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) 1st edition © 2014 Dr. M. Thirumaleshwar & <u>bookboon.com</u> ISBN 978-87-403-0715-3

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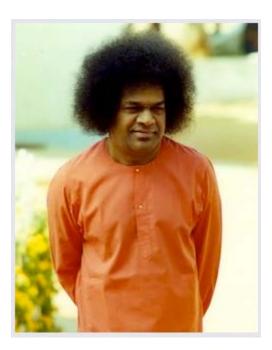
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Dedication

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.



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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 <u>www.bookboon.com</u>

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: <u>www.thermofluids.net</u>)

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 <u>www.thermofluids.net</u> 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

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1 Gas Power Cycles

Learning objectives:

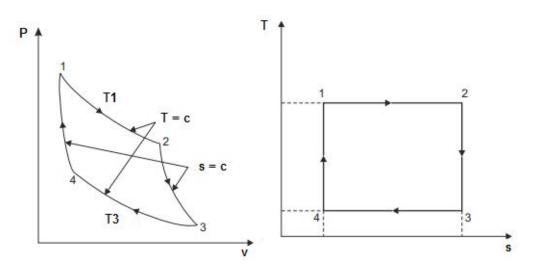
- 1. In this chapter, 'Gas Power cycles' are analyzed with 'air standard assumptions'.
- 2. Cycles analyzed are: (a) Otto cycle (b) Diesel cycle, (c) Dual cycle, and (d) Stirling cycle
- 3. Otto cycle is used in Spark Ignition (S.I.) engines (i.e. petrol engines) and Diesel cycle and Dual cycle are used 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:



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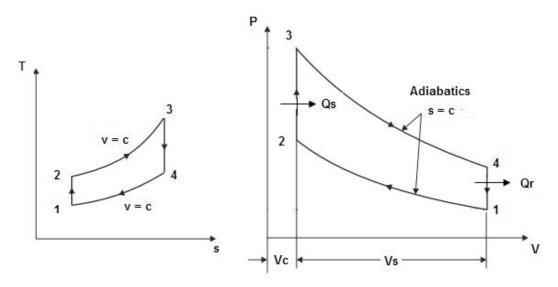
For Carnot cycle:

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

Gas Power Cycles

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

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:
$$MEP = \frac{p1 \cdot r \cdot (rp - 1) \cdot (r^{\gamma - 1} - 1)}{(\gamma - 1) \cdot (r - 1)} \qquad Pa....if p1 is in Pa$$

where
$$rp = \frac{p3}{p2} = \frac{p4}{p1} \qquadpressure ratio$$



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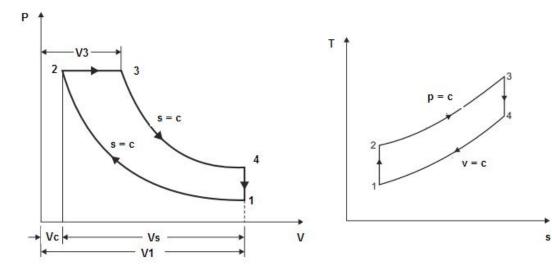
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1.1.4 Diesel cycle (i.e. const. pressure cycle)...for Diesel engines:



For Diesel cycle:

Compression ratio: $\mathbf{r} = \frac{\mathbf{v}1}{\mathbf{v}2}$ Cut off ratio: $\mathbf{r}_{c} = \frac{\mathbf{v}3}{\mathbf{v}2}$ $\frac{\mathrm{T2}}{\mathrm{T1}} = \left(\frac{\mathbf{v}1}{\mathbf{v}2}\right)^{\gamma-1} = \mathbf{r}^{\gamma-1}$ $\frac{\mathrm{T3}}{\mathrm{T4}} = \left(\frac{\mathbf{v}4}{\mathbf{v}3}\right)^{\gamma-1} = \left(\frac{\mathbf{v}1}{\mathbf{v}3}\right)^{\gamma-1}$

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·v1·r^(\gamma-1)
$$\cdot \left[\frac{\gamma \cdot (rc-1) - r^{1-\gamma} \cdot (rc^{\gamma}-1)}{\gamma-1} \right]$$
 J/kg

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

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

Gas Power Cycles

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

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

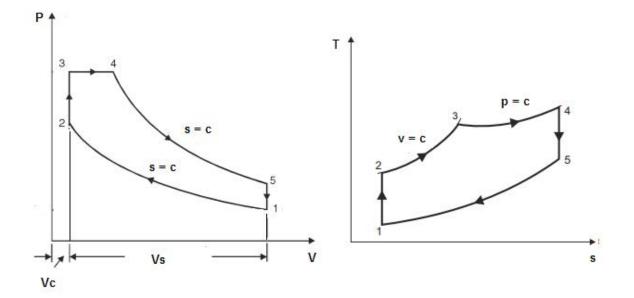
For example, cut off ratio is 8 % of stroke means:

$$\frac{v^3 - v^2}{v^1 - v^2} = 0.08$$

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: $p = \frac{p_3}{p_2}$

$$\frac{T2}{T1} = \left(\frac{v1}{v2}\right)^{\gamma-1} = r^{\gamma-1}$$
$$\frac{T5}{T4} = \left(\frac{v4}{v5}\right)^{\gamma-1}$$

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

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

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 = $\frac{W}{v_s} = \frac{W}{v_1 - v_2}$

Gas Power Cycles

Also:

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

where $r = \frac{v1}{v2}$...compression ratio $rc = \frac{v3}{v2}$...cut off ratio $rp = \frac{p3}{p^2}$...pressure ratio, or explosion ratio



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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.

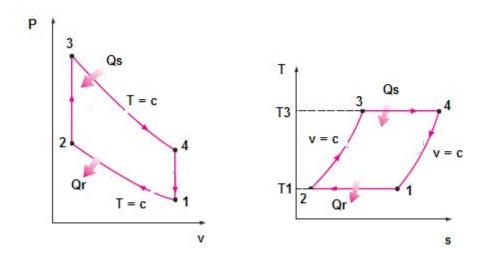
Here, we have:

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: $r = \frac{v1}{v2} = \frac{v4}{v2}$

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: $Q_s = p_3 \cdot v_3 \cdot ln \left(\frac{v_4}{v_3}\right) = R \cdot T_3 \cdot ln(r)$ J/kg Heat rejected: $Q_r = p_1 \cdot v_1 \cdot ln \left(\frac{v_1}{v_2}\right) = R \cdot T_1 \cdot ln(r)$ 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} :

 $\begin{array}{lll} \text{Heat supplied:} & Q_{s} \equiv R \cdot T3 \cdot \ln(r) + \left(1 - \eta_{reg}\right) \cdot cv \cdot (T3 - T1) & J/kg \\ \text{Heat rejected:} & Q_{r} \equiv R \cdot T1 \cdot \ln(r) + \left(1 - \eta_{reg}\right) \cdot cv \cdot (T3 - T1) & J/kg \\ \text{Work done:} & W \equiv Q_{s} - Q_{r} \equiv R \cdot \ln(r) \cdot (T3 - T1) & J/kg \\ \text{Thermal efficiency:} & \eta_{th} \equiv \frac{W}{Q_{s}} \equiv \frac{R \cdot \ln(r) \cdot (T3 - T1)}{R \cdot T3 \cdot \ln(r) + \left(1 - \eta_{reg}\right) \cdot cv \cdot (T3 - T1)} \end{array}$

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.

Gas Power Cycles

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:

$$\begin{aligned} r &= \text{compression ratio = (Vc+Vs)/Vc} & \text{gamma = sp. heat ratio} \\ rp &= p3/p2 = p4/p1 \\ \text{OTTOEFF}(\mathbf{r},\gamma) &:= 1 - \frac{1}{r^{\gamma-1}} & \dots \text{Thermal efficiency} \\ \text{OTTOW}(p1,V1,\mathbf{r},\mathbf{rp},\gamma) &:= \frac{p1\cdot V1}{\gamma-1} \cdot (\mathbf{rp}-1) \cdot \left(\mathbf{r}^{\gamma-1}-1\right) & \dots \text{Work output} \\ \text{OTTOMEP}(p1,\mathbf{r},\mathbf{rp},\gamma) &:= \frac{p1\cdot \mathbf{r} \cdot (\mathbf{rp}-1) \cdot \left(\mathbf{r}^{\gamma-1}-1\right)}{(\gamma-1) \cdot (\mathbf{r}-1)} & \dots \text{Mean effective pressure} \end{aligned}$$

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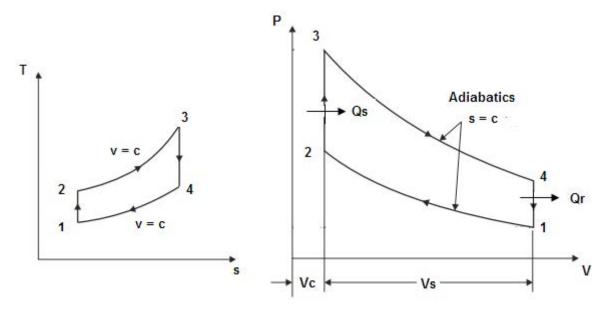


Fig.Prob.1.1

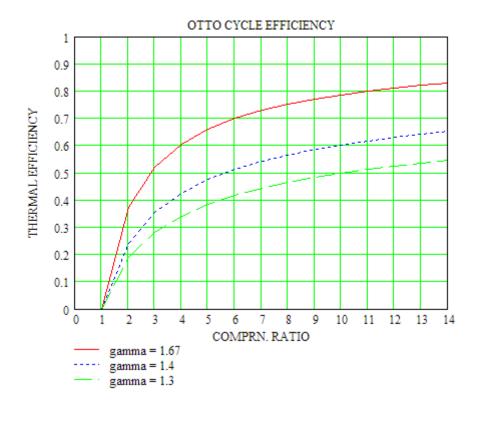
Let us take the range for compression ratio, r as 1 to 14:

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

f =	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:



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.]

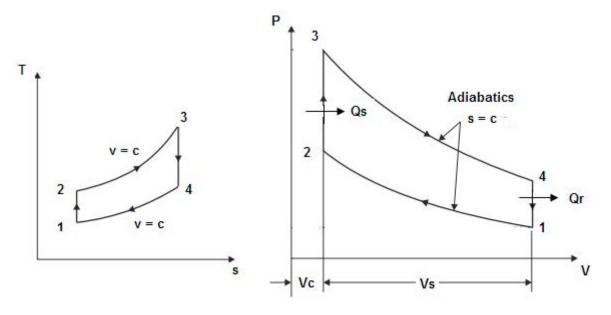


Fig.Prob.1.2

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

Gas Power Cycles

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



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And,

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

i.e. T3 = 2.5 × 10³ K

Then:

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

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

i.e.
$$P3 = 58.466 \qquad \text{bar... Max. pressure in the cycle....Ans.}$$

Now:

$$Q_{\rm S} := cv \cdot (T3 - T2)$$

i.e. $Q_{\rm S} = 1.25 \times 10^3$ 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]

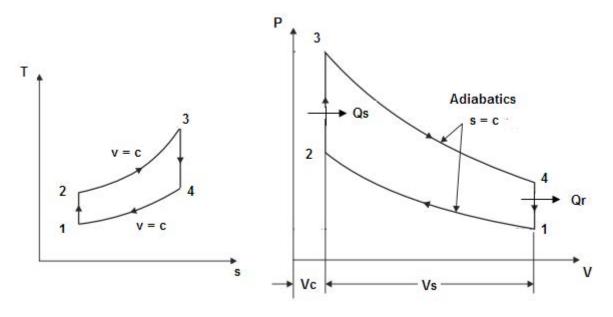


Fig.Prob.1.3

Mathcad Solution:

Data:

γ := 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 := 2comprn ratio... to start the calculations.

Calculations:

We have: $\frac{P1 \cdot v1}{R_{air} \cdot T1} = m_{air} \dots$ from Ideal Gas Law

i.e.
$$v1 := \frac{m_air \cdot R_air \cdot T1}{100}$$
 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.



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



Process 3-4:

 $T_3 = T_4 \cdot r^{\gamma - 1}$

- 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:

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

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

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

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

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

Recollect:

$$\begin{split} & \text{OTTOEFF}(r,\gamma) \coloneqq 1 - \frac{1}{r^{\gamma-1}} & \text{...Thermal efficiency} \\ & \text{OTTOW}(p1,\text{V1},r,rp,\gamma) \coloneqq \frac{p1\cdot\text{V1}}{\gamma-1}\cdot(rp-1)\cdot\left(r^{\gamma-1}-1\right) & \text{...Work output} \\ & \text{OTTOMEP}(p1,r,rp,\gamma) \coloneqq \frac{p1\cdot r\cdot(rp-1)\cdot\left(r^{\gamma-1}-1\right)}{(\gamma-1)\cdot(r-1)} & \text{...Mean effective pressure} \end{split}$$

We re-write these functions for the present case:

Thermal effcy:

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

i.e. η_{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.

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

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

Mean Effective Pressure, MEP:

 $mep(r) := OTTOMEP(P1, r, rp(r), \gamma)$ 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..14range 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



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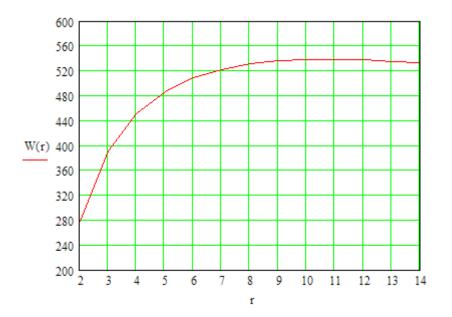


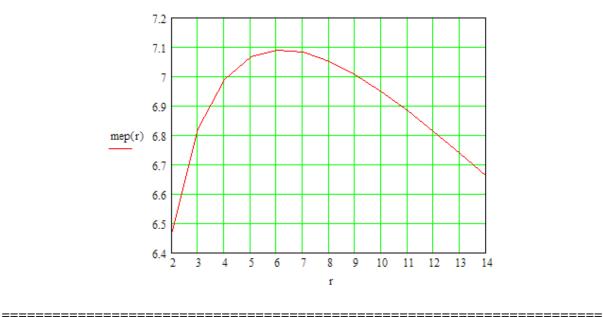
Now, plot the results:

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.]

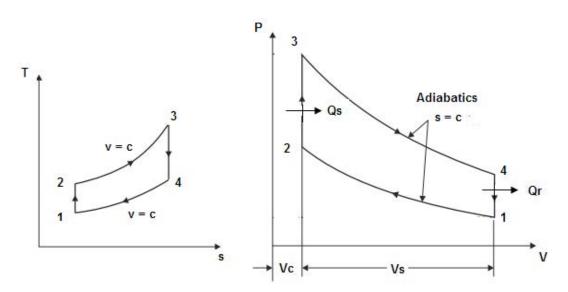


Fig.Prob.1.4

Mathcad Solution:

Data:

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

 $Q_{\rm S} := 210$ kJ ev := 0.714 kJ/kg.K $\gamma := 1.4$

R := 287 J/kg.K

Calculations:

Mass of air:

 $m:=\frac{P1{\cdot}10^{5}{\cdot}V1}{R{\cdot}T1} \hspace{1cm} i.e. \hspace{1cm} m=0.575 \hspace{1cm} kg/cycle$

Process 1-2:

$$r := \left(\frac{P2}{P1}\right)^{\gamma}$$
 ...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 × 10³ K...Ans.

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

i.e. P3 = 24.806 bar..Ans

Process 3-4:

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

And,

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

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





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Work output:

 $W := Q_S - Q_R$

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

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

i.e. mep = 2.617 × 10⁵ 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.]

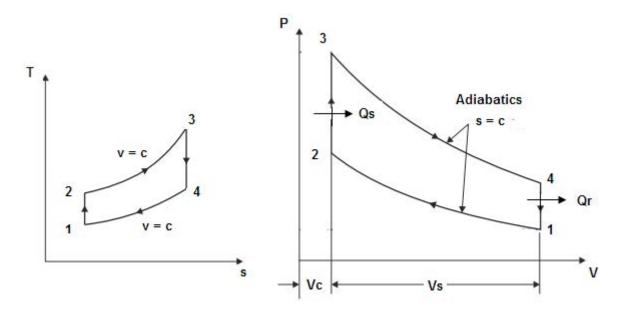


Fig.Prob.1.5

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 := 8comprn. 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 × 10³ K....Ans.

Heat supplied:

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

Heat rejected:

 $\label{eq:QR} \mathsf{Q}_R \coloneqq \mathsf{cv}{\cdot}(\mathsf{T4-T1}) \qquad \text{i.e.} \quad \mathsf{Q}_R = \text{799.758} \quad \text{kJ/kg}$

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.

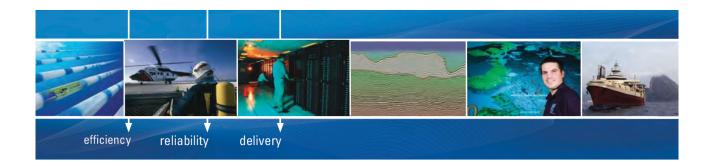
Mean Effective Pressure:

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

Therefore:

$$\begin{split} \text{mep} &\coloneqq \frac{W \cdot 10^3}{V1 \cdot \left(1 - \frac{1}{r}\right)} & \dots \text{mean effective pressure} \\ \text{i.e.} & \text{mep} = 1.377 \times 10^6 & \text{Pa} &= 13.77 \text{ bar}....\text{Ans.} \end{split}$$

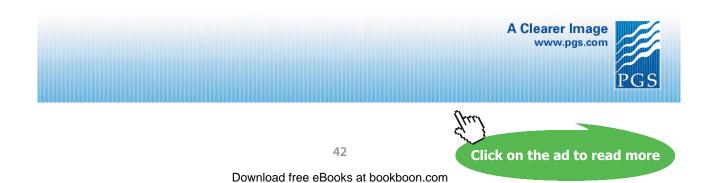
Prob.1.6. Find the efficiency of an Otto cycle engine having max. pressure of 21 bar and temp. 1600 C and min. pressure of 1 bar and temp. 38C. What would be the efficiency of a Carnot engine working between the same max. and min. temp.? Assume working fluid as air. [M.U.]



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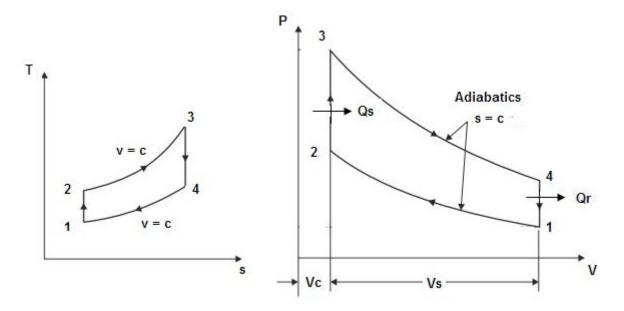


Fig.Prob.1.6

Mathcad Solution:

Data:

P1 := 1 bar T1 := 38 + 273 i.e. T1 = 311 K ev := 0.717 kJ/kg.K P3 := 21 bar T3 := 1600 + 273 i.e. T3 = 1.873×10^3 K

Note that compression ratio, $r = v1/v2 = (P2^*T1)/(T2^*P1) = (P3^*T1)/(T3^*P1) \dots$ since P2/T2 = P3/T3

Therefore:

 $\mathbf{r} := \frac{\mathbf{P3} \cdot \mathbf{T1}}{\mathbf{T3} \cdot \mathbf{P1}}$ i.e. $\mathbf{r} = 3.487$...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: $q1 := cv \cdot (T3 - T2) \qquad i.e. \quad q1 = 975.442 \qquad kJ/kg...heat supplied$ Work output: $W := \eta \cdot q1 \qquad i.e. \quad W = 383.574 \qquad kJ/kg.....work done per kg$ Carnot efficiency: $\eta_{carnot} := \frac{T3 - T1}{T3} \qquad ...by definition$ i.e. $\eta_{carnot} = 0.834 \qquad ...Carnot effcy....Ans.$

Prob.1.7. The compression and expansion curves in a petrol engine follow the law $PV^{1.3} = \text{const.}$ 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.

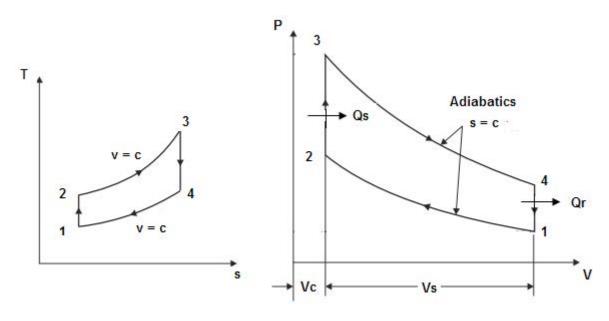


Fig.Prob.1.7

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

Mathcad Solution:

Data:

cv := 0.7175 kJ/kg.K 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.
$$\frac{\text{Vs}}{\text{Vc}} \cdot 0.11 = 0.52$$

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

Therefore:

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 = 1.11×10^3 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.
$$MEP = \frac{W_{net}}{v1 \cdot \left(1 - \frac{1}{r}\right)}$$
where r = comprn. ratio

For 1 kg of air, v1 is calculated as:

$$\frac{P1 \cdot v1}{R \cdot T1} = 1$$
 ...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^A3

Therefore:

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

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

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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:

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

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

P4(T3) := P3(T3)
$$\cdot \left(\frac{1}{r}\right)^n$$
 bar
T4(T3) := T3 $\cdot \left(\frac{1}{r}\right)^{n-1}$ K

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

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

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

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

49

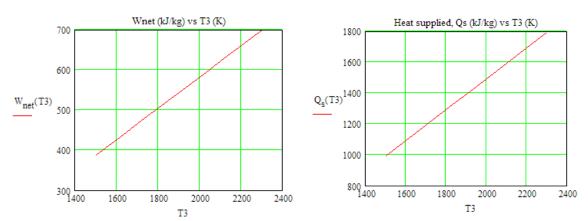
Now, plot the results:

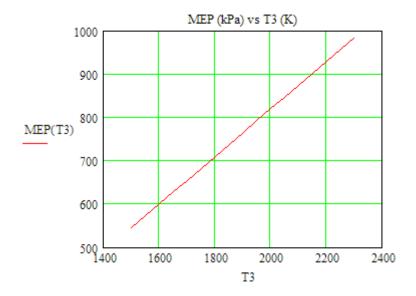
T3 := 1500, 1550 2300 K	define a ran	ge variable T3
-------------------------	--------------	----------------

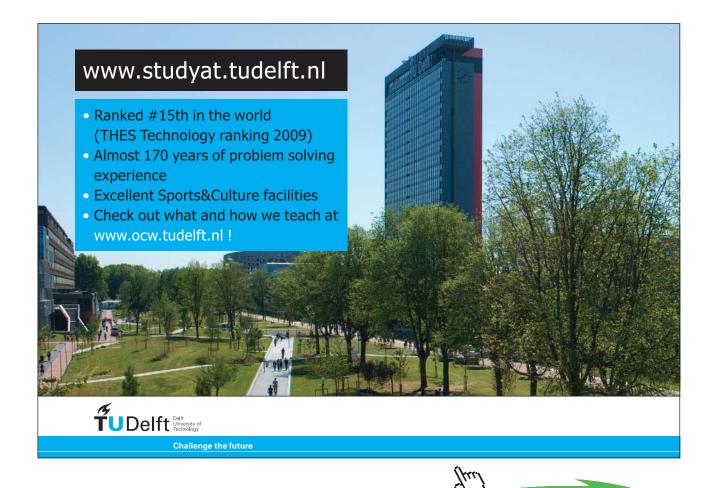
T3 =	$W_{net}(T3) =$	$\eta_{th}(T3) =$	MEP(T3) =	$Q_s(T3) =$
1500	387.43	0.39	545.17	993.196
1550	406.927	0.39	572.604	1043.176
1600	426.423	0.39	600.039	1093.156
1650	445.92	0.39	627.473	1143.136
1700	465.416	0.39	654.907	1193.116
1750	484.912	0.39	682.341	1243.096
1800	504.409	0.39	709.776	1293.076
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

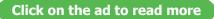
It is noted that Thermal effcy. does not vary with T3.

