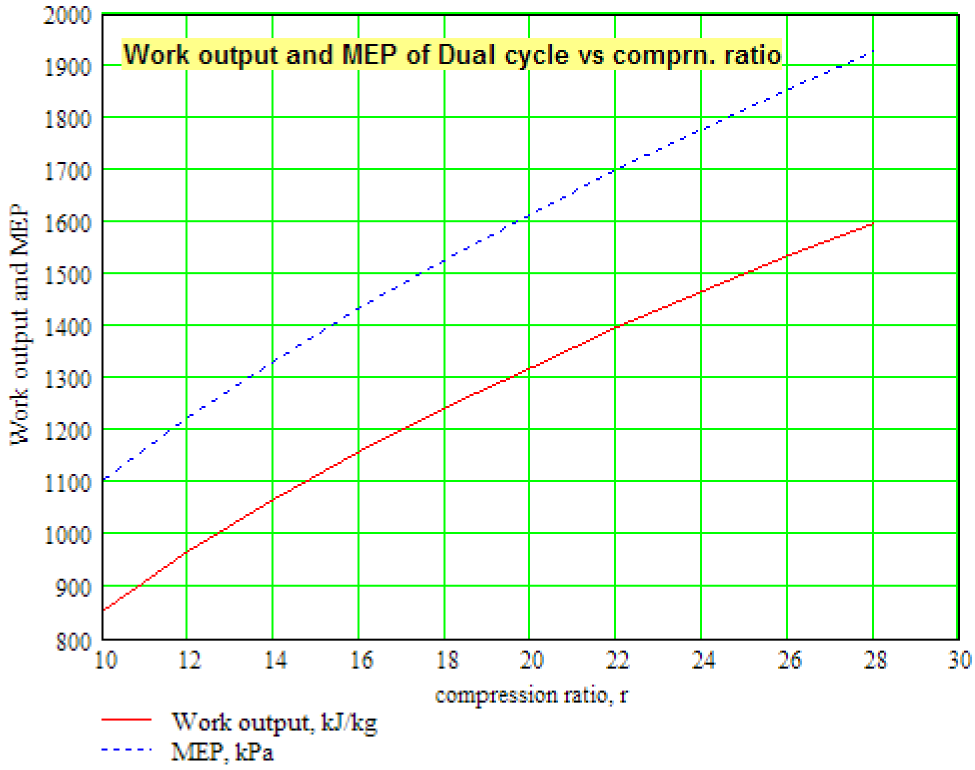
With the above Mathcad Functions, plotting the desired graphs is very easy:

$r := 10, 12..28$ **....define r as a range variable from 10 to 28.**

r =	$\eta_{th}(r, rc, rp, \gamma)$	$W(r, rc, rp, P1, v1, \gamma)$	$MEP(r, rc, rp, \gamma, P1)$
10	0.587	856.245	$1.105 \cdot 10^3$
12	0.616	966.653	$1.225 \cdot 10^3$
14	0.639	$1.066 \cdot 10^3$	$1.334 \cdot 10^3$
16	0.658	$1.158 \cdot 10^3$	$1.435 \cdot 10^3$
18	0.673	$1.243 \cdot 10^3$	$1.529 \cdot 10^3$
20	0.687	$1.323 \cdot 10^3$	$1.617 \cdot 10^3$
22	0.699	$1.397 \cdot 10^3$	$1.7 \cdot 10^3$
24	0.709	$1.468 \cdot 10^3$	$1.779 \cdot 10^3$
26	0.718	$1.536 \cdot 10^3$	$1.855 \cdot 10^3$
28	0.726	$1.6 \cdot 10^3$	$1.927 \cdot 10^3$

Now, plot the results:





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Prob.1.37. The compression ratio and expansion ratio of an oil engine working on the dual cycle are 9 and 5 respectively. The initial pressure and temp of air are 1 bar and 30 C. The heat liberated at const. pressure is twice the heat liberated at const. vol. The expansion and compression follow the law p.v^1.25 = const. Determine: (i) P and T at all salient points (ii) MEP of the cycle (iii) Efficiency of the cycle (iv) Power of the engine, if working cycles per sec are 8. Assume cylinder bore = 250 mm and stroke length = 400 mm. [VTU]

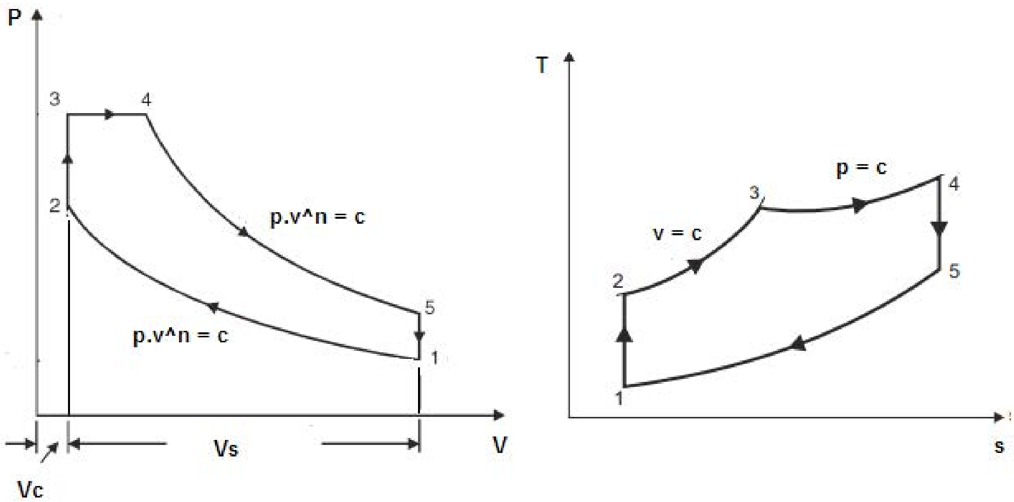


Fig.Prob.1.37

Mathcad Solution:

Note: In this problem, compression and expansion are polytropic, and not isentropic.

Therefore, we can not write W as Qs – Qin; Instead, W = area of the cycle in the p-v diagram.

Data:

$r := 9$ ....comprn. ratio $re := 5$ ...expansion ratio = v5/v4

$P1 := 1$ bar $T1 := 303$ K $n := 1.25$ $\gamma := 1.4$ $R := 287$ J/kg.K

$D := 0.25$ m $L := 0.4$ m

We have, for cut off ratio:

$$rc = \frac{v4}{v3} = \frac{v4}{v5}\cdot\frac{v5}{v3} = \frac{1}{re}\cdot\frac{v1}{v2} = \frac{r}{re}$$

i.e. $rc := \frac{r}{re}$ i.e. $rc = 1.8$ ...cut off ratio

Calculations:

$V_s := \frac{\pi \cdot D^2}{4}\cdot L$ i.e. $V_s = 0.02$ m^3.... stroke volume

$V_c := \frac{V_s}{r-1}$ i.e. $V_c = 2.454 \times 10^{-3}$ m^3.... clearance volume

Also: $V3 := V_c$ $V2 := V3$

$V1 := r \cdot V_c$ i.e. $V1 = 0.022$ m^3

$V4 := rc \cdot V3$ $V5 := V1$

Process 1-2: ... polytropic process:

$T2 := T1 \cdot r^{n-1}$ i.e. $T2 = 524.811$ **K...Ans.**

$P2 := P1 \cdot r^{n}$ i.e. $P2 = 15.588$ **bar....Ans.**

Process 2-3: ... const. volume process

By data: cp*(T4-T3) = 2*cv*(T3-T2)

i.e. $\frac{(T4 - T3)\cdot\gamma}{2} = T3 - T2$ Also: $\frac{T4}{T3} = rc$

Then, we get:

$$T3\cdot\left(\frac{T4}{T3} - 1\right)\cdot\gamma = 2\cdot(T3 - T2)$$

i.e. $T3\cdot(rc - 1)\cdot\gamma = 2\cdot(T3 - T2)$

i.e. $T2 = T3\cdot(1 - 0.56)$

i.e. $T3 := \frac{T2}{0.44}$

i.e. $T3 = 1.193 \times 10^3$ **K....Ans.**

And: $T4 := T3 \cdot rc$

i.e. $T4 = 2.147 \times 10^3$ **K ... Ans.**

Process 3-4, const. pressure process:

$P3 := P2 \cdot \frac{T3}{T2}$ i.e. $P3 = 35.428$ bar

$P4 := P3$ i.e. $P4 = 35.428$ bar

Process 4-5: ... polytropic process:

$T5 := \frac{T4}{re^{n-1}}$ i.e. $T5 = 1.436 \times 10^3$ **K....Ans.**

$P5 := \frac{P4}{re^{n}}$ i.e. $P5 = 4.738$ **bar....Ans.**

Work output:

W = area 12345

Therefore:

$$W := \left[P3 \cdot (V4 - V3) + \frac{(P4 \cdot V4 - P5 \cdot V5)}{n-1} - \frac{(P2 \cdot V2 - P1 \cdot V1)}{n-1}\right] \cdot 100 \quad \text{kJ}$$

i.e. $W = 21.227$ **kJ .... Ans.**

Mean Effective Pressure:

$mep := \frac{W}{V_s}$ i.e. $mep = 1.081 \times 10^3$ **kPa = 10.81 bar ... Ans.**

Heat supplied….taking in to account only the heat supplied in Processes 2-3 and 3-4:

(Remember: there is heat transfer in the polytropic processes 1-2 and 4-5 too.)

$m := \frac{P1 \cdot 10^5 \cdot V1}{R \cdot T1}$ i.e. $m = 0.025$ kg/cycle $cp := 1005$ J/kg.K $cv := 718$ J/kg.K

$Q_s := m \cdot [\, cv \cdot (T3 - T2) + cp \cdot (T4 - T3)\,]$

i.e. $Q_s = 3.654 \times 10^4$ J

Thermal efficiency:

$\eta := \dfrac{W \cdot 10^3}{Q_s}$ i.e. $\eta = 0.581$ **= 58.1 % .... Ans.**

Power developed when no. of cycles is 8 per sec.:

$Power := W \cdot 8$

i.e. $Power = 169.818$ **kW ... Ans.**

Prob.1.38. In an air standard dual cycle, P and T at the start of the compression stroke are 100 kPa and 300K. Compression ratio is 15. Max. temp of cycle is 3000 K and max pressure is 7 MPa. Determine:

1) Work done per kg of air
2) energy added per kg of air
3) MEP …..[VTU]

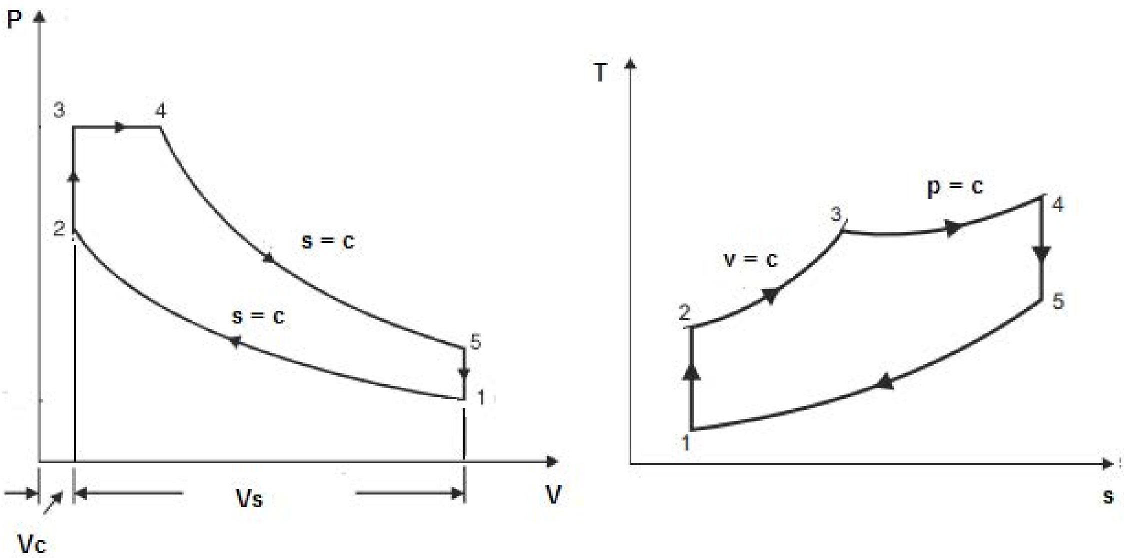


Fig.Prob.1.38

Mathcad Solution:

Data:

$P1 := 1$ bar $\quad T1 := 300$ K $\quad r := 15 \quad P4 := 70$ bar $\quad T4 := 3000$ K $\quad P3 := P4$

$R := 0.287$ kJ/kg.K $\quad \gamma := 1.4$

$cv := \dfrac{R}{\gamma - 1}$ i.e $cv = 0.718$ kJ/kg.K $\quad cp := \dfrac{R \cdot \gamma}{\gamma - 1}$ i.e. $cp = 1.005$ kJ/kg.K

Calcuations:

Process 1-2:

$T2 := T1 \cdot r^{\gamma - 1}$ i.e $T2 = 886.253$ K

$P2 := P1 \cdot r^{\gamma}$ i.e $P2 = 44.313$ bar

Process 2-3:

$T3 := \dfrac{P3}{P2} \cdot T2$ i.e $T3 = 1.4 \times 10^{3}$ K

Process 4-5:

$T5 := T4 \cdot \left(\frac{1}{r} \cdot \frac{T4}{T3}\right)^{\gamma - 1}$ i.e $T5 = 1.377 \times 10^3$ K

Heat supplied:

$Q_S := cv \cdot (T3 - T2) + cp \cdot (T4 - T3)$ i.e. $Q_S = 1.976 \times 10^3$ **kJ/kg...heat added...Ans.**

Heat rejected:

$Q_R := cv \cdot (T5 - T1)$ i.e. $Q_R = 773.084$ kJ/kg

Work output:

$W := Q_S - Q_R$ i.e. $W = 1.203 \times 10^3$ **kJ/kg...Ans**

Mean effective pressure:

$V1 := \frac{R \cdot 10^3 \cdot T1}{P1 \cdot 10^5}$ i.e. $V1 = 0.861$ m^3

Therefore:

$mep := \frac{W \cdot 10^3}{V1 \cdot \left(1 - \frac{1}{r}\right)}$ i.e. $mep = 1.497 \times 10^6$ **Pa.. = 14.97 bar.... Ans.**

Verify the above results with the Mathcad Functions written earlier:

We have: $r = 15$ ..comprn. ratio

$rc = \frac{v4}{v3} = \frac{T4}{T3}$ i.e. $rc := \frac{T4}{T3}$ i.e. $rc = 2.143$ ....cut off ratio

$rp := \frac{P3}{P2}$ i.e. $rp = 1.58$ ..pressure ratio $V1 = 0.861$ m^3

We have the Mathcad Functions:

$$W(r, rc, rp, p1, v1, \gamma) := \frac{p1 \cdot v1 \cdot \left[rp \cdot \gamma \cdot (rc - 1) \cdot r^{\gamma-1} + (rp - 1) \cdot r^{\gamma-1} - \left(rp \cdot rc^{\gamma} - 1\right)\right]}{\gamma - 1}$$

$$\eta_{th}(r, rc, rp, \gamma) := 1 - \frac{1}{r^{\gamma-1}} \cdot \left[\frac{rp \cdot rc^{\gamma} - 1}{(rp - 1) + \gamma \cdot rp \cdot (rc - 1)}\right]$$

$$MEP(r, rc, rp, \gamma, p1) := \frac{p1}{(r - 1) \cdot (\gamma - 1)} \cdot \left[r^{\gamma} \cdot [rp \cdot \gamma \cdot (rc - 1) + (rp - 1)] - r \cdot \left(rp \cdot rc^{\gamma} - 1\right)\right]$$

Therefore:

$W(r, rc, rp, P1 \cdot 100, V1, \gamma) = 1.203 \times 10^{3}$ **kJ/kg....Ans.**

$\eta_{th}(r, rc, rp, \gamma) = 0.609$ **= 60.9 %....Ans.**

$MEP(r, rc, rp, \gamma, P1) = 14.967$ **bar...Ans.**

Note that the results with Mathcad Functions match very well with the results obtained above.

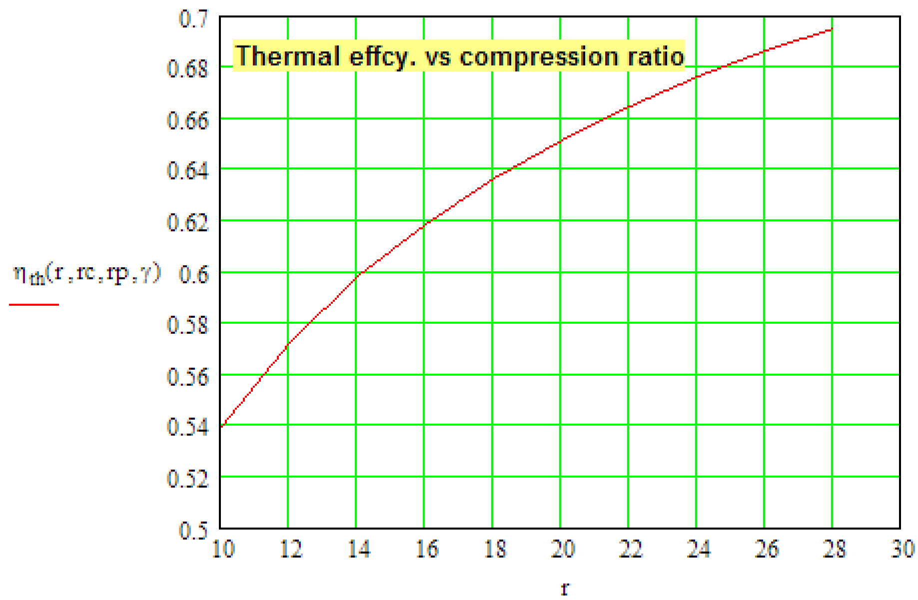
(b) Plot the variation of efficiency, work output and MEP as compression ratio varies from 10 to 28, other conditions remaining the same:

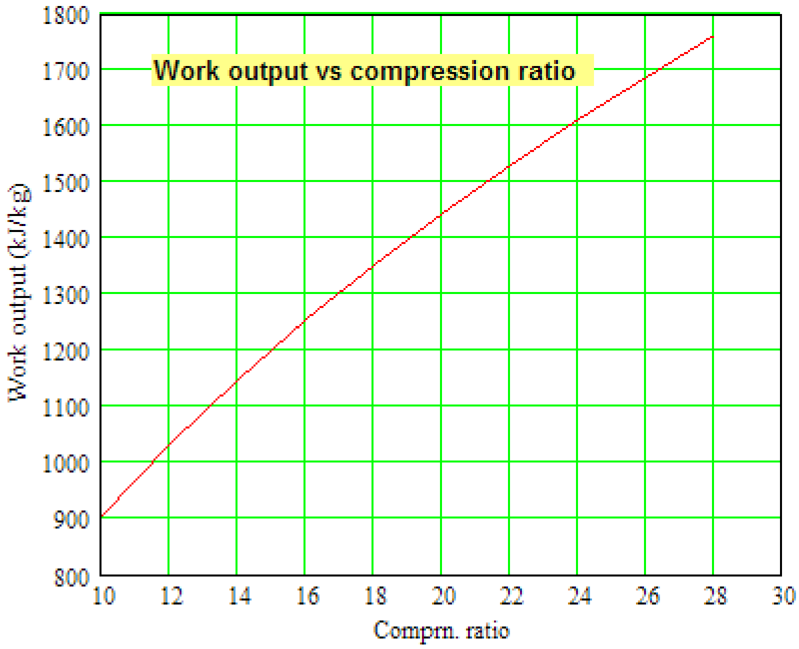
With the use of these Functions, it is very easy to plot the graphs:

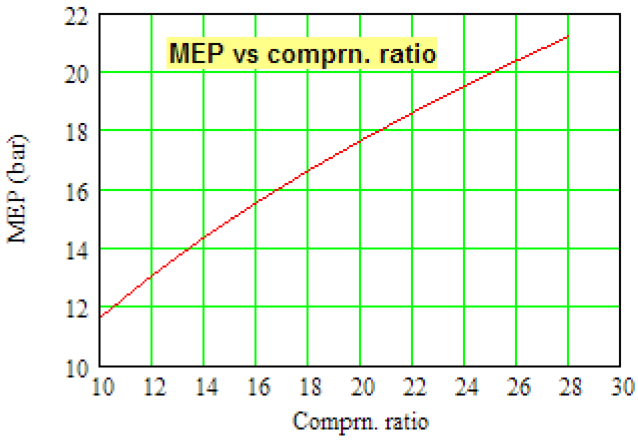
$r := 10, 12 .. 28$ ....define r as a range variable

$r =$	$W(r, rc, rp, P1 \cdot 100, V1, \gamma)$	$\eta_{th}(r, rc, rp, \gamma)$	$MEP(r, rc, rp, \gamma, P1)$
10	906.916	0.54	11.704
12	$1.034 \cdot 10^{3}$	0.572	13.101
14	$1.149 \cdot 10^{3}$	0.598	14.371
16	$1.254 \cdot 10^{3}$	0.619	15.54
18	$1.352 \cdot 10^{3}$	0.636	16.629
20	$1.444 \cdot 10^{3}$	0.651	17.65
22	$1.53 \cdot 10^{3}$	0.664	18.614
24	$1.611 \cdot 10^{3}$	0.676	19.529
26	$1.689 \cdot 10^{3}$	0.686	20.401
28	$1.763 \cdot 10^{3}$	0.695	21.235

Now, plot the graphs:







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Prob.1.39. An engine working on air standard dual cycle has a compression ratio of 10. The cylinder diameter is 25 cm and stroke, 30 cm. P and T at the beginning of compression are 1 bar and 27 C. Pressure at the end of const. vol. heat addition is 50 bar. If the heat addition during const. pressure is up to 5% of stroke, calculate:

i) net work done during the cycle
ii) amount of heat added
iii) amount of heat rejected [M.U]

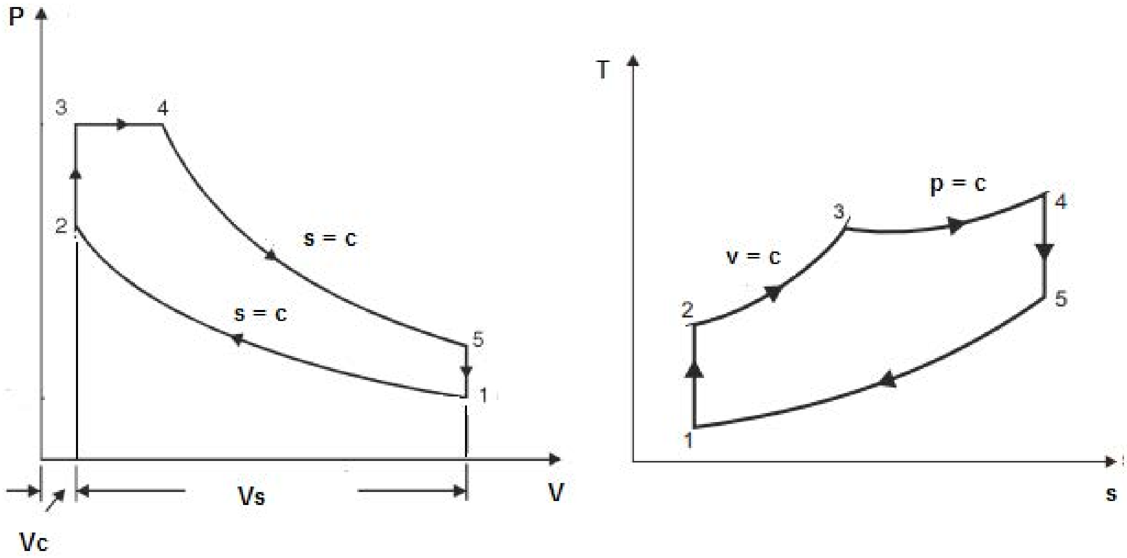


Fig.Prob.1.39

Mathcad Solution:

Data:

$r := 10$ $T1 := 300$ K $P1 := 1$ bar

$P3 := 50$ bar $P4 := P3$ $D := 0.25$ m $L := 0.3$ m

$\gamma = 1.401$ $R := 0.287$ kJ/kg.K

$cp := \frac{R \cdot \gamma}{\gamma - 1}$ i.e. $cp = 1.003$ kJ/kg.K

$cv := \frac{R}{\gamma - 1}$ i.e. $cv = 0.716$ kJ/kg.K

Calculations:

$V_s := \frac{\pi \cdot D^2}{4} \cdot L$ i.e. $V_s = 0.015$ m^3....stroke volume

Process 1-2:

$P2 := P1 \cdot r^{\gamma}$ i.e. $P2 = 25.151$ bar

$T2 := T1 \cdot r^{\gamma - 1}$ i.e. $T2 = 754.539$ K

Process 2-3:

$T3 := T2 \cdot \frac{P3}{P2}$ i.e. $T3 = 1.5 \times 10^{3}$ K

Process 3-4:

$V_c := \frac{V_s}{r - 1}$ i.e. $V_c = 1.636 \times 10^{-3}$ m^3

$V1 := V_s + V_c$ i.e. $V1 = 0.016$ m^3

$V4 := V_c + 0.05 \cdot V_s$ i.e. $V4 = 2.373 \times 10^{-3}$ m^3

$T4 := T3 \cdot \frac{V4}{V_c}$ i.e. $T4 = 2.175 \times 10^{3}$ K

Process 4-5: $P4 := P3$

$$T5 := T4 \cdot \left(\frac{T4}{T3} \cdot \frac{1}{r}\right)^{\gamma - 1}$$ $T5 = 1.004 \times 10^{3}$ K

$$P5 := \left(\frac{V4}{V1}\right)^{\gamma} \cdot P4$$ $P5 = 3.345$ bar

Heat supplied:

$$m := \frac{P1 \cdot 10^{5} \cdot V1}{R \cdot 10^{3} \cdot T1}$$ i.e. $m = 0.019$ kg...mass of air per cycle

$$Q_s := m \cdot cv \cdot (T3 - T2) + m \cdot cp \cdot (T4 - T3)$$

i.e. $Q_s = 23.023$ **kJ/cycle.... heat supplied.... Ans.**

Heat rejected:

$Q_r := m \cdot cv \cdot (T5 - T1)$ i.e. $Q_r = 9.58$ **kJ/cycle.... heat rejected.... Ans.**

Net Work output:

$W := Q_s - Q_r$ i.e. $W = 13.443$ **kJ/cycle.....Ans.**

Air standard effcy.:

$$\eta := \frac{Q_s - Q_r}{Q_s}$$

i.e. $\eta = 0.584$ **= 58.4 %....Ans.**

Mean Effective Pressure:

$$MEP := \frac{W \cdot 10^{3}}{V_s}$$ i.e. $MEP = 9.129 \times 10^{5}$ **Pa = 9.129 bar .... Ans.**

Verify the above results with Mathcad Functions written earlier:

We have: $r = 10$ ..comprn. ratio

$rc = \frac{v4}{v3} = \frac{T4}{T3}$ i.e. $rc := \frac{T4}{T3}$ i.e. $rc = 1.45$ ....cut off ratio

$rp := \frac{P3}{P2}$ i.e. $rp = 1.988$ ..pressure ratio $V1 = 0.016$ m^3

We have the Mathcad Functions:

$$W(r, rc, rp, p1, v1, \gamma) := \frac{p1 \cdot v1 \cdot \left[rp \cdot \gamma \cdot (rc - 1) \cdot r^{\gamma - 1} + (rp - 1) \cdot r^{\gamma - 1} - \left(rp \cdot rc^{\gamma} - 1 \right) \right]}{\gamma - 1}$$

$$\eta_{th}(r, rc, rp, \gamma) := 1 - \frac{1}{r^{\gamma - 1}} \cdot \left[\frac{rp \cdot rc^{\gamma} - 1}{(rp - 1) + \gamma \cdot rp \cdot (rc - 1)} \right]$$

$$MEP(r, rc, rp, \gamma, p1) := \frac{p1}{(r - 1) \cdot (\gamma - 1)} \cdot \left[r^{\gamma} \cdot [rp \cdot \gamma \cdot (rc - 1) + (rp - 1)] - r \cdot \left(rp \cdot rc^{\gamma} - 1 \right) \right]$$

Therefore:

$W(r, rc, rp, P1 \cdot 100, V1, \gamma) = 13.443$ **kJ/kg....Ans.**

$\eta_{th}(r, rc, rp, \gamma) = 0.584$ **= 58.4 %....Ans.**

$MEP(r, rc, rp, \gamma, P1) = 9.129$ **bar...Ans.**

Note that the results with Mathcad Functions match very well with the results obtained above.

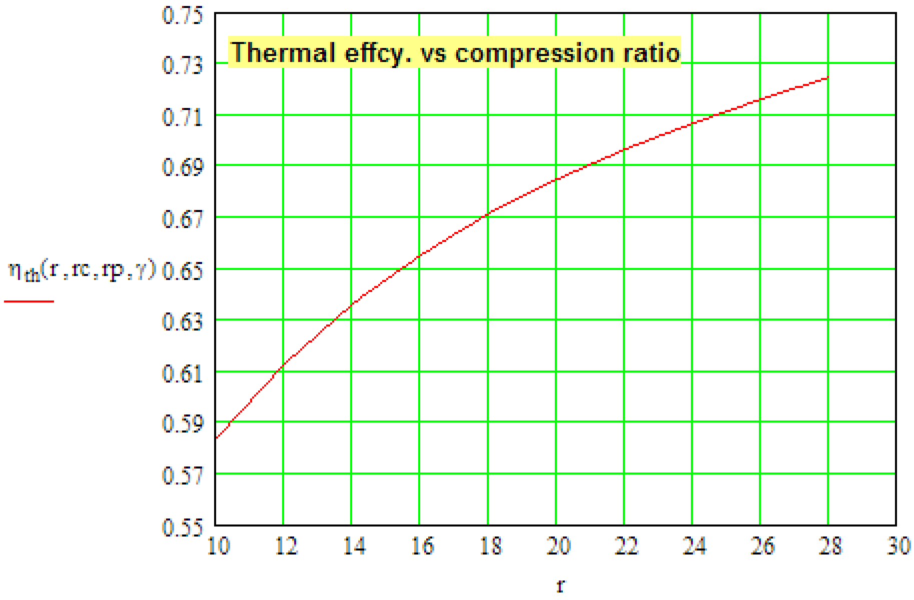
(b) Plot the variation of efficiency, work output and MEP as compression ratio varies from 10 to 28, other conditions remaining the same:

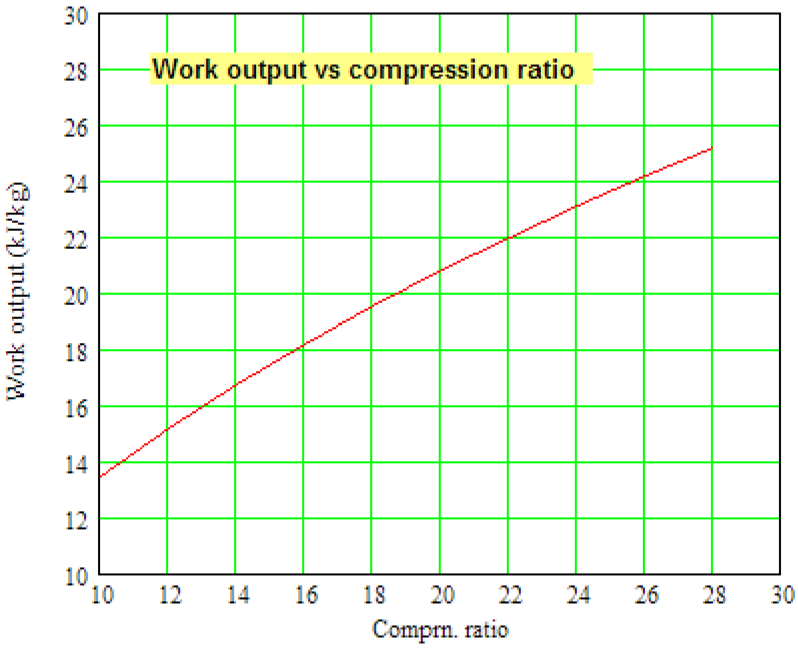
With the use of these Functions, it is very easy to plot the graphs:

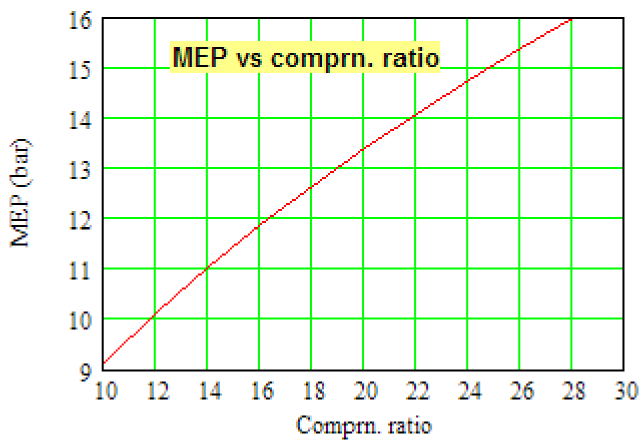
$r := 10, 12 .. 28$ ....define r as a range variable

r =	$W(r, rc, rp, P1 \cdot 100, V1, \gamma)$	$\eta_{th}(r, rc, rp, \gamma)$	$MEP(r, rc, rp, \gamma, P1)$
10	13.443	0.584	9.129
12	15.188	0.613	10.126
14	16.765	0.636	11.034
16	18.213	0.655	11.873
18	19.555	0.671	12.654
20	20.811	0.685	13.388
22	21.994	0.697	14.082
24	23.114	0.707	14.74
26	24.179	0.716	15.368
28	25.196	0.725	15.969

Now, plot the graphs:







==

Prob.1.40. In an air standard dual cycle, the air is at a pressure of 100 kPa and a temp of 27 C before the isentropic compression begins. In this process, volume of air is reduced from 0.07 m^3 to 0.004 m^3. During the process of heat addition at const. pressure, the temp of air is increased from 1160 C to 1600 C. Determine: (i) compression ratio (ii) Cut off ratio (iii) thermal efficiency. (iv) m.e.p. [M.U.]

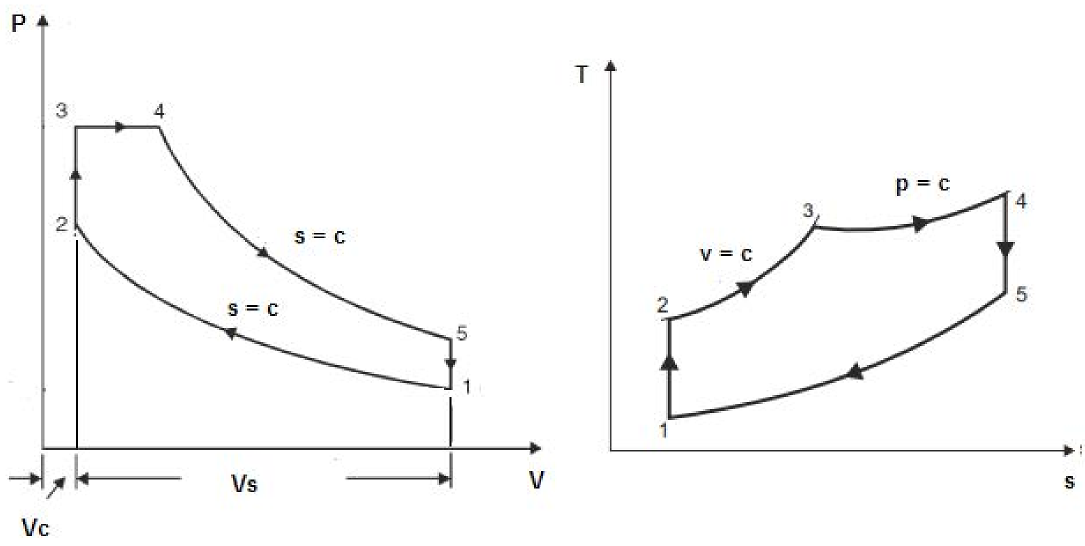


Fig.Prob.1.40

Mathcad Solution:

Data:

P1 := 1 bar T1 := 300 K V1 := 0.07 m^3 V2 := 0.004 m^3 V3 := V2

T3 := 1160 + 273 K T4 := 1600 + 273 K R := 0.287 kJ/kg.K γ := 1.4

Calculations:

Compression ratio:

$r := \frac{V1}{V2}$ i.e. $r = 17.5$ **...Ans.**

Cut off ratio:

$rc = \frac{V4}{V3} = \frac{T4}{T3}$ ....since Process 3-4 is at constant pressure

i.e. $rc := \frac{T4}{T3}$ i.e. $rc = 1.307$ **...Ans.**

Pressure ratio:

Process 1-2:

$T2 := T1 \cdot r^{\gamma - 1}$ i.e. $T2 = 942.62$ K

$rp = \frac{P3}{P2} = \frac{T3}{T2}$ ....since Process 2-3 is at constant volume

i.e. $rp := \frac{T3}{T2}$ i.e. $rp = 1.52$

Now, use the Mathcad Functions written earlier:

Thermal efficiency:

$$\eta_{th}(r, rc, rp, \gamma) := 1 - \frac{1}{r^{\gamma - 1}} \cdot \left[\frac{rp \cdot rc^{\gamma} - 1}{(rp - 1) + \gamma \cdot rp \cdot (rc - 1)} \right]$$

i.e. $\eta_{th}(r, rc, rp, \gamma) = 0.671$ **= 67.2 % ... Ans.**

Mean Effective Pressure:

$$MEP(r, rc, rp, \gamma, p1) := \frac{p1}{(r - 1) \cdot (\gamma - 1)} \cdot \left[r^{\gamma} \cdot [rp \cdot \gamma \cdot (rc - 1) + (rp - 1)] - r \cdot \left(rp \cdot rc^{\gamma} - 1 \right) \right]$$

i.e. $MEP(r, rc, rp, \gamma, P1) = 6.566$ **bar ....Ans.**

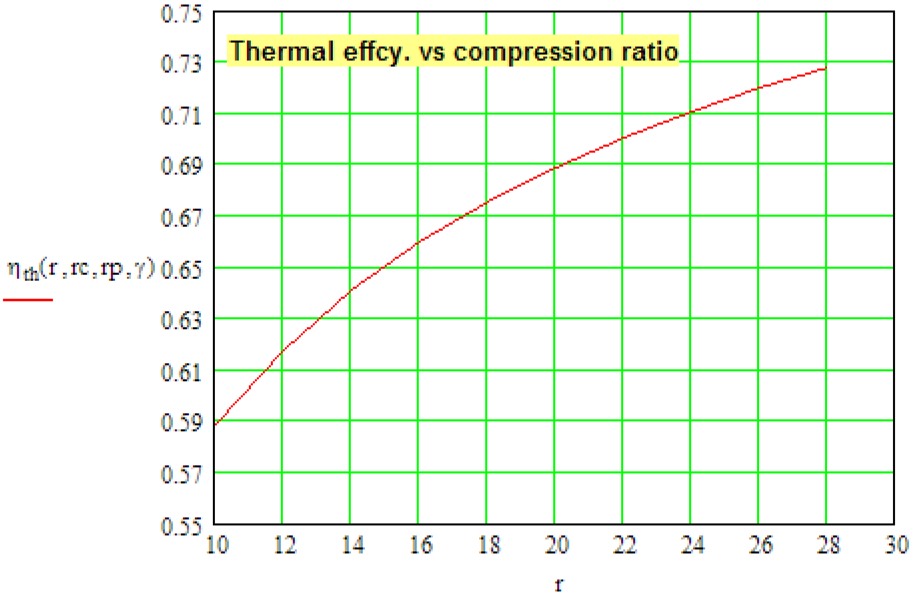
(b) Plot the variation of efficiency and MEP as compression ratio varies from 10 to 28, other conditions remaining the same:

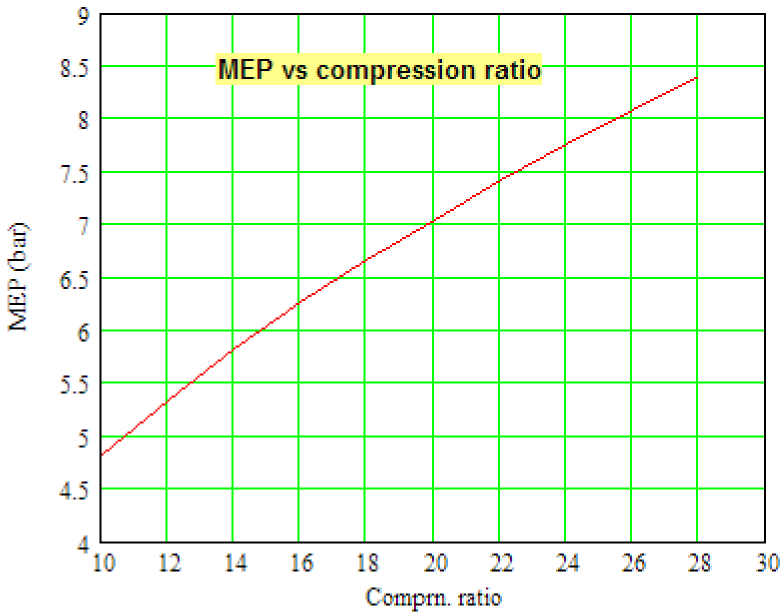
With the use of these Functions, it is very easy to plot the graphs:

$r := 10, 12 .. 28$ ....define r as a range variable

$r =$	$\eta_{th}(r, rc, rp, \gamma)$	$MEP(r, rc, rp, \gamma, P1)$
10	0.589	4.824
12	0.618	5.345
14	0.641	5.819
16	0.659	6.257
18	0.675	6.665
20	0.689	7.049
22	0.7	7.411
24	0.71	7.755
26	0.72	8.084
28	0.728	8.398

Now, plot the graphs:





==

1.4.2 Problems solved with EES:

"**Prob.1.41.** Write EES Functions for: (i) thermal efficiency, (ii) work output and (iii) mean effective pressure, for an air standard Dual (or, limited pressure) cycle."

```
$UnitSystem SI Pa C J

"EES Functions:"

"Dual cycle- Functions:"

FUNCTION EFFCY_Dual(rr, rc, rp, gamma)

"Thermal effcy. of Air standard Dual cycle"

"Inputs: rc = cut off ratio = V4/V3,
rr = comprn. ratio = V1/V2,
rp = pressure ratio = P3/P2
gamma = sp. heat ratio = 1.4 for air"

"Outputs: EFFCY_Dual = Thermal effcy. of Dual cycle"

EFFCY_Dual := 1 – (1/rr^(gamma-1))* (rp * rc^gamma – 1)/((rp – 1) + rp * gamma * (rc – 1))

END

"==================================================================="

FUNCTION W_net_Dual( rr, rc, rp, P1, V1, gamma)

"W_net of Air standard Dual cycle"

"Inputs: rc = cut off ratio = V4/V3,
rr = comprn. ratio = V1/V2,
rp = pressure ratio = P3/P2
gamma = sp. heat ratio = 1.4 for air"

"Outputs: W_net_Dual = Net work output of Dual cycle"

A := P1 * V1/(gamma – 1)
B := gamma * rp * rr^(gamma – 1) * (rc – 1)
C := rr^(gamma – 1)* (rp -1)
D:= (rp * rc^gamma -1)
```

W_net_Dual := A * (B + C – D)

END

"==="

FUNCTION MEP_Dual(rr, rc, rp, gamma, P1)

"MEP of Air standard Dual cycle"

"Inputs: rc = cut off ratio = V4/V3,
rr = comprn. ratio = V1/V2,
rp = pressure ratio = P3/P2
gamma = sp. heat ratio = 1.4 for air"

"Outputs: MEP_Dual = MEP of Dual cycle"

A := P1/((gamma – 1) * (rr – 1))
B := gamma * rp * rr^gamma * (rc – 1)
C := rr ^ gamma * (rp – 1)
D:= rr * (rp * rc^gamma – 1)

MEP_Dual := A * (B + C – D)

END

"=="

"Example:"

"From Prob.1.39, we have:"
rr = 10; rc = 1.45; rp = 1.988; gamma = 1.4
P1 = 100 "kPa"; V1 = 0.0164 "m^3"
"Then, applying the EES Functions written above, we get:"
W_net = W_net_Dual(rr, rc, rp, P1, V1, gamma)"kJ"
eta = EFFCY_Dual(rr, rc, rp, gamma)
MEP = MEP_Dual(rr, rc, rp, gamma, P1)"kPa"

Results:

Unit Settings: SI C Pa J mass deg

η = 0.5834	γ = 1.4	MEP = 912 [kPa]	P1 = 100 [Pa]
rc = 1.45	rp = 1.988	rr = 10	V1 = 0.0164 [m^3]
W_{net} = 13.46 [kJ]			

Thus:

Thermal efficiency, eta = 58.34 % … Ans.

Work output, W_net = 13.46 kJ …. Ans.

MEP = 912 kPa = 9.12 bar …. Ans.

==

"**Prob.1.42**. An air standard limited pressure cycle has a compression ratio of 15 and compression begins at 0.1 MPa, 40 C. The max. pressure is limited to 6 MPa and the heat added is 1.675 MJ/kg. Compute: (i) the heat supplied at constant volume per kg of air, (ii) heat supplied at const. pressure per kg of air, (iii) work done per kg of air, (iv) cycle efficiency, (v) cut off ratio, and (vi) the MEP of the cycle. [VTU-ATD-July 2007]"

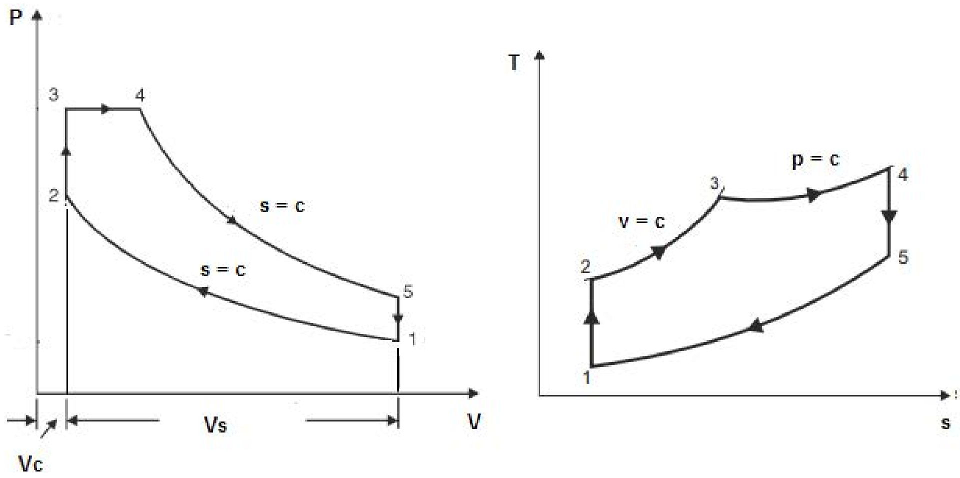


Fig.Prob.1.42

EES Solution:

"Data:"

T1=40+273"K"

R=0.287"kJ/kg.K"

cp=1.005"kJ/kg.K"

gamma=1.4

cp/cv=gamma"finds cv, kJ/kg.K"

p1=100"kPa"

rr=15"..comprn. ratio"

m=1"kg"

q_in=1.675*10^3"kJ"

p3=6*10^3"kPa, max. pressure"

p4=p3 "for Process 3-4"

"Calculations:"

"Process 1-2:"

p1 * V1= m * R * T1"To calculate V1, m^3/kg"

p2 / p1= rr^gamma"finds p2, Pa"

T2 / T1= rr^(gamma-1)"finds T2, K"

V1 / V2= rr"To find V2, m^3"

"Process 2-3:"

V3 = V2

p3 / T3 = p2 / T2"finds T3, K"

"Process 3-4:"

m * cv * (T3-T2) + m * cp * (T4-T3) = q_in"finds T4, K"

V3 / T3 = V4 / T4"finds V4, m^3"

"Process 4-5:"

V5 = V1

T4 / T5 = (V5 / V4)^(gamma-1)"finds T5, K"

"---"

q_cv= m * cv * (T3-T2)"kJ … heat supplied during const. vol. process 2-3"

q_cp= m * cp * (T4-T3)"kJ… heat supplied during const. pressure process 3-4"

q_out = cv * (T5-T1)"kJ … heat rejected during const. vol. process 5-1"

w_net = q_in – q_out "kJ … net work output"

eta_th = w_net / q_in"…thermal efficiency"

mep = w_net / (V1-V2)"kPa …. mean effective pressure"

rc = V4 / V3"cut-off ratio"

rp = p3/p2 "…pressure ratio"

"=="

"Verify with EES Functions written above:"

W_net2 = W_net_Dual(rr, rc, rp, P1, V1, gamma)"kJ"

eta_th2 = EFFCY_Dual(rr, rc, rp, gamma)

MEP_2 = MEP_Dual(rr, rc, rp, gamma, P1)"kPa"

Results:

Unit Settings: SI C Pa J mass deg

cp = 1.005 [J/kg-K]	cv = 0.7179 [J/kg-K]	η_{th} = 0.6057	η_{th2} = 0.6057
γ = 1.4	m = 1 [kg]	mep = 1210 [kPa]	MEP_2 = 1209 [kPa]
p1 = 100 [kPa]	p2 = 4431 [kPa]	p3 = 6000 [kPa]	p4 = 6000 [kPa]
q_{cp} = 1440 [kJ]	q_{cv} = 235 [kJ]	q_{in} = 1675 [kJ]	q_{out} = 660.5 [kJ]
R = 0.287 [kJ/kg-K]	rc = 2.144	rp = 1.354	rr = 15
T1 = 313 [K]	T2 = 924.7 [K]	T3 = 1252 [K]	T4 = 2685 [K]
T5 = 1233 [K]	V1 = 0.8983 [m^3]	V2 = 0.05989 [m^3]	V3 = 0.05989 [m^3]
V4 = 0.1284 [m^3]	V5 = 0.8983 [m^3]	w_{net} = 1014 [kJ]	W_{net2} = 1014 [kJ]

Thus:

Heat supplied at const. volume = q_cv = 235 kJ/kg … Ans.

Heat supplied at const. pressure = q_cp = 1440 kJ/kg … Ans.

Work output = w_net = 1014 kJ/kg … Ans.

Cycle efficiency = eta_th = 0.6057 = 60.57% … Ans.

Cut off ratio = r_c = 2.144 … Ans.

MEP of the cycle = mep = 1210 kPa = 12.1 bar … Ans.