Plots:









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				
114	¹ r _k ⊻	2 Σ 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 gam	ıma = 1.667
▶ 114	1 r _k	² ⊻ 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

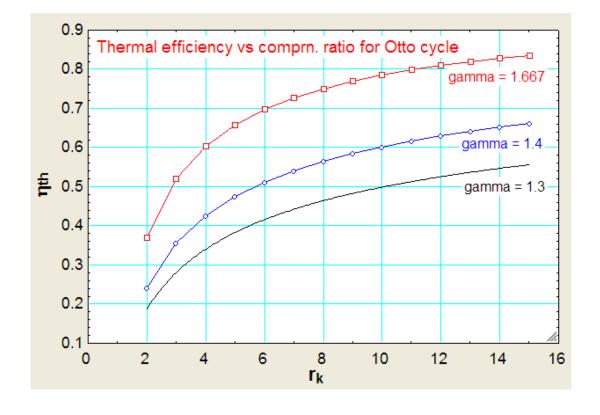
iii) **gamma = 1.667**

😼 Parametr	ic Table				
gamma = 1.4	gamma = 1.4 gamma = 1.3 gamma = 1.667				
▶ 114	1 r _k 2	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			

Gas Power Cycles

Gas Power Cycles

Now, plot the results:







"**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."

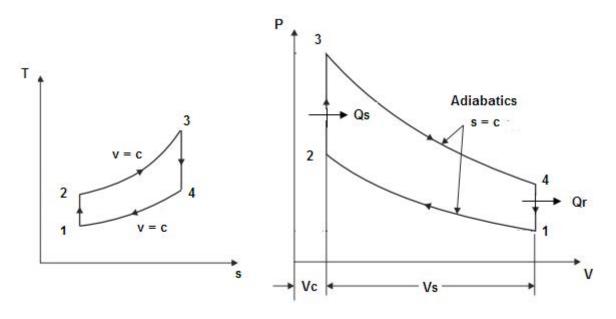


Fig.Prob.1.9

"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]
P1	=100 [kPa]
Qin	= 1800 [kJ/kg]
	= 300 [K]
V1	= 0.861 [m ³]
Wn	_{et} = 1017 [kJ/kg]

 $\begin{array}{l} \eta_{th} = 0.5647 \\ P2 = 1838 \ [kPa] \\ Q_{out} = 783.5 \ [kJ/kg] \\ \hline T2 = 689.2 \ [K] \\ V2 = 0.1076 \ [m^3] \end{array}$

γ = 1.4
P3 = 8532 [kPa]
R = 0.287 [kJ/(kg-K)]
T3 = 3200 [K]
∨3 = 0.1076 [m ³]

MEP = 1349	[kPa]
P4 = 464.2	[kPa]
rr _k = 8	
T4 =1393	[K]
V4 = 0.861	[m ³]

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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:

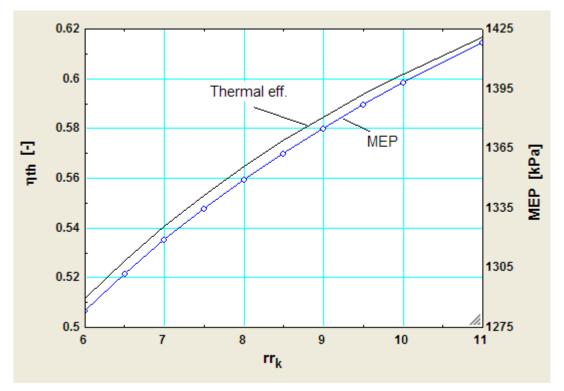
Plot the variation of eta_th, MEP and W_net as comprn. Ratio varies from 6 to 11:

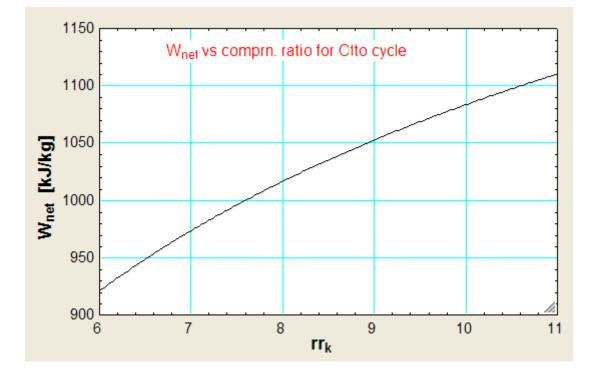
First, compute the Parametric Table:

110	1 Σ η _{th}	2 MEP [kPa]	³ ₩ W _{net} [kJ/kg]	⁴ rr _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

Gas Power Cycles

Now, plot the results:





"**Prob.1.10.** An engine, 250 mm bore, 375 mm stroke, works on Otto cycle. The clearance volume is 0.00263 m³. 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."

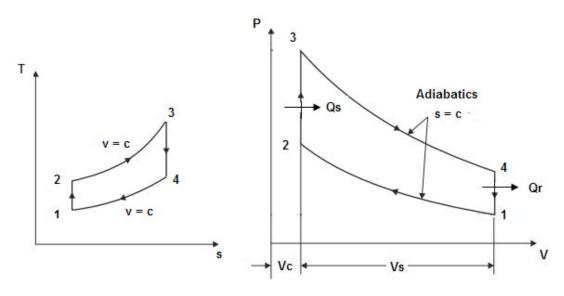


Fig.Prob.1.10



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"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."

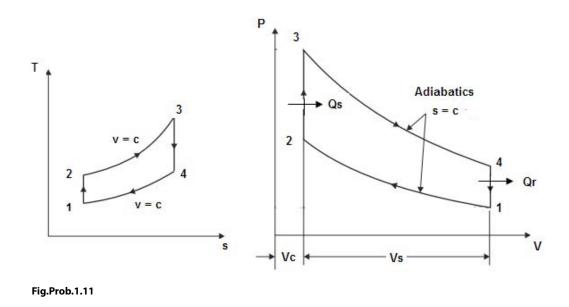
MEP=W_net/V_s "kPa m.e.p.. by definition"

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]	∨1 = 0.02104 [m ³]	∨2 = 0.00263 [m ³]	∨3 = 0.00263 [m ³]
∨4 =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]"



"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"



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Results:

Unit Settings: SI K kPa kJ mass deg

cv = 0.717 [kJ/kg-K]	η _{th} = 0.518	γ = 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]	rr _k = 6.2
T1 = 301 [K]	T2 = 624.5 [K]	T3 = 2305 [K]	T4 = 1111 [K]
∨1 = 0.8639 [m ³]	∨2 = 0.1393 [m ³]	V3 = 0.1393 [m ³]	∨4 = 0.8639 [m³]
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.

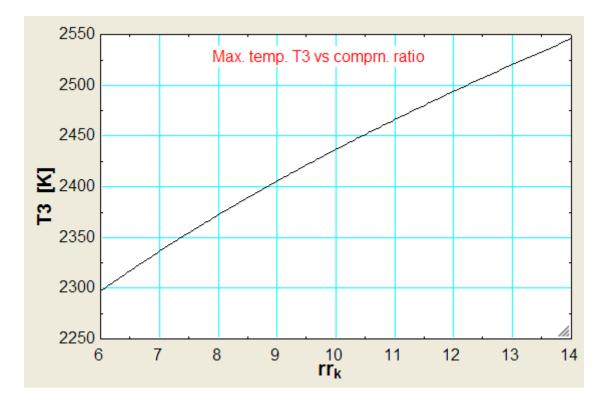
In addition:

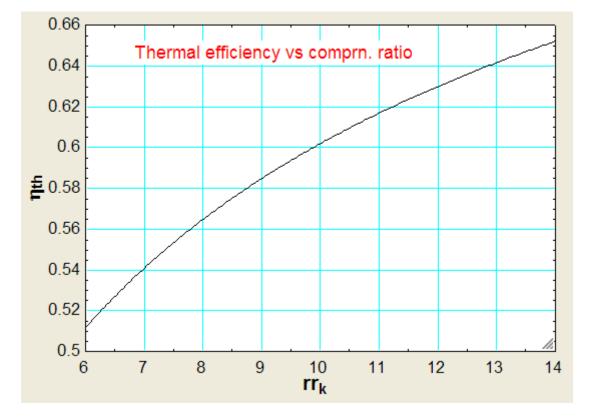
Plot peak temp. T3, eta_th, W_net and MEP as compression ratio varies from 6 to 14, keeping the heat supplied, Q_in un-altered:

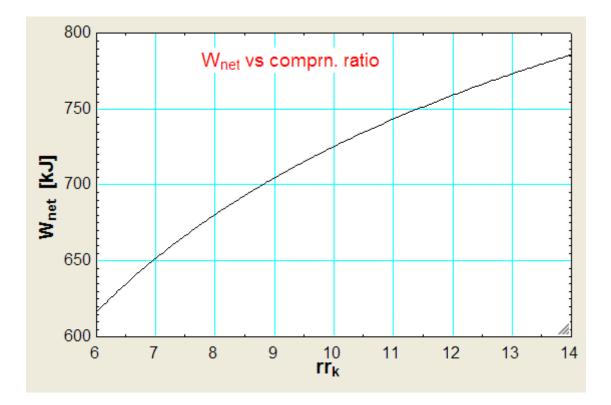
First, compute the Parametric Table:

Table 1					
▶ 19	1 rr _k	² T3 [K]	3 Σ η _{th}	⁴ W _{net} [kJ]	⁵ 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:









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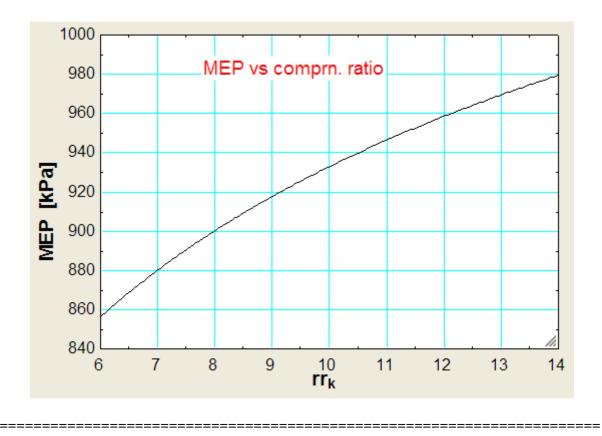
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"Prob.1.12. An ideal Otto cycle has a compression ratio of 8. At the beginning of compression process, air is at 95 kPa and 27 C, and 750 kJ/kg of heat is transferred to air during the const. vol. heat addition process. Using const. sp. heats at room 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]"

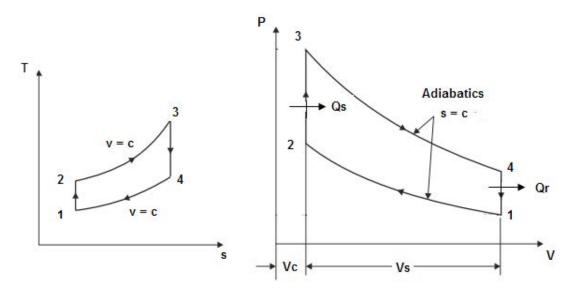


Fig.Prob.1.12

Gas Power Cycles

"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:

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d. All F

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]	rr _k = 8	W _{net} = 423.5 [kJ/kg]

Main				
Sort	¹	² T _i [K]	³ ∨ _i [m ³]	₄ ⊻ 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

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

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:

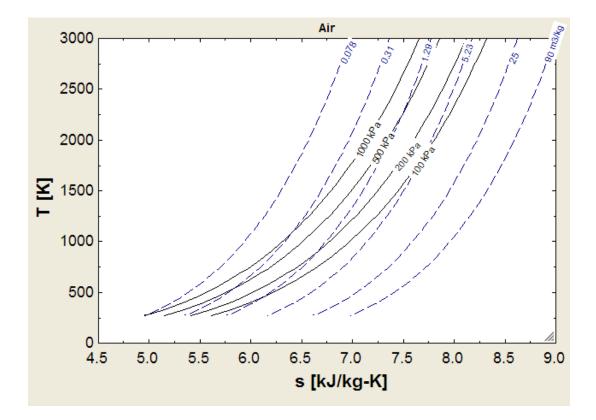
First, in the EES menu: go to Plots – Property Plot:



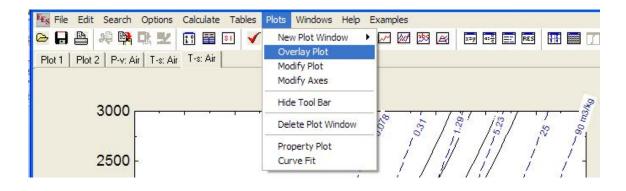
Clicking on Property Plot gives:

cetone	luid Info		Туре			🗸 ок
kir_ha kirH2O kirH2O kmmonia kmmonia kr krgon kenzene 2H2	_mh		 T - s T - v P - v P - h h - s T - h 			X Cancel
X] Inclu	de lines of			Inclu	ude lines o	f
▼ P =	100	[kPa]		¥=	0.078	[m3/kg]
▼ P =	200	[kPa]	V	v =	0.31	[m3/kg]
▼ P =	500	[kPa]		v =	1.29	 [m3/kg]
▼ P =	1000	[kPa]	~	v =	5.23	 [m3/kg]
□ P =		[kPa]	~	v =	25	 [m3/kg]
	-	[kPa]		v =	90	 [m3/kg]

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:

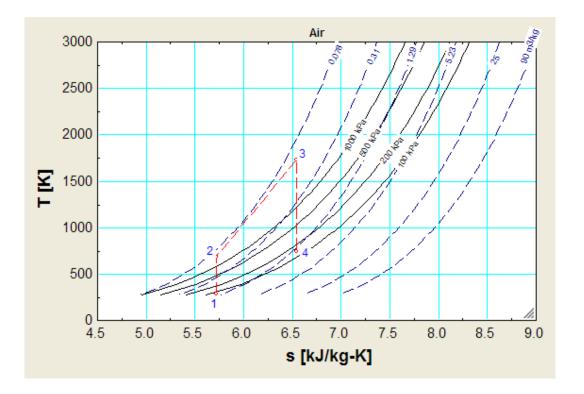


And choose the Arrays Table under the 'Table' tab. And choose T[i] for Y-axis and s[i] for X-axis, as shown below:

etup Overlay on T-s: Air		2		
ab Name: T-s: Air		Print Description with plot		
escription: X-Axis	Y-Axis	Table		
P(i) T(i)	P[i] T[i]	Arrays Table		
V[i] s[i]	V(i) s(i)	Main		
X1 (lower X-scale)	Y2 (right Y-scale)	First Run 1		
Format A 1	Format A 0	Add legend item		
Minimum 4.5	Minimum 0	Show array indices		
Maximum 9.0	Maximum 3000	Line		
Interval 0.5	Interval 500	Symbol 🔹 🗾		
C Linear C Log	@ Linear C Log	Color Auto - Color K Cancel		

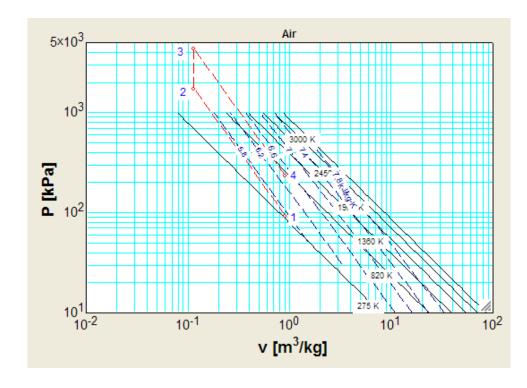


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Click OK. Format the plot to get X and Y grid lines. We get:

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



Similarly, get the P-v plot:

====

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.

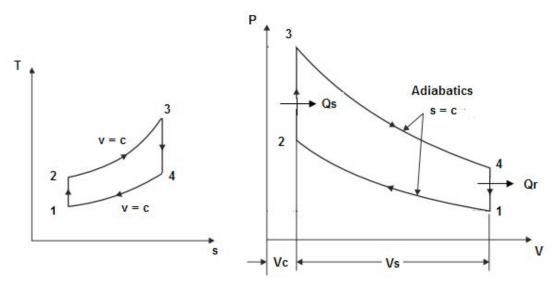


Fig.Prob.1.13

"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]	∨1 = 0.861 [m ³]	∨2 = 0.1435 [m ³]
∨3 = 0.1435 [m ³]	∨4 = 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:

comprn.ratio = 6	6		
112	1 T3 [K]	² ₩ _{net} [kJ]	³ 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



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For rr_k = 8:

112	1 T3 [K]	² ₩ _{net} [kJ]	³ 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

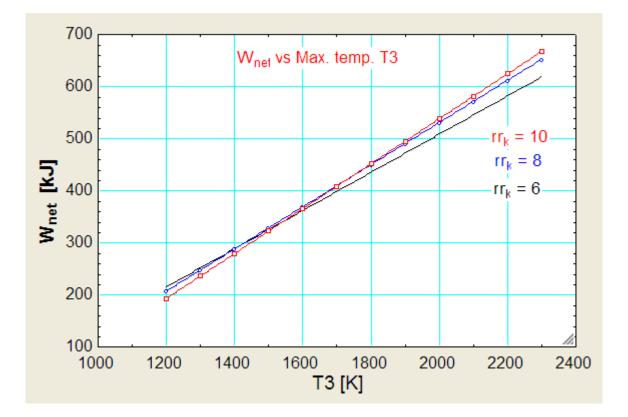
For **rr_k** = 10:

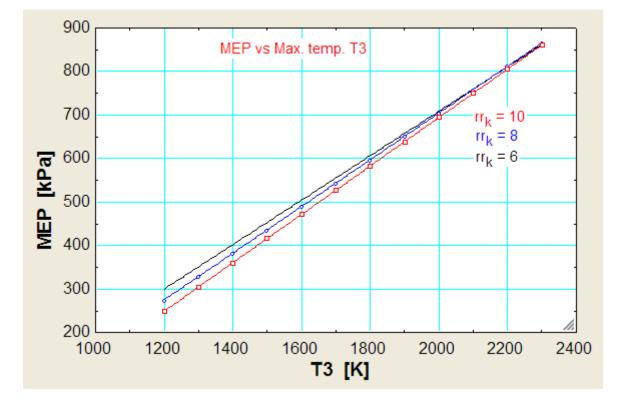
112	1 T3 [K]	2 V _{net} [kJ]	³
Run 1	1200	192.7	248.6
Run 2	1300	235.8	304.3
Run 3	1400	279	360
Run 4	1500	322.1	415.7
Run 5	1600	365.3	471.4
Run 6	1700	408.4	527.1
Run 7	1800	451.6	582.8
Run 8	1900	494.8	638.5
Run 9	2000	537.9	694.2
Run 10	2100	581.1	749.9
Run 11	2200	624.2	805.5
Run 12	2300	667.4	861.2

=====

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 m³. 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]

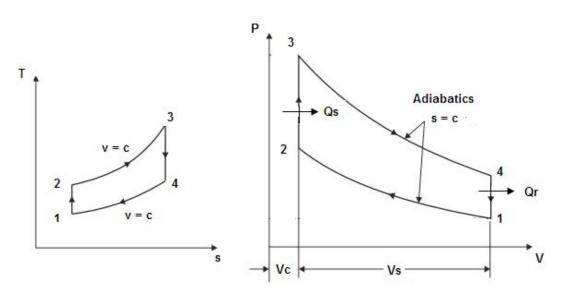


Fig.Prob.1.14



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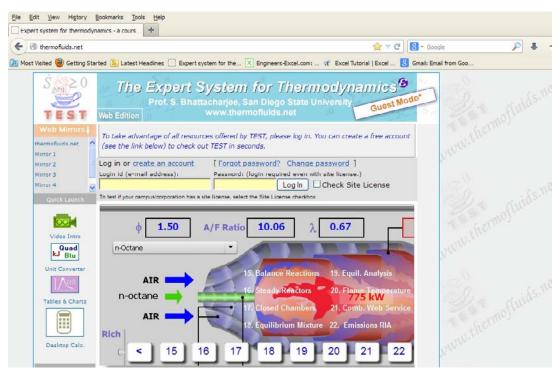
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TEST Solution:

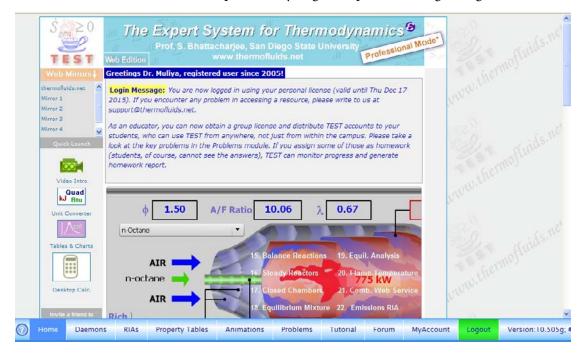
It is assumed that one has already visited <u>www.thermofluids.net</u> and completed the 'free registration'.

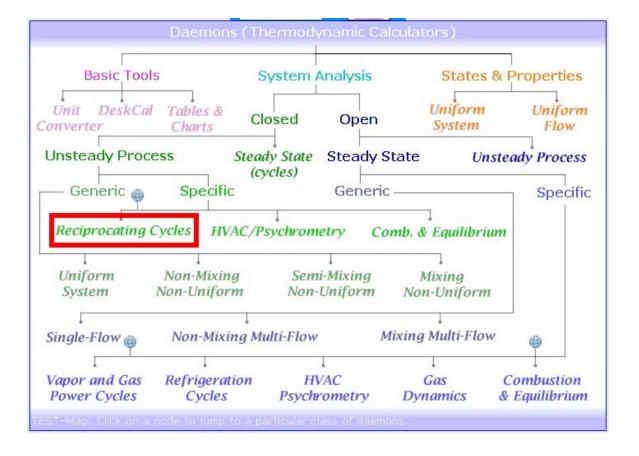
Following are the steps:

1. Go to <u>www.thermofluids.net</u>:



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

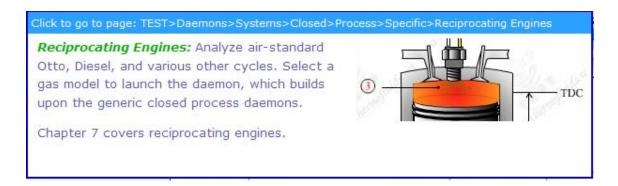




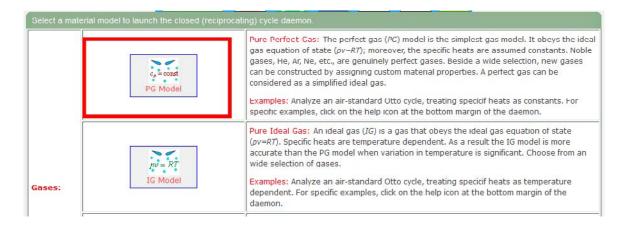
3. Click on Daemons at the bottom of screen above. We get:

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.