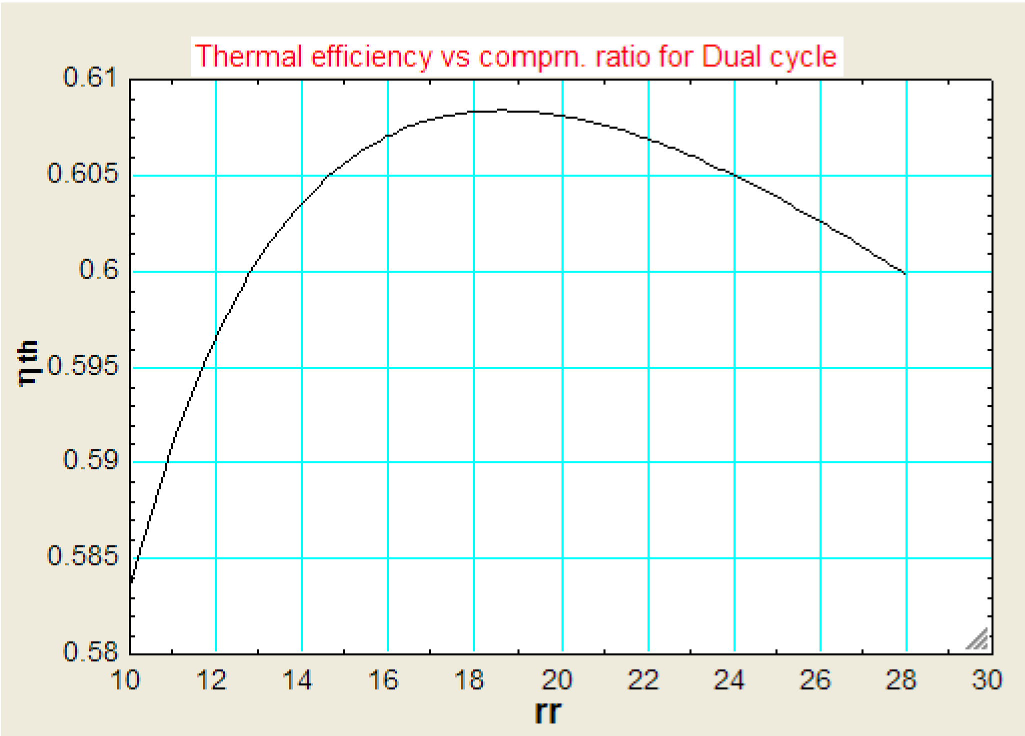
Note that results calculated with EES Functions, viz. eta_th2, w_net2 and MEP2 match very well with the above results.

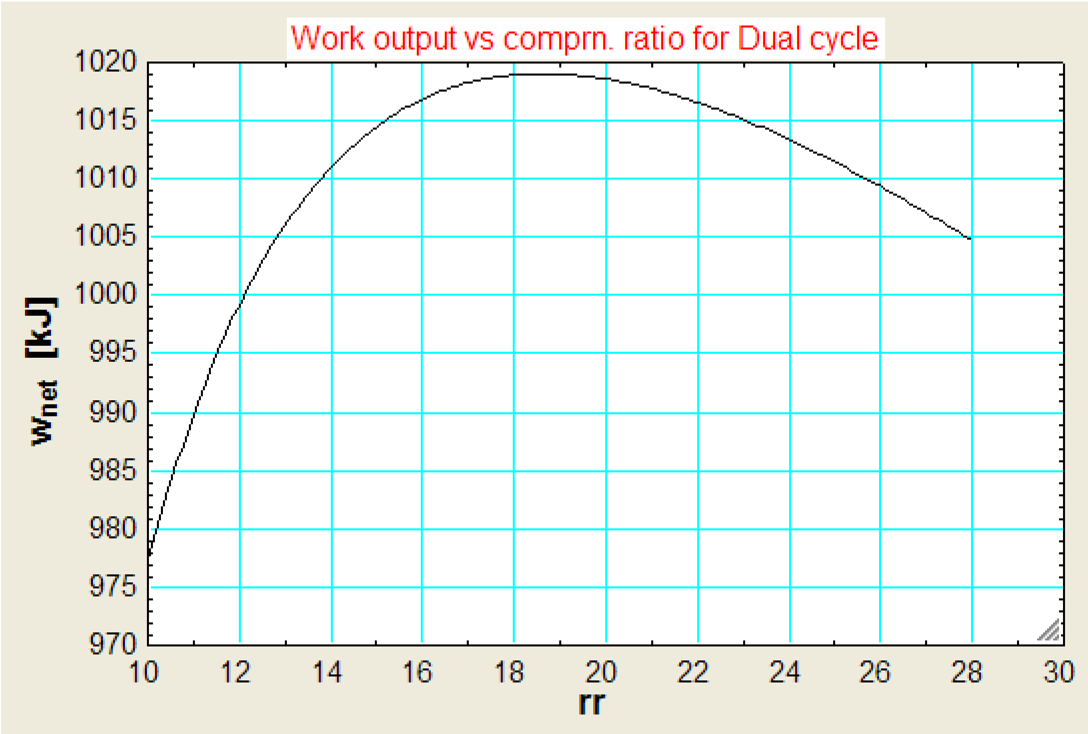
(b) In addition, plot eta_th, W_net and MEP as compression ratio varies from 10 to 28, other conditions remaining the same:

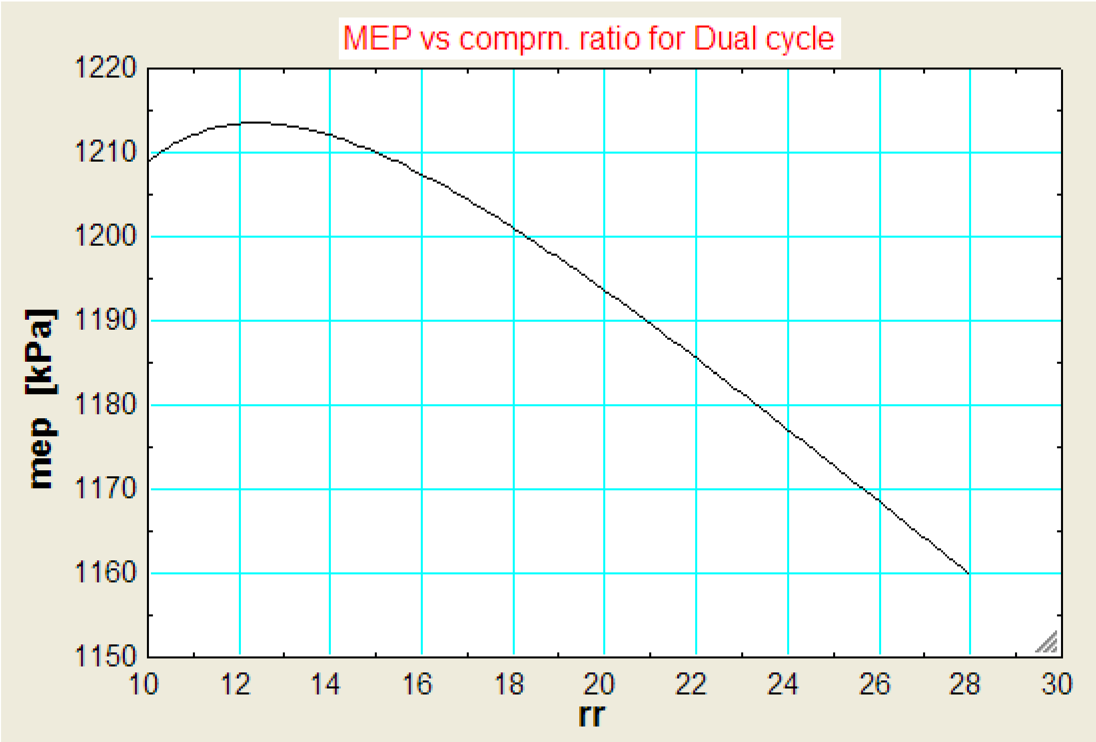
First, compute the Parametric Table:

1..10	rr	η_{th}	w_{net} [kJ]	mep [kPa]
Run 1	10	0.5835	977.3	1209
Run 2	12	0.5965	999.2	1213
Run 3	14	0.6036	1011	1212
Run 4	16	0.6071	1017	1207
Run 5	18	0.6083	1019	1201
Run 6	20	0.6081	1019	1194
Run 7	22	0.6069	1017	1186
Run 8	24	0.605	1013	1177
Run 9	26	0.6026	1009	1168
Run 10	28	0.5998	1005	1160

Now, plot the results:




Work output vs comprn. ratio for Dual cycle
1020
1015
1010
1005
1000
995
990
985
980
975
970
Wnet [kJ]
10
12
14
16
18
20
22
24
26
28
30
rr



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Prob.1.43. The compression ratio and expansion ratio of an oil engine working on the dual cycle are 9 and 5 respectively. The initial pressure and temp of air are 1 bar and 30 C. The heat liberated at const. pressure is twice the heat liberated at const. vol. The expansion and compression follow the law p.v^1.25 = const. Determine: (i) P and T at all salient points (ii) MEP of the cycle (iii) Efficiency of the cycle (iv) Power of the engine, if working cycles per sec are 8. Assume cylinder bore = 250 mm and stroke length = 400 mm. [VTU]

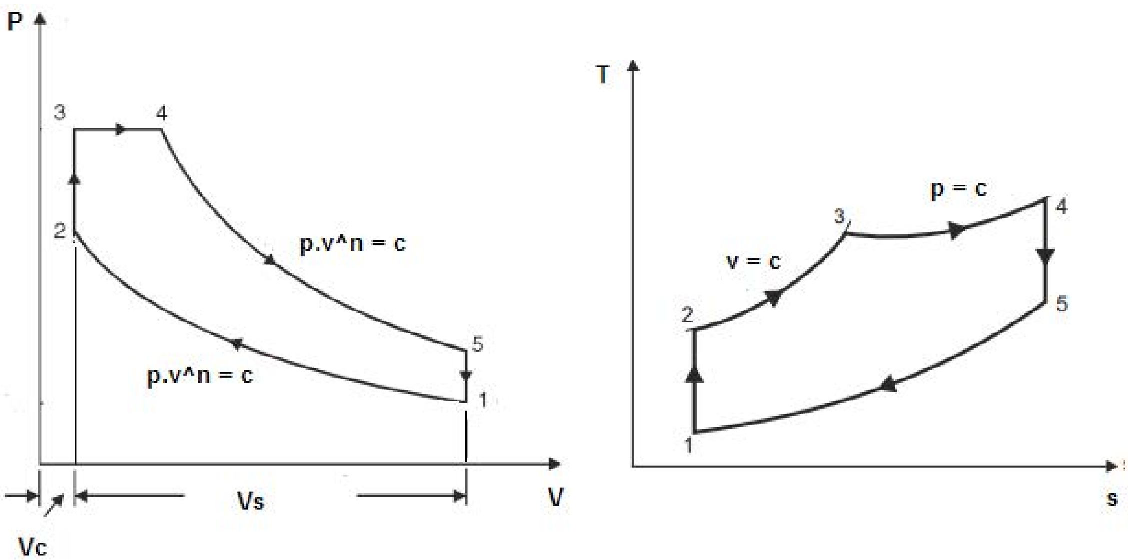


Fig.Prob.1.43

This problem is the same as Prob.1.37 which was solved with Mathcad.

Now, let us solve it with EES and draw plots of eta_th. W_net and MEP vs comprn. ratio.

Note: In this problem, compression and expansion are polytropic, and not isentropic.

Therefore, we can not write W as Qs – Qin; Instead, W = area of the cycle in the p-v diagram.

EES Solution:

```
"Data:"

T1=30+273"K"
P1=100"kPa"
R=0.287"kJ/kg.K"
cp=1.005"kJ/kg.K"
n =1.25"…polytropic index"
cp/cv=gamma"finds cv, kJ/kg.K"
gamma = 1.4
rr=9"..comprn. ratio"
re = 5 "expn. ratio"
D = 0.25 "m ….. dia of cylinder"
L = 0.4 "m …. stroke length"
cyclespersec = 8"…no. of working cycles per sec"

"Calculations:"
V_s = pi * L * D^2 / 4 "m^3 …. stroke volume"
V2 = V_s / (rr -1) "…finds V2"
rc = rr / re "…cut off ratio"
"Process 1-2:"
P1 * V1= m * R * T1"finds m, kg"
P2 / P1= rr^n"finds P2, Pa"
T2 / T1= rr^(n – 1)"finds T2, K"
"Process 2-3:"
V3 = V2
P3 / T3 = P2 / T2"finds T3, K"
q_cv = m * cv * (T3 – T2) "kJ … heat supplied during const. vol. process 2-3"
q_cp = m * cp * (T4-T3) "kJ… heat supplied during const. pressure process 3-4"
q_cp = 2 * q_cv "..heat liberated at const. pressure. is twice that at const. vol."
```

“Process 3-4:”

rc = V4 / V3“…finds V4”

T4 = T3 * rc “finds T4, K”

P4 = P3

“Process 4-5:”

re = V5 / V4 “…expn. ratio”

V5 = V1

T4 / T5 = re^(n-1)“finds T5, K”

P4 / P5 = re^n

“--”

q_in = q_cv + q_cp “kJ… total heat input”

q_out = m* cv * (T5-T1)“kJ … heat rejected during const. vol. process 5-1”

w_net = P3 * (V4 – V3) + (P4 * V4 – P5 * V5)/ (n-1) – (P2 * V2 – P1 * V1) / (n – 1) “kJ … net work output”

eta_th = w_net / q_in“…thermal efficiency”

mep = w_net / (V1-V2)“kPa …. mean effective pressure”

Power = w_net * cyclespersec “kW…power developed”

Results:

Unit Settings: SI C Pa J mass deg

cp = 1.005 [kJ/kg-K]	cv = 0.7179 [J/kg-K]	cyclespersec = 8	D = 0.25 [m]
η_{th} = 0.581	γ = 1.4	L = 0.4 [m]	m = 0.0254 [kg]
mep = 1081 [kPa]	n = 1.25	P1 = 100 [kPa]	P2 = 1559 [kPa]
P3 = 3543 [kPa]	P4 = 3543 [kPa]	P5 = 473.8 [kPa]	Power = 169.8 [kW]
q_{cp} = 24.36 [kJ]	q_{cv} = 12.18 [kJ]	q_{in} = 36.54 [kJ]	q_{out} = 20.66 [kJ]
R = 0.287 [kJ/kg-K]	rc = 1.8	re = 5	rr = 9
T1 = 303 [K]	T2 = 524.8 [K]	T3 = 1193 [K]	T4 = 2147 [K]
T5 = 1436 [K]	V1 = 0.02209 [m^3]	V2 = 0.002454 [m^3]	V3 = 0.002454 [m^3]
V4 = 0.004418 [m^3]	V5 = 0.02209 [m^3]	V_s = 0.01963 [m^3]	w_{net} = 21.23 [kJ]

Thus:

P and T at the salient points:

P1 = 100, P2 = 1559, P3 = 3543, P4 =3543, P5 = 473.8 kPa … Ans.

T1 = 303, T2 = 524.8, T3 = 1193, T4 = 2147, T5 = 1436 K …. Ans.

MEP = 1081 kPa = 10.81 bar …. Ans.

Efficiency = eta_th = 0.581 = 58.1% … Ans.

Net work output = w_net = 21.23 kJ….Ans.

Power developed for 8 cycles per sec. = 169.8 kW … Ans.

Note: These values match with those obtained with Mathcad in Prob.1.37.

===

"**Prob.1.44.** The compression ratio of an air standard Dual cycle is 8. Air is at 100 kPa, 300 K at the beginning of the compression process. The temp of air at the end of constant pressure heat addition process is 1300 K. The heat transfer to the cycle is 480 kJ/kg. Determine: (i) heat transferred at constant volume per kg of air, and (ii) the cycle efficiency. [VTU]"

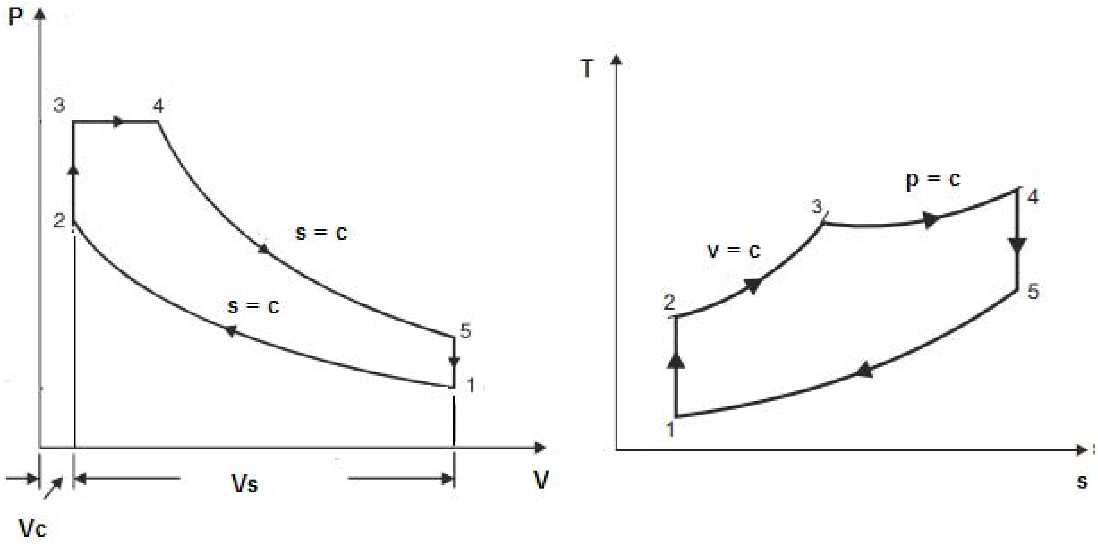


Fig.Prob.1.44

EES Solution:

"Data:"

T1=300"k"

p1 = 100 "kPa"

R=0.287"kJ/kg.K"

cp=1.005"kJ/kg.K"

gamma=1.4

cp/cv=gamma"findst cv, kJ/kg.K"

rr=8 "comprn. ratio"

T4 = 1300 "K"

q_in = 480 "kJ/kg"

m=1"kg"

"Calculations:"

"Process 1-2:"

p1 * V1= m * R * T1"finds V1, m^3/kg"

p2 / p1= rr^gamma"finds p2, Pa"

T2 / T1= rr^(gamma-1)"finds T2, K"

V1 / V2= rr"To find V2, m^3"

"Process 2-3:"

V3 = V2

p3 / T3 = p2 / T2"finds p3, kPa"

```
"Process 3-4:"
m * cv * (T3-T2) + m * cp * (T4-T3) = q_in"finds T3, K"
V3 / T3 = V4 / T4"finds V4, m^3"
"Process 4-5:"
V5 = V1
T4 / T5 = (V5 / V4)^(gamma-1)"finds T5, K"
"---------------------------------------------"
q_cv= m * cv * (T3-T2)"kJ … heat supplied during const. vol. process 2-3"
q_cp= m * cp * (T4-T3)"kJ… heat supplied during const. pressure process 3-4"
q_out = m* cv * (T5-T1)"kJ … heat rejected during const. vol. process 5-1"
w_net = q_in – q_out "kJ … net work output"
eta_th = w_net / q_in"…thermal efficiency"
mep = w_net / (V1-V2)"kPa …. mean effective pressure"
rc = V4 / V3"cut-off ratio"
rp = p3/p2 "…pressure ratio"
"==================================================================="
"Verify with EES Functions written above:"
W_net2 = W_net_Dual( rr, rc, rp, P1, V1, gamma)"kJ"
eta_th2 = EFFCY_Dual(rr, rc, rp, gamma)
MEP_2 = MEP_Dual( rr, rc, rp, gamma, P1)"kPa"
```

Results:

Unit Settings: SI C Pa J mass deg

$cp = 1.005$ [kJ/kg-K]	$cv = 0.7179$ [J/kg-K]	$\eta_{th} = 0.5615$
$\eta_{th2} = 0.5615$	$\gamma = 1.4$	$m = 1$ [kg]
$mep = 357.8$ [kPa]	$MEP_2 = 357.6$ [kPa]	$p1 = 100$ [kPa]
$p2 = 1838$ [kPa]	$p3 = 3081$ [kPa]	$q_{cp} = 145.4$ [kJ]
$q_{cv} = 334.6$ [kJ]	$q_{in} = 480$ [kJ]	$q_{out} = 210.5$ [kJ]
$R = 0.287$ [kJ/kg-K]	$rc = 1.125$	$rp = 1.676$
$rr = 8$	$T1 = 300$ [K]	$T2 = 689.2$ [K]
$T3 = 1155$ [K]	$T4 = 1300$ [K]	$T5 = 593.2$ [K]
$V1 = 0.861$ [m^3]	$V2 = 0.1076$ [m^3]	$V3 = 0.1076$ [m^3]
$V4 = 0.1211$ [m^3]	$V5 = 0.861$ [m^3]	$W_{net} = 269.5$ [kJ]
$W_{net2} = 269.4$ [kJ]		

Thus:

Heat transferred during const. vol. process = q_cv =334.6 kJ/kg …. Ans.

Cycle efficiency = eta_th = 0.5615 = 56.15% ….. Ans.

Note that results calculated with EES Functions, viz. eta_th2, W_net2 and MEP2 match well with the above results.

==

1.4.3 Problems solved with TEST:

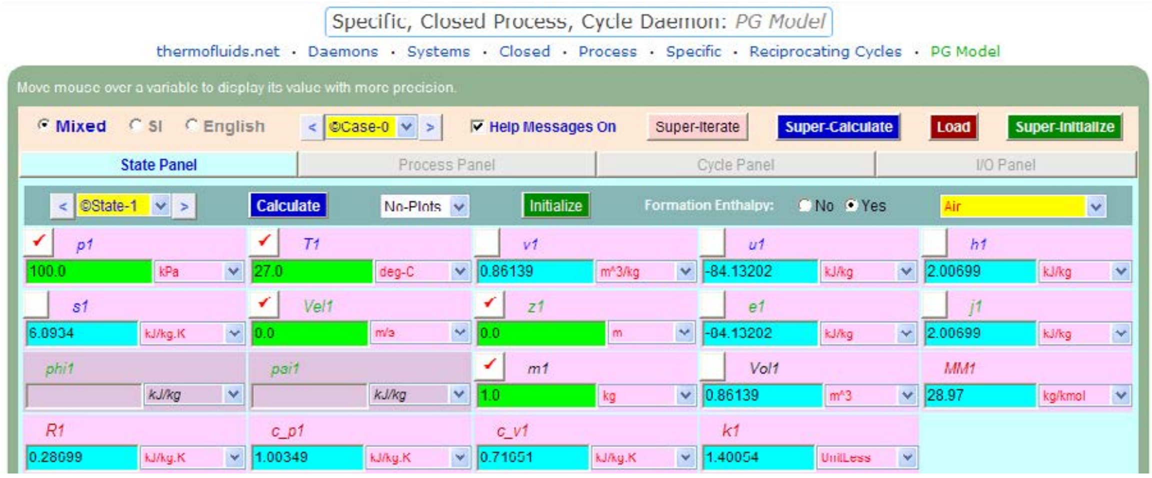
Prob.1.45. An engine working on Dual combustion cycle draws air at 1 bar, 27 C. Max. pressure is limited to 55 bar. Compression ratio is 15. If the heat transfer at constant volume is twice that at constant pressure, determine: (i) cut off ratio, (ii) explosion ratio, (iii) temperatures at salient points, and (iv) air standard efficiency. [VTU]

TEST Solution:

Following are the steps:

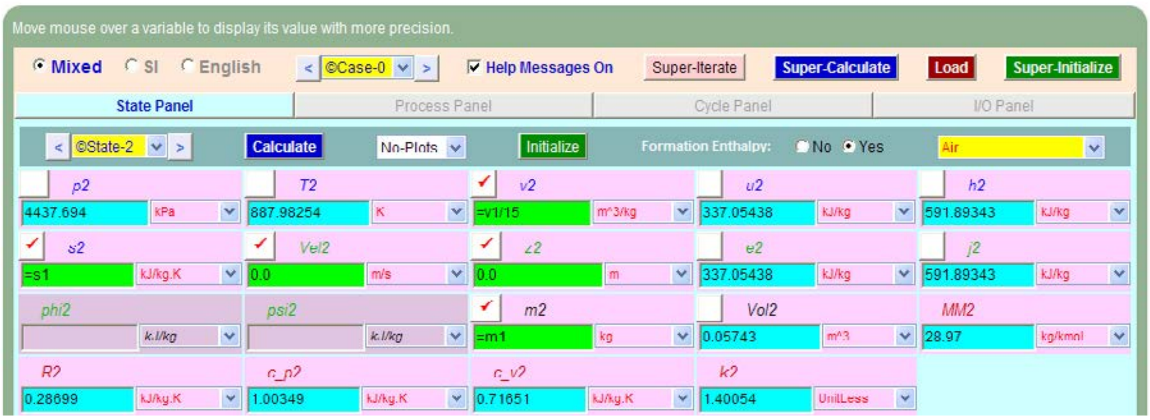
Steps 1 to 4 are the same as for Problem 1.32, using PG model.

5. Select Air as the working substance and fill in data for p1= 100 kPa, T1= 27 C, and m1= 1 kg for State 1, i.e. at beginning of compression, and hit Enter. We get:



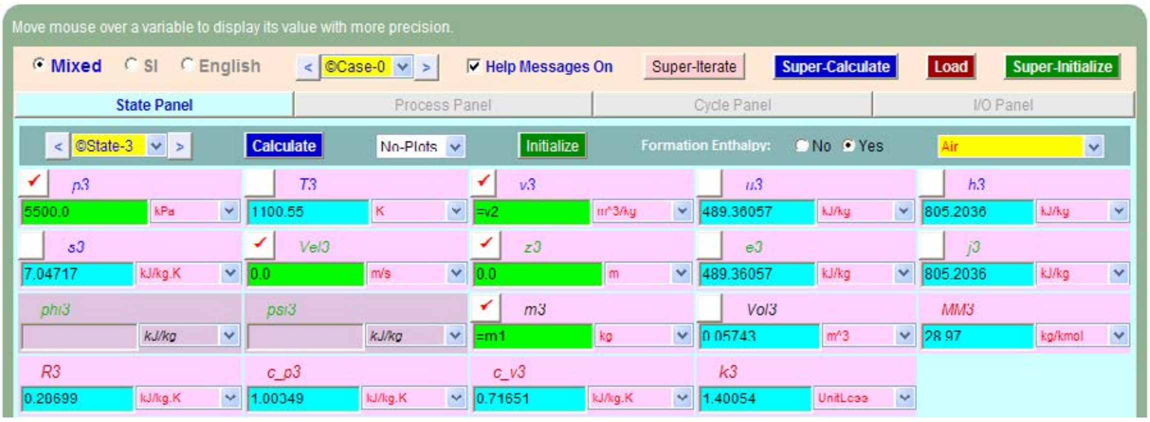
Note that properties for State 1 are calculated.