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Priyanka Sawant Manager



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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:

	Home of TEST		X		()dl	c,-0	onst	
wer a variable to disp								
C SI C Engl	ish <mark>< ©Ca</mark>	se-0 💙 >	🔽 Help Message	es On	Super-Iterate	Super-Calculate	Load	Super-Initialize
State Panel		Process	Panel		Cycle Panel		I/O F	Panel
ate 1 🐱 >	Calculate	No-Plots	✓ Initializa		Formation Enthalpy:	ONo OYes	Air	~
	✓ T1		vt		ut		ht	
kPa 💌	47.0	deg-C	· 0.91879	m^3/kg	· -69.80187	kJ/kg	✓ 22.07687	kJ/kg 🗸
	✓ Vel1		¥ z1		et		jt	
kJ/kg.K 🗸	0.0	m/s	✓ 0.0	m	← -69.80187	kJ/kg	✓ 22.07687	kJ/kg 🗸
	psit		m1		 Vol1 		MM1	
kJ/kg 🛩		kJ/kg	··· 0.03148	kg	-0.01052+(pi/4)*C m^3	✓ 28.97	kg/kmol 🗸
	c_p1		c_vt		k1			
kJ/kg.K 🗸	1 00349	kJ/kg.K	✓ 0.71651	kJ/kg.K	✓ 1 40054	UnitLess	~	

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

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

• Mixed	C SI CE	Ingli	sh < ©C	ase-0 v >	1	✓ Help M	essages On	Super-I	terate	Super-Calculate	Load	Super-Initialize
St	ate Panel			Proces	s Pa	inel	1	3	Cycle Panel		1/0) Panel
< ©State-	2 🛩 >		Calculate	No-Plots	¥		nitialize	Formatio	on Entholpy:	⊙No •Yes	Air	~
p2			T2		-	v	2		U2		h2	
12.33865	kPa	¥	480.0742	K	٧	0.33413	m*3/kg	×	44.785	kJ/kg	× 182.5598	1 kJ/kg
s2			✓ Vel2			1	2		e2		j2	
s1	kJ/kg.K	×	0.0	m/e	۷	0.0	m	V	44.785	kJ/kg	· 182.5598	1 kJ/kg
phi2			psi2			* n	2		✓ Vol2		MM2	
	kJ/kg	¥		kJ/kg	¥	=m1	kg	*	0.01052	m*3	¥ 28.97	kg/kmol

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:

Process					
1100000	Panol	Cycle Panel		I/O Par	iel
No-Plots	v Initialize	Formation Enthalpy:	ON0 •Yes	Air	~
T3	v3	<i>u</i> 3		h3	
.679 K	✓ 0.33413 m*3/4	9 💉 1786.3314	kJ/kg 😪	2621.6572	kJ/kg
Vol3	¥ 23	03		13	
m/s	✓ 0.0 m	¥ 1786 3314	kJ/kg 👻	2621 6572	kJ/kg
3	✓ m3	✓ Vol:	3	ММЭ	
kJ/kg	✓ m1 kg	✓ =Vol2	m^3 🗸	28.97	kg/kmol
	73 1679 K Vol3 m/s	T3 v3 079 K 0.33413 m*26 Vol3 ✓ z3 m<36	T3 V3 U3 679 K Ø.33413 m*3/kg 1780.3314 Vol3 ✓ z3 o3 m/s Ø.0 m 1786.3314 Ø3 ✓ m3 ✓	73 V3 U3 679 K 0.33413 m*3kg 1780.3314 kUkg × Vol3 ✓ z3 o3 m/s V00 m ¥ 1788.3314 kUkg × i3 ✓ m3 ✓ Vol3	T3 V3 U3 h3 679 K 0.33413 m*3/kg 1760.3314 kU/kg 2621.6572 Vol3 ✓ z3 o3 j3 m/s V 0.0 m 1786.3314 kU/kg 2621.6572 Vol3 ✓ z3 o3 j3 m/s ✓ 0.0 m ✓ 1786.3314 kU/kg 2621.6572 I3 ✓ m3 ✓ Vol3 MM/3

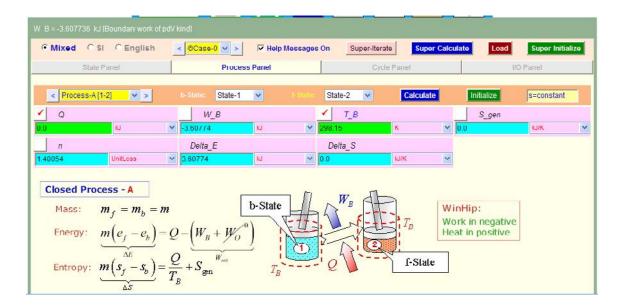
Note that T3 = 2910.679 K.

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

I/O Panel
Air 🗸
h4
1048.0520 kJ/kg
j4
r 1048.0520 kJ/kg
MM4
r 28.97 kg/kmol

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:

Mixed C SI C English	< ©Case-0 ✓ > IF Help M	essages On Super-Iterate Super	r Calculate Load Super Initialize
State Panel	Process Panel	Cycle Panel	I/O Panel
Process, P 12,21	In States State-2	State 2 av	Mat-constant
< Process-B [2-3] >	b-State: State-2 💌	Calculate	
< Process-B [2-3] v > Q 4.83211 kJ	0-State: Stale-2 ▼	Calculate T_B 293.15	e Initiatize Vol=constant S_gen

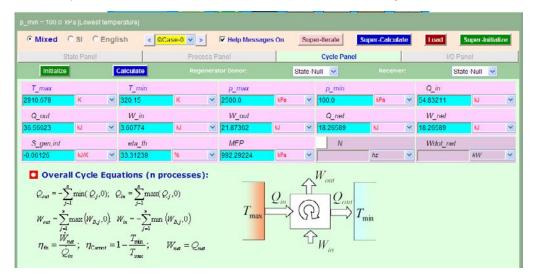
11. Similarly, for Process-C, i.e. process 3-4 in the Otto cycle: Now, Q = 0. Hit Calculate. We get:

• Mixed • SI • English	< ©Case-0 ♥ > ▼ Help Message	es On Super-Iterate Super-Colcu	late Load Super-Initialize
State Panel	Process Panel	Cycle Panel	I/O Panel
< Process-C [3-4]	h-State: State-3 💌 1 suite	State-4 V Calculate	Initialize s=constant
12	W_B	✓ T_B	S_gen
	W_B ▼ 21.87362 kJ ▼	The second se	
	The second se		

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

• Mixed © SI © English	< ©Case 0 ~	> I Help I	Messages On	Super Iterate	Super-Calcu	late Load	Super-Initializ	
State Panel	Process Panel			Cycle Pa	nel	I/O Panel		
< Process-D [4-1]	b-State: State	-4 💙	1-state: St	tate-1 💌	Calculate	Initialize	Vol=constant	
0	W_B		1	T_B		S gen		
				the second se		0.08199	k.I/K	
36.56623 kl	✓ 0.0	ki	✓ 298.	.15 K	Y	0.08188	Reality	
36.56623 KI	✓ 0.0 Delta_E	kl		.15 K Delta_S	*	0.08199	ALCON .	

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



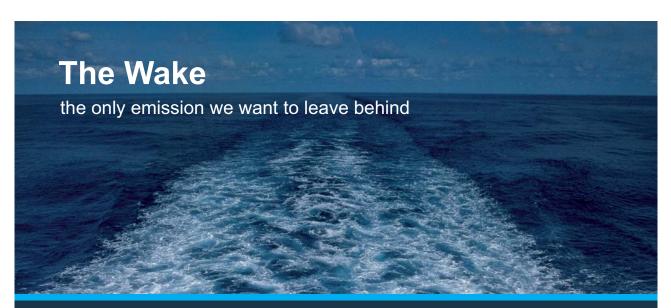
Applied Thermodynamics: Software Solutions Part-I (Gas Power cycles)

Here, all cycle calculations are available.

Thus:

Thermal efficiency = eta_th = 33.31% Ans.

MEP = 992.29 kPa = 9.923 bar ... Ans.



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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*0.2	5*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; }
	}
Analys	sis {
	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;

#		m	2= "m1"kg	; Vol2= 0.010)52 m^3;				
#			Ũ			2 K; v2= 0.3	341 m^3/kg;		
#			1	J/kg; h2= 18			e		
#				C		c	0.287 kJ/kg.K;		
#				e			2= 1.4005 UnitLess;		
#	State-3	: Air > PG-		, ₀ , =		<i>y.</i> 8	· · · · · · · · ,		
#				Pa; Vel3= 0.0	m/s; z3= ().0 m;			
#		-		; Vol3= "Vol					
#			Ũ			3/kg; u3= 1	.786.3315 kJ/kg;		
#						-	/86.3315 kJ/kg;		
#				Ũ		C C	0.287 kJ/kg.K;		
#		•		C		·	3= 1.4005 UnitLess;		
#	State-4	: Air > PG-	-	C		C			
#		Given: s4=	= "s3"kJ/kg.	K; Vel4= 0.0	m/s; z4= 0	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	5 kJ/kg.K; c_	v4= 0.7165	kJ/kg.K; k	4= 1.4005 UnitLess;		
#	Proper	ty spreadsh	eet starts: #	ŧ					
#	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		
#	Proper	ty spreadsh	eet ends						
# Mass	s, Energy	, and Entr	opy Analys	is Results:					
#	Process	s-A: b-State	= State-1;	f-State = Stat	e-2;				
#		Given: Q=	= 0.0 kJ; T_	B= 298.15 K;	;				
#		Calculated	l: W_B= -3	8.607736 kJ;	S_gen= -0.	.0 kJ/K; n=	1.4005353 UnitLess; Delta_E=		
3.6077	36 kJ;								
#		D	elta_S= -0.0	0 kJ/K;					
#	Process	s-B: b-State	= State-2; f	f-State = Stat	e-3;				
#		Given: T_	B= 298.15	К;					
#		Calculated	l: Q= 54.8	3211 kJ; W_	_B= 0.0 k	J; S_gen=	-0.14325188 kJ/K; n= Infinity		
UnitLe	ess;								
#				.83211 kJ; D)40655926 l	κJ/K;		
#	Process			f-State = Stat					
#		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;
<pre># Process-D: b-State = State-4; f-State = State-1;</pre>
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;

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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]

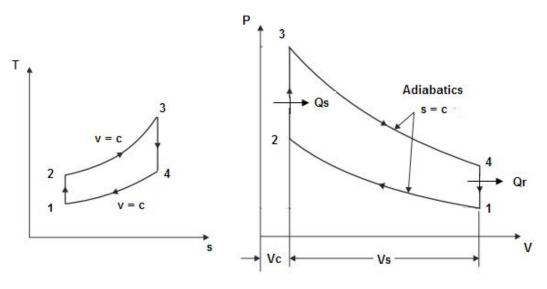


Fig.Prob.1.15

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:

	Specific Clo	sed Process Cycle	Daemon: PG Model		
the			Process > Specific > Cycles	s > PG-Model	
	Home of		(At 🗛 🚟	$c_{\mu} = \text{const.}$	
	TEST				
ove mouse over a variable to displ					
Mixed O SI C Englis	sh < ©Case-0 🛩 >	🔽 Help Messages On	Super-Iterate Super-O	Calculate Load	Super-Initialize
State Panel	Process	Panel	Cvde Panel		0 Panel
		_	51 1653 M. MAR 2000	Company of the second se	
< OState-1 V >	Calculate No-Plots	✓ Initialize	Formation Enthalpy: 🔅 No	Yes Air	~
✓ p1	✓ T1	vt	ut	ht	
100.0 kPa 💉	50.0 deg-C	✓ 0.9274 m ³ /	kg 💉 -67.65235 k	J/kg 🛛 🖌 25.08735	i kJ/kg
s1	✓ Vel1	✓ z1	et	it	
6.96749 kJ/kq.K 🗡	0.0 m/s	✓ 0.0 m	✓ -67.65235 k	J/kg 💉 25.08735	i kJ/kg
phi1	pci1	m1	Vol1	MM1	
kJ/kg 💙	kJ/kg	✓ 0.02268 kg	✓ =0.00263+(pi/4)*C r	n^3 ♥ 28.97	kg/kmol
R1	c_p1	0_v1	k1		
0.28699 ki/kg K 🗸 🗸	1.00349 k.l/kg K	✓ 0.71651 k.l/kg	K 🛛 1.40054 Ur	iitl ess 🗸	

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:

• Mixed C SI C	Englis	h < ©C:	ase-0 🛩 >	F	Help Messages On	Super	r-Iterate	Super Calculate	Load	Super Initialize
State Panel			Procest	s Pa	nel		Cycle Panel		I/O Pi	anel
< <mark>©State-2</mark> V >		Calculate	No-Plots	v	Initialize	Format	tion Enthalpy:	🔿 No 💿 Yes	Air	~
p2		T2			v2		u2		h2	
1839 6912 kPa	×	743 19904	К	۷	0 11594 m	'3/kg 😽	233 31593	kJ/kg	446 60406	kJ/kg
62		✓ Vol2			✓ z2		c2		j2	
s1 kJ/kg.K	Y	0.0	m/s	٧	0.0	m 🗸	233.31593	kJ/kg	446.60406	kJ/kg
phi2		psi2			✓ m2		Vol2		MM2	
kJ/kg	×		kJ/kg	~	=m1 kg	×	0.00263	m^3	28.97	kg/kmol

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:

• Mixed C SI	C Englis	sh < ©Ca	se-0 🗸 >		Help Messages (On	Super-Iterate	Super-Calculate	Load	Super-Initialize
State P	anel		Process	Pane	1		Cycle Panel		I/O F	anel
< OState-3 V	>	Calculate	No-Plots	~	Initialize		Formation Enthalpy:	🔘 No 💿 Yes	Air	~
p3		T3			V3		и3		h3	
500.0 k	Pa 🗸 🗸	1009.9508	К	× 0	11594	m^3/kg	₩ 424.44556	kJ/kg 💊	714.28784	kJ/kg
s3		✓ Ve/3			z3		e3		<i>j</i> 3	
18724 kJ/k	q.K 💌	0.0	m/s	× 0	.0	m	✓ 424.44556	kJ/kg 💊	714.28784	kJ/kg
phi3		psi3			m3		Vol3		ММЗ	
k.J.	rka 🗸		kJ/kg	× =	m2	kg	✓ =Vol2	m^3 🗸 🗸	28.97	kg/kmol

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:

Mixed C SI C Englis	sh <mark>< ©Cas</mark>	e-0 ~ >	🔽 Help Messages (On Super-	Iterate	uper-Calculate	Load	uper-Initialize
State Panel		Process Pa	anel		Cycle Panel		I/O Par	iel
< <mark>©State-4 v</mark> >	Calculate	No-Plots 💌	Initialize	Formati	on Enthalpy:	○ No ● Yes	Air	~
p4	T4		v4		u4		h4	
135 89236 kPa 💙	439 1362	K 🗸	0.9274	m^3/kg 💉	15 45263	kJ/kg 💙	141 4788	kJ/kg
s1	✓ Vel/		✓ z1		e1		j1	
s3 kJ/kg.K 💙	0.0	m/s 💙	0.0	m 🗸	15.45263	kJ/kg 🗸	141.4788	kJ/kg
phi4	psi4		✓ m4		✓ Vol4		MM4	
KJ/Kg 💙		kJ/kg 💙	=m3	kg 🗸 🗸	=\/011	m^3 🗸	28.97	kg/kmol

Note that p4, T4 are now calculated.

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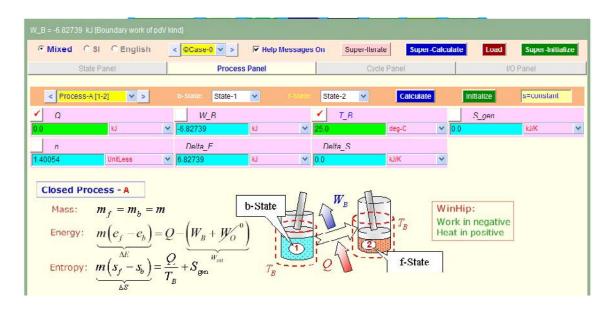
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9. Now, go to Process Panel. For Process-A, choose State 1 for b-state (i.e. begin state) and State 2 for f-state (i.e. finish state). Q = 0, since process 1-2 is adiabatic. Hit Enter. We get:



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

			Super Iterate Sup	er-Calculate Load	Super-Initialize
State Panel	Process	s Panel	Cycle Panel		I/O Panel
< Process-B [2-3] V >	b-State: State-2	v i-State: S	tate-3 v Calcula	te Initialize	Vol=constant
	Unite 2				
Q	W_B	1	T_B	S_gen	
3573 kJ	₩ 0.0	kJ 💙 25.0	deg-C	✓ -0.00956	kJ/K

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

State Panel Process Panel Cycle Panel VO Panel	Mixed C SI C English	< ©Case-0 ✓ > ✓ Help Mes	ssages On Super-Iterate Super-Calculate	e Load Super-Initializ
	State Panel	Process Panel	Cycle Panel	I/O Panel
	COMPLEX (1015)	FOLCAS FADE	52(18.17008)	and a company
	< Process-C [3-4] V >	b-State: State-3 💌	State-4 Calculate	Initialize s=constant
< Process-C [3-4] V > b-State: State-3 V i-State: State-4 V Calculate Initialize s=c				
	Q	W_B	✓ T_B	S_gen
Process-C [3-4] > b-State: State-3 Calculate Initialize s=column Q W_B T_B S_gen				
Q W_B T_B S_gen	8J	✓ 9.2779 kJ	V 25.0 deg-C V 0.0	kJ/K

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

• Mixed C SI C English	< @Case-0 v > 🔽	Help Messages On	Super-Iterate Super	-Calculate Load	Super-Initialize
State Panel	Process Pan	el	Cycle Panel		I/O Panel
		10			
< Process-D [4-1] 👻 >	b-State: State-4 📝	CSinte. Stat	te-1 Calculate	Initialize	Vol=constant
Q	W_B	1	Т_В	S_gen	
					kJ/K
1.88522 kJ	✓ 0.0 kJ	✓ 25.0	deg-C	✓ 0.00134	NUN
l.88522 kJ	0.0 kJ Delta E		deg C ta_S	0.00134	NUN

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

ate Panel			Case-0 🛩	2	Help Messag	les On	Super	r-Iterate	Super-Calcu	late	Load	Super-In	nitialize
ste i difei			Pro	ocess P	anel			Cycle Pan	el		1	O Panel	
	C	alculate					State-N	uli 💌				State-Null	~
		T_min			p_max			p_min			Q_in		
к	Y	323.15	к	Y	2500.0	kPa	Y	100.0	kPa	v	4.33573	k1	
		W_in			W_out			Q_nel			W_net		
kJ	Y	6.82739	kJ	¥	9.2779	kJ	4	2.45051	kJ	Y	2.45051	kJ	
		ota_th			MEP			N			Wdot n	ot	
kJ/K	~	56.51905	%	~	133 12381	kPa	~		hz	*		kW	
	N	K V	к у 323.15 W_ini Ы б.82739 oto_th	T_min K ♥ 323.15 K W_in ⊌ ♥ 6.02739 ⊌ ota_th	T_min K ♥ 323.15 K ♥ W_in W 6.02739 W ♥ ota_th	T_min p_max K ▼ 323.15 K ▼ 2500.0 W_in W_oul 0<	T_min p_max K 323.15 K ✓ 2500.0 KPa W_in W_out 6.02739 ⊌ ♥.2779 ⊌ ota_th MEP	T_min p_max K 323.15 K 2500.0 kPa V W_in W_oul 0.02779 U 9.2779 U V ota th MEP 0.0279 MEP 0.0279 MEP 0.000	T min p max p min K 323.15 K ✓ 2500.0 №№ 100.0 W_in W_oul Q_nel ↓ 245051 ⋈ 6.02739 ⋈ 9.2779 ⋈ ✓ 245051 ota th MEP N N	T min p max p min K ¥ 323.15 K ¥ 2500.0 KPa 100.0 KPa Win Woul Q_mel W 6.02739 M 9.2779 M 2.45051 M ota th MEP N	T_min p_max p_min K 323.15 K 2500.0 kPa 100.0 kPa v Win W_oul Q_nel 0.2779 U 2.45051 U v ota th MEP N N 100.0 <td< th=""><th>T min p max p min Q in K 323.15 K 2500.0 KPa 100.0 KPa 4.33573 Win Woul Q nel Wnel 0 Wnel 245051 W 245051 W 6.02739 M 9.2779 M 2.45051 W 2.45051 ota th MEP N Water N Water N</th><th>T_min p_max p_min Q_in K 323.15 K 2500.0 KPa 100.0 KPa 4.3357.3 KI W_in W_oul Q_nel W_nel W 6.027.39 W 9.2779 KI 2.45051 KI 2.45051 KI ota th MEP N Wdot_not KI MU MU</th></td<>	T min p max p min Q in K 323.15 K 2500.0 KPa 100.0 KPa 4.33573 Win Woul Q nel Wnel 0 Wnel 245051 W 245051 W 6.02739 M 9.2779 M 2.45051 W 2.45051 ota th MEP N Water N Water N	T_min p_max p_min Q_in K 323.15 K 2500.0 KPa 100.0 KPa 4.3357.3 KI W_in W_oul Q_nel W_nel W 6.027.39 W 9.2779 KI 2.45051 KI 2.45051 KI ota th MEP N Wdot_not KI MU MU

Here, all cycle calculations are available.

Thus:

Thermal efficiency = eta_th = 56.52% Ans.

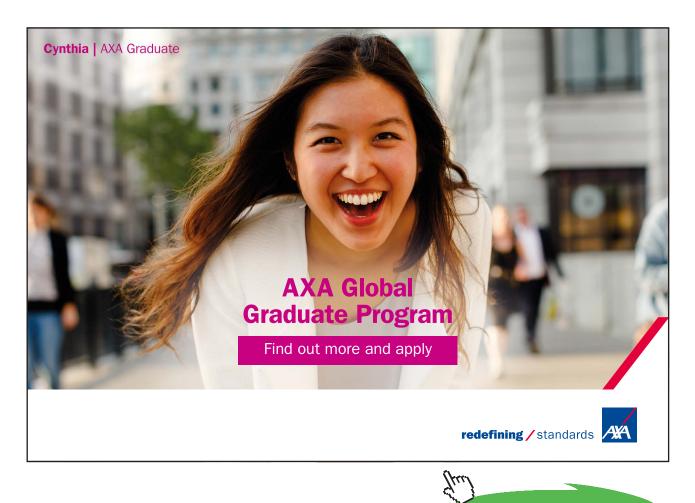
MEP = 133.124 kPa = 1.33 bar ... Ans.

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 {
    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)*0.3
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= 0.00263 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; }
        }
```



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#		End	of TEST-o	code						
		erty spreads								
#	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			
#	Prop	erty spreads	heet ends							
# M	ass, Ener	gy, and Ent	ropy Ana	lysis Results:						
#	Proce	ess-A: b-Stat	e = State-	1; f-State = St	ate-2;					
#		Given: Q	e= 0.0 kJ; 7	Г_B= 25.0 deg	g-C;					
#		Calculate	ed: W_B=	-6.82739 kJ;	S_gen= -0.	0 kJ/K; n=	1.4005353 UnitLess; Delta_E=			
6.82	2739 kJ;									
#										
#	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										
Uni	tLess;									
#				4.335728 kJ; I		049849246	kJ/K;			
#	Proce			3; f-State = St						
#				Г_B= 25.0 deş	-					
#		Calculate	ed: W_B=	9.277903 kJ;	S_gen= -0.	0 kJ/K; n=	1.4005353 UnitLess; Delta_E=			
	77903 kJ;	-		0.011/17						
#	D		Delta_S= -	, ,						
#	Proce			4; f-State = St	ate-1;					
#			B = 25.0	e		.I. C	0.0012201100 LT/IZ I			
# T Trai	tI aaa	Calculate	ea: Q= -1.	8852158 KJ;	VV_B= 0.0 k	l; S_gen=	0.0013381199 kJ/K; n= Infinity			
	tLess;	т	Dolto F	1 0050150 1-1	Dolta C	0 00 409 407	$M \in \mathbb{H}/\mathbb{K}$			
# # C	velo Anal	ı ysis Results		1.8852158 kJ	, Dena_3= -	0.00498492	240 KJ/K;			
# C #	yele Allal			- 1000 0508	K.T. min-	373 15 K. +	p_max= 2500.0 kPa;			
# #				= 1009.9508 1)0.0 kPa; Q_ir		-				
# #		-		2739 kJ; W_c						
#							$f_{2,45051}(k)$; eta_th= 56.51905 %;			
#				5.12381 kPa;	5-11,1110,	55522 KJ/K	, ••••_•••= = = = = = = = = = = = = = = =			
		1								

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.

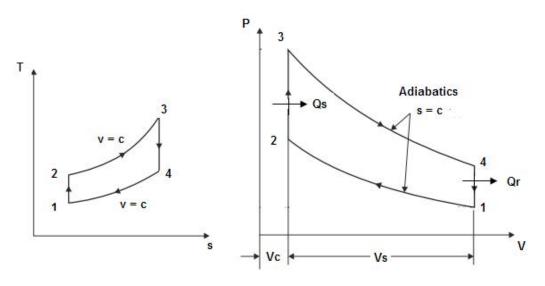


Fig.Prob.1.16

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:

			9	Specific, C	losed	Process,	Cycle D	aemo	n: PG Mo	del				
		ther	Home of		s > Sys	stems > Clos	ed > Pro ∫ ^f _b (-	cess >) <i>dt</i>	Specific >		-Moc			
• Mixed	C SI C E	Inglis	h < 🧟	Case-0 🗸 >		Help Message	s On	Super-It	erate S	uper-Calculat	e	Load	Super-Initial	li7e
5	State Panel			Proc	coo Pan	ol -		C	Dycle Panel			1/0	Panel	
< ©State	-1 × >		Calculate	No-Plo	ts 🗸	Initialize		ormatio	n Enthalpy:		5	Air		~
🖌 p1			 ✓ T1 			v1			u1			h1		
100.0	kPa	~	27.0	deg-C	~ 0	.80139	m*3/kg	~	-84.13202	kJ/kg	~	2.00099	kJ/kg	
st			Vel1			< L1			et			jt		
6.8934	kJ/kg.K	~	0.0	m/s	~ (.0	m	~	-84.13202	kJ/kg	~	2.00699	kJ/kg	
phi1			psi1			m1			Vol1			MM1		
	kJ/kg	~		kJ/kg	~	.0	kg	~	0.86139	m^3	~	28.97	kg/kmol	1
R1			c_p1			c_v1			k1					
0.28699	kJ/kg.K	~	1.00349	kJ/kg.K	~ 0	.71651	kJ/kg.K	~	1.40054	UnitLees	~			

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:

×J/kg
kJ/ka
k.l/ka
kJ/kg
kg/kmol

Note that $p_2 = 2514.98$ kPa, $T_2 = 754.87$ K.



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 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:

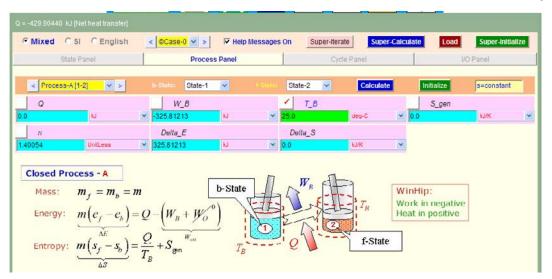
• Mixed	C SI C E	ingli	sh <mark>< ©C</mark>	- 🛰 0-eze	1	✓ Help	Messages O	On Supe	-Iterate	Sup	er Calculate		Load	Super Initial	ize
	State Panel			Proces	ss Pa	anel	-		Cycle I	Panel	1		I/O Par	nel	
< ©Stat	03 ~ >		Calculate	No-Plots	~		Initialize	Forma	ion Entl	halpy: 🜔	No 📀 Yes	;	Air		~
p3			T3			1	v3			u3			h3		
7542.4395	kPa	~	2263.8633	ĸ	*	=v2	1	m*3/kg 💉	1322	.8832	k.l/kg	۷	1972.5814	k.l/kg	
\$3			 Vel3 			1	z3			e3			j3		
=34	kJ/kg.K	*	0.0	m/s	~	0.0		m	1322	.0032	kJ/kg	٣	1972.5814	kJ/kg	1
phi3			psi3			1	m3			Vol3			ММЗ		
	kJ/kg	×		kJ/kg	Y	=m1		kg 🗸	0.086	514	m^3	٧	28.97	kg/kmol	•
R3	nurny		c_p3	nurny		C_1		NY	k3				20.51	Rentino	
0.28699	kJ/kg.K	v	1.00349	kJ/kg.K	v	0.716	51 k	J/kg.K 🗸	1.400	054	UnitLess	v			

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

	SI CE	Inglis	sh	< ©Ca	se-0 🛩 >	1	₹ Hel	p Messages	On	Super-	Iterate	Super-Calculat	e	Load	Super-Initia	lize
Sta	te Panel				Proces	s Pa	inel	0		4	Cycle Pane			1/0 P	anel	
< ©State-4	¥ >	1	Calcu	ilate	No-Plots	~		Initialize		Formati	on Enthalpy	⊙No ⊙Ye	5	Air		~
p4			1	T4			-	v4			U4			h4		
299.90005	kPa	~	627.0		deg-C	~	=v1		m*3/kg	*	345.77246	kJ/kg	~	604.1034	kJ/kg	
s4			*	Vel4			-	z4			e4			j4		
7.68032	kJ/kg.K	~	0.0		m/s	~	0.0		m	~	345.77246	kJ/kg	~	604.1034	kJ/kg	
phi4			psi	4			1	<i>m</i> 4			Vol	4		MM4		
n i	kJ/kg	Y			kJ/kg	۷	=m1		kg	¥	0.86139	m^3	*	28.97	kg/kmol	1
R4			0	54			¢	_v4			k1					
0.28699	kJ/kg.K	~	1.003	49	kJ/kg.K	~	0.71	651	kJ/kg.K	~	1.40054	UnitLess	*			

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:

Mixed CSI CEnglish	< ©Case-0 ❤ > IIel	p Messages On Super-Iterate	Super-Calculate	Load Super-Initialize
State Panel	Process Panel	Cycle	Panel	I/O Panel
	FIGURA FIGUR	. agran	- mina	INTERNIE I
< Process-B [2-3] V >	b-State: State-2 💌	1-State: State-3	Calculate	itialize Vol=constant
0	W_B	✓ T_B		S gen
				0_90//
) 91,2031 kJ	✓ 0.0 kJ	✓ 25.0	deg-C ¥ -2.839	45 kJ/K

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

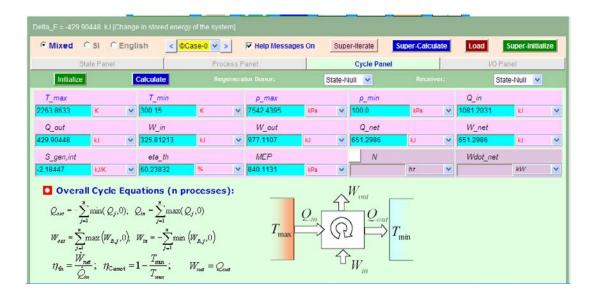
i/O Panel	Initialize	yde Panel	Cy		rocess Panel	P	anel	State P
ialize s-constant	Initializa							
ialize s-constant	Initializa				in the second			
	Indanzo	Calculate	State-1 💌		te-3 💌	b-State: Sta	-1] 💙 >	< Process-C [3-
S_gen	S_gen		T_B			W_B		Q
kJ/K	₩ 0.0	deg-C 💉	25.0	× 2	kJ	977.1107	kJ	
		deg-C 💉	1_0		kJ		N	1975.0



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

	Development (10 Devel	Mixed CSI CEnglish	< Case-0 > F Help Message	es On Super-Iterate Super-Calcul	ate Load Super-Initialize
State Panel Process Panel Cycle Panel VO Panel	Cycle Panel I/O Panel	State Panel	Process Panel	Cycle Panel	I/O Panel
		< Process-D [4-1] >	D-State: State-4 M	State-1 Calculate	Initialize Vol-constant
< Process-D [4-1] > b-State: State-1 (-State: State-1 Calculate Initialize Vol-con	> b-State: State-1 • Calculate Initialize Vol-constant	Q	W_B	✓ T_B	S_gen

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-CA	LCULATE		
#	Daemon	Path: Syster	ns>Closed>]	Process>Specif	fic>PowerCyc	le>PG-Mode	l; v-10.ca08
#		Start of TE	ST-code				
States	{						
	State-1: A	Air;					
	Given: {	p1= 100.0 kP	a; T1= 27.0	deg-C; Vel1= 0	.0 m/s; z1= 0.	0 m; m1= 1.0	kg; }
	State-2: A	Air;					
	Given: {	v2= "v1/10"n	n^3/kg; s2=	"s1"kJ/kg.K; Ve	el2 = 0.0 m/s; z	z2= 0.0 m; m2	2= "m1"kg; }
	State-3: A	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: A	Air;					
	Given: {	T4= 627.0 de	eg-C; v4= "v]	1"m^3/kg; Vel4	= 0.0 m/s; z4=	= 0.0 m; m4=	"m1"kg; }
	}						
Analys	sis {						
	Process-	A: b-State = $\$$	State-1; f-Stat	te = State-2;			
	Given: {	$T_B = 25.0 de$	eg-C;				
	Process-2	B: b-State = S	tate-2; f-Stat	e = State-3;			
	Given: {	$T_B = 25.0 de$	eg-C;				
	Process-	C: b-State = S	State-3; f-Stat	te = State-4;			
	Given: {	Q= 0.0 kJ; T_	_B= 25.0 deg	;-C; }			
	Process-2	D: b-State = S	State-4; f-Stat	te = State-1;			
	Given: {	T_B= 25.0 de	eg-C; }				
	}						
#		End of T	EST-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	s, Energy,	and Entropy	Analysis Re	esults:			
#	Process-	A: b-State = S	State-1; f-Stat	te = State-2;			
#	(Given: T_B=	25.0 deg-C;				
#	(Calculated: Q	= "-2.84217]	1E-13"kJ; W_B	= -325.81213	kJ; S_gen= "9	.532688E-16"kJ/K;
n= 1.4	005353 Ur	nitLess;					
#		Delta	_E= 325.812	13 kJ; Delta_S=	= -0.0 kJ/K;		
#	Process-	B: b-State = S	tate-2; f-Stat	e = 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;
<pre># Process-C: b-State = State-3; f-State = State-4;</pre>
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;
<pre># Process-D: b-State = State-4; f-State = State-1;</pre>
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:

thermofili D Hor T E	ne 🖉 🚺 🚺		cle Daemon: PG Mode > Process > Specific > Cy [{()dt		
Nove mouse over a variable to display its va	lue with more precision.				
Mixed CSI CEnglish	< Case-0 V >	Help Messages On	Super-Iterate Sup	er-Calculate Lo	ad Super-Initialize
State Panel	Process P	anel	Cycle Panel		I/O Panel
< Calcu	late No-Plots 🗸	Inilialize	Formation Enthalpy:	No 🔍 Yes 🔒	Air 🔽
🖌 p1 🖌	T1	tv	u1		h1
100.0 kPa 💉 28.0	deq-C 💌	0.86426 m ⁴	^3/kg ✓ -83.41551	kJ/kg 💙 3.01	1048 kJ/kg 🗡
61	Vol1	1 z1	c1		j1
6.89674 kJ/kg.K 🛩 0.0	m/s 🗸	0.0	m ⊻ <mark>-83.41551</mark>	kJ/kg 💙 3.0*	1048 kJ/kg 🗸
phi1 psi	1	✓ m1	Vol1	٨	AM1
k.l/kg 🗸	k.l/kg 💙	1.0 kg	0.86426	m^3 🗸 28.9	97 kg/kmol 💌
R1 c_p	1	c_v1	k1		
0.28699 kJ/kg.K 🛩 1.003/	19 kJ/kg.K 🛩	0.71651 kJ/k	kg.K 💉 1.40054	UnitLess 💌	

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:

Mixed CSI CEngl	ish < OCas	e-0 💙 >	Help Messages	On Super	-Iterate	Super-Calculate	Load	Super-Initialize
State Panel		Process	Panel		Cycle Panel		I/O Pa	nel
< OState-2 😽 >	Calculate	No-Plots	Initialize	Format	ion Entholpy:	⊙No ⊙Yes	Air	~
p2	T2		✓ v2		u2		h2	
287.575 kPa 🗸	625.4084	K	✓ =v1/6.2	m^3/kg 💙	148.91806	kJ/kg	328.40186	kJ/kg
52	✓ Vel2		✓ z2		e2		j2	
s1 kJ/kg.K 🛩	0.0	m/e 🔹	✓ 0.0	m 🗸	148.91806	kJ/kg 👌	328.40186	kJ/kg
phi2	psi2		🖌 m2		Vol2		MM2	
kJ/kg 🗸		kJ/kg	✓ 1.0	kg 🗸	0.1394	m^3 🔊	28.97	kg/kmol

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

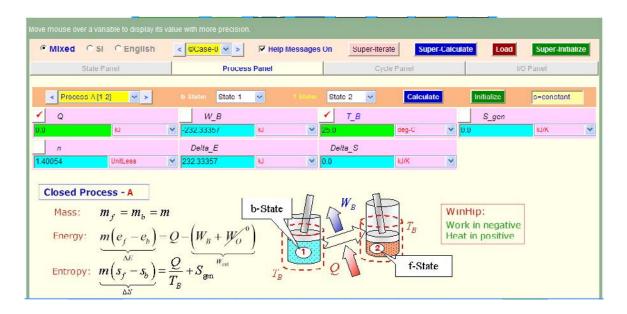
7. For State 3: m3 = m2, v3 = v2, since process 2-3 is at constant volume. Hit Enter. We get (later, after SuperCalculate):

Mixed SI	C Englis	sh <mark>< ©Cas</mark>	e-0 💙 >	₩ Help	Messages On	Super-	Iterate	uper-Calculate	Load	Super-Initialize
State Par	nel		Process F	anel			Cycle Panel		I/O	Panel
< CState-3 V	>	Calculate	No-Plots 🗸	2	Initialize	Formati	on Enthalpy:	No Yes	Air	~
p3		T3		1	v3		<i>u</i> 3		h3	
1749.9585 KPa	~	2307.1772	ĸ	=v2	.m^3/	kg 💌	1353.9181	kJ/kg	✓ 2016.0469	kJ/kg
83		 Vel3 		-	∠ 3		✓ e3		j3	
.83205 kJ/kg.	< v	0.0	m/s 🗸	0.0	m	~	1353.9181	kJ/kg	✓ 2016.0469	kJ/kg
phi3		psi3		1	m3		Vol3		ММЗ	
kJ/kg	· ·		kJ/kg 💊	-m2	kg	~	0.1394	m^3 •	28.97	kg/kmol

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

• Mixed	SI CE	nglis	ih <mark>< ©Ca</mark>	< 🗸 🗸	2	Help Me	ssages On	Super-	Iterate	Super Calculate		Load	Super Initiali	izə
Sta	ate Panel			Process	s Pan	el			Cycle Panel			1/0 Pa	anel	
< ©State-4	v >		Calculate	No-Plots	*	Ir	itialize	Formati	on Enthalpy:	ONO •Yes		Air		~
ρ4			T4						u4			h4		
368.90732	kPa	Y	1110.9644	к	×	=V1	m^3/kj) v	496.82254	kJ/kg	~	815.65436	kJ/kg	
s 4			✓ Vel4				1		e4			j4		
=s3	k.l/kg K	*	0.0	m/s	~	0.0	m	×	496.82254	k.l/kg	v	815.65436	k.l/kg	
phi4			psi4			 m 	4		Vol4			MM4		
	kJ/kg	~		kJ/kg	*	=m3	kg	*	0.86426	m*3	*	28.97	kg/kmol	
R4			u_p4			c_v4			k4					
0.28699	kJ/kg.K	~	1.00349	kJ/kg.K	¥	0.71651	kJ/kg.K	~	1.40054	UnitLess	~			

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:

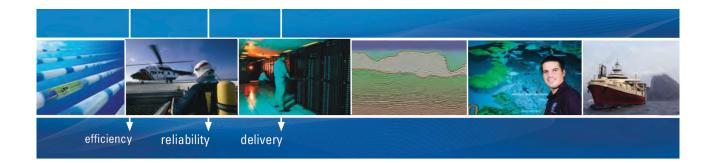
Mixed C SI C English	< Case-0 > F Heij	p Messages On Super-Ite	super-Calcula	ate Load S	uper-initialize
State Panel	Process Panel	C	ycle Panel	I/O Par	iel
< Process-R [2-3] V >	b-State: State-2 🗸	Fstate-3 V	Calculate	Initialize Vo	l=constant
the second se				Received and	
Q	W_B	✓ T_B		S_gen	
	W_B ✓ 0.0		deg C 💌	S_gen	J/K
		✓ T_B	deg C 🛛 👻 💽	S_gen	J/K

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

Mixed C SI C English	< Case-0 > F Help Messa	ges On Super-Iterate Super-Calculat	e Load Super-Initialize
State Panel	Process Panel	Cycle Panel	I/O Panel
< Process-C [3-4] V >	b-State: State-3 💌	State-4 Y	Initialize s=constant
Q	W_B	✓ T_B	S_gen
kJ	× 857.0955 kJ	✓ 25.0 deg-C ✓ 0.0	kJ/K

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

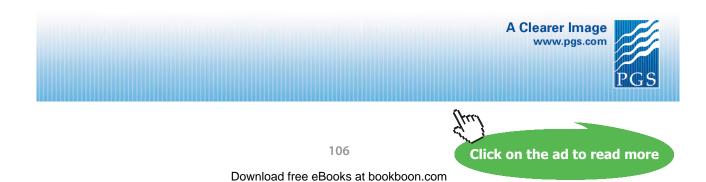
• Mixed C SI C English	< ©Case-0 > F Help Message	s On Super-Iterate Super-Calcula	ate Load Super-Initialize
State Panel	Process Panel	Cycle Panel	I/O Panel
< Process-D [4-1] V >	D-State: State-4 💌 t-state	State-1 V Calculate	Initialize Vol=constant
< Process-D [4-1] ▼ > Q	W_B	✓ T_B	S_gen
	W_B	✓ T_B	
Q	W_B	✓ T_B	S_gen



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

VO Panel State-Null
State-Null 👻
kl
6 kJ
net
ĸW
net

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 -----

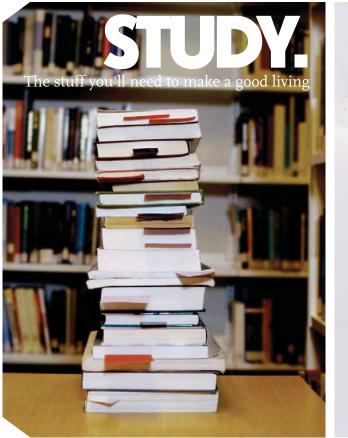
States {

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)
                                     v(m^3/kg) u(kJ/kg)
                                                             h(kJ/kg)
#
                          T(K)
                                                                          s(kJ/kg)
       1
               100.0
                          301.2
                                     0.8643
                                                -83.42
                                                             3.01
                                                                          6.897
#
       2
                                     0.1394
                                                148.92
                                                             328.4
#
               1287.58
                          625.4
                                                                          6.897
               4749.96
#
       3
                          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 \text{ 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;
```

Gas Power Cycles

#	Calculated: W_B= 857.0955 kJ; S_gen= -0.0 kJ/K; n= 1.4005353 UnitLess; Delta_E=
-857.0	955 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
UnitLe	ess;
#	Delta_E= -580.23804 kJ; Delta_S= -0.9353111 kJ/K;
# Cycl	e 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;





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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]

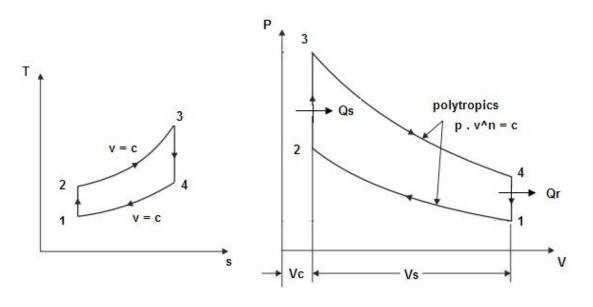


Fig.Prob.1.18

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:

			Spe	ecific, Clos	ed Process, (Cycle Da	emon	: PG Mode	el.				
		the	mofluids.net > ► Home ♂	Daemons >	Systems > Clos	ed > Proce	SS > 5	specific > Cyc					
		B	TEST		<u>ar</u> a	J _a () d	tt 🖌	>•	c _p = 0	onst			
Mixed	C SI C E	Inglis	ih < Case	e-0 💙 >	🔽 Help Message	s On SL	iper-iter	ate Supe	r-Calculate	Í	Load	uper-Initiali	ze
St	tate Panel			Process F	anel		Cy	de Panel		N.	I/O Pan	el	
< ©State-	1 💙 >		Calculate	No-Plots	Initialize	For	mation	Enthalpy: 🔘	No 💽 Yes		Air	v	•
🖌 p1			✓ T1		vt			u1			h1		
100.0	kPa	~	300.0	К 🔷	0.86096	m^3/kg	× 8	4.2305	kJ/kg	¥	1.85646	kJ/kg	v
st			✓ Vel1		✓ z1			et			j1		
6.8929	kJ/kg.K	۷	0.0	m/s 💉	0.0	m	¥ -8	4.2395	kJ/kg	۷	1.85646	kJ/kg	~
phi1			psi1		🖌 m1			Vol1			MM1		
	kJ/kg	×		kJ/kg 💊	1.0	kg	× 0	86096	m^3	۷	28.97	kg/kmol	~
R1			c p1		c v1			k1					
0.20699	kJ/kg.K	~	1.00349	kJ/kg.K	0.71651	kJ/kg.K	~ 1	40054	UnitLcaa	*			

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:

• Mixed C SI C Englis	ih < Case-0 V >	F Help Messages On	Super-Iterate Super-Calculate	Load Super-Initialize
State Panel	Process	Panel	Cycle Panel	I/O Panel
< <mark>©State-2 v</mark> >	Calculate No-Plots	v Initialize	Formation Enthalpy: 💿 No 💿 Yes	Air 🗸
p2	T2	✓ V2	u2	h2
01 * (V1N2)*1.3 kPa 💉	579.9546 K	✓ =v1/9 m^3/kg	116.35007 kJ/kg	✓ 282.78925 kJ/kg *
s2	✓ Vel2	🖌 z2	e2	j2
73462 kJ/kg.K 🗸	0.0 m/s	✓ 0.0 m	✓ 110.35007 kJ/kg	✓ 282.78925 kJ/kg *
phi2	psi2	✓ m2	Vol2	MM2
kJ/kg 💌	k.J/kg	🛩 =m1 kg	✓ 0.09566 m ⁴ 3	28.07 kg/kmol *

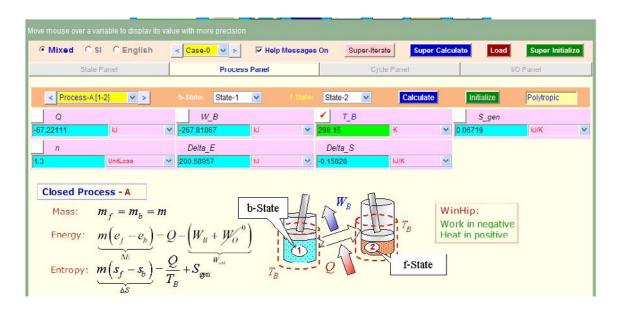
7. For State 3: enter T3 = 2000 K (by data), m3 = m1 and v3 = v2 since process 2-3 is at constant volume. Hit Enter:

	sh < Case-0 ¥	> V Help Messa	iges On S	super-iterate	uper-Calculate	Load	Super-Initialize
State Panel	Pr	ocess Panel		Cycle Panel		I/O Pa	nel
< CState-3 V >	Calculate No-F	Plots 💌 🛛 Initial	lize Fo	rmation Enthalpy:	○No •Yes	Air	~
p3	✓ T3	🖌 v3		u3		h3	
nnn n 🛛 👘 kPa 🛛 🛩	2000.0 K	✓ =v2	m^3/kg	× 1133 8232	kJ/kg 🗸	1707 7963	kJ/kg
s3	✓ Vel3	🖌 z3		e3		j3	
62162 k.l/kg K 💉	0.0 m/s	• 0.0	m	✓ 1133.8232	k.l/kg 🗸 🗸	1707.7963	k.l/kg
phi3	psiJ	🖌 m3		Vol3		ММЭ	
k.l/kg 💙	k.1/kg	✓ =m1	kg	♥ 0.09566	m^3 🗸	28.97	kg/kmnl

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:

	← Mixed ← SI ← English	< Case-0 > F Help	Messages On Super-Iterate	Super-Calculate	Load Super-Initialize
u4 h4 ✓ 442.0809 kJ/kg ✓ 738.98676 kJ/kg ✓ e4 J4 ✓ 442.0809 kJ/kg ✓ 730.98676 kJ/kg ✓ V0/4 MM/4	State Panel	Process Panel	Cycle Pan	el	I/O Panel
✓ 442.0809 ⊌JAg ✓ 738.98676 ⊌JAg ✓ e4 j4 ✓ 442.0009 ₩JAg ✓ 730.98676 ₩JAg ✓ V0/4 MM4	< <mark>@State-4 🗸 > Colo</mark>	ulate No-Plots 👻	Initialize Formation Enthalp	y: ONo OYes	Air 🗸 🗸
e4 j4 442.0009 kJ/kg ♥ 730.98676 kJ/kg • V0/4 MM/4	🖌 p4	T4 🖌	v4 u4	1	h4
✓ 442.0009 kJ/kg ✓ 730.98676 kJ/kg Vol4 MM/4	=p3*(v3/v4)*1.3 kPa 💉 1034	.5637 K 🛩 🕬	m*3/kg 🗡 442.0809) kJ/kg 🖌 7	138.98676 kJ/kg
Vol4 MM4	s4 🖌	Vel4	z4 e4	E	14
	7.7799 kJ/kg.K 😁 0.0	m/s 🗠 0.0	m 💉 442.0009) kJ/kg 🛩 7	738.98676 kJ/kg *
N 0.02002 ml2 N 00.07 kollmal	phi4 pt	14 🖌	m4 Vc	p/4	MM4
· 0.80090 · ···· · · · · · · · · · · · · · ·	kJ/kg 💙	kJ/kg 💌 -m1	kg 💉 0.86096	m^3 🗸 2	28.97 kg/kmol
k4			kg 🕑 0.86096	m*3 🗸 2	

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.