6. For State 2: Enter v2 = v1/15 (since compression ratio is 15), s2 = s1 (since Process 1-2 is isentropic) and m2 = m1. Hit Enter:



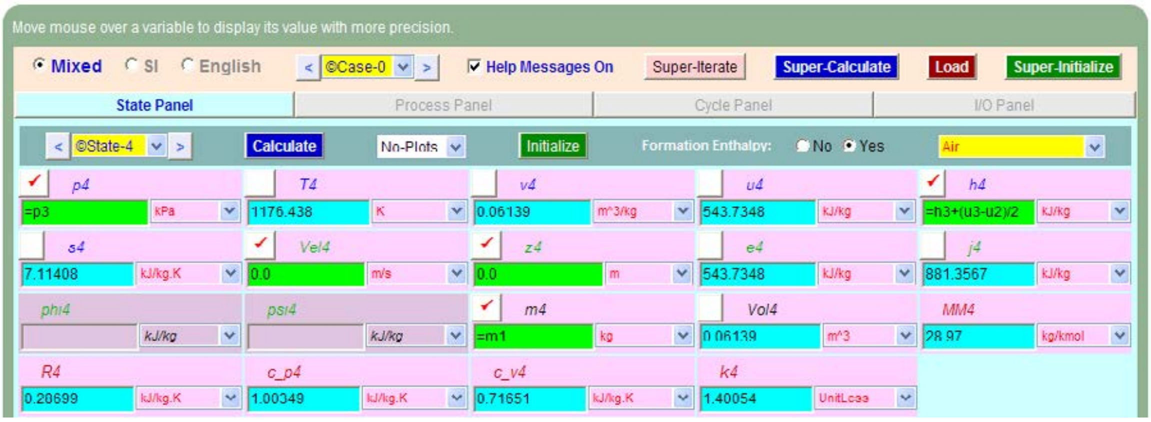
Here, p2 = 4437.694 kPa, T2 = 887.98 K ….Ans.

7. Similarly, for State 3: Enter p3 = 5500 kPa, v3 = v2, and m3 = m1.. Hit Enter, and we get:



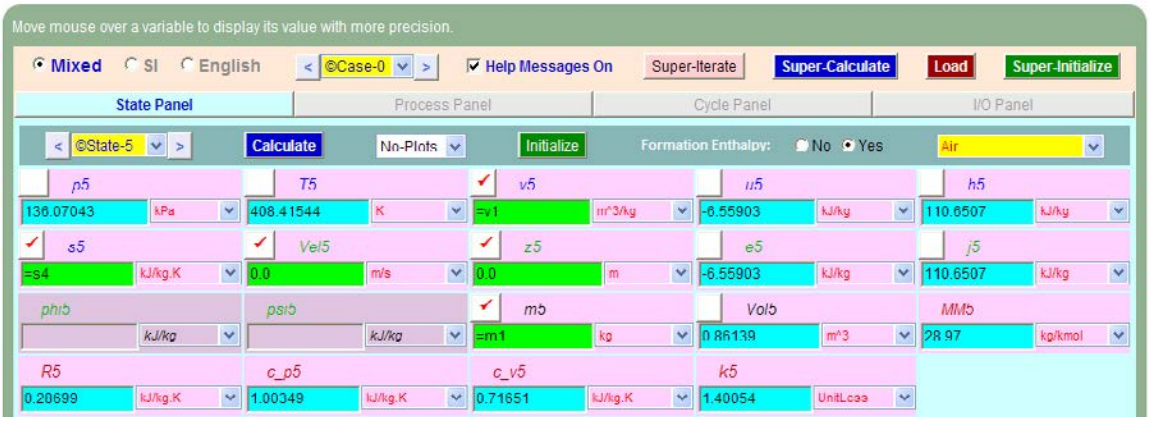
Note that T3 = 1100.55 K … Ans.

8. Now, for State 4: enter p4 = p3, m4 = m1, and since cv * (T3 – T2) = 2 * cp * (T4 – T3), i.e. (u3 – u2) = 2 * (h4 – h3), we enter for h4 as: h4 = h3 + (u3 – u2)/2. Hit Enter. We get:



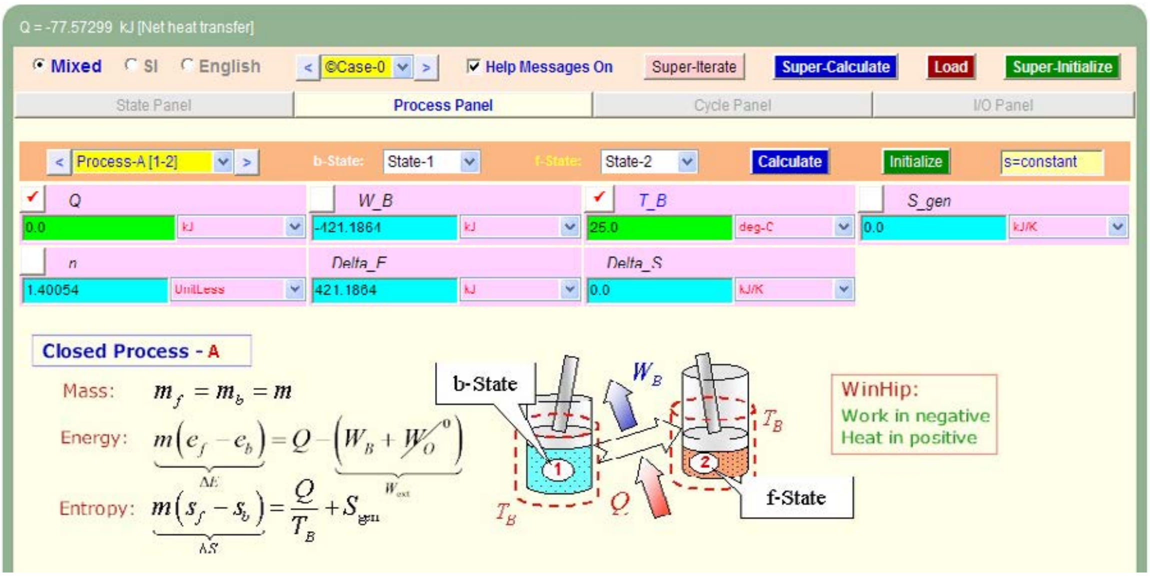
Note that T4 = 1176.44 K….Ans. And, s4 = 7.11408 kJ/kg.K.

9. Now, for State 5: Enter v5 = v1, s5 = s4, m5 = m1, and hit Enter. We get:



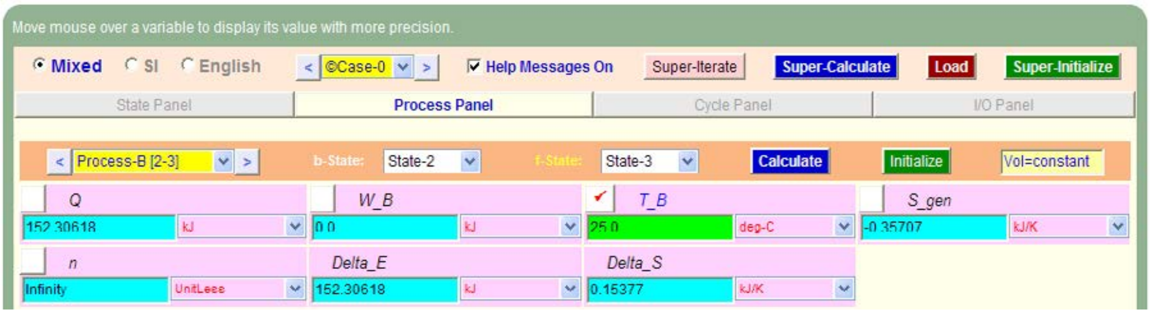
Note that T5 = 408.415 K … Ans.

10. Now, go to the Process Panel. For Process A (i.e. process 1-2), enter State 1 and State 2 for b-state and f-state respectively, and Q = 0 since process 1-2 is adiabatic. Hit Enter, and we get:

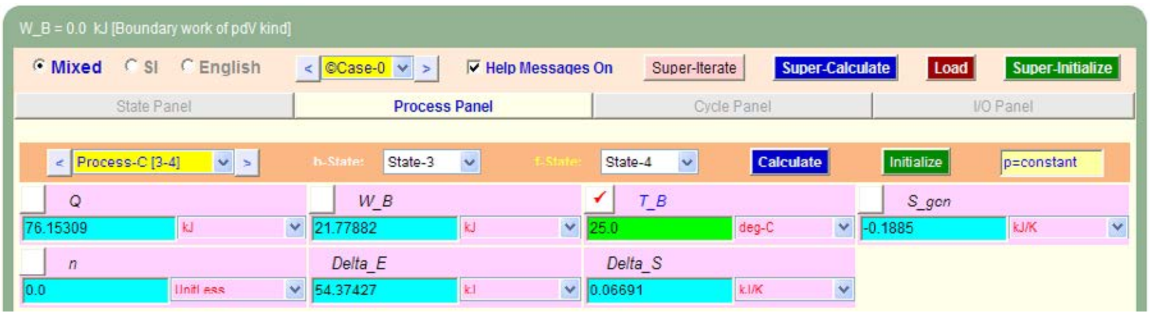


Note that the boundary work, W_B etc for this process are immediately calculated.

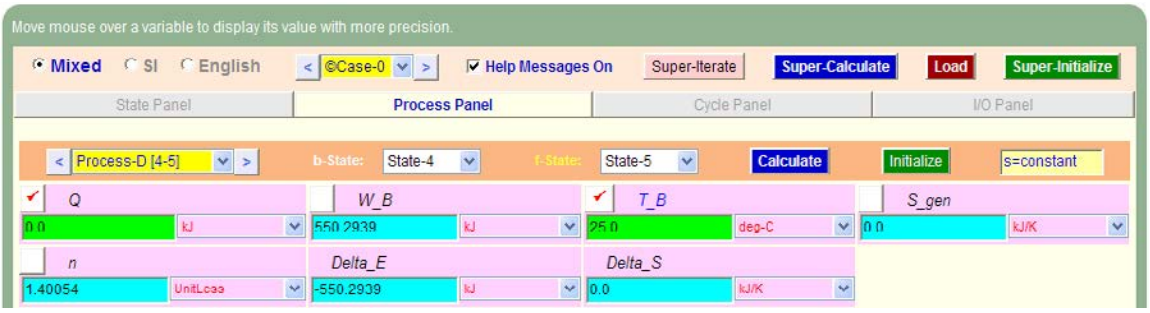
11. Similarly, for Process B (i.e. process 2-3): enter b-state and f-state, hit Enter:



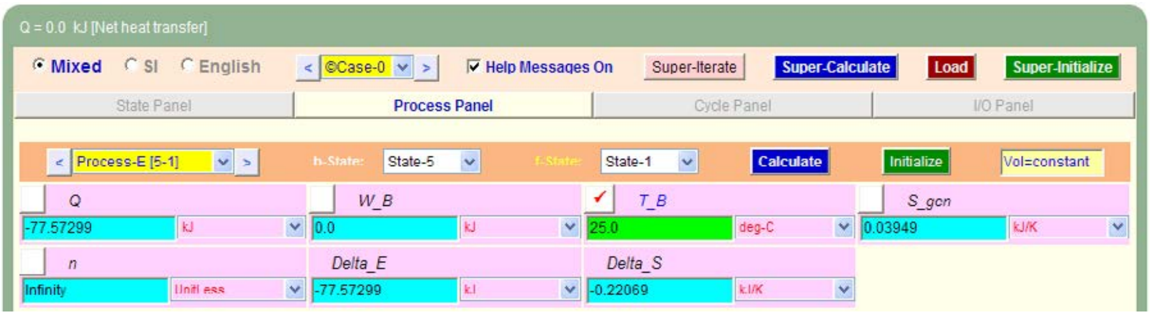
12. And, similarly for Process 3-4:



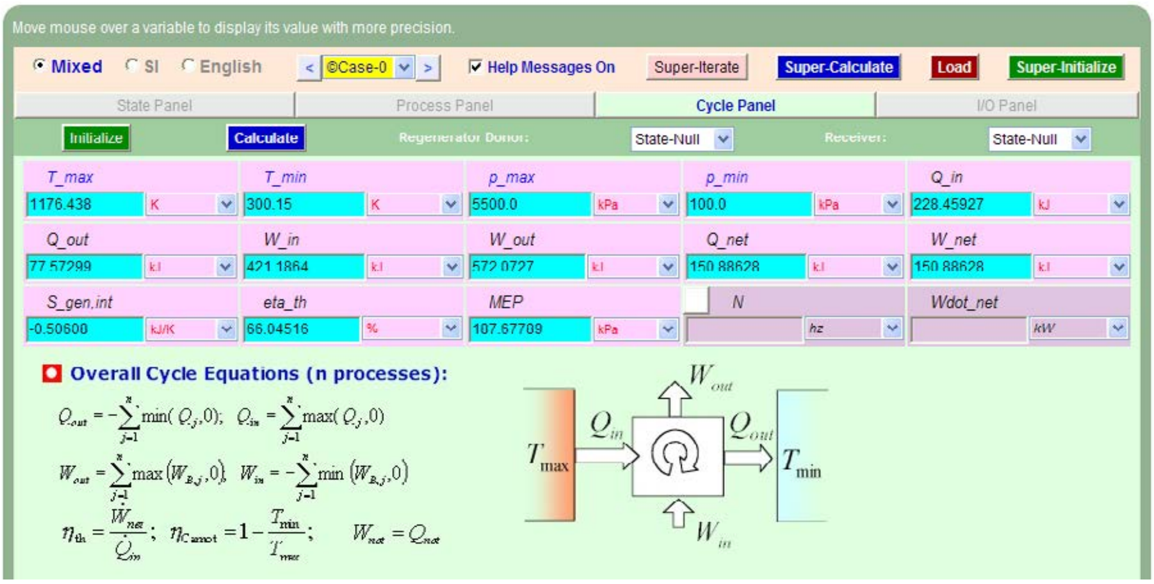
13. Again, for Process 4-5:



14. And, for Process 5-1:



15. Now, go to Cycle Panel, Click on Calculate and SuperCalculate. All calculations are available here:



Note that:

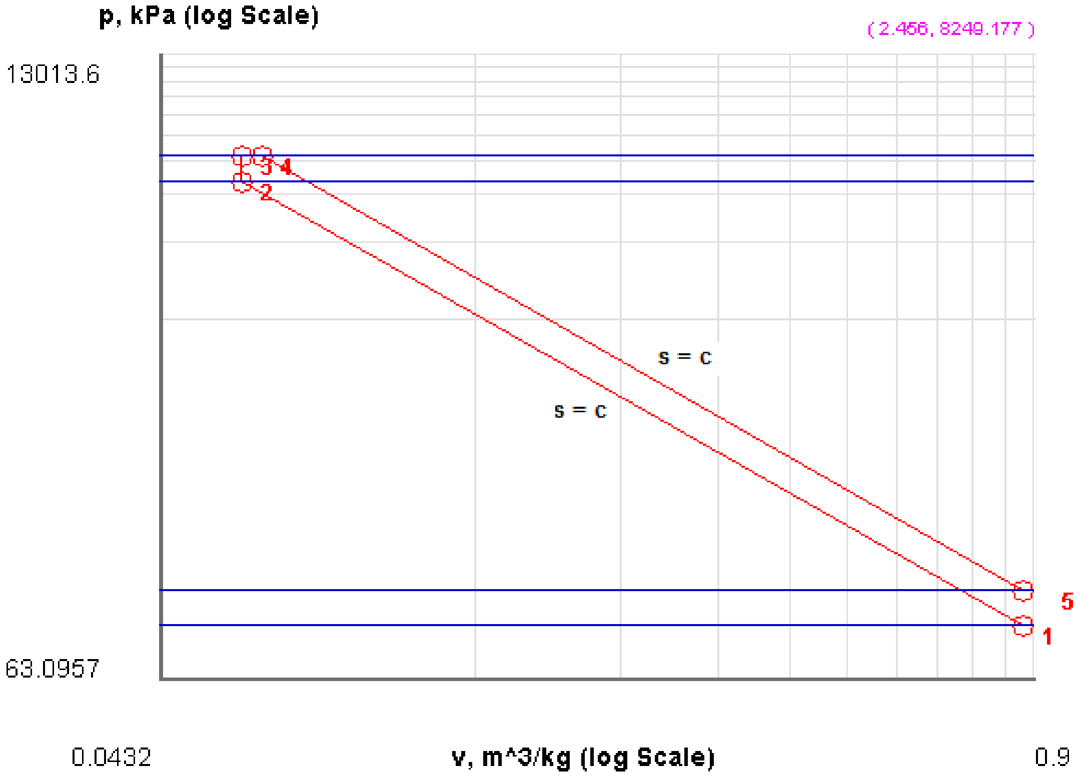
Air standard efficiency = eta_th = 66.05% …. Ans.

MEP = 187.68 kPa = 1.877 bar … Ans.

Cut off ratio = v4/v3 = 1.069…. Ans.

Explosion ratio = p3/p2 = 1.239… Ans.

16. Get the p-v plot from the Plots widget:



17. And get the TEST code etc from the I/O panel:

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

Daemon Path: Systems>Closed>Process>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; m1= 1.0 kg; }

State-2: Air;

Given: { v2= "v1/15"m^3/kg; s2= "s1"kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; m2= "m1"kg; }

State-3: Air;

Given: { p3= 5500.0 kPa; v3= "v2"m^3/kg; Vel3= 0.0 m/s; z3= 0.0 m; m3= "m1"kg; }

State-4: Air;

Given: { p4= "p3"kPa; h4= "h3+(u3-u2)/2"kJ/kg; Vel4= 0.0 m/s; z4= 0.0 m; m4= "m1"kg; }

State-5: Air;

Given: { v5= "v1"m^3/kg; s5= "s4"kJ/kg.K; Vel5= 0.0 m/s; z5= 0.0 m; m5= "m1"kg; }

}

```
Analysis {
        Process-A: b-State = State-1; f-State = State-2;
        Given: { Q= 0.0 kJ; T_B= 25.0 deg-C; }
        Process-B: b-State = State-2; f-State = State-3;
        Given: { T_B= 25.0 deg-C; }
        Process-C: b-State = State-3; f-State = State-4;
        Given: { T_B= 25.0 deg-C; }
        Process-D: b-State = State-4; f-State = State-5;
        Given: { Q= 0.0 kJ; T_B= 25.0 deg-C; }
        Process-E: b-State = State-5; f-State = State-1;
        Given: { 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       4437.69   888.0    0.0574      337.05     591.89     6.893
#       3       5500.0    1100.6   0.0574      489.36     805.2      7.047
#       4       5500.0    1176.4   0.0614      543.73     881.36     7.114
#       5       136.07    408.4    0.8614      -6.56      110.65     7.114
#--------Property spreadsheet ends-----------------------------------------------------------------
```

 # Mass, Energy, and Entropy Analysis Results:

```
#       Process-A: b-State = State-1; f-State = State-2;
#       Given: Q= 0.0 kJ; T_B= 25.0 deg-C;
#       Calculated: W_B= -421.1864 kJ; S_gen= -0.0 kJ/K; n= 1.4005353 UnitLess; Delta_E= 421.1864
kJ;
#       Delta_S= -0.0 kJ/K;
#       Process-B: b-State = State-2; f-State = State-3;
#       Given: T_B= 25.0 deg-C;
#       Calculated: Q= 152.30618 kJ; W_B= 0.0 kJ; S_gen= -0.3570654 kJ/K; n= Infinity UnitLess;
#       Delta_E= 152.30618 kJ; Delta_S= 0.15377201 kJ/K;
#       Process-C: b-State = State-3; f-State = State-4;
#       Given: T_B= 25.0 deg-C;
#       Calculated: Q= 76.15309 kJ; W_B= 21.778816 kJ; S_gen= -0.1885046 kJ/K; n= 0.0 UnitLess;
#       Delta_E= 54.37427 kJ; Delta_S= 0.066914104 kJ/K;
#       Process-D: b-State = State-4; f-State = State-5;
#       Given: Q= 0.0 kJ; T_B= 25.0 deg-C;
#       Calculated: W_B= 550.2939 kJ; S_gen= -0.0 kJ/K; n= 1.4005353 UnitLess; Delta_E= -550.2939
kJ;
#       Delta_S= -0.0 kJ/K;
```

\#   Process-E: b-State = State-5; f-State = State-1;
\#   Given: T_B= 25.0 deg-C;
\#   Calculated: Q= -77.57299 kJ; W_B= 0.0 kJ; S_gen= 0.03949498 kJ/K; n= Infinity UnitLess;
\#   Delta_E= -77.57299 kJ; Delta_S= -0.22068611 kJ/K;

 # Cycle Analysis Results:

\#   Calculated: T_max= 1176.438 K; T_min= 300.15 K; p_max= 5500.0 kPa;
\#   p_min= 100.0 kPa; Q_in= 228.45927 kJ; Q_out= 77.57299 kJ;
\#   W_in= 421.1864 kJ; W_out= 572.0727 kJ; Q_net= 150.88628 kJ;
\#   **W_net= 150.88628 kJ;** S_gen,int= -0.50608 kJ/K**; eta_th= 66.04516 %;**
\#   **MEP= 187.67789 kPa;**

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

#Cut off ratio:

=v4/v3

v4/v3 = 1.0689545558054636… Ans.

#Explosion ratio:

=p3/p2

p3/p2 = 1.2393824892196206….Ans.

(b) If the variation of sp. heat with temp is to be taken in to account:

In conventional calculations, we use Gas Tables for Ideal Gas properties of air. This table, shown below, [Ref: 3] tabulates enthalpy (h), internal energy (u), relative pressure (p_r), relative volume (v_r) etc. against T (K).

Important: *For an isentropic process 1-2,* we use the relations:

$$\frac{p_2}{p_1} = \frac{p_{r2}}{p_{r1}} \quad \text{and}$$

$$\frac{v2}{v1} = \frac{v_{r2}}{v_{r1}}$$

For, example, in the above problem, we have:

P1 = 1 bar, T1 = 300 K. … Then, from the Table, vr1 = 621.2

Process 1-2 is isentropic. And, since compression ratio is 15, v1/v2 = 15.

Therefore:

v1/v2 = vr1/vr2 = 15. So, vr2 = vr1/15 = 41.433

Now, interpolate from the Table to get T2 corresponding to vr2 = 41.433.

We get: T2 = 840 K approx.

TABLE A-22 Ideal Gas Properties of Air

T(K), h and u(kJ/kg), s° (kJ/kg · K)

				when $\Delta s = 0$[1]						when $\Delta s = 0$	
T	h	u	s°	p_r	v_r	T	h	u	s°	p_r	v_r
200	199.97	142.56	1.29559	0.3363	1707.	450	451.80	322.62	2.11161	5.775	223.6
210	209.97	149.69	1.34444	0.3987	1512.	460	462.02	329.97	2.13407	6.245	211.4
220	219.97	156.82	1.39105	0.4690	1346.	470	472.24	337.32	2.15604	6.742	200.1
230	230.02	164.00	1.43557	0.5477	1205.	480	482.49	344.70	2.17760	7.268	189.5
240	240.02	171.13	1.47824	0.6355	1084.	490	492.74	352.08	2.19876	7.824	179.7
250	250.05	178.28	1.51917	0.7329	979.	500	503.02	359.49	2.21952	8.411	170.6
260	260.09	185.45	1.55848	0.8405	887.8	510	513.32	366.92	2.23993	9.031	162.1
270	270.11	192.60	1.59634	0.9590	808.0	520	523.63	374.36	2.25997	9.684	154.1
280	280.13	199.75	1.63279	1.0889	738.0	530	533.98	381.84	2.27967	10.37	146.7
285	285.14	203.33	1.65055	1.1584	706.1	540	544.35	389.34	2.29906	11.10	139.7
290	290.16	206.91	1.66802	1.2311	676.1	550	554.74	396.86	2.31809	11.86	133.1
295	295.17	210.49	1.68515	1.3068	647.9	560	565.17	404.42	2.33685	12.66	127.0
300	300.19	214.07	1.70203	1.3860	621.2	570	575.59	411.97	2.35531	13.50	121.2
305	305.22	217.67	1.71865	1.4686	596.0	580	586.04	419.55	2.37348	14.38	115.7
310	310.24	221.25	1.73498	1.5546	572.3	590	596.52	427.15	2.39140	15.31	110.6
315	315.27	224.85	1.75106	1.6442	549.8	600	607.02	434.78	2.40902	16.28	105.8
320	320.29	228.42	1.76690	1.7375	528.6	610	617.53	442.42	2.42644	17.30	101.2
325	325.31	232.02	1.78249	1.8345	508.4	620	628.07	450.09	2.44356	18.36	96.92
330	330.34	235.61	1.79783	1.9352	489.4	630	638.63	457.78	2.46048	19.84	92.84
340	340.42	242.82	1.82790	2.149	454.1	640	649.22	465.50	2.47716	20.64	88.99
350	350.49	250.02	1.85708	2.379	422.2	650	659.84	473.25	2.49364	21.86	85.34
360	360.58	257.24	1.88543	2.626	393.4	660	670.47	481.01	2.50985	23.13	81.89
370	370.67	264.46	1.91313	2.892	367.2	670	681.14	488.81	2.52589	24.46	78.61
380	380.77	271.69	1.94001	3.176	343.4	680	691.82	496.62	2.54175	25.85	75.50
390	390.88	278.93	1.96633	3.481	321.5	690	702.52	504.45	2.55731	27.29	72.56
400	400.98	286.16	1.99194	3.806	301.6	700	713.27	512.33	2.57277	28.80	69.76
410	411.12	293.43	2.01699	4.153	283.3	710	724.04	520.23	2.58810	30.38	67.07
420	421.26	300.69	2.04142	4.522	266.6	720	734.82	528.14	2.60319	32.02	64.53
430	431.43	307.99	2.06533	4.915	251.1	730	745.62	536.07	2.61803	33.72	62.13
440	441.61	315.30	2.08870	5.332	236.8	740	756.44	544.02	2.63280	35.50	59.82

1. p_r and v_r data for use with Eqs. 6.43 and 6.44, respectively.