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

State Panel Process Panel Cycle Panel I/O Panel	Mixed C SI C English	< Case-0 > F Help Messages	s On Super-Iterate Super-Calo	ulate Load Super-Initial
	State Panel	Process Panel	Cycle Panel	I/O Panel
	State Fallel	Process Panel	Cycle Panel	I/O Panel
Process P 12 21 V State State 2 V State State 2 V Calculate Initialize Mal-soundary	Process P 19 21	h States Ctate 2	State 2 Calculate	Initializa Val-constant
Process-B [2-3] V > b-State: State-2 V f-State: State-3 V Calculate Initialize Vol-constar	< Process-B (2-3)	b-State: State-2 🗸	State-3 V Calculate	Initialize Vol-constant
W_B / T_B S_gen	Q	W_B	✓ T_B	S_gen

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

• Mixed C SI C English	< Case-0 > V Help	o Messages On Super-Iterate	Super Calculate	oad Super Initialize
State Panel	Process Panel	Cyde Pan	el	I/O Pariel
				_
< Process-C [3-4] V >	b-State: State-3 💉	State-4	Calculate Initialize	Polytropic
< Process-C [3-4] V >	otate-5	Cials 4		i olynopie
Q	W_B	✓ T_B	S_ge	
0	W_B	and the second		
	W_B	✓ T_B		an

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

• Mixed • SI • English	< Case-0 ∨ > I Help Me	ssages On Super-Iterate Supe	er-Calculate Load Super-Initializ
State Panel	Process Panel	Cycle Panel	I/O Panel
< Process-D [4-1]	b-State: State-4	State-1 V Calculat	te Initialize Vol=constant
< Process-D [4-1]	h-State: State-4	AState-1 V Calculat	te Initialize Vol=constant
< Process-D [4-1]	h-State: State-4 ▼ F	State-1 Calculat	te Initialize Vol=constant

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

St				> V Help Messag	es On	Supe	er-Iterate	Super-Calc	ulate	Load	Super-	Initializ
	ate Panel		Pro	cess Panel			Cycle Pane	4		VC) Panel	
Initialize		Calculate				State N	luli 🐱				State Null	~
I_max		I_min		p_max			p_min			Q_in		
000.0	К	✓ 300.0	К	✓ 6000.0	kPa	*	100.0	kPa	~	1249.2882	kJ	
Q_out		W_in		W_out			Q_net			W_net		
93.5415	N	267.81067	kJ .	✓ 923.5574	kJ	*	655.7467	KJ -	*	655.7467	kJ.	
S gen, int		eta th		MEP			N			Wdot ne	ət	
19939	kJ/K	52.48963	%	✓ 856.8521	kPa	*		hz	~		kW	

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:

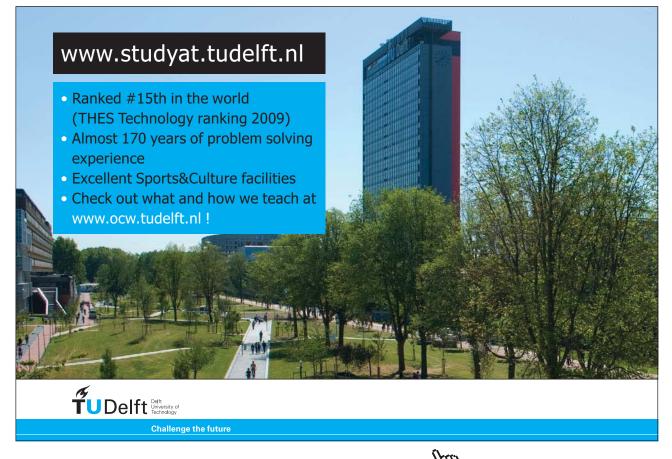
#~~~~~OUTPUT OF SUPER-CALCULATE

#	Daemon Path: Systems>Closed>Process>Specific>PowerCycle>PG-Model; v-10.ca08
#	Start of TEST-code
States	{

State-1: Air;

Gas Power Cycles

```
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; }
        }
```



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#		End of T	TEST-code -				
#	Proper	ty spreadsheet	t 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
#	Proper	ty spreadsheet	t ends				
# Ma	ss, Energ	y, and Entrop	y Analysis I	Results:			
#	Proces	s-A: b-State =	State-1; f-St	ate = State-2;			
#		Given: T_B=	298.15 K;				
#		Calculated: (Q= -67.221	115 kJ; W_B=	-267.8107 kJ; S	_gen= 0.0671	8519 kJ/K;
Unit	Less;						
#		Delt	a_E= 200.58	8957 kJ; Delta_	S= -0.15827553	kJ/K;	
#	Proces	s-B: b-State =	State-2; f-St	ate = State-3;			
#		Given: T_B=	298.15 K;				
#		Calculated:	Q= 1017.47	314 kJ; W_B=	0.0 kJ; S_gen	= -2.5256193	kJ/K; n= In
Unit	Less;						
#		Delta	a_E= 1017.4	47314 kJ; Delta	_S= 0.8870023	kJ/K;	
#	Proces	s-C: b-State =	State-3; f-St	ate = State-4;			
#		Given: T_B=	298.15 K;				
#		Calculated: (Q= 231.815	08 kJ; W_B= 9	923.5574 kJ; S_	gen= -0.61923	3605 kJ/K; 1
Unit	Less;						
#		Delt	a_E= -691.7	423 kJ; Delta_9	S= 0.15827553	kJ/K;	
#	Proces	s-D: b-State =	State-4; f-St	tate = State-1;			
#		Given: T_B=	298.15 K;				
#		Calculated:	Q= -526.32	04 kJ; W_B=	0.0 kJ; S_gen=	= 0.87828493	kJ/K; n= I
Unit	Less;						
#		Delt	a_E= -526.3	204 kJ; Delta_9	S= -0.8870023 l	κJ/K;	
# Cy	cle Analys	sis Results:					
#		Calculated: 7	$\Gamma_{max} = 200$	00.0 K; T_min=	300.0 K; p_ma	ax= 6000.0 kPa	a;
#		p_m	in= 100.0 k	Pa; Q_in= 1249	9.2882 kJ; Q_ou	ıt= 593.5415 k	J;
#		W_i	n= 267.8106	67 kJ; W_out=	923.5574 kJ; Q_	_net= 655.746	7 kJ;
#		W_r	net= 655.74	67 kJ; S_gen,in	t= -2.19939 kJ/	K; eta_th= 52	.48963 %;
			P= 856.8521	1 -			

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:

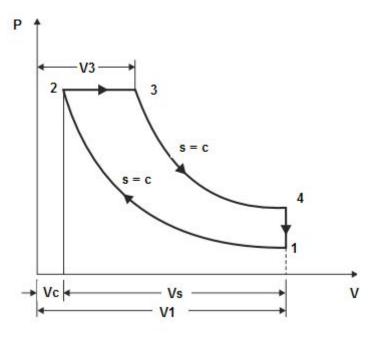


Fig.Prob.1.19

We have:

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

Define Mathcad Functions:

$$\begin{split} & \text{EFF}\big(rc,r,\gamma\big) \coloneqq 1 - \frac{1}{r^{\gamma-1}} \cdot \left[\frac{rc^{\gamma}-1}{\gamma \cdot (rc-1)} \right] \qquad \text{...Thermal efficiency} \\ & \text{W}\big(p1,\text{V1},r,rc,\gamma\big) \coloneqq p1 \cdot \text{V1} \cdot r^{(\gamma-1)} \cdot \left[\frac{\gamma \cdot (rc-1) - r^{1-\gamma} \cdot \left(rc^{\gamma}-1\right)}{\gamma-1} \right] \qquad \text{...Work output} \\ & \text{MEP}\big(p1,r,rc,\gamma\big) \coloneqq p1 \cdot \left[\frac{\gamma \cdot r^{\gamma} \cdot (rc-1) - r \cdot \left(rc^{\gamma}-1\right)}{(\gamma-1) \cdot (r-1)} \right] \qquad \text{...Work output} \end{split}$$

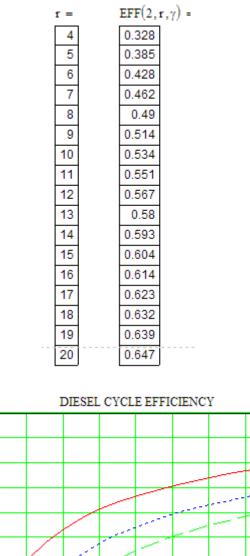
Now, use the above Functions to draw the graphs:

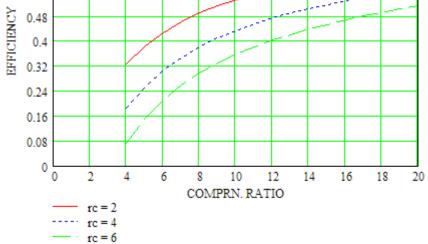
1) Thermal efficiency:

0.8 0.72 0.64 0.56

y := 1.4 r := 4,5..20 comprn. ratio defined as range variable

For cut off ratios of 2, 4, 6:





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

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

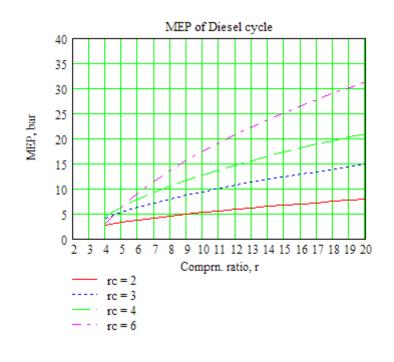
$\gamma := 1.4$ p1 := 1 bar

r =	$MEP(p1,r,2,\gamma)$	$M\!E\!P(p1,r,3,\gamma)$	$\texttt{MEP}(\texttt{p1},\texttt{r},\texttt{4},\gamma)$	$MEP(p1, r, 6, \gamma)$
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





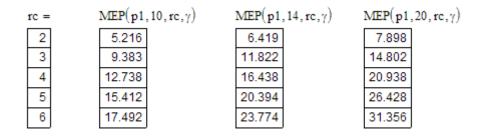
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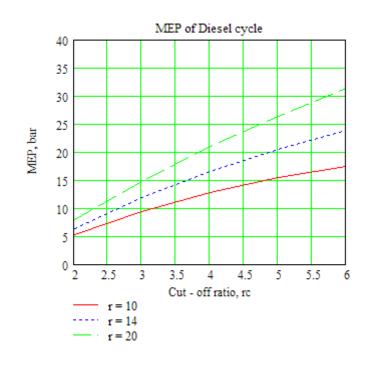


3) Mean Effective Pressure (MEP) vs cut-off ratio:

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

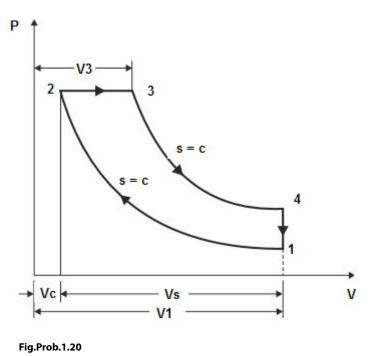
$\gamma := 1.4$ p1 := 1 bar





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:



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.

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Alternatively:

```
\gamma := 1.4 \quad \mathbf{r} := 14 \quad \text{mep} := 7.5 \quad \mathbf{p1} := 1 \quad \text{bar}\mathbf{rc} := 6 \quad \text{Trial value}Given\mathbf{mep} = \frac{\mathbf{p1}}{\mathbf{r} - 1} \cdot \left[ \mathbf{r}^{\gamma} \cdot (\mathbf{rc} - 1) + \frac{\mathbf{r}^{\gamma} \cdot \mathbf{rc} - \mathbf{rc}^{\gamma} \cdot \mathbf{r}}{\gamma - 1} - \frac{\mathbf{r}^{\gamma} - \mathbf{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:

$$\frac{V_3 - V_c}{V_s} = \frac{V_3 - V_c}{V_1 - V_c} = \frac{\frac{V_3}{V_c} - 1}{\frac{V_1}{V_c} - 1} = \frac{rc - 1}{r - 1}$$

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

Therefore:

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

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.]

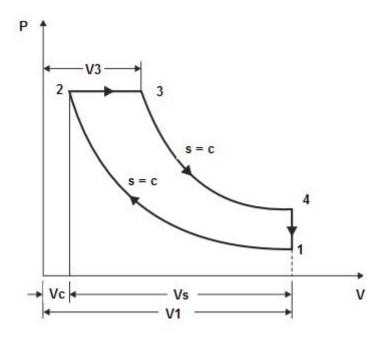


Fig.Prob.1.21

Mathcad Solution:

Data:

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

r := 16comprn. ratio

γ := 1.4 R := 287 J/kg.K

Gas Power Cycles

Calculations:

$$V_s := \frac{\pi \cdot D^2}{4} \cdot L$$
 i.e. $V_s = 9.425 \times 10^{-3}$ m^A3... stroke vol.

$$V2 := \frac{V_s}{r-1}$$
 i.e. $V2 = 6.283 \times 10^{-4}$ m^A3....clearance vol.

 $V1 := V_s + V2$ i.e. V1 = 0.01 m^A3

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



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i.e. $r_c := 2.5$ cut off ratio

T3 := $r_c \cdot T2$ i.e. T3 = 2.274 × 10³ 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 × 10³ K...Ans

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

Heat added, Qs:

Now:
$$m := \frac{P1 \cdot 10^{2} \cdot V1}{R \cdot T1}$$
 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:

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:

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

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

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

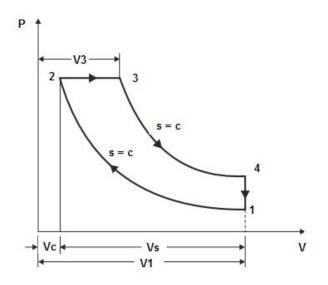
$$\begin{split} & \text{EFF}\big(rc,r,\gamma\big) \coloneqq 1 - \frac{1}{r^{\gamma-1}} \cdot \left[\frac{rc^{\gamma}-1}{\gamma \cdot (rc-1)} \right] \qquad \text{...Thermal efficiency} \\ & \text{W}\big(\text{P1},\text{V1},r,rc,\gamma\big) \coloneqq \text{P1} \cdot \text{V1} \cdot r^{(\gamma-1)} \cdot \left[\frac{\gamma \cdot (rc-1) - r^{1-\gamma} \cdot \left(rc^{\gamma}-1\right)}{\gamma-1} \right] \qquad \text{...Work output} \\ & \text{MEP}\big(\text{P1},r,rc,\gamma\big) \coloneqq \text{P1} \cdot \left[\frac{\gamma \cdot r^{\gamma} \cdot (rc-1) - r \cdot \left(rc^{\gamma}-1\right)}{(\gamma-1) \cdot (r-1)} \right] \qquad \text{...Mean effective pressure} \end{split}$$

We get:

$$EFF(\mathbf{r}_{c}, \mathbf{r}, \gamma) = 0.591 = 59.1 \% \dots \text{ Ans.}$$
$$W(P1 \cdot 10^{5}, V1, \mathbf{r}, \mathbf{r}_{c}, \gamma) = 9.448 \times 10^{3} \text{ J/cycle } \dots \text{ Ans.}$$
$$MEP(P1, \mathbf{r}, \mathbf{r}_{c}, \gamma) = 10.025 \text{ bar.... Ans.}$$

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.]





Mathcad Solution:

Data:

Calculations:

Find temps. at all the four salient points:

Process 1-2:

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

Then:

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

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

Process 2-3:

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

Process 3-4:

$$\begin{split} P4 &:= P3 \cdot \left(\frac{1}{r} \cdot \frac{T3}{T2}\right)^{\gamma} & \text{ i.e. } P4 = 2.331 \quad \text{ bar.,} \\ \\ T4 &:= T3 \cdot \left(\frac{P4}{P3}\right)^{\frac{\gamma}{1}} & \text{ i.e. } T4 = 706.365 \quad \text{ K.} \end{split}$$

Heat rejected, QR:

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



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Therefore:

 $\label{eq:QR} \mathsf{Q}_R := \mathsf{cv} \cdot (\mathsf{T4} - \mathsf{T1}) \qquad \text{i.e.} \qquad \mathsf{Q}_R = \mathsf{289.414} \qquad \mathsf{kJ/kg....} \text{ heat rej.}$

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.]

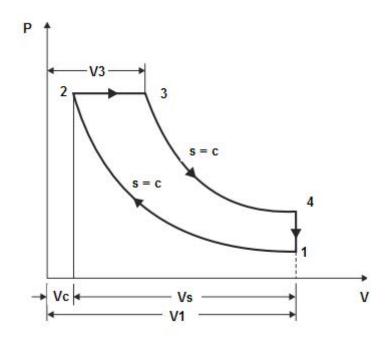


Fig.Prob.1.23

Mathcad Solution:

Data:

 $\label{eq:L} \begin{array}{cccccccc} L := 0.12 & m & D := 0.1 & m & P1 := 1 & bar & T1 := 303 & K & T3 := 1850 & K \\ \gamma := 1.4 & R := 287 & J/kg.K & n := 4 & \dots no. \ of \ cyl. & N := 2200 & rpm \end{array}$

Calculations:

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

$$V_s := \frac{\pi \cdot D^-}{4} \cdot L$$
 i.e. $V_s = 9.425 \times 10^{-4}$ m^A3... 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^A3

Process 1-2:

T2 := T1· $r^{\gamma-1}$ 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
$$\left(\frac{r_c}{r}\right)^{\gamma}$$
 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.



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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.:

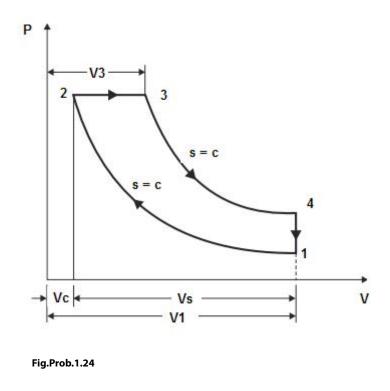
$$\eta := \frac{W}{Q_s} \cdot 100$$
 i.e. $\eta = 61.77$ %....Ans.

Mean Effective Pressure:

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

i.e. $mep = 7.012 \times 10^{3}$ 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 cm³ 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.]



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

Mathcad Solution:

Data:

 $L := 0.25 \ \text{m} \qquad D := 0.2 \ \text{m} \qquad P1 := 1.05 \ \text{bar} \qquad T1 := 350 \ \text{K}$

 $\gamma := 1.4$ R := 287 J/kg.K V2 := 500.10⁻⁶ 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^A3... stroke vol.

$$V1 := V_s + V2$$
 i.e. $V1 = 8.354 \times 10^{-3}$ m^A3

$$\mathbf{r} := \frac{V1}{V2}$$
 i.e. $\mathbf{r} = 16.708$...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

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

Gas Power Cycles

Therefore:

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

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

And,

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

Heat added, Qs:

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 $m := \frac{P1 \cdot 10^{5} \cdot V1}{R \cdot T1}$ 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

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Heat rejected, Qr:

$$\begin{split} cv &:= \frac{R}{\gamma-1} & \text{i.e. } cv = 717.5 & \text{J/kg.K} \\ Q_r &:= m \cdot cv \cdot (T4-T1) & \text{i.e. } Q_r = 2.744 \times 10^3 & \text{Joules/cycle.} \end{split}$$

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:

$$\begin{split} \text{EFF} \Big(\mathbf{r}_{c}, \mathbf{r}, \gamma \Big) &\coloneqq 1 - \frac{1}{r^{\gamma - 1}} \cdot \left[\frac{\mathbf{r}_{c}^{\ \gamma} - 1}{\gamma \cdot (\mathbf{r}_{c} - 1)} \right] \qquad \text{...Thermal efficiency of Diesel cycle} \\ \eta &\coloneqq \text{EFF} \Big(\mathbf{r}_{c}, \mathbf{r}, \gamma \Big) \qquad \text{i.e.} \quad \eta = 0.631 \quad = \textbf{63.1 \%....Ans.} \end{split}$$

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.

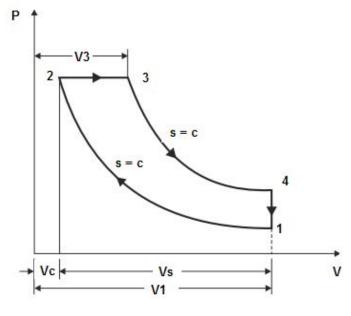


Fig.Prob.1.25

"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
-----	------	---

For rc = 4

116	1 rr	2 τ 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

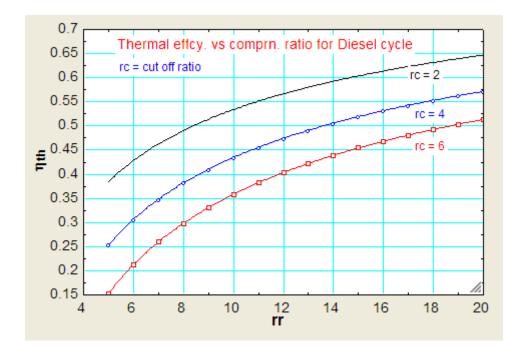
116	t rr	2 ν _{th}
Run 1	5	0.254
Run 2	6	0.3065
Run 3	7	0.348
Run 4	8	0.3819
Run 5	9	0.4103
Run 6	10	0.4346
Run 7	11	0.4558
Run 8	12	0.4744
Run 9	13	0.491
Run 10	14	0.5058
Run 11	15	0.5193
Run 12	16	0.5315
Run 13	17	0.5428
Run 14	18	0.5531
Run 15	19	0.5627
Run 16	20	0.5715

Gas Power Cycles

For **rc** = 6:

116	1 rr	2 ▼ ηth
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:



"**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 m³, 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]"

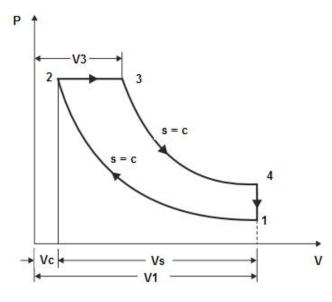


Fig.Prob.1.27



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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
η _{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]
∨1 = 0.01415 [m ³]	√2 = 0.0008844 [m ³]	∨3 = 0.002211 [m ³]
∨4 =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:

114	1 rr	² Q _s [kJ/cycle]	³	4 ▼ η _{th}	⁵
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



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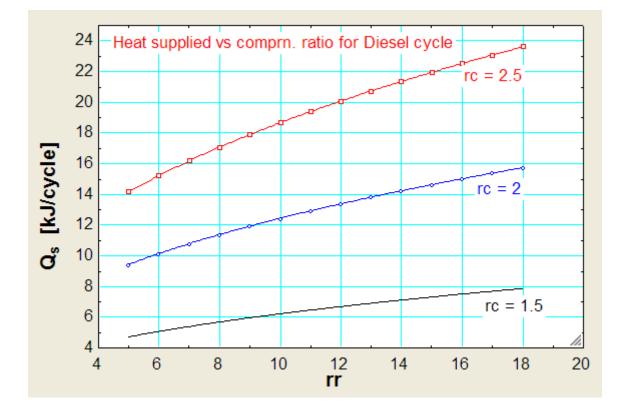
For **rc** = 2:

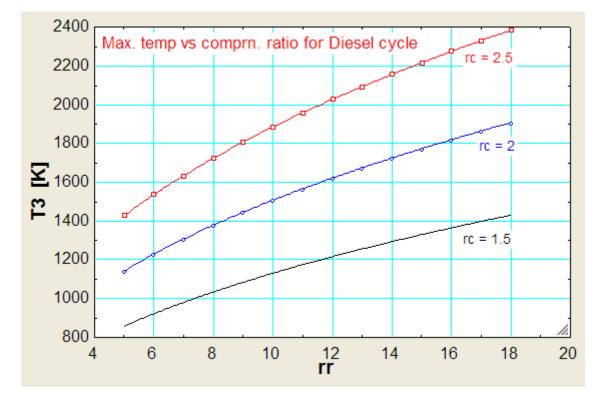
114	1 rr	² Q _s [kJ/cycle]	³ T3 [K]	4 ν _{th}	⁵
Run 1	5	9.428	1142	0.385	320.7
Run 2	6	10.14	1229	0.4283	368.3
Run 3	7	10.79	1307	0.4625	411.3
Run 4	8	11.38	1378	0.4904	450.7
Run 5	9	11.93	1445	0.5139	487.3
Run 6	10	12.44	1507	0.5339	521.6
Run 7	11	12.92	1566	0.5514	553.9
Run 8	12	13.38	1621	0.5667	584.6
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:

114	1 rr	² Q _s [kJ/cycle]	³ T3 [K]	4 ν _{th}	⁵ 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:





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Priyanka Sawant Manager



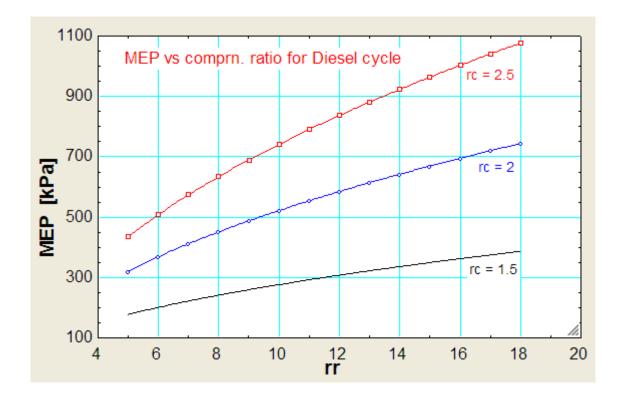
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"**Prob.1.28.** Air in a piston – cylinder device of bore = 200 mm, stroke = 300 mm and a clearance volume = 7% of stroke volume, undergoes a Diesel cycle. The P and T of air at the beginning of compression are 1 bar and 27 C. The max. temp. in the 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]"

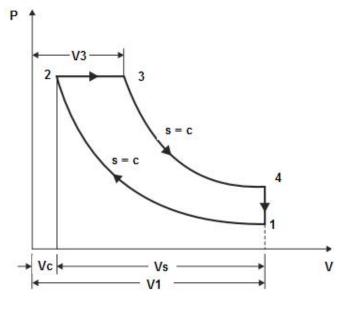


Fig.Prob.1.28

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." $V_c = 0.07 * V_s m_3...clearance vol."$ 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]
∨1 =0.01008 [m ³]	∨2 = 0.0006597 [m ³]	∨3 = 0.001404 [m ³]
∨4 =0.01008 [m ³]	∨ _c =0.0006597 [m ³]	∨ _s = 0.009425 [m ³]
W = 7.113 [kJ/cycle]		

Thus:

Comprn. ratio = rr = 15.29 Ans.

Cut-off ratio = rc = 2.128 Ans.



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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:"
```