TABLE A-22 *(Continued)*

T(K), *h* and *u*(kJ/kg), s° (kJ/kg · K)

				when $\Delta s = 0^1$						when $\Delta s = 0$	
T	h	u	s°	p_r	v_r	T	h	u	s°	p_r	v_r
750	767.29	551.99	2.64737	37.35	57.63	1300	1395.97	1022.82	3.27345	330.9	11.275
760	778.18	560.01	2.66176	39.27	55.54	1320	1419.76	1040.88	3.29160	352.5	10.747
770	789.11	568.07	2.67595	41.31	53.39	1340	1443.60	1058.94	3.30959	375.3	10.247
780	800.03	576.12	2.69013	43.35	51.64	1360	1467.49	1077.10	3.32724	399.1	9.780
790	810.99	584.21	2.70400	45.55	49.86	1380	1491.44	1095.26	3.34474	424.2	9.337
800	821.95	592.30	2.71787	47.75	48.08	1400	1515.42	1113.52	3.36200	450.5	8.919
820	843.98	608.59	2.74504	52.59	44.84	1420	1539.44	1131.77	3.37901	478.0	8.526
840	866.08	624.95	2.77170	57.60	41.85	1440	1563.51	1150.13	3.39586	506.9	8.153
860	888.27	641.40	2.79783	63.09	39.12	1460	1587.63	1168.49	3.41247	537.1	7.801
880	910.56	657.95	2.82344	68.98	36.61	1480	1611.79	1186.95	3.42892	568.8	7.468
900	932.93	674.58	2.84856	75.29	34.31	1500	1635.97	1205.41	3.44516	601.9	7.152
920	955.38	691.28	2.87324	82.05	32.18	1520	1660.23	1223.87	3.46120	636.5	6.854
940	977.92	708.08	2.89748	89.28	30.22	1540	1684.51	1242.43	3.47712	672.8	6.569
960	1000.55	725.02	2.92128	97.00	28.40	1560	1708.82	1260.99	3.49276	710.5	6.301
980	1023.25	741.98	2.94468	105.2	26.73	1580	1733.17	1279.65	3.50829	750.0	6.046
1000	1046.04	758.94	2.96770	114.0	25.17	1600	1757.57	1298.30	3.52364	791.2	5.804
1020	1068.89	776.10	2.99034	123.4	23.72	1620	1782.00	1316.96	3.53879	834.1	5.574
1040	1091.85	793.36	3.01260	133.3	22.39	1640	1806.46	1335.72	3.55381	878.9	5.355
1060	1114.86	810.62	3.03449	143.9	21.14	1660	1830.96	1354.48	3.56867	925.6	5.147
1080	1137.89	827.88	3.05608	155.2	19.98	1680	1855.50	1373.24	3.58335	974.2	4.949
1100	1161.07	845.33	3.07732	167.1	18.896	1700	1880.1	1392.7	3.5979	1025	4.761
1120	1184.28	862.79	3.09825	179.7	17.886	1750	1941.6	1439.8	3.6336	1161	4.328
1140	1207.57	880.35	3.11883	193.1	16.946	1800	2003.3	1487.2	3.6684	1310	3.944
1160	1230.92	897.91	3.13916	207.2	16.064	1850	2065.3	1534.9	3.7023	1475	3.601
1180	1254.34	915.57	3.15916	222.2	15.241	1900	2127.4	1582.6	3.7354	1655	3.295
1200	1277.79	933.33	3.17888	238.0	14.470	1950	2189.7	1630.6	3.7677	1852	3.022
1220	1301.31	951.09	3.19834	254.7	13.747	2000	2252.1	1678.7	3.7994	2068	2.776
1240	1324.93	968.95	3.21751	272.3	13.069	2050	2314.6	1726.8	3.8303	2303	2.555
1260	1348.55	986.90	3.23638	290.8	12.435	2100	2377.4	1775.3	3.8605	2559	2.356
1280	1372.24	1004.76	3.25510	310.4	11.835	2150	2440.3	1823.8	3.8901	2837	2.175
						2200	2503.2	1872.4	3.9191	3138	2.012
						2250	2566.4	1921.3	3.9474	3464	1.864

Source: Tables A-22 are based on J. H. Keenan and J. Kaye, *Gas Tables*, Wiley, New York, 1945.

For given T get p_r and v_r from the Table.

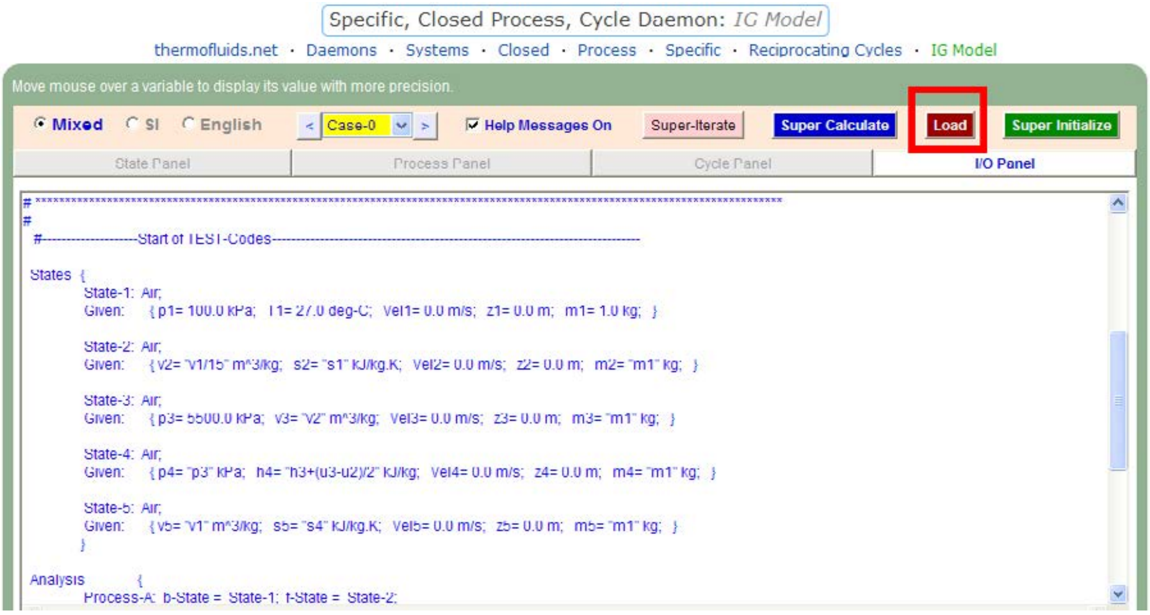
For given p_r or v_r, interpolate the value of T from the Table.

Obviously, referring to the Table, interpolating etc is tedious.

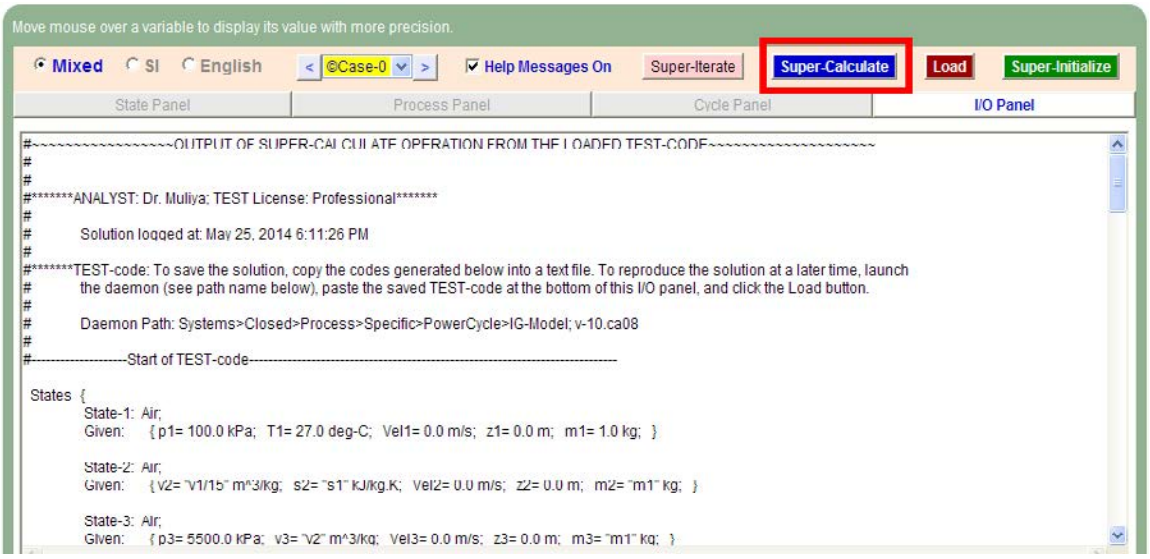
All this labor is avoided if we use TEST for calculations, as illustrated below:

If the variation of sp. heat with temp is to be taken in to account, it is done very easily in TEST:

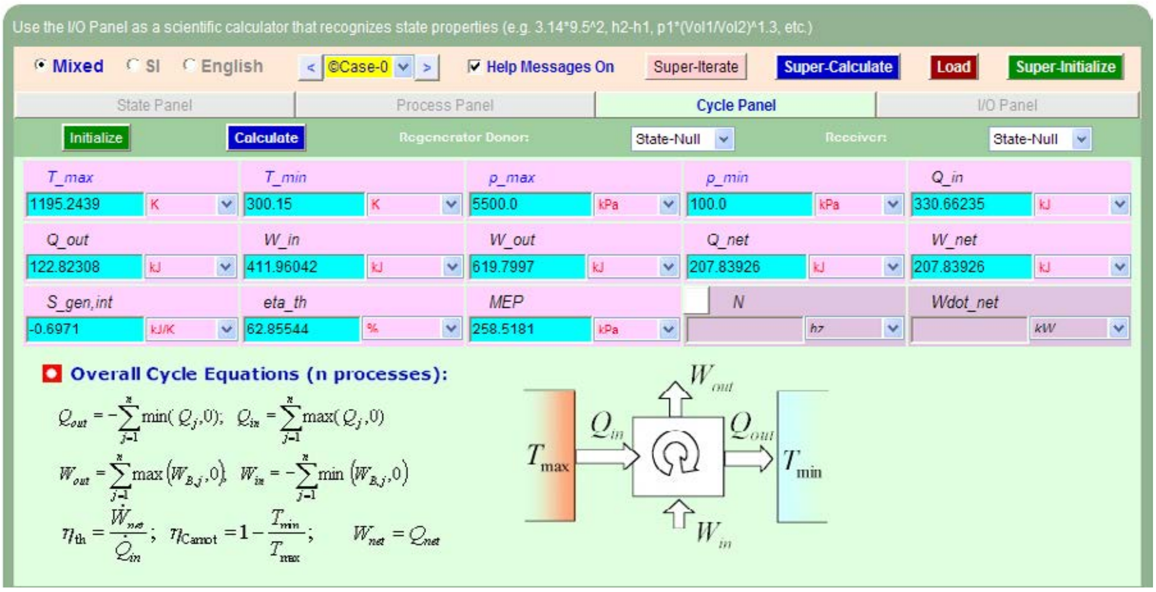
a) Just choose Ideal Gas (IG) model, instead of PG model. In IG model, variation of sp. heat with temp is taken in to account.
b) Select air as working substance, and copy the TEST code to the I/O panel
c) Click on Load to load this TEST code.



d) Now, click on SuperCalculate, and immediately, all calculations are up-dated.



e) Go to Cycle panel and see the results:



Thus:

Air standard efficiency = eta_th = 62.86% …. Ans.

MEP = 258.52 kPa = 2.585 bar … Ans.

Cut off ratio = v4/v3 = 1.086…. Ans.

Explosion ratio = p3/p2 = 1.312… Ans.

f) **TEST Code etc are gven below, briefly:**

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

Daemon Path: Systems>Closed>Process>Specific>PowerCycle>IG-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; m1= 1.0 kg; }

State-2: Air;

Given: { v2= "v1/15"m^3/kg; s2= "s1"kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; m2= "m1"kg; }

State-3: Air;

Given: { p3= 5500.0 kPa; v3= "v2"m^3/kg; Vel3= 0.0 m/s; z3= 0.0 m; m3= "m1"kg; }

State-4: Air;

```
        Given: { p4= “p3”kPa; h4= “h3+(u3-u2)/2”kJ/kg; Vel4= 0.0 m/s; z4= 0.0 m; m4= “m1”kg; }
        State-5: Air;
        Given: { v5= “v1”m^3/kg; s5= “s4”kJ/kg.K; Vel5= 0.0 m/s; z5= 0.0 m; m5= “m1”kg; }
        }
Analysis {
        Process-A: b-State = State-1; f-State = State-2;
        Given: { Q= 0.0 kJ; T_B= 25.0 deg-C; }
        Process-B: b-State = State-2; f-State = State-3;
        Given: { T_B= 25.0 deg-C; }
        Process-C: b-State = State-3; f-State = State-4;
        Given: { T_B= 25.0 deg-C; }
        Process-D: b-State = State-4; f-State = State-5;
        Given: { Q= 0.0 kJ; T_B= 25.0 deg-C; }
        Process-E: b-State = State-5; f-State = State-1;
        Given: { 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	-84.12	2.02	6.893
#	2	4193.16	839.1	0.0574	327.84	568.64	6.893
#	3	5500.0	1100.6	0.0574	548.29	864.13	7.122
#	4	5500.0	1195.2	0.0624	631.33	974.35	7.218
#	5	156.04	468.3	0.8614	38.71	173.12	7.218

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

 # Cycle Analysis Results:

\# Calculated: T_max= 1195.2439 K; T_min= 300.15 K; p_max= 5500.0 kPa;

\# p_min= 100.0 kPa; Q_in= 330.66235 kJ; Q_out= 122.82308 kJ;

\# W_in= 411.96042 kJ; W_out= 619.7997 kJ; Q_net= 207.83926 kJ;

\# **W_net= 207.83926 kJ;** S_gen,int= -0.6971 kJ/K; **eta_th= 62.85544 %;**

\# **MEP= 258.5181 kPa**;

\#

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

#Cut off ratio:

v4/v3 = 1.0860422812893336 …. Ans.

#Explosion ratio:

p3/p2 = 1.3116600154084803.., Ans.

===

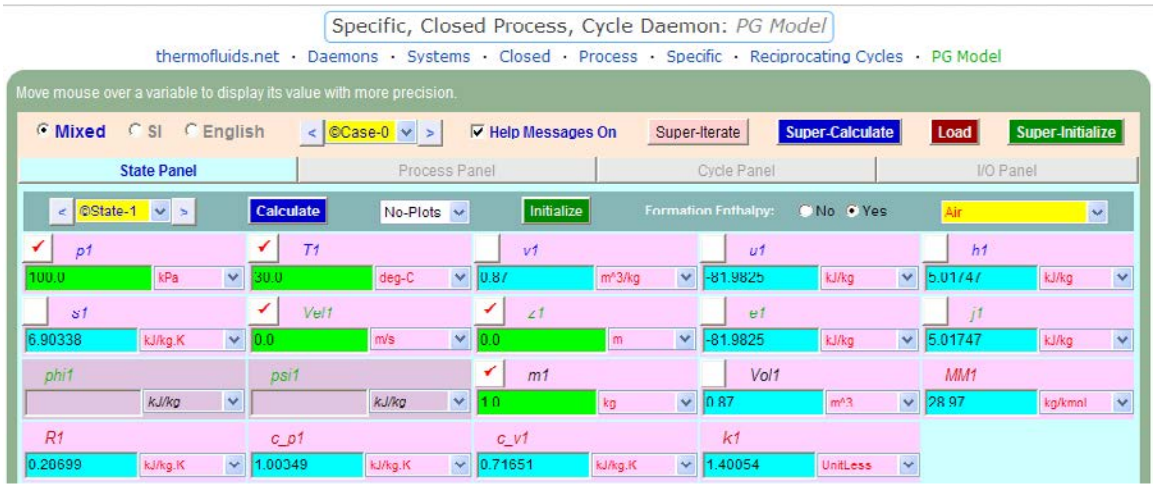
Prob.1.46. An engine working on Dual combustion cycle takes in air at 1 bar and 30 C. The clearance is 6% of the stroke and cut off takes place at 10% of the stroke. The max. pressure in the cycle is limited to 70 bar. Find: (i) the temperatures and pressures at salient points, and (ii) air standard efficiency. [VTU]

TEST Solution:

Following are the steps:

Steps 1 to 4 are the same as for Problem 1.32, using PG model.

5. Select Air as the working substance and fill in data for p1= 100 kPa, T1= 30 C, and m1= 1 kg for State 1, i.e. at beginning of compression, and hit Enter. We get:



Note that properties for State 1 are calculated.

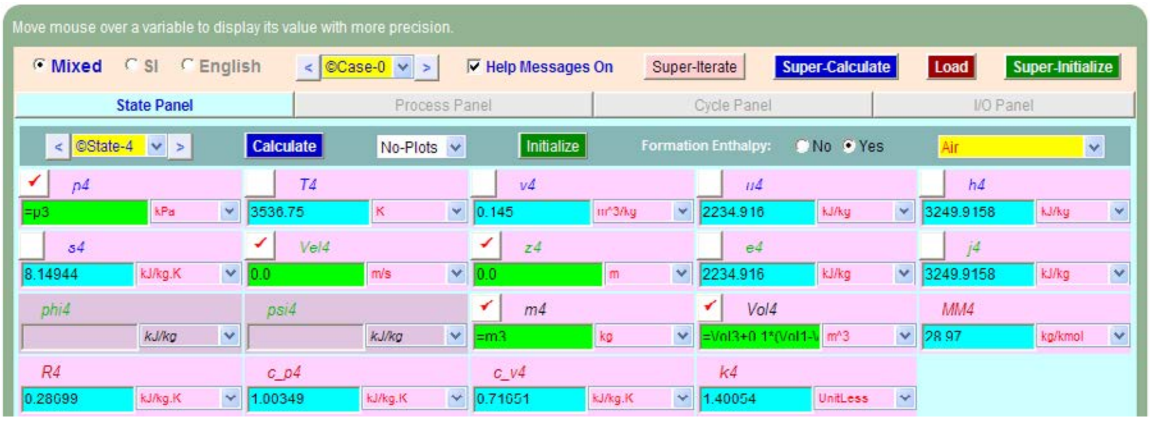
6. For State 2: Enter Vol2 = 0.08 * (Vol1 – Vol2) i.e. Vol2 = 0.08 * Vol1 / 1.08, s2 = s1 (since Process 1-2 is isentropic) and m2 = m1. Hit Enter:

Here, p2 = 3828.89 kPa, T2 = 859.8 K ….Ans.

7. Similarly, for State 3: Enter p3 = 7000 kPa, Vol3 = Vol2, and m3 = m2. Hit Enter, and we get:

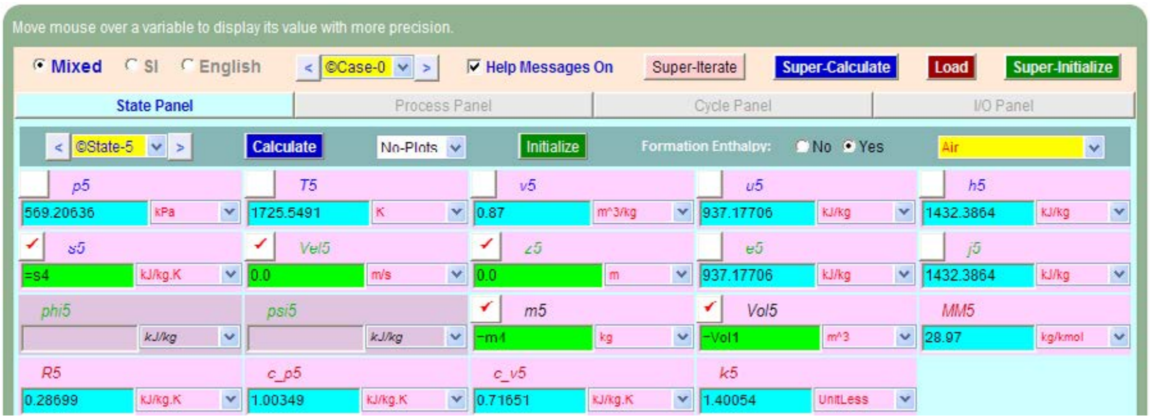
Note that T3 = 1571.89 K … Ans.

8. Now, for State 4: enter p4 = p3, m4 = m3, and (Vol4 –Vol3) = 0.1 * (Vol1 – Vol2), i.e. Vol4 = Vol3 + 0.1 * (Vol1 – Vol2) since cut off occurs at 10% of stroke. Hit Enter. We get:



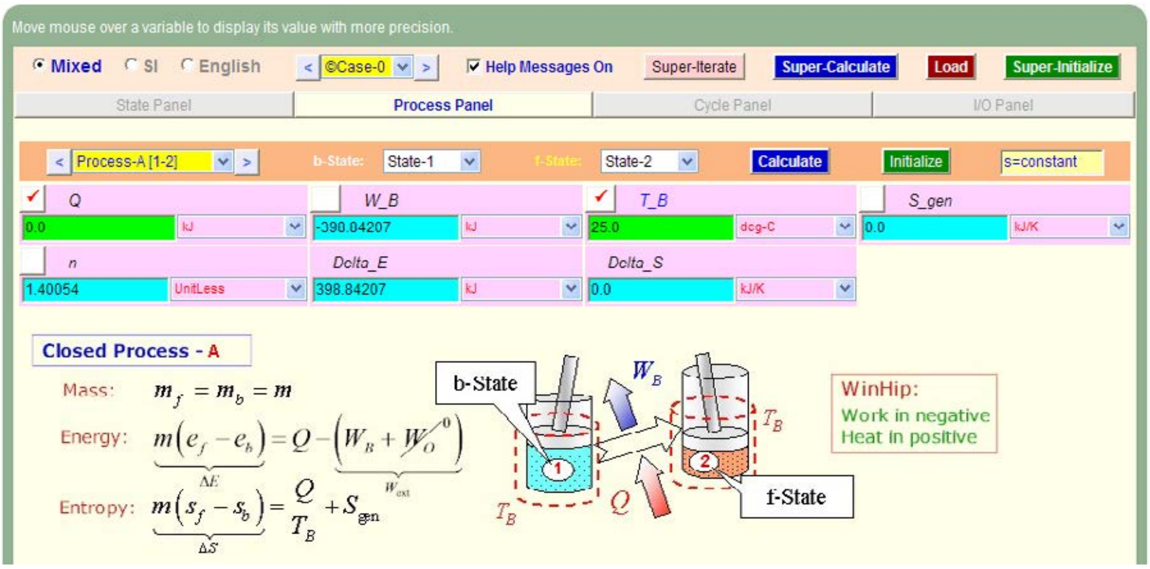
Note that T4 = 3536.75 K….Ans. And, s4 = 7.11408 kJ/kg.K.

9. Now, for State 5: Enter Vol5 = Vol1, s5 = s4, m5 = m4, and hit Enter. We get:



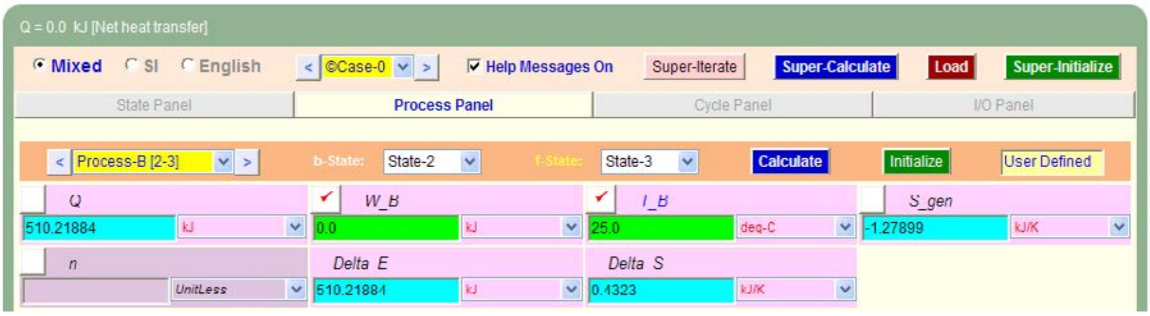
Note that p5 = 569.21 kPa, T5 = 1725.55 K … Ans.

10. Now, go to the Process Panel. For Process A (i.e. process 1-2), enter State 1 and State 2 for b-state and f-state respectively, and Q = 0 since process 1-2 is adiabatic. Hit Enter, and we get:

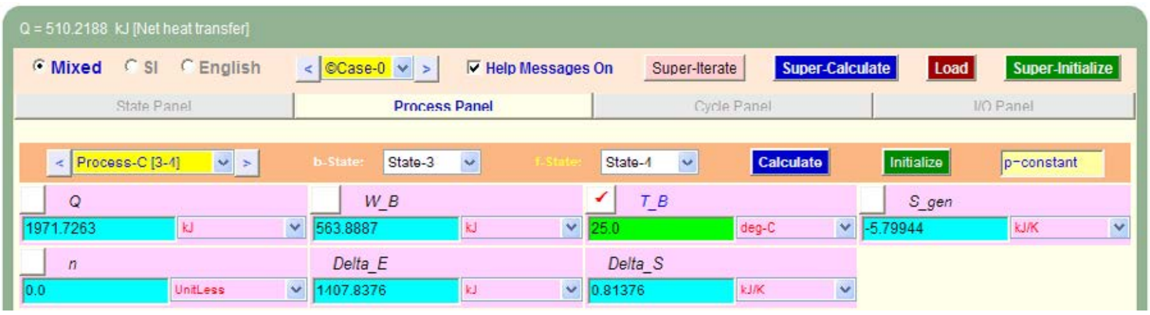


Note that the boundary work, W_B etc for this process are immediately calculated.

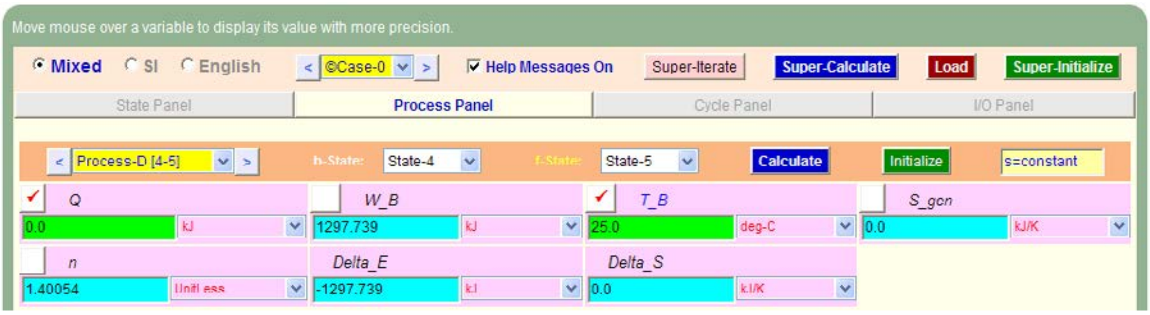
11. Similarly, for Process B (i.e. process 2-3): enter b-state and f-state, hit Enter:



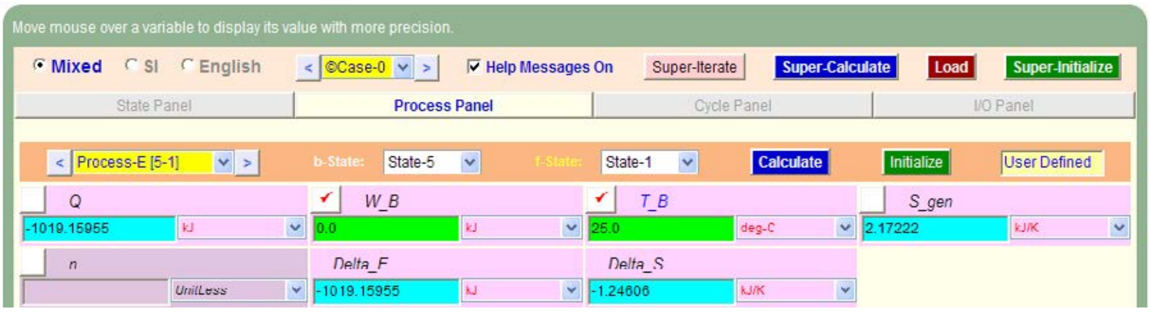
12. And, similarly for Process 3-4:



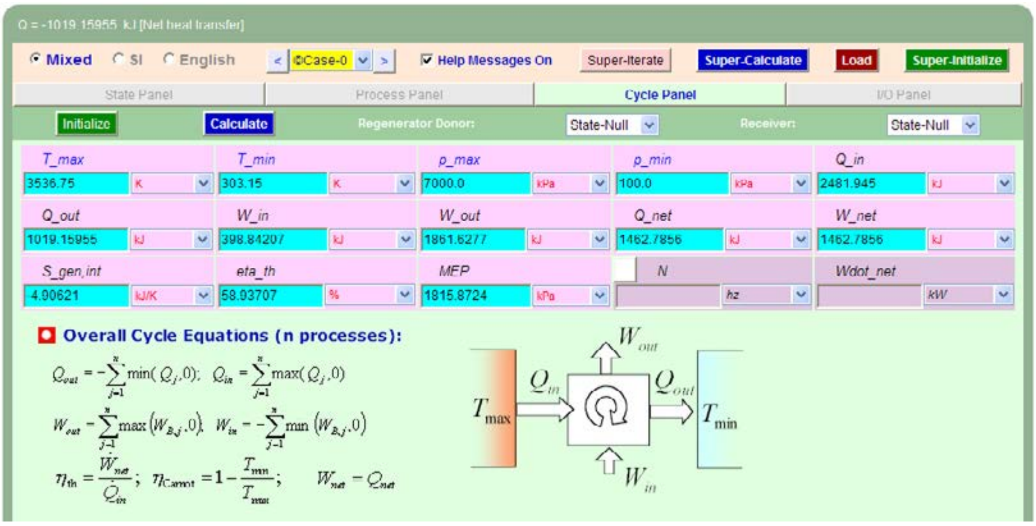
13. Again, for Process 4-5:



14. And, for Process 5-1:



15. Now, go to Cycle Panel, Click on Calculate and SuperCalculate. All calculations are available here:

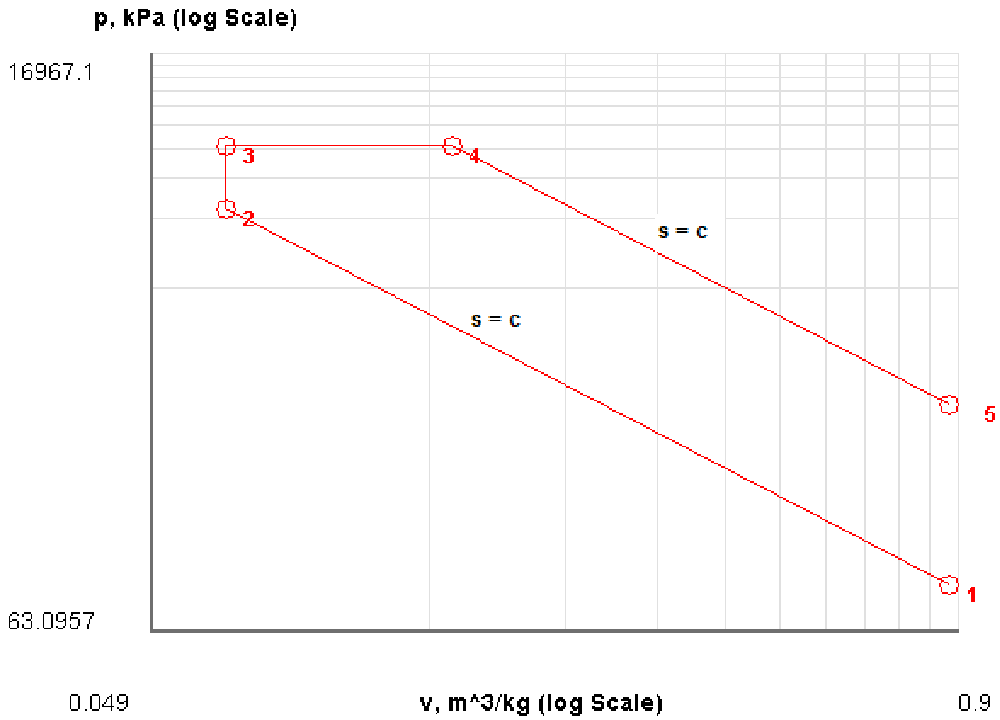


Note that:

Air standard efficiency = eta_th = 58.94% …. Ans.

MEP = 1815.87 kPa = 18.16 bar … Ans.

16. Get the p-v plot from the Plots widget:



17. And get the TEST code etc from the I/O panel:

```
#~~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE
#     Daemon Path: Systems>Closed>Process>Specific>PowerCycle>PG-Model; v-10.ca08
#-------------------Start of TEST-code -----------------------------------------------------------------------
States    {
          State-1: Air;
          Given: { p1= 100.0 kPa; T1= 30.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; m1= 1.0 kg; }
          State-2: Air;
          Given: { s2= "s1"kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; m2= "m1"kg; Vol2= "0.08*Vol1/1.08"m^3;
}
          State-3: Air;
          Given: { p3= 7000.0 kPa; Vel3= 0.0 m/s; z3= 0.0 m; m3= "m2"kg; Vol3= "Vol2"m^3; }
          State-4: Air;
          Given: { p4= "p3"kPa; Vel4= 0.0 m/s; z4= 0.0 m; m4= "m3"kg; Vol4= "Vol3+0.1*(Vol1-Vol3)"m^3;
}
          State-5: Air;
          Given: { s5= "s4"kJ/kg.K; Vel5= 0.0 m/s; z5= 0.0 m; m5= "m4"kg; Vol5= "Vol1"m^3; }
          }
Analysis {
          Process-A: b-State = State-1; f-State = State-2;
          Given: { Q= 0.0 kJ; T_B= 25.0 deg-C; }
          Process-B: b-State = State-2; f-State = State-3;
          Given: { W_B= 0.0 kJ; T_B= 25.0 deg-C; }
          Process-C: b-State = State-3; f-State = State-4;
          Given: { T_B= 25.0 deg-C; }
          Process-D: b-State = State-4; f-State = State-5;
          Given: { Q= 0.0 kJ; T_B= 25.0 deg-C; }
          Process-E: b-State = State-5; f-State = State-1;
          Given: { W_B= 0.0 kJ; 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     303.2    0.87        -81.98     5.02       6.903
#     2       3828.89   859.8    0.0644      316.86     563.61     6.903
#     3       7000.0    1571.9   0.0644      827.08     1278.19    7.336
#     4       7000.0    3536.8   0.145       2234.92    3249.92    8.149
#     5       569.21    1725.5   0.87        937.18     1432.39    8.149
#--------Property spreadsheet ends-----------------------------------------------------------------
```

 # Mass, Energy, and Entropy Analysis Results:

Process-A: b-State = State-1; f-State = State-2;

Given: Q= 0.0 kJ; T_B= 25.0 deg-C;

Calculated: W_B= -398.84207 kJ; S_gen= -0.0 kJ/K; n= 1.4005353 UnitLess; Delta_E= 398.84207 kJ;

Delta_S= -0.0 kJ/K;

Process-B: b-State = State-2; f-State = State-3;

Given: W_B= 0.0 kJ; T_B= 25.0 deg-C;

Calculated: Q= 510.2188 kJ; S_gen= -1.2789873 kJ/K; Delta_E= 510.2188 kJ; Delta_S= 0.43229505 kJ/K;

Process-C: b-State = State-3; f-State = State-4;

Given: T_B= 25.0 deg-C;

Calculated: Q= 1971.7263 kJ; W_B= 563.8887 kJ; S_gen= -5.799439 kJ/K; n= 0.0 UnitLess;

Delta_E= 1407.8376 kJ; Delta_S= 0.8137636 kJ/K;

Process-D: b-State = State-4; f-State = State-5;

Given: Q= 0.0 kJ; T_B= 25.0 deg-C;

Calculated: W_B= 1297.739 kJ; S_gen= -0.0 kJ/K; n= 1.4005353 UnitLess; Delta_E= -1297.739 kJ;

Delta_S= -0.0 kJ/K;

Process-E: b-State = State-5; f-State = State-1;

Given: W_B= 0.0 kJ; T_B= 25.0 deg-C;

Calculated: Q= -1019.15955 kJ; S_gen= 2.1722193 kJ/K; Delta_E= -1019.15955 kJ; Delta_S= -1.2460587 kJ/K;

 # Cycle Analysis Results:

Calculated: T_max= 3536.75 K; T_min= 303.15 K; p_max= 7000.0 kPa;

p_min= 100.0 kPa; Q_in= 2481.945 kJ; Q_out= 1019.15955 kJ;

W_in= 398.84207 kJ; W_out= 1861.6277 kJ; Q_net= 1462.7856 kJ;

W_net= 1462.7856 kJ; S_gen,int= -4.90621 kJ/K; **eta_th= 58.93707 %;**

MEP= 1815.8724 kPa;

==

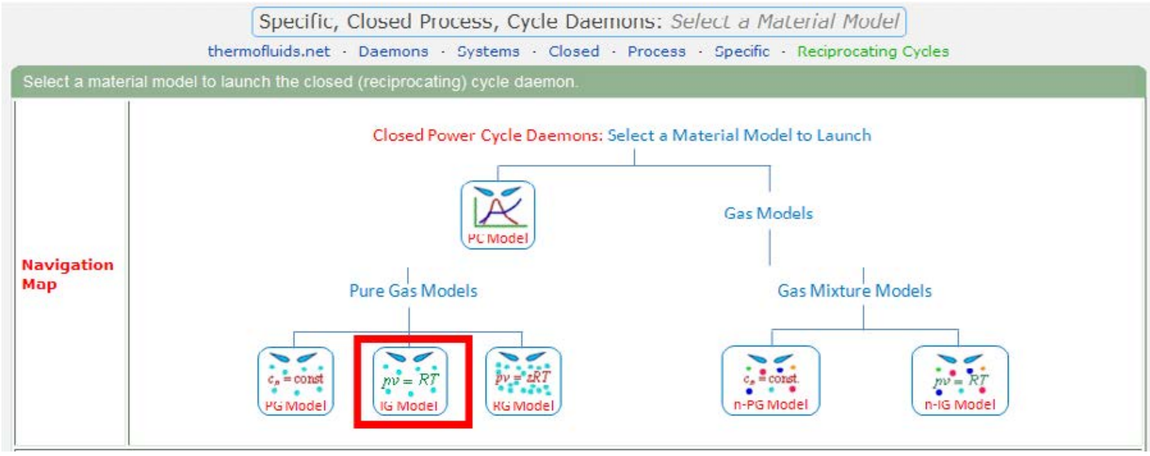
Prob.1.47. An air standard Dual cycle uses 1 kg of air and has a compression ratio of 14. The P and T at the beginning of the adiabatic compression are 1 bar and 30 C respectively. The temp at the end of constant volume and constant pressure heat addition are 1200 C and 1500 C respectively. Taking into account the variation of sp. heat with temp, calculate: (i) heat supplied, (ii) heat rejected, (iii) net work done, and (iv) air standard efficiency.

TEST Solution:

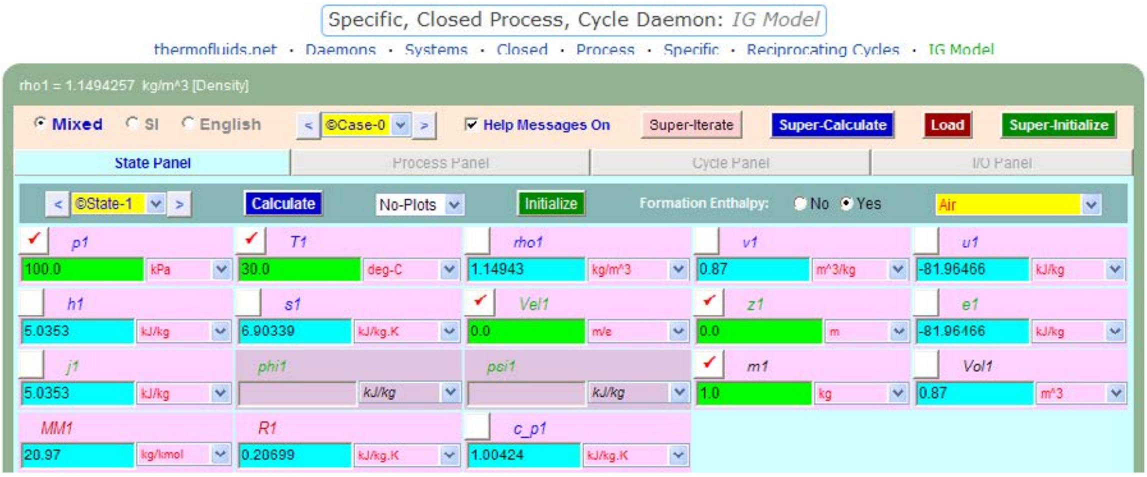
Following are the steps:

Steps 1 to 3 are the same as for Problem 1.32.

4. For Materials model choose IG model, where cp is dependent on temp:

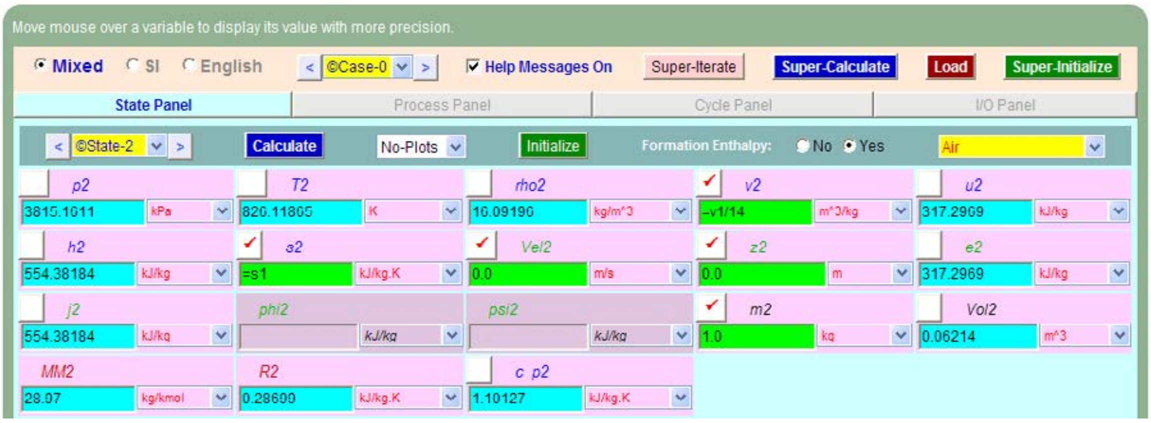


5. Select Air as the working substance and fill in data for p1= 100 kPa, T1= 30 C, and m1= 1 kg for State 1, i.e. at beginning of compression, and hit Enter. We get:



Note that properties for State 1 are calculated.

6. For State 2: Enter v2 = v1/14 (since comprn. ratio is 14), s2 = s1 (since Process 1-2 is isentropic) and m2 = 1 kg. Hit Enter:

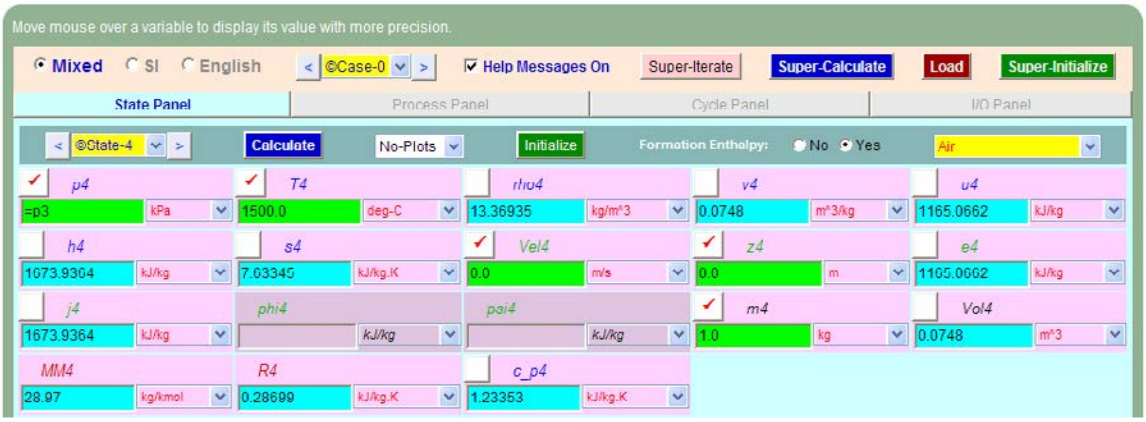


Here, p2 = 3815.16 kPa, T2 = 826.12 K ….Ans.

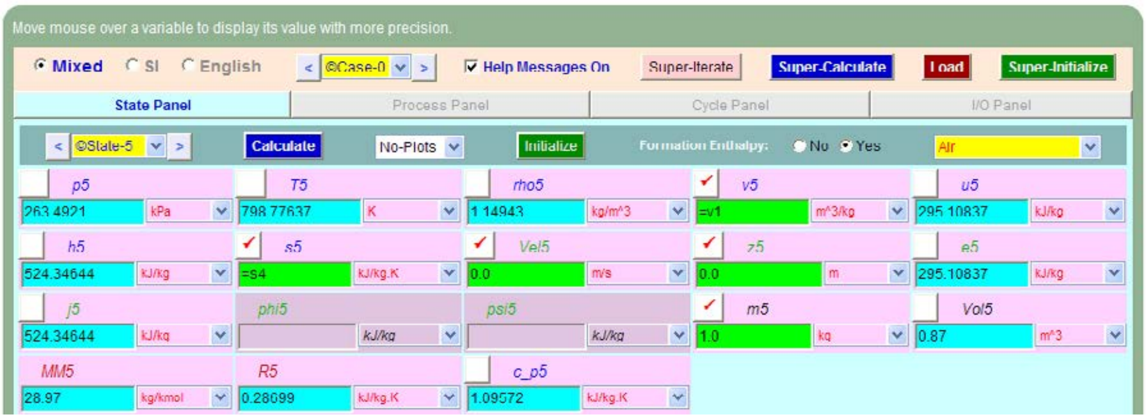
7. Similarly, for State 3: Enter T3 = 1200 C, v3 = v2, and m3 = 1 kg. Hit Enter, and we get:

Note that p3 = 6803.27 kPa … Ans.

8. Now, for State 4: enter p4 = p3, m4 = 1 kg, and T4 = 1500 C , and hit Enter. We get:

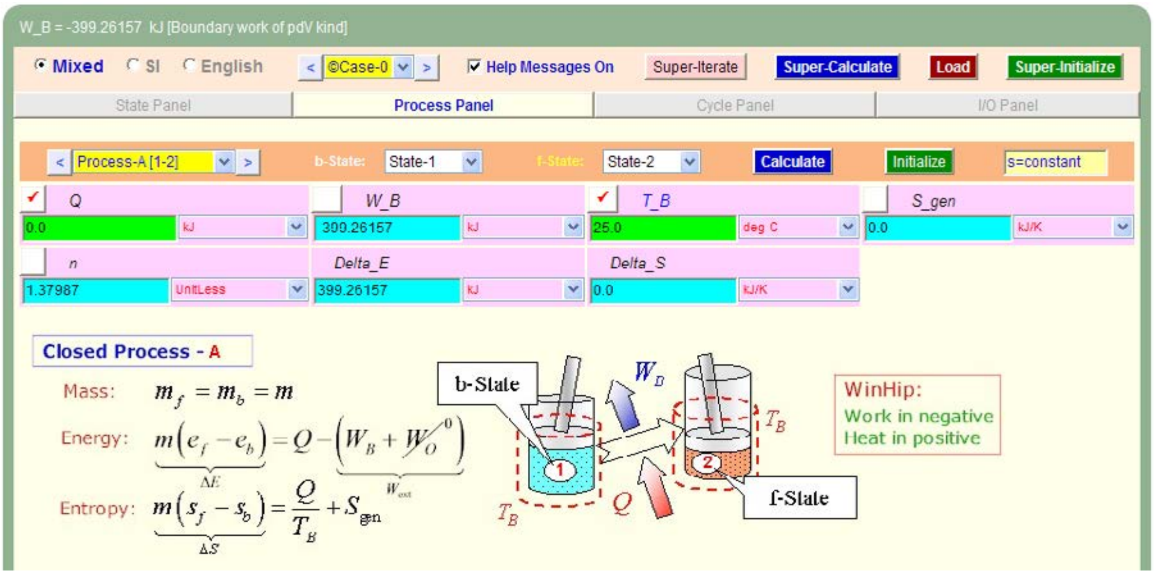


9. Now, for State 5: Enter v5 = v1, s5 = s4, m5 = 1 kg, and hit Enter. We get:



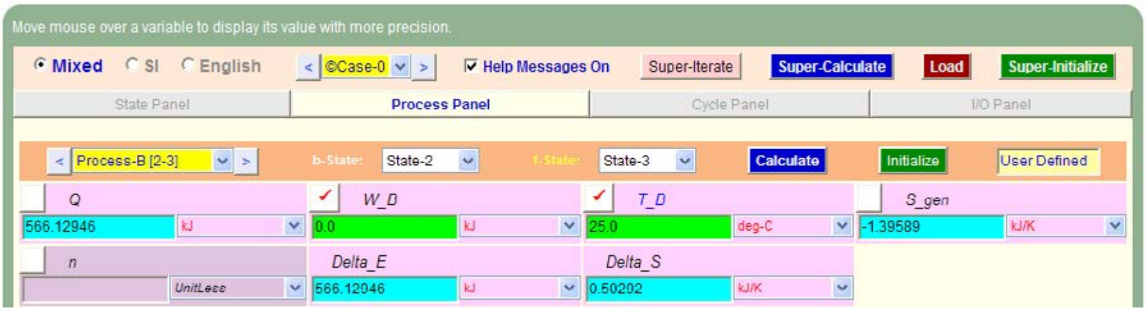
Note that p5 = 283.49 kPa, T5 = 798.78 K … Ans.

10. Now, go to the Process Panel. For Process A (i.e. process 1-2), enter State 1 and State 2 for b-state and f-state respectively, and Q = 0 since process 1-2 is adiabatic. Hit Enter, and we get:

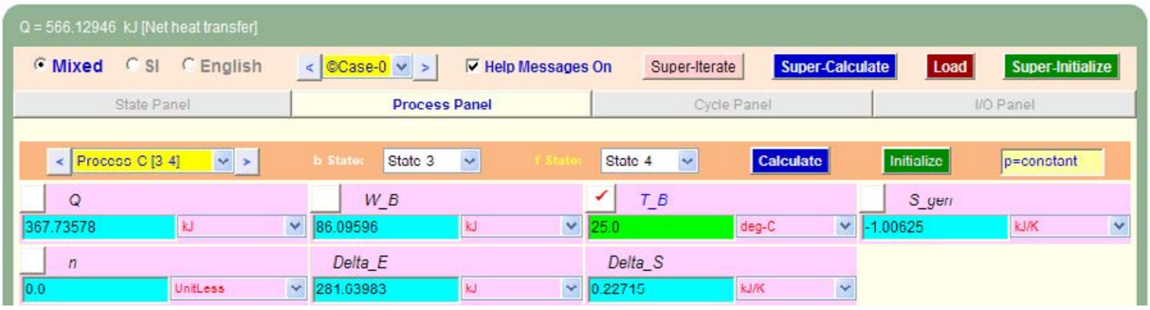


Note that the boundary work, W_B etc for this process are immediately calculated.

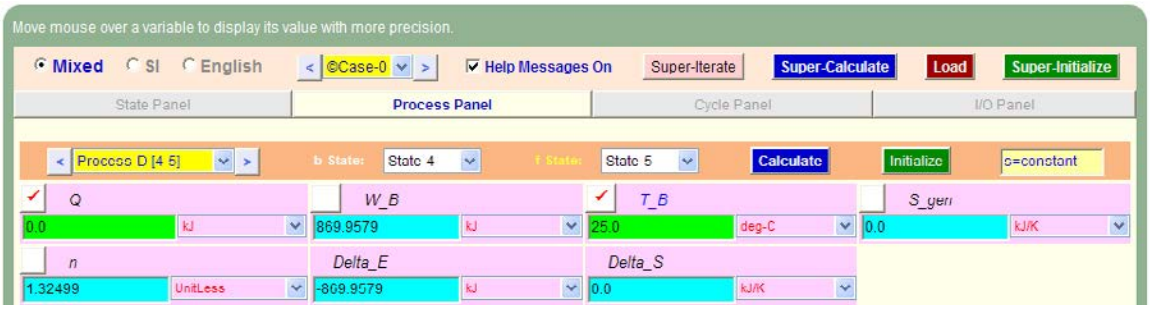
11. Similarly, for Process B (i.e. process 2-3): enter b-state and f-state, hit Enter:



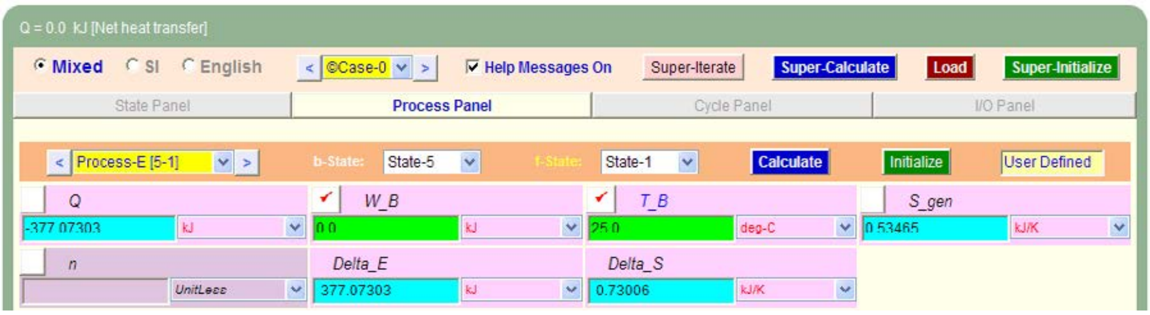
12. And, similarly for Process 3-4:



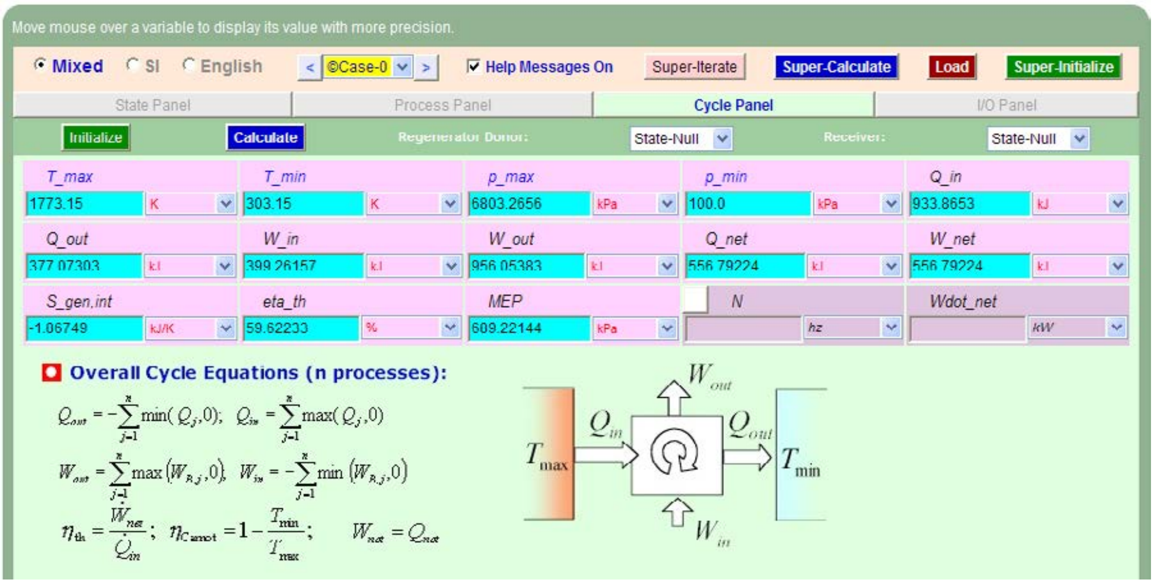
13. Again, for Process 4-5:



14. And, for Process 5-1:



15. Now, go to Cycle Panel, Click on Calculate and SuperCalculate. All calculations are available here:



Note that:

Heat supplied = Q_in = 933.87 kJ … Ans.

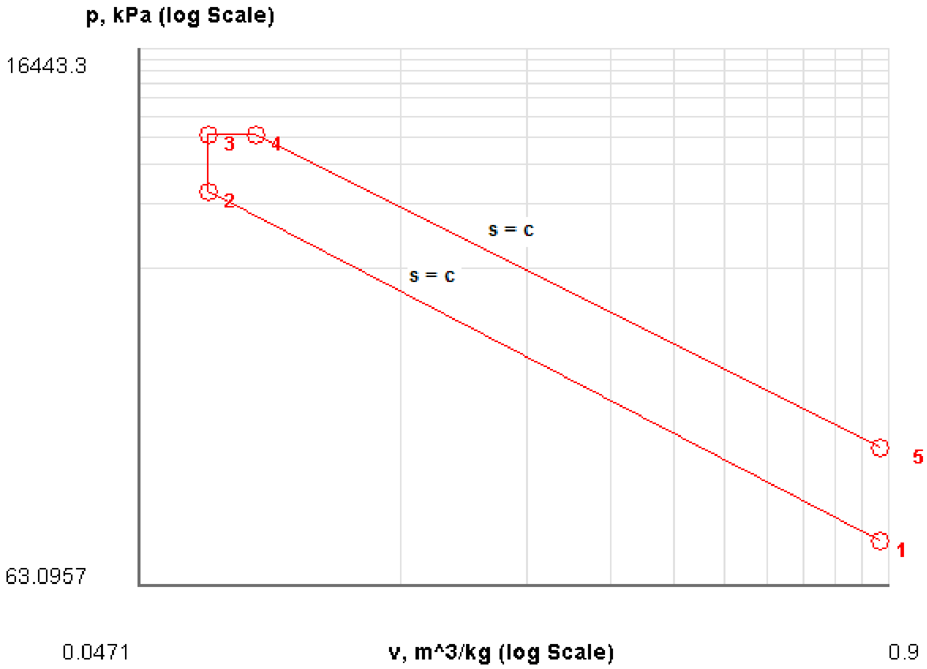
Heat rejected = Q_out = 377.07 kJ …. Ans.

Net work done = W_net = 556.70 kJ …. Ans.

Air standard efficiency = eta_th = 59.62% …. Ans.

MEP = 689.22 kPa = 6.892 bar … Ans.

16. Get the p-v plot from the Plots widget:



17. Get the TEST code etc from the I/O panel:

```
#~~~~~~~~~~~~~~~~~~~~~OUTPUT OF SUPER-CALCULATE
#        Daemon Path: Systems>Closed>Process>Specific>PowerCycle>IG-Model; v-10.ca08
#-------------------Start of TEST-code -----------------------------------------------------------------------
States   {
         State-1: Air;
         Given: { p1= 100.0 kPa; T1= 30.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; m1= 1.0 kg; }
         State-2: Air;
         Given: { v2= "v1/14"m^3/kg; s2= "s1"kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; m2= 1.0 kg; }
         State-3: Air;
         Given: { T3= 1200.0 deg-C; v3= "v2"m^3/kg; Vel3= 0.0 m/s; z3= 0.0 m; m3= 1.0 kg; }
         State-4: Air;
         Given: { p4= "p3"kPa; T4= 1500.0 deg-C; Vel4= 0.0 m/s; z4= 0.0 m; m4= 1.0 kg; }
         State-5: Air;
         Given: { v5= "v1"m^3/kg; s5= "s4"kJ/kg.K; Vel5= 0.0 m/s; z5= 0.0 m; m5= 1.0 kg; }
         }
Analysis {
         Process-A: b-State = State-1; f-State = State-2;
         Given: { Q= 0.0 kJ; T_B= 25.0 deg-C; }
         Process-B: b-State = State-2; f-State = State-3;
         Given: { W_B= 0.0 kJ; T_B= 25.0 deg-C; }
         Process-C: b-State = State-3; f-State = State-4;
         Given: { T_B= 25.0 deg-C; }
         Process-D: b-State = State-4; f-State = State-5;
         Given: { Q= 0.0 kJ; T_B= 25.0 deg-C; }
         Process-E: b-State = State-5; f-State = State-1;
         Given: { W_B= 0.0 kJ; 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     303.2    0.87       -81.96     5.04       6.903
#        2       3815.16   826.1    0.0621     317.3      554.38     6.903
#        3       6803.27   1473.2   0.0621     883.43     1306.2     7.406
#        4       6803.27   1773.2   0.0748     1165.07    1673.94    7.633
#        5       263.49    798.8    0.87       295.11     524.35     7.633
#--------Property spreadsheet ends----------------------------------------------------------------
```

 # Mass, Energy, and Entropy Analysis Results:

Process-A: b-State = State-1; f-State = State-2;

Given: Q= 0.0 kJ; T_B= 25.0 deg-C;

Calculated: W_B= -399.26157 kJ; S_gen= -0.0 kJ/K; n= 1.3798746 UnitLess; Delta_E= 399.26157 kJ;

Delta_S= -0.0 kJ/K;

Process-B: b-State = State-2; f-State = State-3;

Given: W_B= 0.0 kJ; T_B= 25.0 deg-C;

Calculated: Q= 566.12946 kJ; S_gen= -1.3958921 kJ/K; Delta_E= 566.12946 kJ; Delta_S= 0.5029155 kJ/K;

Process-C: b-State = State-3; f-State = State-4;

Given: T_B= 25.0 deg-C;

Calculated: Q= 367.73578 kJ; W_B= 86.09596 kJ; S_gen= -1.0062462 kJ/K; n= 0.0 UnitLess;

Delta_E= 281.63983 kJ; Delta_S= 0.22714564 kJ/K;

Process-D: b-State = State-4; f-State = State-5;

Given: Q= 0.0 kJ; T_B= 25.0 deg-C;

Calculated: W_B= 869.9579 kJ; S_gen= -0.0 kJ/K; n= 1.3249912 UnitLess; Delta_E= -869.9579 kJ;

Delta_S= -0.0 kJ/K;

Process-E: b-State = State-5; f-State = State-1;

Given: W_B= 0.0 kJ; T_B= 25.0 deg-C;

Calculated: Q= -377.07303 kJ; S_gen= 0.534648 kJ/K; Delta_E= -377.07303 kJ; Delta_S= -0.7300611 kJ/K;

 # Cycle Analysis Results:

Calculated: T_max= 1773.15 K; T_min= 303.15 K; p_max= 6803.2656 kPa;

p_min= 100.0 kPa; Q_in= 933.8653 kJ; Q_out= 377.07303 kJ;

W_in= 399.26157 kJ; W_out= 956.05383 kJ; Q_net= 556.79224 kJ;

W_net= 556.79224 kJ; S_gen,int= -1.86749 kJ/K; **eta_th= 59.62233 %;**

MEP= 689.22144 kPa;

==

1.5 Problems on Stirling cycle:

1.5.1 Problem solved with TEST:

Prob. 1.48. Following data refers to an ideal Stirling cycle with ideal regenerator. P, T and V of the working medium at the beginning of isothermal compression are 100 kPa, 30 C and 0.05 m^3 respectively. The clearance volume is 1/10 of the initial volume. The max. temp attained in the cycle is 700 C. Draw the p-v and T-s diagrams. Calculate: (i) net work, (ii) thermal efficiency with 100% regenerator efficiency, and (iv) thermal efficiency without the regenerator. [VTU]

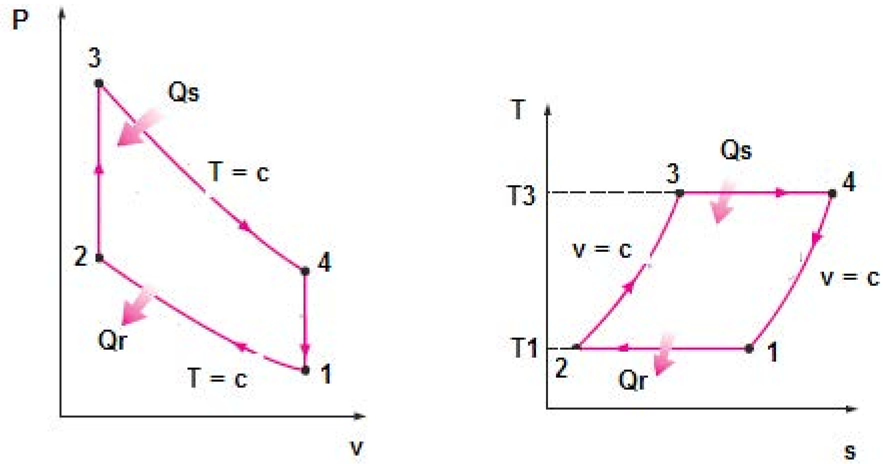


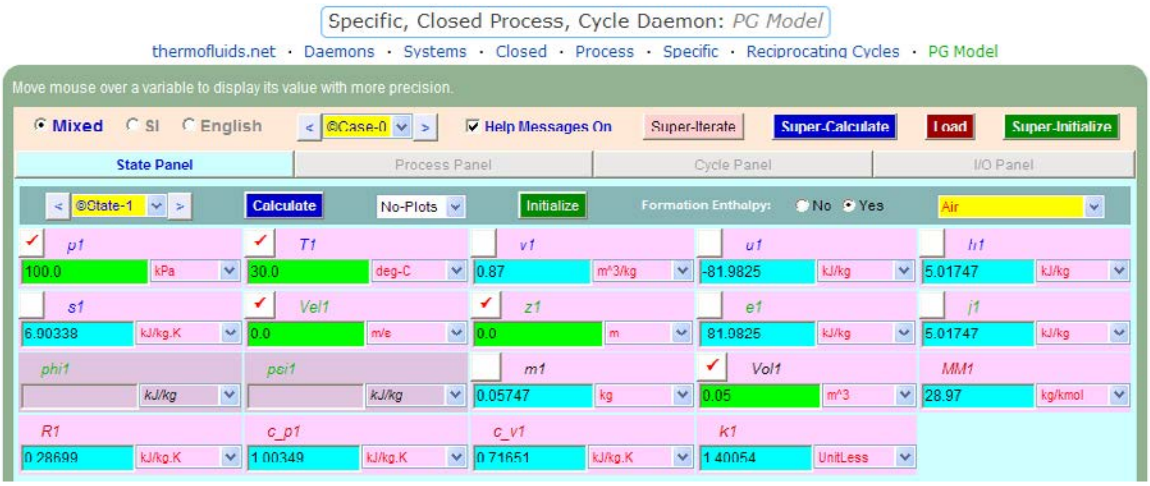
Fig.Prob.1.48

TEST Solution:

Following are the steps:

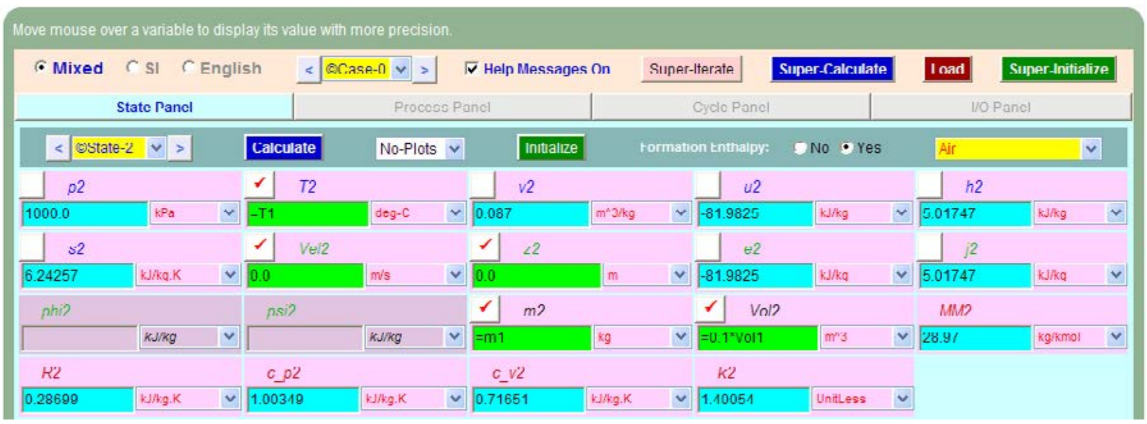
Steps 1 to 4 are the same as for Problem 1.32, using PG model.

5. Select Air as the working substance and fill in data for p1= 100 kPa, T1= 30 C, and Vol1= 0.05 m^3 for State 1, i.e. at beginning of compression, and hit Enter. We get:



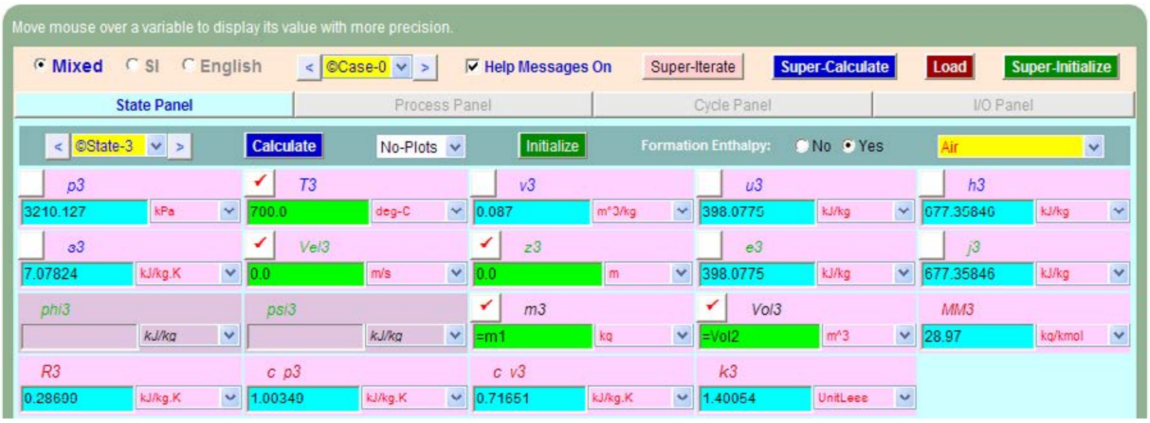
Note that properties for State 1 are calculated.

6. For State 2: Enter Vol2 = 0.1 * Vol1, T2 = T1 (since Process 1-2 is isothermal) and m2 = m1. Hit Enter:



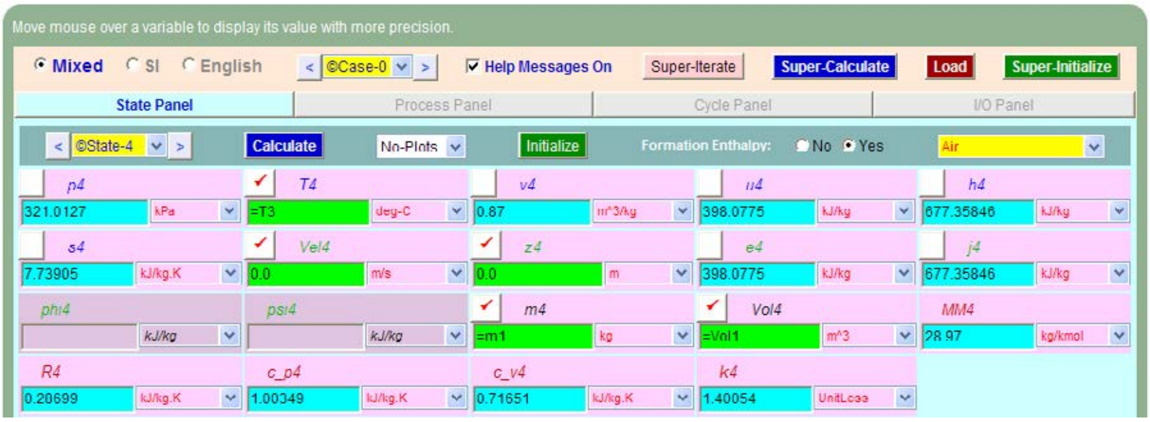
Here, we get p2 = 1000 kPa.

7. Similarly, for State 3: Enter T3 = 700 C, Vol3 = Vol2, and m3 = m1. Hit Enter, and we get:



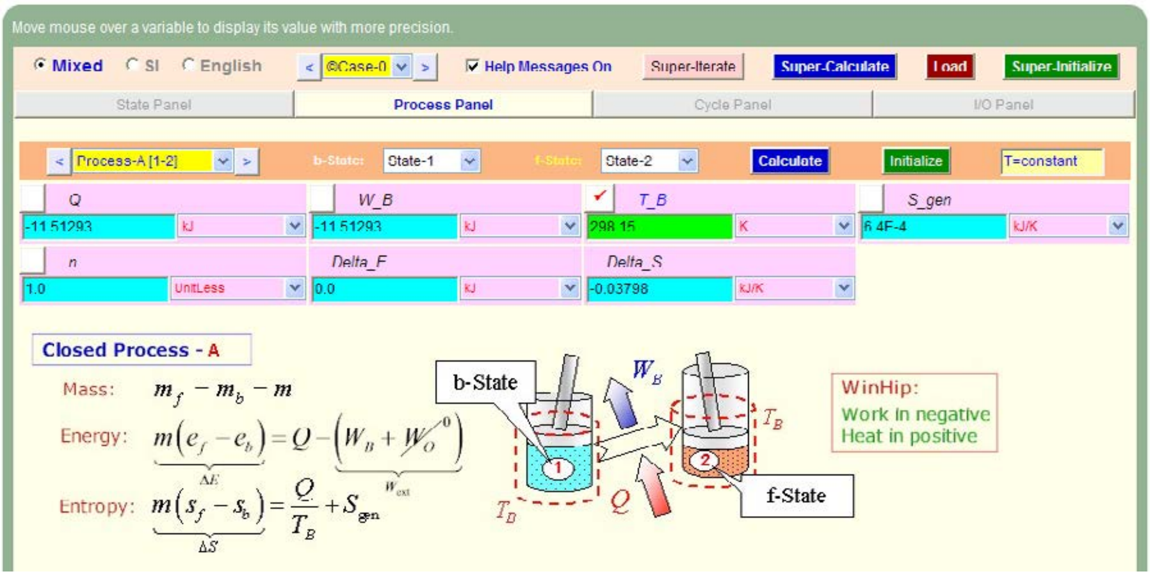
Note that p3 = 3210.13 kPa.

8. Now, for State 4: enter T4 = T3, m4 = m1, and Vol4 =Vol1. Hit Enter. We get:



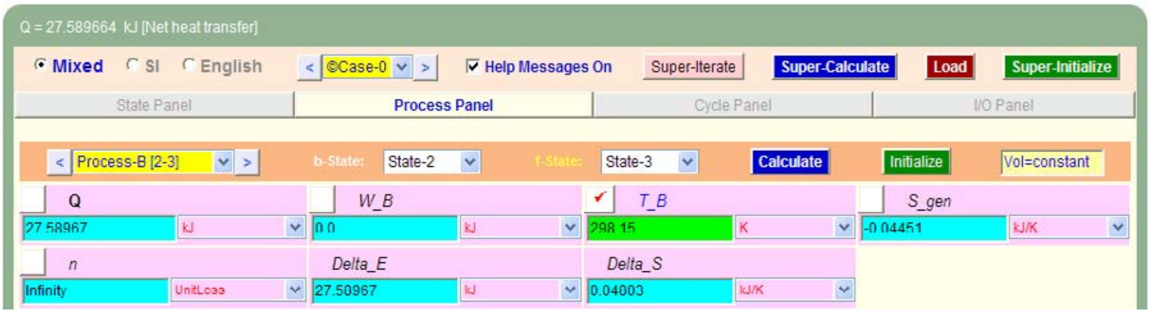
Note that p4 = 321.01 kPa

9. Now, go to the Process Panel. For Process A (i.e. process 1-2), enter State 1 and State 2 for b-state and f-state respectively, Hit Enter, and we get:

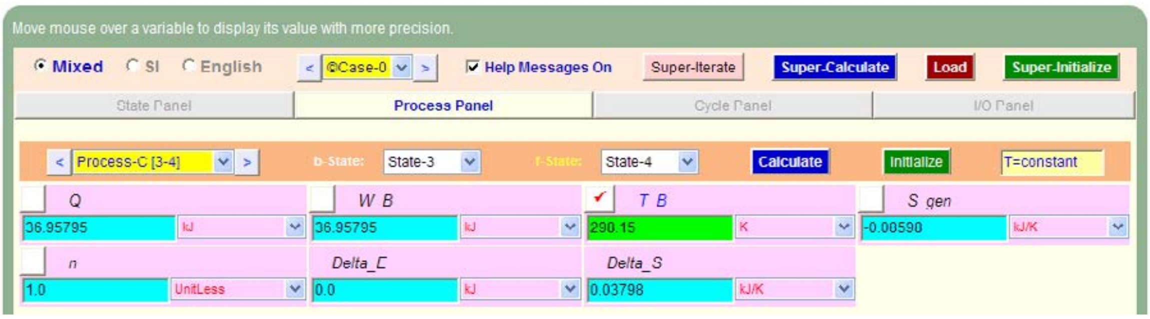


Note that the boundary work, W_B, Q etc for this process are immediately calculated.

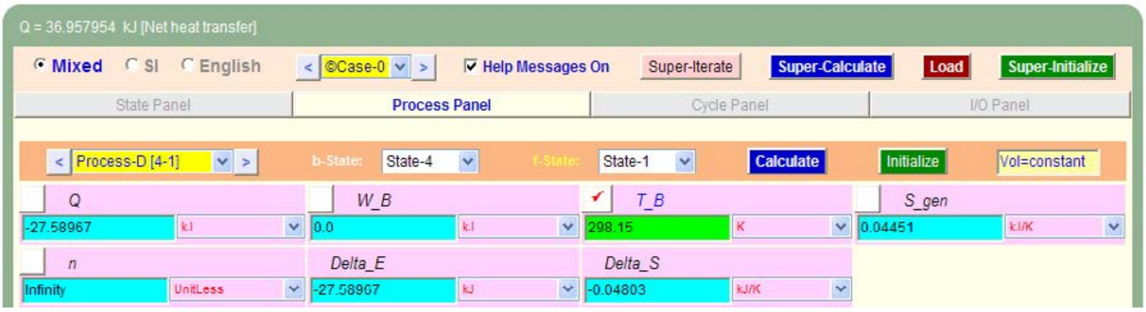
10. Similarly, for Process B (i.e. process 2-3): enter b-state and f-state, hit Enter:



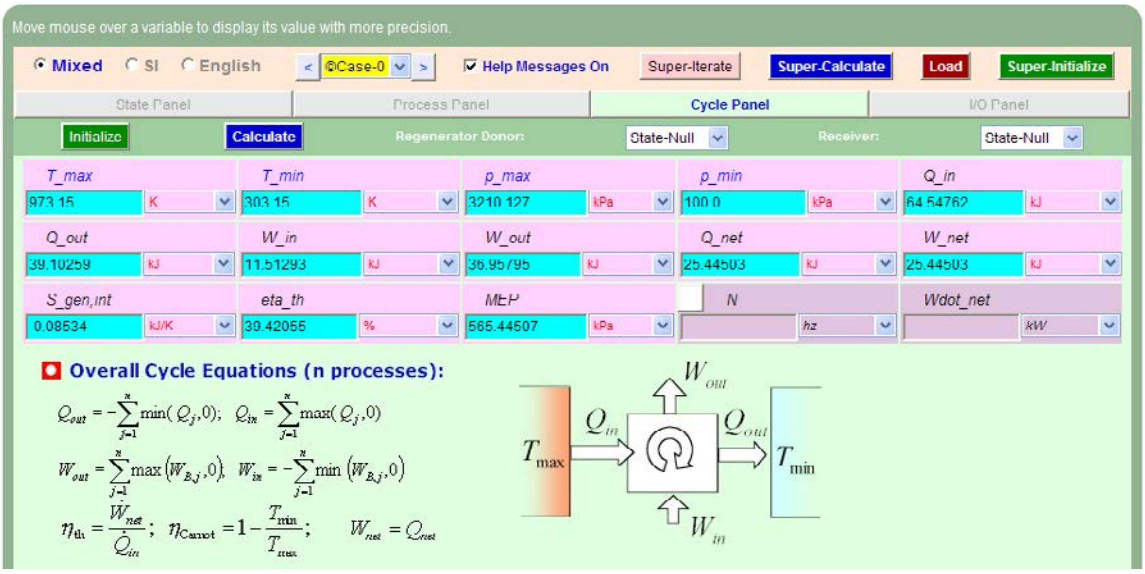
11. And, similarly for Process 3-4:



12. Again, for Process 4-1:



13. Now, go to Cycle Panel, Click on Calculate and SuperCalculate. All calculations are available here:



Note that values obtained here are for the case *when there is no regenerator*:

Air standard efficiency = eta_th = 39.42% …. Ans.

MEP = 565.445 kPa = 5.654 bar … Ans.

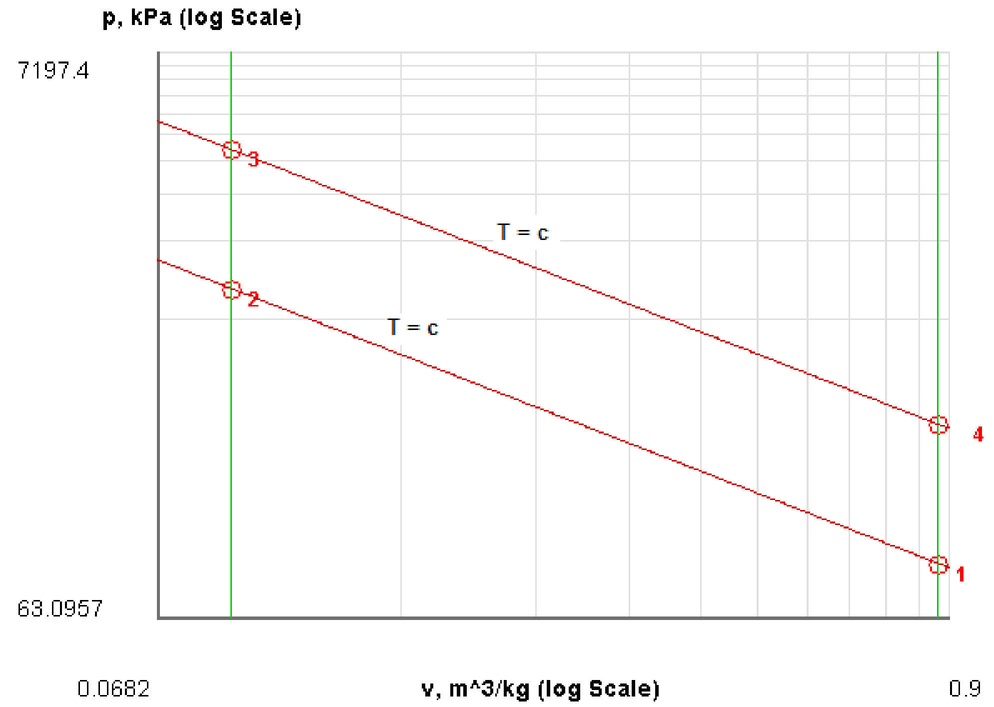
Now: *when there is a regenerator with 100% efficiency:*

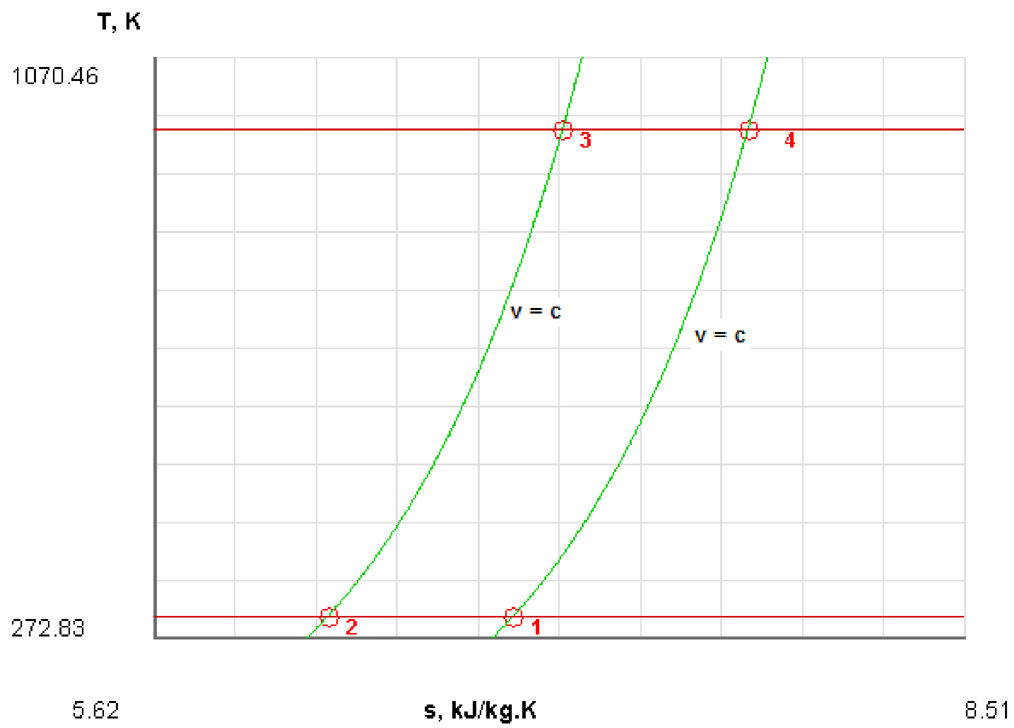
Thermal efficiency is equal to that of a Carnot engine.

i.e. eta_th = (TH _ TL) / TH where temps are in Kelvin.

We get: eta_th = (T3 – T1) / T1 = 0.6885 = 68.85% … Ans.

14. Get the p-v plot from the Plots widget:





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

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

Daemon Path: Systems>Closed>Process>Specific>PowerCycle>PG-Model; v-10.ca08

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

States {

State-1: Air;

Given: { p1= 100.0 kPa; T1= 30.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; Vol1= 0.05 m^3; }

State-2: Air;

Given: { T2= “T1”deg-C; Vel2= 0.0 m/s; z2= 0.0 m; m2= “m1”kg; Vol2= “0.1*Vol1”m^3; }

State-3: Air;

Given: { T3= 700.0 deg-C; Vel3= 0.0 m/s; z3= 0.0 m; m3= “m1”kg; Vol3= “Vol2”m^3; }

State-4: Air;

Given: { T4= “T3”deg-C; Vel4= 0.0 m/s; z4= 0.0 m; m4= “m1”kg; Vol4= “Vol1”m^3; }

}

Analysis {

Process-A: b-State = State-1; f-State = State-2;

Given: { T_B= 298.15 K; }

Process-B: b-State = State-2; f-State = State-3;

Given: { T_B= 298.15 K; }