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

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."
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]	ov = 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]

Thus:

W_{net} = 658.8 [kJ/kg]

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.

Gas Power Cycles

"**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]"

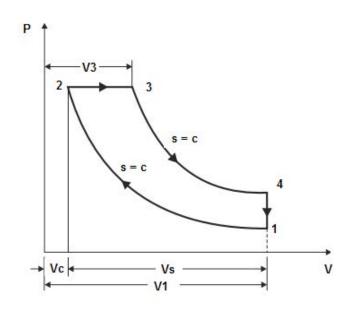


Fig.Prob.1.27

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:" $Q_r = m * cv * (T4 - T1) "kJ/kg \dots$ 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" "_____»

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"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]	$\eta_{th} = 0.6602$
$\eta_{th,2} = 0.6602$	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]
∨1 = 0.5453 [m ³]	V2 = 0.02727 [m ³]	∨3 =0.04666 [m ³]
∨4 = 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:

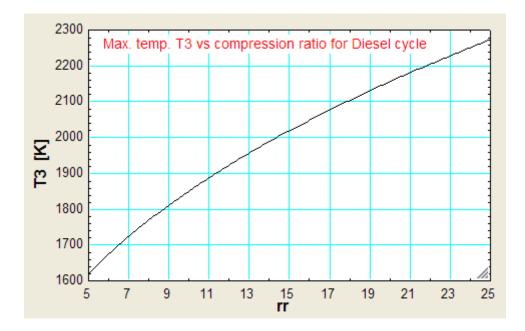
i.e. eta_th_2 = 0.6602, W_net_2 = 594.2 kJ/kg, and MEP_2 = 1147 kPa.

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

121	1 rr	² ▼ T3 [K]	3 rc	⁴ ₩ _{net} [kJ/kg]	5 Σ η _{th}	⁸ 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

First, compute the Parametric Table:

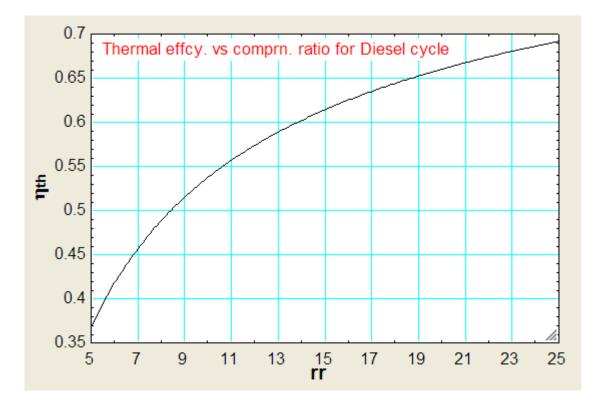
Now, plot the results:

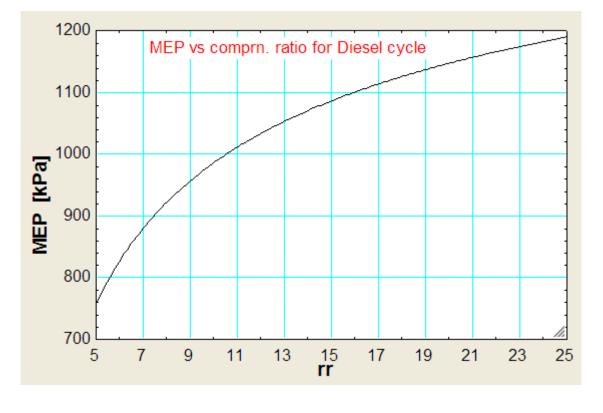






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"**Prob.1.31.** An oil engine works on ideal Diesel cycle, with a compression ratio of 20. Heat addition at constant pressure takes place up to 10% of stroke. Initial pressure and temp are 1 bar and 67 C. Compression and expansion follow the law P. $v^{1.3}$ = 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."

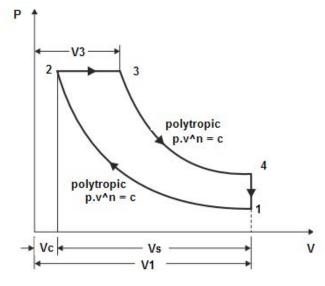


Fig.Prob.1.31

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EES Solution:

Note that here, the compression and expansion are <u>not</u> 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. $W_{net} = P2 * (V3 - V2) + R * (T3 - T4) / (n-1) - R * (T2 - T1) / (n - 1) ... kJ/kg...net work output"$ $W_{net} = P2 * (V3 - V2) + R * (T3 - T4) / (n-1) - R * (T2 - T1) / (n - 1) "...kJ/kg"$

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

"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]	√1 = 0.9758 [m ³]
∨2 = 0.04879 [m ³]	√3 = 0.1415 [m ³]	∨4 = 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:

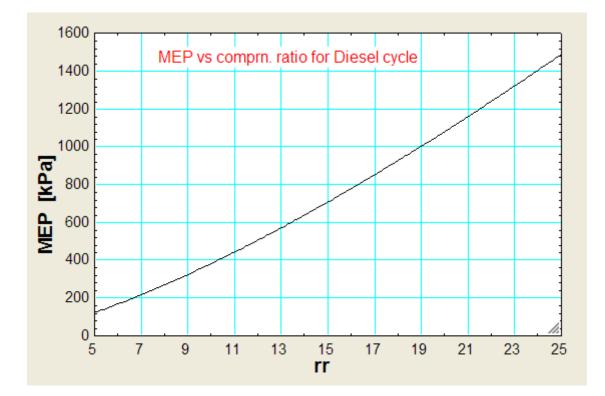
First, compute the Parametric Table:

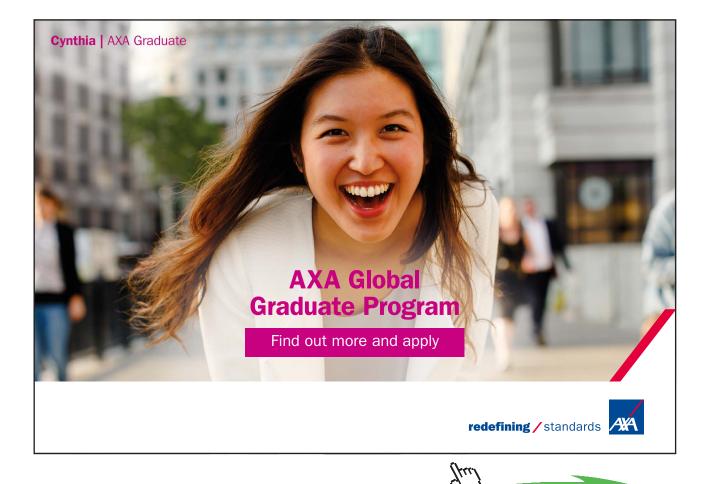
121	1 rr	² ₩ _{net} [kJ/kg]	³ MEP [kPa]	4 Σ η _{th}
Run 1	5	95.64	122.5	0.432
Run 2	6	136.2	167.5	0.4658
Run 3	7	180.9	216.3	0.4924
Run 4	8	229.2	268.5	0.5138
Run 5	9	280.8	323.8	0.5317
Run 6	10	335.4	381.9	0.5468
Run 7	11	392.5	442.5	0.5598
Run 8	12	452.2	505.5	0.5711
Run 9	13	514.1	570.7	0.5811
Run 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

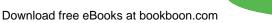
Now, plot the results:



Gas Power Cycles

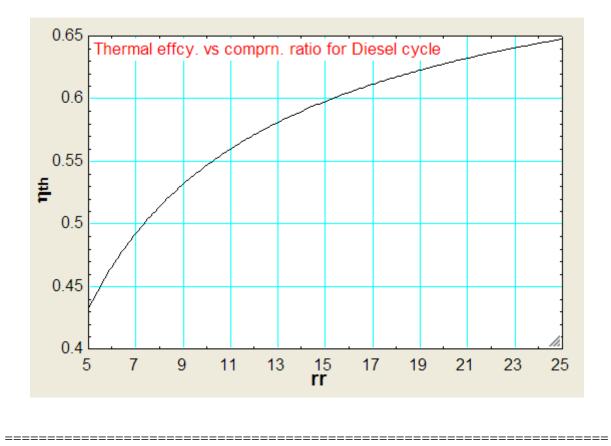






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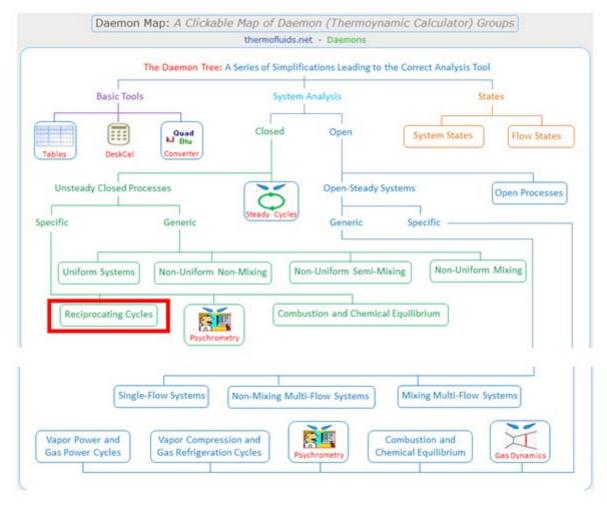
1.3.3 Problems solved with TEST:

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:

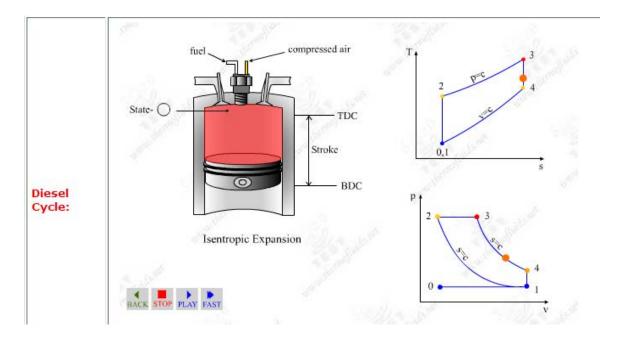
1. From the TEST daemon tree, select the 'Reciprocating cycles' daemon:



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:





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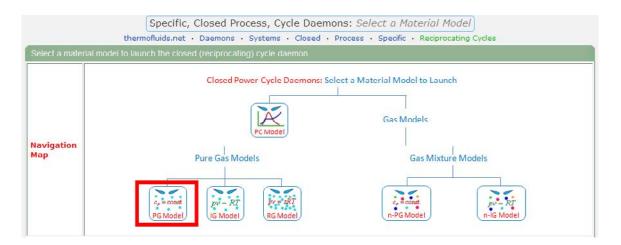
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* Figures taken from London Business School's Masters in Management 2010 employment report



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::

				Spe	ecific, Cl	ose	d P	rocess, (Cycle [Daemo	on: PG I	Model				
	thermo	ofluids	.net	Daemo	ns • Syst	ems	• (Closed • P	rocess	• Spec	tific • Red	iprocating Cyc	les	• PG Model		
Nove mouse ove	er a variable f	o displ	ay its v	alue with n	nore precisi	on										
• Mixed	C SI CI	Engli	sh	< ©Ca	sc 0 🗸 >		₩ Ho	Ip Messages	On	Super	Iterate	Super-Calcula	te	Load	Super-Initia	lize
1	State Panel				Proce	ss Pa	anel		1		Cycle Pane	6		I/O F	anel	
< ©State	<mark>-1</mark> ¥ >		Calcu	late	No-Plots	6 Y		initialize		Formatic	on Enthalpy:	ONO •Ye	s	Air		~
🖌 p1		- 1	1	T1				v1			u1		. 1	h1		
98.0	kPa	~	100.0		dcg-C	~	1.00)275	m^3/kg	~	31.82608	kJ/kg	~	75.26205	kJ/kg	~
61			-	Vol1			1	z1			01			j1		
7.11766	kJ/kg.K	~	0.0		nvs	*	0.0		m	*	-31.82698	kJ/kg	×	75.26205	kJ/kg	~
phi1			psi	1			1	m1			Vol	1		MM1		
	kJ/kg	~			kJ/kg	~	1.0		kg	~	1.09275	m^3	~	28.97	kg/kmol	~
R1			c_p	1			c	1			k1					
0.28699	kJ/kg.K	*	1.0034	19	kJ/kg.K	~	0.71	1651	kJ/kg.K	~	1.40054	UnitLess	Y			

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:

Mixed CSI CEnglish	< ©Case-0 🛩 >	🔽 Help Messages O	Super-Iterate	Super-Calculate	Load	uper-Initialize
State Panel	Process	s Panel	Cycle Pane	el 🔰	I/O Pan	el
< ©State-2 v > Ca	culate No-Plots	v Initialize	Formation Enthalpy	No 💿 Yes	Air	~
p2	T2	✓ v2	u2	9	h2	
48.3792 kPa 🗡 107	3.8613 K	✓ =v1/14	*3/kg ¥ 470.2379	kJ/kg 💉	778.42163	kJ/kg 🗸 🗸
s2 🗸	Vel2	1 27	e2		12	
1 kJ/kg.K 🛛 0.0	m/s	✓ 0.0	m × 470.2379	kJ/kg 💉	770.42163	kJ/kg 🗠
phi2 p	si2	✓ m2	Vo	12	MM2	
k.l/kg 💙	k.l/kg	🗙 =m1 🕴	o ✓ 0.07805	m^3 💉	28.97	kg/kmal 🗸

Here, p2 = 3948.38 kPa, T2 = 1073.86 KAns.

7. Similarly, for State 3: Enter $p_3 = p_2$ (since Process 2-3 is a const. pressure process), $v_3 = v_2 * 2.2$ (since cut off ratio is 2.2), and $m_3 = m_1$. Hit Enter, and we get:

Mixed OSI CEnglish	< ©Case-0 🛩 >	🔽 Help Messages On	Super-Iterate	Super-Calculate	Load	per-Initialize
State Panel	Proces	s Panel	Cycle Panel		I/O Pane	1
< <mark>©State-3 v</mark> >	alculate No-Plots	✓ Initialize	Formation Enthalpy:	ONO • Yes	Air	~
p3	T3	🖌 v3	u3	(h3	
p2 kPa 💉 🛛	362.4949 K	✓ =v2*2.2 m*3/	kg 🖌 1393.5535	i kJ/kg 🗡	2071.5576	kJ/kg 💊
\$3	Vel3	🖌 z3	e3		j3	
90887 kJ/kg.K 🛩 0	0 m/s	🗙 0.0 m	1393.5535	kJ/kg 🗠	2071.5576	kJ/kg
phi3	psi3	✓ m3	Vol	3	ММЗ	
kJ/kg 💙	kJ/kg	🗙 =m1 kg	⊻ 0.17172	m^3 🗸	28.97	kg/kmol

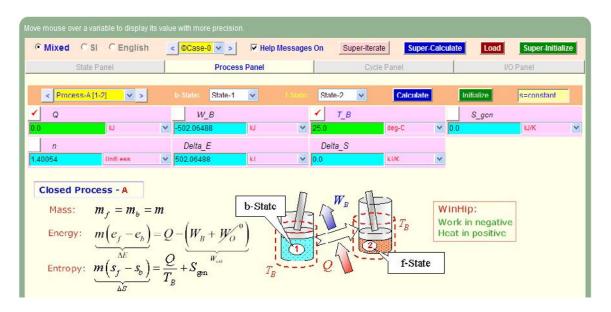
Here, p3 = p2 = 3948.38 kPa, T3 = 2362.49 KAns.

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:

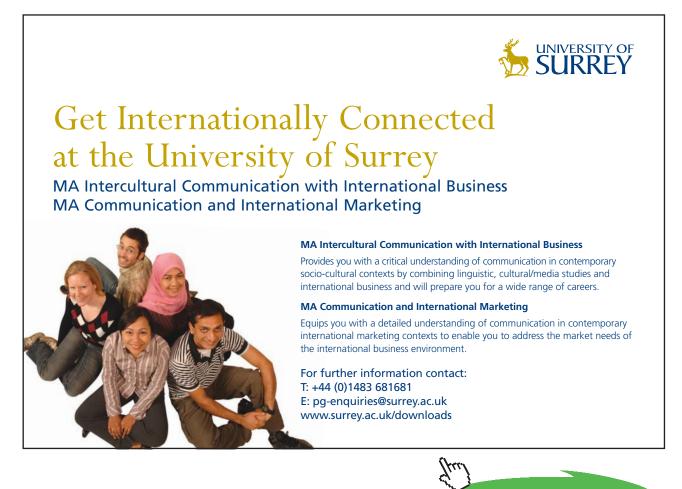
Mixed SI	C Engli	sh < Ca	se-0 💌 >	🔽 Help	Messages On	Super-	-Iterate	Super-Calculate	L	oad	Super-Initiali	ize
State Pa	anel		Process	Panel			Cycle Panel			I/O Pa	nel	
< <mark>©State-4</mark> ¥	>	Calculate	No Plots	~	Initialize	Formati	on Enthalpy:	ONo OYes	/	Air		-
p4		T4		*	v4		u4			h4		
295.66583 kP	a ~	1125.7928	K	∽ =v1	mt	3/kg 🛩	507.44727	kJ/kg	× 830	0.53467	kJ/kg	1
* 54		✓ Vel4		*	74		e4			<i>j4</i>		
=s3 kJ/kg	.К 👻	0.0	m/s	~ 0.0	r	n 👻	507.44727	kJ/kg	~ 030	0.53467	kJ/kg	1
phi4		psi4		-	m4		Vol4		1	MM4		
k.J/k	g 🖌		kJ/kg	∽ =m1	kg	~	1.09275	m^3	~ 28.	97	kg/kmol	
R4		c_p4		C_1	v4		k4					
0.28699 kJ/kg	.K 🗸	1.00349	kJ/kg.K	· 0.716	51 kJ/k	g.K 🗸	1.40054	UnitLess	~			

Here, p4 = 295.67 kPa, T1 = 1125.79 KAns.

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.