```
        Process-C: b-State = State-3; f-State = State-4;
        Given: { T_B= 298.15 K; }
        Process-D: b-State = State-4; f-State = State-1;
        Given: { 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     303.2   0.87        -81.98     5.02       6.903
#    2       1000.0    303.2   0.087       -81.98     5.02       6.243
#    3       3210.13   973.2   0.087       398.08     677.36     7.078
#    4       321.01    973.2   0.87        398.08     677.36     7.739
#--------Property spreadsheet ends-----------------------------------------------------------------
# Mass, Energy, and Entropy Analysis Results:
#       Process-A: b-State = State-1; f-State = State-2;
#               Given: T_B= 298.15 K;
#               Calculated: Q= -11.512925 kJ; W_B= -11.512925 kJ; S_gen= "6.368884E-4"kJ/K; n= 1.0
UnitLess;
#                       Delta_E= -0.0 kJ; Delta_S= -0.037977654 kJ/K;
#       Process-B: b-State = State-2; f-State = State-3;
#               Given: T_B= 298.15 K;
#               Calculated: Q= 27.589664 kJ; W_B= 0.0 kJ; S_gen= -0.04450915 kJ/K; n= Infinity
UnitLess;
#                       Delta_E= 27.589664 kJ; Delta_S= 0.04802704 kJ/K;
#       Process-C: b-State = State-3; f-State = State-4;
#               Given: T_B= 298.15 K;
#               Calculated: Q= 36.957954 kJ; W_B= 36.957954 kJ; S_gen= -0.08597993 kJ/K; n= 1.0
UnitLess;
#                       Delta_E= -0.0 kJ; Delta_S= 0.037977654 kJ/K;
#       Process-D: b-State = State-4; f-State = State-1;
#               Given: T_B= 298.15 K;
#               Calculated: Q= -27.589664 kJ; W_B= 0.0 kJ; S_gen= 0.04450915 kJ/K; n= Infinity
UnitLess;
#                       Delta_E= -27.589664 kJ; Delta_S= -0.04802704 kJ/K;
# Cycle Analysis Results:
#               Calculated: T_max= 973.15 K; T_min= 303.15 K; p_max= 3210.127 kPa;
#                       p_min= 100.0 kPa; Q_in= 64.54762 kJ; Q_out= 39.10259 kJ;
#                       W_in= 11.51293 kJ; W_out= 36.95795 kJ; Q_net= 25.44503 kJ;
#                       W_net= 25.44503 kJ; S_gen,int= -0.08534 kJ/K; eta_th= 39.42055 %;
#                       MEP= 565.44507 kPa;
```

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

Carnot Efficiency: = (TH – TL) / TH, temps in Kelvin

(T3 – T1) / T3 = 0.6884858449365463 … **Carnot efficy.**

==

1.5.2 Problem solved with EES:

"**Prob.1.49**. For a hot air engine working on Stirling cycle, following data is given: Temp limits: 800 K and 300 K. Compression ratio = 2, efficiency of regenerator = 90%, and initial pressure of air = 1 bar. Find: (i) heat supplied par kg of air (ii) heat rejected per kg of air (iii) net work done per kg of air (iv) mean effective pressure, and (v) Thermal efficiency. Compare the thermal efficiency with that of ideal Stirling cycle with a 100% efficient regenerator"

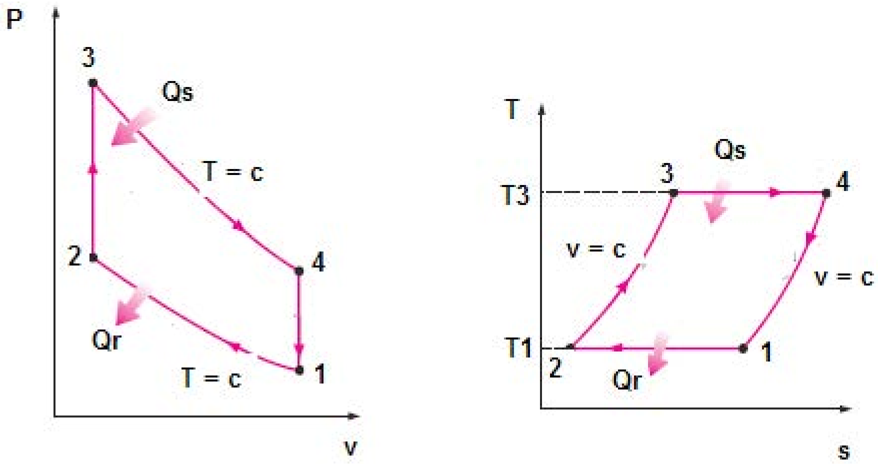


Fig.Prob.1.49

EES Solution:

"Data:"

T1 = 300 "K"

T3 = 800 "K"

T2 = T1

T4 = T3

rr = 2 "…comprn. ratio"

eta_reg = 0.9 "…efficiency of regenerator"

P1 = 100"kPa"

m = 1"kg"

R = 0.287 "kJ/kg.K….. gas constant for air"

cv = 0.718 "kJ/kg.K… sp.heat at const. volume"

"Calculations:"

P1 * v1 / (R * T1) = m"..finds v1, m^3"

v2 = v1/rr "…finds v2, m^3"

v_s = v1 – v2 "m^3 … stroke volume"

Q_s = R * T3 * ln (rr) + (1 – eta_reg) * cv * (T3 – T1) "kJ/kg …. heat supplied"

Q_r = R * T1 * ln (rr) + (1 – eta_reg) * cv * (T3 – T1)"kJ/kg …. heat rejected"

W_net = Q_s – Q_r "kJ/kg …. net work done"

MEP = W_net / v_s "kPa….mean effective pressure"

eta_th = (Q_s – Q_r) / Q_s "….thermal effcy. with regenerator effcy. considered"

eta_ideal = (T3 – T1) / T3 "…Ideal or Carnot efficiency"

Results:

Unit Settings: SI C kPa kJ mass deg

cv = 0.718 [kJ/kg-K]	η_{ideal} = 0.625	η_{reg} = 0.9
η_{th} = 0.51	m = 1 [kg]	MEP = 231 [kPa]
P1 = 100 [kPa]	Q_r = 95.58 [kJ/kg]	Q_s = 195 [kJ/kg]
R = 0.287 [kJ/kg-K]	rr = 2	T1 = 300 [K]
T2 = 300 [K]	T3 = 800 [K]	T4 = 800 [K]
v1 = 0.861 [m^3]	v2 = 0.4305 [m^3]	v_s = 0.4305 [m^3]
W_{net} = 99.47 [kJ/kg]		

Thus:

Heat supplied = Q_s = 195 kJ/kg …. Ans.

Heat rejected = Q_r = 95.58 kJ/kg …. Ans.

Work done = W_net = 99.47 kJ/kg … Ans.

MEP = 231 kpa = 2.31 bar …Ans.

Thermal efficiency = eta_th = 0.51 = 51% ….Ans.

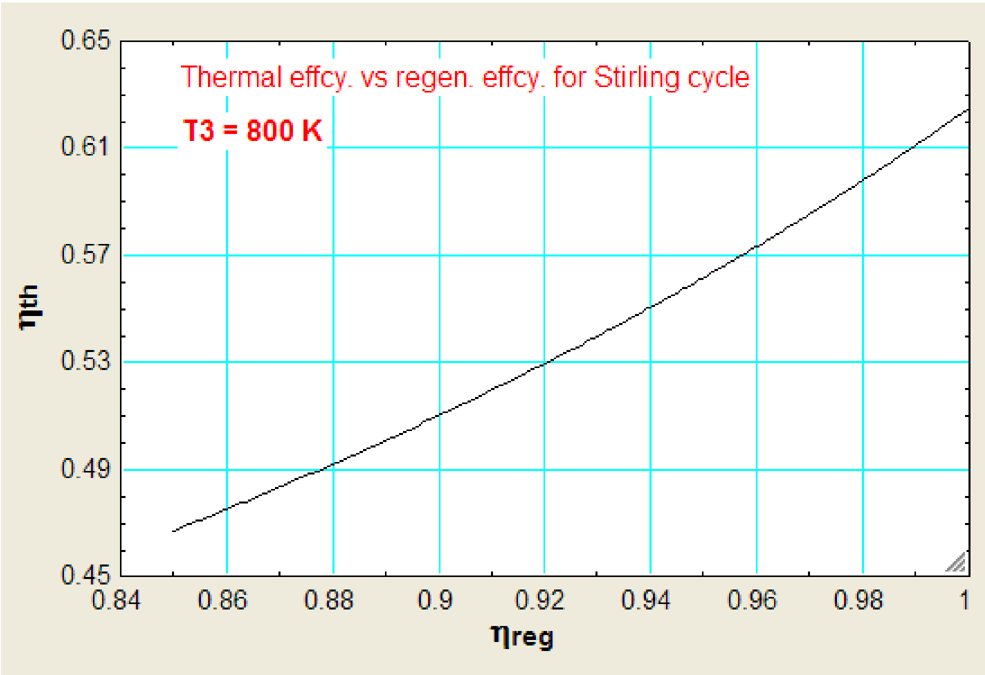
Ideal or Carnot efficiency = eta_ideal = 0.625 = 62.5% …. Ans.

(b) Plot the variation of eta_th as regenerator efficiency varies from 0.85 to 1, other conditions remaining same:

First, compute the Parametric Table:

1..16	η_{reg}	η_{th}
Run 1	0.85	0.467
Run 2	0.86	0.475
Run 3	0.87	0.4833
Run 4	0.88	0.4919
Run 5	0.89	0.5007
Run 6	0.9	0.51
Run 7	0.91	0.5195
Run 8	0.92	0.5295
Run 9	0.93	0.5398
Run 10	0.94	0.5505
Run 11	0.95	0.5617
Run 12	0.96	0.5733
Run 13	0.97	0.5854
Run 14	0.98	0.598
Run 15	0.99	0.6112
Run 16	1	0.625

Now, plot the graph:



(c) Plot the variation of eta_th as the high temp. T3 varies from 800 to 1300 K, for regenerator efficiencies of 0.85, 0.9, 0.95 and 1:

First, compute the Parametric Table:

eta_reg = 0.85

1..11	T3 [K]	η_{th}
Run 1	800	0.467
Run 2	850	0.4792
Run 3	900	0.4899
Run 4	950	0.4993
Run 5	1000	0.5076
Run 6	1050	0.5151
Run 7	1100	0.5218
Run 8	1150	0.5279
Run 9	1200	0.5334
Run 10	1250	0.5385
Run 11	1300	0.5431

eta_reg = 0.9

1..11	T3 [K]	η_{th}
Run 1	800	0.51
Run 2	850	0.5246
Run 3	900	0.5374
Run 4	950	0.5487
Run 5	1000	0.5588
Run 6	1050	0.5679
Run 7	1100	0.5761
Run 8	1150	0.5835
Run 9	1200	0.5902
Run 10	1250	0.5964
Run 11	1300	0.6021

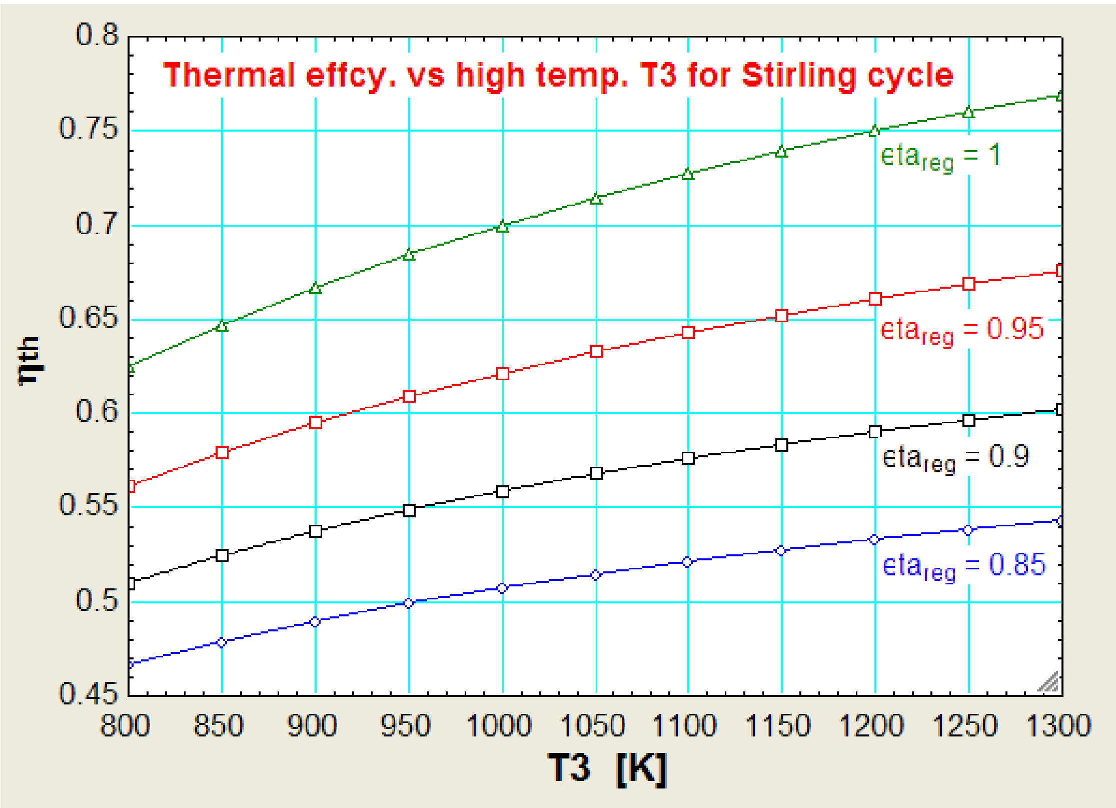
eta_reg = 0.95

1..11	T3 [K]	η_{th}
Run 1	800	0.5617
Run 2	850	0.5794
Run 3	900	0.5951
Run 4	950	0.609
Run 5	1000	0.6215
Run 6	1050	0.6327
Run 7	1100	0.6429
Run 8	1150	0.6521
Run 9	1200	0.6606
Run 10	1250	0.6683
Run 11	1300	0.6755

eta_reg = 1

1..11	T3 [K]	η_{th}
Run 1	800	0.625
Run 2	850	0.6471
Run 3	900	0.6667
Run 4	950	0.6842
Run 5	1000	0.7
Run 6	1050	0.7143
Run 7	1100	0.7273
Run 8	1150	0.7391
Run 9	1200	0.75
Run 10	1250	0.76
Run 11	1300	0.7692

Now, plot the results:



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1.6 References

1. *Yunus A. Cengel & Michael A. Boles*, Thermodynamics, An Engineering Approach, 7th Ed. McGraw Hill, 2011.
2. *Sonntag, Borgnakke & Van Wylen*, Fundamentals of Thermodynamics, 6th Ed. John Wiley & Sons, 2005.
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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