Click on the ad to read more

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

• Mixed CSI CEnglish	< Case-0 > Felp Messages	s On Super-Iterate Super-Calcu	late Load Super-Initialize
State Panel	Process Panel	Cycle Panel	I/O Panel
	CONTRACTOR OF A DESCRIPTION OF A DESCRIP	Contraction of the second s	
< Process-B [2-3] 🗸 >	h-State: State-2 💌 6-State:	State-3 V Calculate	Initialize p=constant
< Process-B (2-3) >	W_B	✓ T_B	Initialize p=constant S_gen
Q	W_B	✓ T_B	S_gen
	W_B	✓ T_B 25.0 deg-C ♥	
	W_B	✓ T_B	S_gen

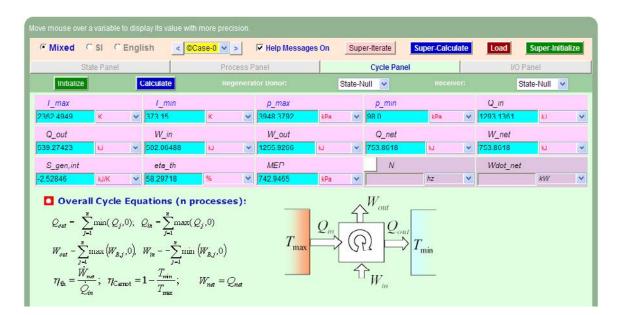
11. And, similarly for Process 3-4:

Q = 1293.1361 kJ [Net heat transfer]			
• Mixed C SI C English	< Case-0 > Felp Messages	On Super-Iterate Super-Calcu	late Load Super-Initialize
State Panel	Process Panel	Cycle Panel	I/O Panel
< Process-C [3-4] >	is-State: State-3 💌 F-State:	State-4 Calculate	Initialize s=constant
<u>~</u> q	W_B	✓ Т_В	S_gen
0.0 kJ	✓ 886.1062 kJ ✓	25.0 deg-C 💙	0.0 kJ/K 💙
n	Delta_E	Delta_S	
1.40054 UnitLess	✓ -886.1062 kJ ✓	0.0 kJ/K 🛩	

12. Again, for Process 4-1:

• Mixed C SI C English	< Case-0 V >	Help Messages On	Super-Iterate Super	r-Calculate Load	Super-Initialize
State Panel	Process P	anel	Cycle Panel		I/O Panel
< Process-D [4-1] ¥ >	b-State: State-4	 E-State: State 	-1 V Calculate	e Initialize	Vol=constant
	1				
Q	W_B		I_B	S_gen	
					kJ/K
	₩ 0.0	kJ 💙 25.0	deq-C	✓ 1.01752	kJ/K
	0.0 Delta E	⊌ <u>≥</u> 25.0 Delt	The second second	✓ 1.01752	kJ/K

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; }
	}

Analys	is {										
	Process	-A: b-State =	State-1; f-Stat	e = State-2;							
	Given:	{ Q= 0.0 kJ; T	_B= 25.0 deg	-C; }							
	Process	-B: b-State = 3	State-2; f-State	e = State-3;							
	Given:	{ T_B= 25.0 d	.eg-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 d	.eg-C; }								
	}										
#		End of T	EST-code								
#	Propert	ty 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				
#	Propert	ty 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 \text{ 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;
```

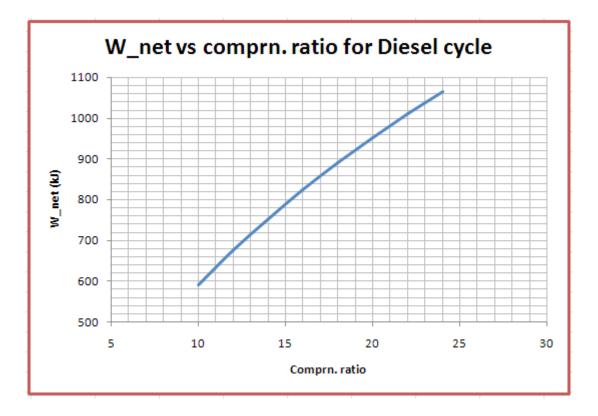
In addition:

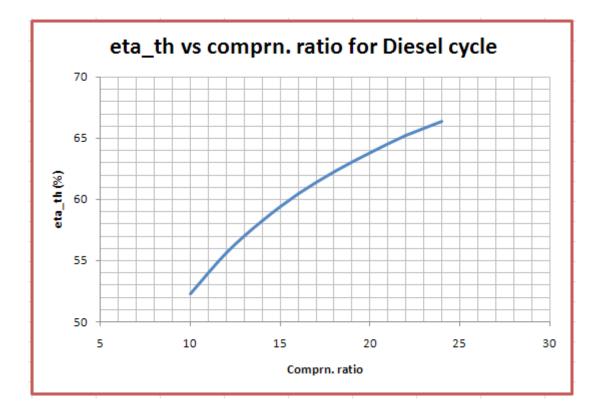
To plot the variation of W_net, eta_th and MEP with compression ratio varying from 10 to 24, following are the steps:

- 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:



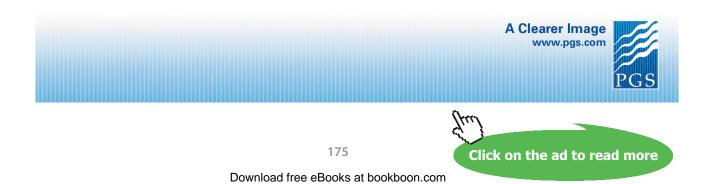


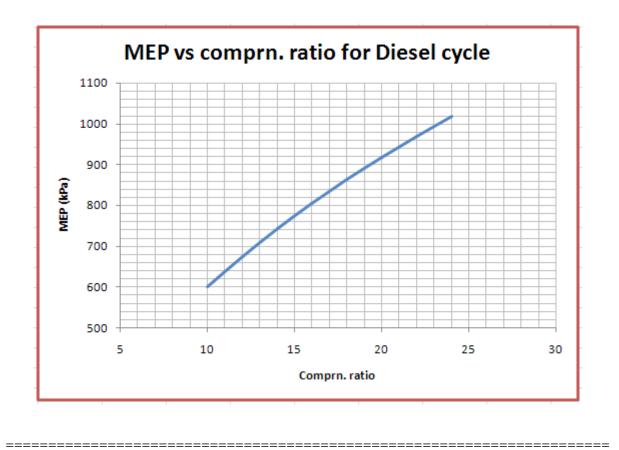


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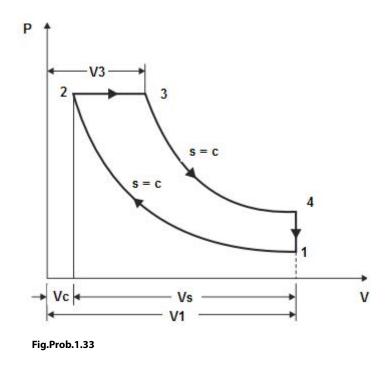
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Prob.1.33. The compression ratio of a Compression Ignition engine working on Diesel cycle is 16. Temp and pressure of air at the beginning of compression is 300 K and 1 bar, and the temp of air at the end of expansion is 900 K. Determine: (i) cut off ratio (ii) expansion ratio, and (iii) the cycle efficiency.



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:

	therm	ofluids	.net ·		101. 1 10 10 10 10		Process, C Closed · Pr		100000000000000000000000000000000000000		procating Cyc	les	PG Model		
ove mouse ov	11.000	7 81.05 5		5.10	1313										
Mixed				< Case-0	* >		lelp Messages	On	Super-	Iterate	Super-Calculat	e	Load	Super-Initial	ize
	State Panel		1		Process	Pane	L.			Cycle Panel	1		I/O P	anel	
< @Stat	e-1 v >		Calcula	te	No-Plots	~	Initialize		Formatio	on Enthalpy:	ONo OYes	5	Air		~
✓ p1			< T	1			v1			u1			h1		
100.0	kPa	~	300.0		<	~ 0.	06096	m^3/kg	~	-04.2395	kJ/kg	*	1.05646	kJ/kg	•
st			1	Vel1			21			et			jt		
0.8929	kJ/kg.K	*	0.0	n	vs.	~ 0.	0	m	¥	-84.2395	kJ/kg	~	1.85646	kJ/kg	2
phi1			psi1			1	m1			Vol1			MM1		
	kJ/kg	~		k	J/kg	~ 1	0	kg	*	0.80090	m*0	*	28.97	kg/kmol	
R1			c	_p1			c_v1			k1					
0.28099	kJ/kg.K	*	1.00349	kJ	kg.K	~ 0.	71051	kJ/kg.K	*	1.40054	UnitLess	~			

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:

• Mixed	C SI CI	Englis	sh <mark>< Ca</mark>	ise-0 💙 >		₩ He	lp Messages	On	Super-	Iterate	Super-Calculate	•	Load	Super-Initial	ize
5	itate Panel			Proc	ess Pa	anel			(Cycle Panel			I/O Pa	nel	
< ©State	2 × >		Calculate	No-Plo	ts 👻		Initialize	Ţ	ormatic	on Enthalpy:	ON0 •Yes		Air		~
p2			T2			1	v2			u2			h2		
4857.497	kPa	~	910.7807	K	¥	=v1/	/16	m^3/kg	~	353.38943	k.l/kg	×	614.77124	k.l/kg	8
✓ s2			✓ Vel2			-	z2			e2			j2		
=s1	kJ/kg.K	*	0.0	n√s	*	0.0		m	~	353.38943	kJ/kg	*	614.77124	kJ/kg	
phi2			psi2			-	m2			Vol2			MM2		
	kJ/kg	~		kJ/kg	~	=m1	1	kg	~	0.05381	m^3	~	28.97	kg/kmol	
R2			c_p2				c_v2			k2					
0.28699	kJ/kg.K	4	1.00349	kJ/kg.K	Y	0.71	1651	kJ/kg.K	Y	1.40054	UnitLess	v			

Here, p2 = 4857.497 kPa, T2 = 910.78 KAns.

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:

• Mixed	C SI C	Englis	sh 🤜	ase 0 🗸 >	1	✓ Help	p Messages	On	Super	Iterate	Super-Calculat	6	Load	Super-Initial	ize
S	tate Panel			Proce	ess Pa	anel		1		Cycle Panel			1/0 P	anel	
< ©State-	4 ¥ >		Calculate	No-Plot	s 🗸		Initialize	F	ormatio	on Enthalpy:	ONO •Yes	X	Air		~
p4			 ✓ T4 			1	v4			u4			h4		
300.0	kPa	~	900.0	К	~	=v1		m^3/kg	~	345.66498	kJ/kg	~	603.9529	kJ/kg	•
s4			✓ Vel4			1	z4			e4			j4		
7.68006	kJ/kg.K	~	0.0	m/s	*	0.0		m	*	345.66498	kJ/kg	~	603.9529	kJ/kg	1
phi4			psi4			-	m4			Vol4			MM4		
	kJ/kg	~		kJ/kg	~	=m1		kg	~	0.86096	m^3	*	28.97	kg/kmol	
R4			c_p1				c_v1			k1					
0.28699	kJ/kg.K	*	1.00349	kJ/kg.K	~	0.716	851	kJ/kg.K	*	1.40054	UnilLess	~			

Note that p4 = 300 kPa, T4 = 900 K. And, s4 is also calculated as s4 = 7.68006 kJ/kg.K

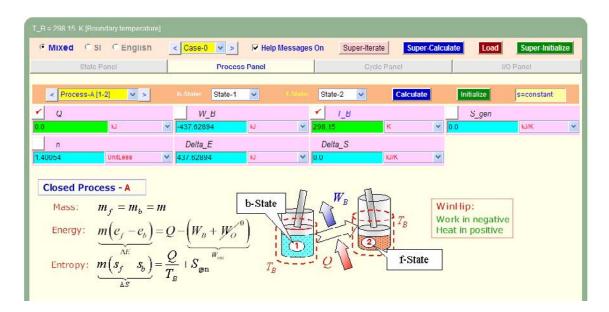


8. Then, go back to State 3. Remember that now s3 = s4. Click on Calculate. We get:

• Mixed CSI CEng	lish < Case	<mark>:-0 ♥</mark> >	Help Messages O	n Super-It	terate	uper-Calculate	Load	Super-Initialize
State Panel		Process Pa	anei	C	Cycle Panel		I/O Pai	nel
< State-3 V >	Calculate	No-Plots 💌	Initialize	Formatio	n Enthalpy:	ONO Yes	Air	~
p3	T3		v3		u3		h3	
kPa 😽	1995.6504	K 🗸	0.11791 n	r^3/kg 😽	1130.7067	kJ/kg 😽	1703.4314	kJ/kg
s3	✓ Vel3		✓ z3		e3		j3	
s4 kJ/kg.K 🚿	0.0	m/s 🗸	0.0	m 💉	1130.7067	kJ/kg 💙	1703.4314	kJ/kg
phi3	psi3		✓ m3		Vol3		MM3	
kJ/kg 💉	2	kJ/kg 💙	-m1 i	9 😽	0.11791	m^3 🛩	28.97	kg/kmol

Here, p3 = p2 = 4857.497 kPa, T3 = 1995.65 KAns.

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:

• Mixed C SI C Engl	sh < Case-0 > 🔽	Help Messages On Super-Itera	te Super Calculate	Load Super Initialize
State Panel	Process Pan	nel Cyd	e Panel	I/O Panel
< Process B [2-3]	> b State: State 2 🛩	f filmer State 3 💌	Calculate	nitialize p=constant
< Process B (2-3)			Calculate	
	 b State: State:2 W_B 311.343 kJ 	•.5inor. State 3 ▼ ✓ T_B ▼ 298.15	Calculate	S_gen

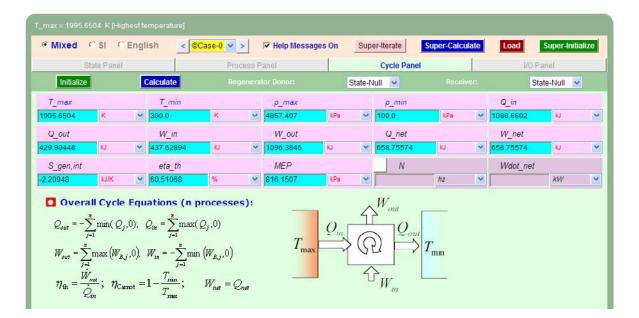
11. And, similarly for Process 3-4:

T_B = 298.15 K [Boundary temperature]			
• Mixed CSI CEnglish	Case-0 > Felp Messages	On Super-Iterate Super-Calcu	ulate Load Super-Initialize
State Panel	Process Panel	Cycle Panel	I/O Panel
Process-C [3-4]	b-State: State-3 💌 f-State:	State-1 Calculate	Initialize s-constant
<u>~</u> Q	W_B	✓ T_B	S_gen
0.0 KJ	Y /85.041/ ₩ Y	298.15 K 🗸	0.0 kJ/K 🗡
n	Delta_E	Delta_S	
1.40054 UnitLess	✓ -785.0417 kJ ✓	0.0 kJ/K 🛩	

12. Again, for Process 4-1:

Q W_D T_D S_gen	-1) V > b-State: State-4 V F-State: State-1 V Calculate Initialize Vol=constant
Q W_D T_B S_gen	W_B ✓ T_B S_gen № 0.0 № 298.15 K ¥ 0.654/4 №/К
Q W_B 1 T_B S_gen	W_D ✓ T_D S_gen № 0.0 № 298.15 К У 0.654/4 КЫК
Q W_B 1 T_D S_gen	W_B ✓ T_D S_gen № 0.0 № ✓ 298.15 К ✓ 0.654/4 №/К
	ki ♥ 0.0 ki ♥ 298.15 K ♥ 0.654/4 ki/K
	ki ♥ 0.0 ki ♥ 298.15 K ♥ 0.654/4 ki/K

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



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Gas Power Cycles

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:

#~~~~	~~~~~	~~~~~~	~~~OUTP	UT OF SUPER	R-CALCUL	ATE	
#	Daem	on Path: Sys	stems>Clos	ed>Process>S	pecific>Pov	verCycle>PG	-Model; v-10.ca08
#		Start of	TEST-code				
States	{						
	State-1	: Air;					
	Given:	{ p1= 100.0	kPa; T1= 3	800.0 K; Vel1=	0.0 m/s; z1=	= 0.0 m; m1=	1.0 kg; }
	State-2	: Air;					
	Given:	{ v2= "v1/1	6"m^3/kg;	s2= "s1"kJ/kg.l	K; Vel2= 0.0) m/s; z2= 0.0	m; m2= "m1"kg; }
	State-3	: Air;					
	Given:	{ p3= "p2"k	:Pa; s3= "s4	"kJ/kg.K; Vel3	= 0.0 m/s; z	3= 0.0 m; m3	= "m1"kg; }
	State-4	: Air;					
	Given:	{ T4= 900.0) K; v4= "v1	m^3/kg; Vel4	= 0.0 m/s; z	z4= 0.0 m; m ²	4= "m1"kg; }
	}						
Analys	sis {						
	Proces	s-A: b-State	= State-1; f	-State = State-2	2;		
	Given:	$\{ Q = 0.0 \ kJ \}$; T_B= 298.	.15 K; }			
	Proces	s-B: b-State	= State-2; f	-State = State-3	3;		
	Given:	{ T_B= 298	.15 K; }				
	Proces	s-C: b-State	= State-3; f	-State = State-4	4;		
	Given:	$\{ Q = 0.0 \ kJ \}$; T_B= 298	.15 K; }			
	Proces	s-D: b-State	= State-4; f	-State = State-	1;		
	Given:	{ T_B= 298	.15 K; }				
	}						
#		End o	f TEST-cod	e			
#	Proper	ty spreadsh	eet 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
#	Proper	ty spreadshe	et ends				
# Ma	ss, Energy	y, and Entro	py Analysis	Results:			
#	Process	s-A: b-State =	= State-1; f-3	State = State-2	2;		
#		Given: Q=	0.0 kJ; T_B=	= 298.15 K;			
#		Calculated:	W_B= -432	7.62894 kJ; S_	_gen= -0.0 k	J/K; n= 1.400	5353 UnitLess; Delta_E=
437.6	2894 kJ;						
#		De	$ta_S = -0.0$	кJ/К;			
#	Process	s-B: b-State =	= State-2; f-S	State = State-3	;;		
#		Given: T_B	= 298.15 K;				
#		Calculated:	Q= 1088.6	6602 kJ; W_H	3= 311.343	kJ; S_gen= -	2.8642204 kJ/K; n= 0.0
UnitI	Less;						
#		De	lta_E= 777.3	3172 kJ; Delta	_S= 0.7871	639 kJ/K;	
#	Process	s-C: b-State =	= State-3; f-3	State = State-4	1 ;		
#		Given: Q=	0.0 kJ; T_B=	= 298.15 K;			
#		Calculated:	W_B= 785	.0417 kJ; S_g	en= -0.0 kJ	/K; n= 1.400	5353 UnitLess; Delta_E=
-785.	0417 kJ;						
#		De	lta_S= -0.0	кJ/К;			
#	Process	s-D: b-State =	= State-4; f-	State = State-1	1;		
#		Given: T_B	= 298.15 K;				
#		Calculated:	Q= -429.9	0448 kJ; W_	B= 0.0 kJ;	S_gen= 0.65	47428 kJ/K; n= Infinity
UnitI	Less;						
#		Del	lta_E= -429	.90448 kJ; Del	lta_S= -0.78	71639 kJ/K;	
# Cyc	le Analys	is Results:					
#		Calculated:	$T_max = 19$	995.6504 K; T	_min= 300.	0 K; p_max=	4857.497 kPa;
#		p_1	min= 100.0	kPa; Q_in= 1	088.6602 kJ	; Q_out= 429	.90448 kJ;
#		W_	_in= 437.628	894 kJ; W_ou	t= 1096.384	6 kJ; Q_net=	658.75574 kJ;
#		W_	_net= 658.75	5574 kJ; S_ger	n,int= -2.20	948 kJ/K; eta_	_th= 60.51068 %;
#		ME	EP= 816.150)7 kPa;			
#****	**CALCU	LATE VARI	ABLES: Typ	e in an expre	ssion startii	ng with an '='	sign ('= mdot1*(h2-h1)',
ʻ= sqi	rt(4*A1/P	I), etc.) and]	press the En	ter key)*****	*** *		
=v3/v	/2						
	v3/v2 =	= 2.19114250	697350 77 =	2.1911cut	t off ratio	Ans.	
=v4/v	73						
	v4/v3	= 7.302126	397888614	= 7.302 ex	pansion ra	tioAns.	

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]

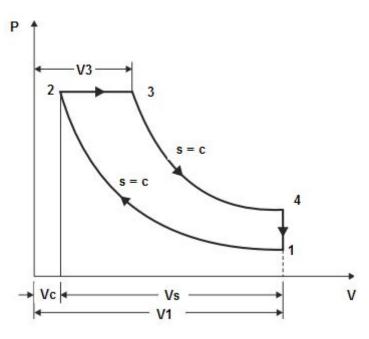
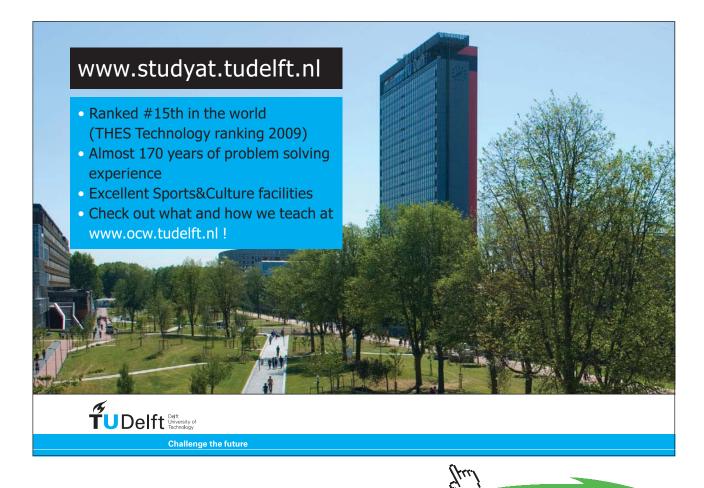
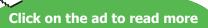


Fig.Prob.1.34





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:

ve mouse ove	er a variable i	o disp	lay its	value with	more precis	ion.										
Mixed	C SI C	Engli	sh	< <mark>©Ca</mark>	ise-0 👻 >		🔽 He	lp Message	s On	Super	Iterate	uper-Calculat		Load	Super-Initial	ize
	State Panel				Proce	ess Pa	anel				Cycle Panel			I/O Pa	nel	
< ©State	-1 💙 >		Calc	ulate	No-Plot	s 🗸		Initialize	h	ormati	on Enthalpy:	No •Yes		Air		v
< p1			1	T1			1	v1			u1			h1		
100.0	kPa	~	15.0		deg-C	¥	0.82	895	m^3/kg	~	-92.73011	k.l/kg	~	-10.03494	k.l/kg	
s1			-	Vel1			-	z1			e1			jt		
6.85246	kJ/kg.K	~	0.0		m/s	*	0.0		m	~	-92.73011	kJ/kg	~	-10.03494	kJ/kg	
phi1			ps	í1			1	m1			Vol1			MM1		
	kJ/kg	×			kJ/kg	v	1.0		kg	~	0.82695	m^3	~	28.97	kg/kmol	

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:

• Mixed C SI C Eng	glish < Case	-0 × >	Help Messages (On Super-Iterate	Super-Calculate	Load	uper-Initialize
State Panel		Process F	Panel	Cycle Pane	21	I/O Pan	el
< <mark>©State-2 v</mark> >	Calculate	No-Plots 🗸	Initialize	Formation Enthalpy	No •Yes	Air	~
p2	T2		🖌 v2	u2		h2	leser.
437.694 kPa	▶ 579.331	deg-C 💊	r =v1/15	n^3/kg 💉 <mark>311.617</mark> 2	5 kJ/kg 🗠	556.2678	kJ/kg
s2	Vel2		🖌 z2	θ2		j2	
s1 k.l/kg K	✓ 0.0	mis 💉	× 0.0	m 💉 311.6172	5 k.l/kg 🗸	556.2678	k.l/kg
phi2	psi2		✓ m2	Vo	12	MM2	
kJ/kg	~	KJ/Kg	< =m1	kg 💉 0.05513	m^3. 🗸	28.97	kg/kmol

Here, p2 = 4437.694 kPa, T2 = 579.331 C.

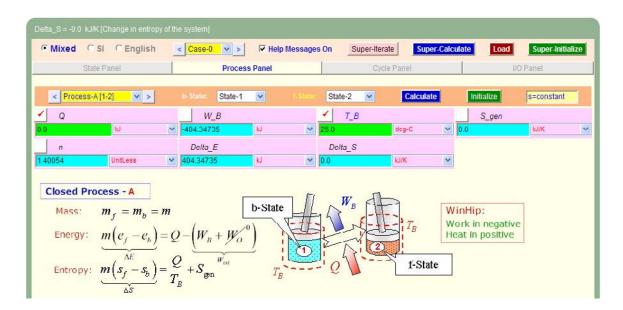
7. Similarly, for State 3: Enter p3 = p2 (since Process 2-3 is a const. pressure process), and m3 = m1. Hit Enter. Not all calculations are completed, since data is not enough:

Mixed CSI CE	nglish	< Case-0	→ >	🔽 Help Messag	jes On Sup	er-Iterate	Super-Calculate	Load	Super-Initialize
State Panel			Process Pa	anel	1	Cycle Panel		I/O Par	nel
< OState-3 V >	Calcu	ilate	No-Plots 💌	Initializ	e Form	ation Enthalpy:	ONO OYes	Air	~
p3		Т3		v3		u3		h3	
p2 kPa	×	(deg-C 💌		m^3/kg	~	kJ/kg 💙		kJ/kg
s3	1	Vel3		🖌 z3		e3		j3	
kJ/kg.K	♥ 0.0	n	Vs 💙	0.0	m	×	kJ/kg 💙		kJ/kg
phi3	ps	13		🖌 m3		Vol3		MM3	
kJ/kg	×	ĸ	J/kg 💙	=m1	kg	~	m^3 💙	28.97	kg/kmol

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:

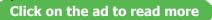
Mixed C SI C Englis	h < Case-0) * >	🔽 Help Messages (On Super-	terate Supe	er-Calculate	Load St	per-Initialize
State Panel		Process P	'anel	(Jycle Panel		I/O Pane	el.
< ©State-4 🗙 >	Calculate	No-Plots 💌	Initialize	Formatic	n Enthalpy: 🛛 🔘	No 💿 Yes	Air	~
p4	T4		🖌 v4		u4		h4	
kPa 💉		deg-C 💙	=v1	m^3/kg 💙		kJ/kg 💉		kJ/kg
s 4	✓ Vel4		🖌 z4		e4		j4	
s3 kJ/kg.K 🛛 🖌	0.0	m/s 🗸	• 0.0	m 🗸		kJ/kg 💌		kJ/kg
phi4	psi4		🖌 m4		Vol4		MM4	
kJ/kg 💙		kJ/kg 😽	-m1	kg 😽	0.82095	m*3 🗸 🗸	28.97	kg/kmol

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:

State Panel Process Panel Cycle Panel VO Panel	inel

Again, data is not enough to make all calculations.

11. And, similarly for Process 3-4:

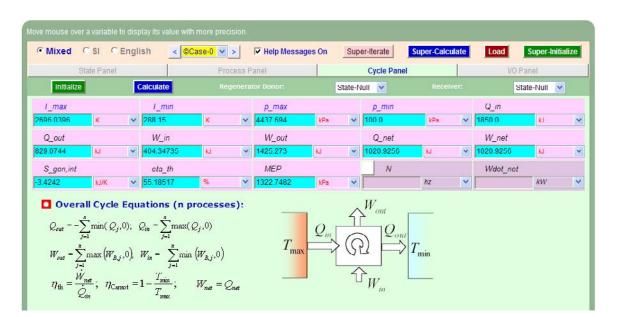
• Mixed C SI C Englis	h < Case-0 < >	✓ Help Messages O	n Super-Iterate	Super-Calculate	Load	Super-Initializ
State Panel	Proces	is Panel	Cycle Panel		I/O	Panel
< Process-C [3-4] V	b-State: State-3	F-State:	State-4 V Cal	culate	Initialize	Process Type
	Oldio O					
	WB	1	TR			
	W_B	- KJ 💙 25	T_B		S_gen	кJ/K
						KJ/K

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:

Mixed CSI CEnglish	< ©Case 0 v > 1	Help Messages On	Super Iterate Supe	er-Calculate Load	Super-Initialia
State Panel	Process Pa	inel	Cycle Panel		I/O Panel
	1967-000 (State of Carlos and Car				
< Process D [4 1] * >	b State: State 4	f State: Sta	te 1 😪 Calculat	c Initialize	Vol=constant
Q	W_B	×	I_B	S_gen	

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:

• Mixed O SI O E	nglish <	Case-U 💙 >		Help Messag	es Un	Super-Iterate	Super-Calculate	Load	Super-Initialize
State Panel		Proce	ss Pane	2]		Cycle Panel		I/O Pa	inel
< ©State-3 💌 >	Calculate	No-Plots	•	Initialize		Formation Enthalpy:	ONo •Yes	Air	¥
р3	T3			v3		u3		h3	
p2 kPa	₩ 2422 8896	deg-C	× 0	17435	m^3/kg	₩ 1632 5408	kJ/kg	2406 2678	kJ/kg
sJ	✓ Vel3			zJ		eJ		 j3 	
1.00787 k.l/kg K	✓ 0.0	m/s	× 0	.0	m	₩ 1632.5408	k.l/kg	2406.2678	k.l/kg
phi3	psiJ			/ m3		Vol3		ММЭ	
k.l/kg	×	k.l/kg	× =	m1	kg	♥ 0.17435	m^3	✓ 28.97	kg/kmol

Note that T3 = 2422.8896 C Max. temp in cycle.

And, State 4:

Mixed C SI C Engl	ish < @Ca	se-0 💙 >	₩ Hel	p Messages On	Super-Iterat	super-	Calculate	I oad	Super-Initializ	7e
State Panel		Process	Panel		Cycle	Panel		I/O Pa	nel	
< OState-4 💙 >	Calculate	No-Plots	/	Initialize	Formation En	thalpy: 💮 N	• Yes	Air	¥	1
p4	T4		1	v4		u4		h4		
01.56345 kPa 🗸	1172.105	deg-C	< =v1	nr*3/k	y 🗡 736	.3443	J/kg 💌	1151.113	kJ/kg	3
\$4	Vel4		1	z4		e4		j4		
s3 kJ/kg.K 🗸	0.0	m/s	× 0.0	m	✓ 736	3443	J/kg 💉	1151 113	kJ/kg	1
phi4	psi4		1	m4		Vol4		MM4		
kJ/kg 💙		kJ/kg	/ =m1	kg	▼ 0.82	2695	m^3 🗸	28.97	kg/kmol	2

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):

Mixed CSI CEnglish	< Case-0 > F He	Ip Messages On Super-Iterate Super-	Calculate Load Super-Initializ
State Panel	Process Panel	Cycle Panel	I/O Panel
< Process-B [2-3] >	b-State: State-2 💌	r-State-3 💌 Calculate	Initialize p=constant
Q	W_B	✓ T_B	S_gen
350.0 kJ	✓ 529 0765 kJ	✓ 25.0 deg-C	✓ -5.04952 kJ/K

Process C (3-4):

• Mixed C SI C English	< ©Case 0 v >	Help Messages On Super-Ite	super-Calculate	Load Super-Initialize
State Panel	Process Pan	el Cy	cle Panel	I/O Panel
< Process-C [3-4] >	b-State-3 😽	tellitor State-4 💌	Calculate Initi	alize s=constant
1		4		
Q	W_B	✓ T_B	5]_gen
	₩_B ₩_B	✓ T_B ✓ 25.0	deg C 🛩 0.0)_gen kJ/K

Process D (4-1):

Mixed CSI CEnglish	< Case-0 > Felp Message	es On Super-Iterate Super-Calcu	ulate Load Super-Initiali
State Panel	Process Panel	Cycle Panel	I/O Panel
		- Jone 1 etter	ine i miner
< Process-D [4-1] V >	b-State: State-4 💌 (-State	State-1 V Calculate	Initialize Vol=constant
< Process-D [4-1] V > Q 20 0744	b-State: State-4 V f-Sinte	🖌 ТВ	Initialize Vol=constant S gen 1.62532 kJ/K

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; }

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Given: { p3 = p2 kPa; Vel3 = 0.0 m/s; z3 = 0.0 m; m3 = m1 kg; } State-4: Air; Given: { $v4= v1^m^3/kg; s4= s3^kJ/kg.K; Vel4= 0.0 m/s; z4= 0.0 m; m4= m1^kg;$ } ļ 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) 100.0 -92.73 6.852 1 288.2 0.827 -10.03 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 8.008 1151.11 #-----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; $Delta_S = -0.0 \text{ kJ/K};$ Process-D: b-State = State-4; f-State = State-1;

Gas Power Cycles

#	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;
# Cyc	ele 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:

	thermo	ofluids	.net ·	1							on: <i>PG M</i> cific • Recip	odel) procating Cycl	<u>es</u> -	• PG Model	5	
• Mixed	C SI C	Engli	sh	< 00:	ase-0 ▼ >	1	₹ He	lp Message	es On	Super-	Ilerale	Super-Calculate	•	Load	Super-Initia	lize
	State Panel			1	Proce	ess Pa	inel		1	1	Cycle Panel	1		1/0	Panel	
< ©Stat	e-1 💌 >		Calcu	ilate	No-Plot	s 🗸		Initialize		ormatio	on Enthalpy:	ONo •Yes		Air		*
🖌 p1			•	T1				vt			u1			ht		
100.0	kPa	*	67.0		deg-C	*	0.97	618	m^3/kg	~	-55.47172	kJ/kg	Y	42.14675	kJ/kg	~
			1	Vel1			1	z1			e1			i1		
7.01094	kJ/kg.K	~	0.0		m/a	~	0.0		m	~	-55.47172	kJ/kg	*	42.14675	kJ/kg	~
phi1			psi	1	-		-	<i>m</i> 1			Vol1			MM1		
	kJ/kg	~			kJ/kg	*	1.0		kg	*	0.97618	m^3	*	28.97	kg/kmol	~
R1			c_p	01			C	_v1			k1					
0.28699	kJ/kg.K	*	1.003	49	kJ/kg.K	~	0.71	651	kJ/kg.K	~	1.40054	UnilLess	¥			

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:

• Mixed OSI OE	nglish <	ase-0 v >	F Hel	p Messages On	Super-Iterate	Super-Calculate	Load	Super-Initialize
State Panel		Process F	anel		Cycle Panel		I/O Pa	nel
< State 2 V	Calculate	No-Plots 🗸		Initialize	Formation Enthalpy:	O No 💿 Yes	Air	~
✔ p2	T2		1	v2	u2		h2	
-p1*(v1/v2)^1.3 kPa	← 562.4135	deg-C 👻	-v1/2	20 m^3/k	299.49570	kJ/kg 💊	539.29120	kJ/kg
s2	✓ Vel2		-	z2	e2		j2	
.80314 kJ/kg.K	✓ 0.0	m/e 😽	0.0	m	209.49576	kJ/kg 💊	539.20126	kJ/kg
phi2	psi2		1	<i>m</i> 2	Vol	2	MM2	
k.l/kg	~	k.l/kg 🗸	=m1	kg	✓ 0.04881	m*3 5	28.97	kg/kmnl

Here, p2 = 4912.91 kPa, T2 = 562.4135 CAns.



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:

• Mixed O SI	C Engli	sh < @Ca	se-0 v >	🔽 Helj	p Messages On	Super-Iterate	Super	r-Calculate	Load	Super-Initialize
State Pa	inel		Process P	anel		Cycle	Panel		I/O Pai	nel
< ©State-3 ¥	>	Calculate	No-Plots 💌		Initialize	Formation Ent	thalpy: 🔅 N	No 💽 Yes	Air	~
✓ p3		T3		*	v3		u3		h3	
ep2 kPi	8 v	2149.9841	deg-C 💌	=v2+	(v1-v2)*0.1 m*3/kg	× 143	7.0021	kJ/kg 🔷 👻	2132.409	kJ/kg
e3		✓ Vol3		1	z3		03		j3	
7.87158 kJ/kg	K v	0.0	m/s 🗸	0.0	m	× 143	7.0021	k.l/kg 🗸 🗸	2132.409	k.l/kg
phi3		psi3		1	m3		Vol3		ММЗ	
KJ/K	g 🗸		kJ/kg 💙	=m1	kg	Y 0.14	155	m^3 🗸	28.97	kg/kmol

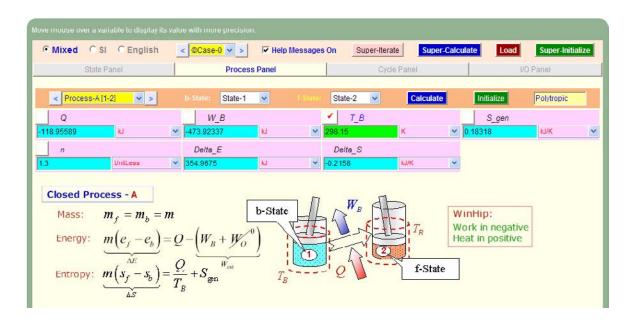
Note that p3 = 4912.91 kPa, T3 = 2149.9841 C.

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:

Mixed CSI CE	ngli	sh <mark>< @Ca</mark>	se-0 v >	2	Help	Messages On	Super-	Iterate	Super-Calculate		Load	Super-Initial	lize
State Panel			Process	Pan	e)			Cycle Panel			I/O Pa	nel	
< ©State-4 V >		Calculate	No-Plots	~		Initialize	Formati	on Enthalpy:	🔘 No 🖲 Yes		Air		~
✔ p4		T4			1	v4		u4	- 225		h4		
p3*(v3/v4)^1.3 kPa	*	1357.6501	К	~	v1	nr*3/k	y 🗸	673.5747	kJ/kg	~	1063.202	kJ/kg	
s4		Vel4			1	z4		e4			j4		
01068 kJ/kg.K	×	0.0	m/s	~	0	m	~	673 5747	kJ/kg	~	1063 202	kJ/kg	
phi4		psi4			1	m4		Vol4			MM4		
kJ/kg	~		kJ/kg	-	m1	kg	~	0.97618	m^3	~	28.97	kg/kmol	

Here, p4 = 399.13 kPa, T4 = 1357.65 KAns.

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:

Mixed CSI CEngli	sh < ©Case-0 × >	Help Mes	sages On Super-Itera	ate Super-Calculat	e Load Super-Ir	itialize
State Panel	Proce	ess Panel	Cyc	le Panel	I/O Panel	
< Process-B [2-3]	> b-State: State-2	2 💌 6	State-3 💌	Calculate	Initialize p=consta	nt
					A	
Q	W_B		T_B		S_gen	
Q 593 1177 kJ	₩_B ¥ 455 61142	kJ	✓ T_B ✓ 298 15	К 🗸 🛃	S_gen 27491 kJ/K	
		ki	Provide Statement of Statement	К 💉 -4		

11. And, for Process 3-4:

• Mixed C SI C English	< @Case-0 > F Hel	Ip Messages On Super-Ite	rate Super-Calculate	Load Super-Initializ
State Panel	Process Panel	Cy	cle Panel	VO Panel
< Process-C [3-4] V >	b-State: State-3 💌	1-State: State-4	Calculate	Initialize polytropic
< Process-C [3-4] >	b-State: State-3	r-State: State-4	Calculate	Initialize polytropic S_gen
Q				
	W_B	✓ T_B		S_gen

12. Again, for Process 4-1:

Mixed C SI C English	< ©Case-0 ♥ >	s On Super-Iterate Super-Calcul	ate Load Super-Initialize
State Panel	Process Panel	Cycle Panel	I/O Panel
< Process-D [4-1] 💌 >	b-State: State-4 💽 I-State	State-1 Calculate	Initialize Vol=constant
Q	W_B	 T_B 	S_gen
	Y 0.0 KJ Y	298.15 K 💉	.4535 kJ/K



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13. And, now go to Cycle Panel. SuperCalculate. All calculations are available here:

VO Panel State-Null
557 81
101
et
533 kJ
t_net
kW

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)
                  100.0
                             340.2
                                                                           7.019
#
       1
                                        0.9762
                                                    -55.47
                                                                42.15
#
       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
                                                                           8.011
                                                                1063.2
#------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:



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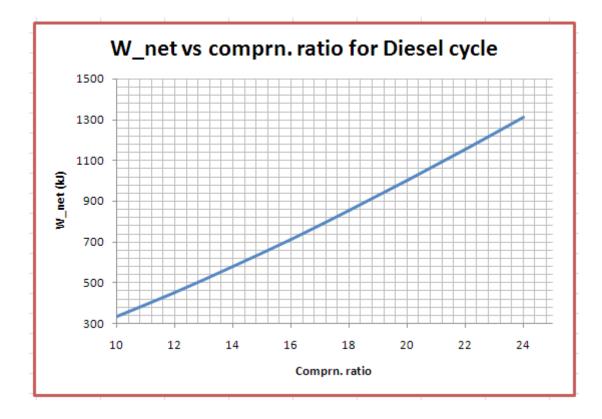


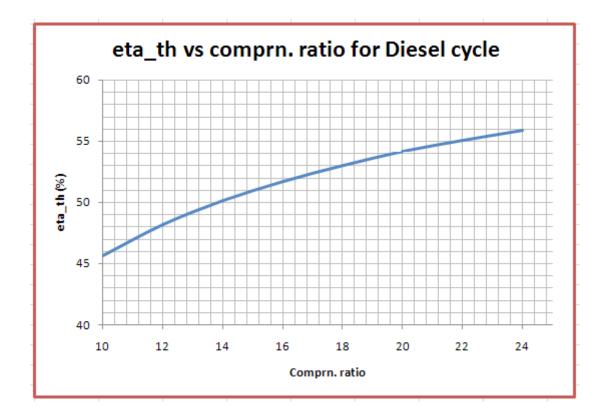
Following are the steps:

- 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:





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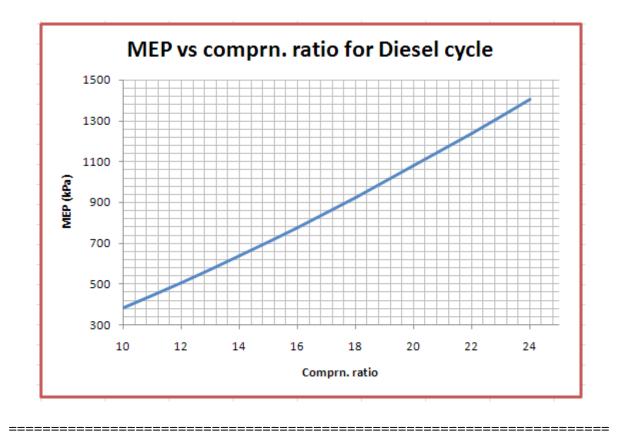
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1.4 Problems on Dual cycle (or, limited pressure cycle):

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]

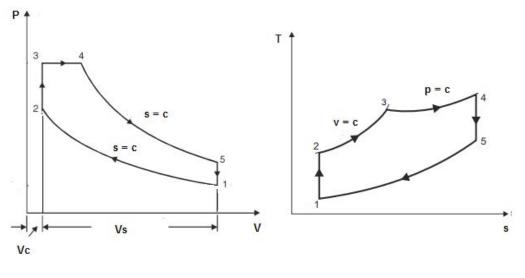


Fig.Prob.1.36

Mathcad Solution:

Data:

r := 9Compression ratio R := 0.287 kJ/kg.K Gas const. for air

P1 := 100 kPa T1 := 300 K γ := 1.4 cv := 0.718 kJ/kg.K cp := 1.005 kJ/kg.K

Q_v := 700 kJ/kg ... heat supplied at const. vol.

Qp := 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:

$$\frac{\mathrm{T4}}{\mathrm{T5}} = \left(\frac{\mathrm{v5}}{\mathrm{v4}}\right)^{\gamma-1} = \left(\frac{\mathrm{v5}}{\mathrm{v2}} \cdot \frac{\mathrm{v2}}{\mathrm{v4}}\right)^{\gamma-1} = \left(\frac{\mathrm{v1}}{\mathrm{v2}} \cdot \frac{\mathrm{v3}}{\mathrm{v4}}\right)^{\gamma-1} = \left(\mathrm{r} \cdot \frac{\mathrm{T3}}{\mathrm{T4}}\right)^{\gamma-1} \qquad \dots \text{since } \mathrm{v5} = \mathrm{v1}, \, \mathrm{v3} = \mathrm{v2}$$

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.

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

Gas Power Cycles

Heat rejected, Qr:

 $Q_r := cv \cdot (T5 - T1)$ i.e. $Q_r = 603.567$ kJ/kg

Heat supplied, Qs:

 $Q_{s} := Q_{v} + Q_{p} \qquad \text{ i.e. } \qquad Q_{s} = 1.4 \times 10^{3} \quad \text{kJ/kg}$

Net work done:

 $W_{net} := Q_s - Q_r$ i.e. $W_{net} = 796.433$ kJ/kg....Ans.

Thermal efficiency:

 $\label{eq:eq:entropy} \eta := \frac{W_{net}}{Q_s} \qquad \mbox{i.e.} \ \eta = 0.569 \ \ \mbox{...Ans}$



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Mean Effective Pressure:

$$v1 := \frac{R \cdot T1}{P1}$$
 i.e. $v1 = 0.861$ m^A3/kg.... volume of 1 kg at state 1

$$v2 := \frac{R \cdot T2}{P2}$$
 i.e. $v2 = 0.096$ m^A3/kg vol. at state 2
Therefore:

mep := $\frac{W_{net} \cdot 10^3}{v1 - v2}$ i.e. mep = 1.0406×10^6 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)

$$\eta_{\text{th}}(\mathbf{r}, \mathbf{rc}, \mathbf{rp}, \gamma) \coloneqq 1 - \frac{1}{r^{\gamma-1}} \cdot \left[\frac{\mathbf{rp} \cdot \mathbf{rc}^{\gamma} - 1}{(\mathbf{rp} - 1) + \gamma \cdot \mathbf{rp} \cdot (\mathbf{rc} - 1)} \right] \quad \dots \text{Thermal effcy}.$$

Work output: P1 in kPa, v1 in m^3/kg:

$$W(\mathbf{r}, \mathbf{re}, \mathbf{rp}, \mathbf{P1}, \mathbf{v1}, \gamma) := \frac{\mathbf{P1} \cdot \mathbf{v1} \cdot \left[\mathbf{rp} \cdot \gamma \cdot (\mathbf{re} - 1) \cdot \mathbf{r}^{\gamma - 1} + (\mathbf{rp} - 1) \cdot \mathbf{r}^{\gamma - 1} - (\mathbf{rp} \cdot \mathbf{re}^{\gamma} - 1) \right]}{\gamma - 1} \quad kJ/kg$$

Mean Effective Pressure: p1 in kpa

$$\mathrm{MEP}\big(r,rc,rp,\gamma,p1\big) \coloneqq \frac{p1}{(r-1)\cdot(\gamma-1)} \cdot \Big[r^{\gamma} \cdot \big[rp \cdot \gamma \cdot (rc-1) + (rp-1)\big] - r \cdot \Big(rp \cdot rc^{\gamma} - 1\Big)\Big] \quad \mathsf{kPa}$$

Remember:

$$r = \frac{v1}{v2} \qquad \dots \text{ compression ratio}$$

$$rc = \frac{v3}{v2} \qquad \dots \text{ cut off ratio}$$

$$rp = \frac{p3}{p2} \qquad \dots \text{ pressure ratio, or explosion ratio}$$

Now, for the above problem:

P1 = 100 kPa v1 = 0.861 m^A3/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:

$$\begin{split} &\eta_{th}(r,rc,rp,\gamma)=0.569 &= 56.9 \ \text{\% Ans.} \\ &W(r,rc,rp,P1,v1,\gamma)=796.018 \ \text{ kJ/kg... Ans.} \\ &\text{MEP}(r,rc,rp,\gamma,P1)=1.0401 \times 10^3 \ \text{ kPa}=10.401 \ \text{bar ...Ans.} \end{split}$$

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..28define r as a range variable from 10 to 28.

f =	$\eta_{th}(\mathbf{r}, \mathbf{rc}, \mathbf{rp}, \gamma)$	$W(r, rc, rp, P1, v1, \gamma)$	$MEP(r, rc, rp, \gamma, P1)$
10	0.587	856.245	1.105·10 ³
12	0.616	966.653	1.225·10 ³
14	0.639	1.066·10 ³	1.334·10 ³
16	0.658	1.158·10 ³	1.435·10 ³
18	0.673	1.243·10 ³	1.529·10 ³
20	0.687	1.323·10 ³	1.617·10 ³
22	0.699	1.397·10 ³	1.7·10 ³
24	0.709	1.468·10 ³	1.779·10 ³
26	0.718	1.536·10 ³	1.855·10 ³
28	0.726	1.6·10 ³	1.927·10 ³

Now, plot the results:





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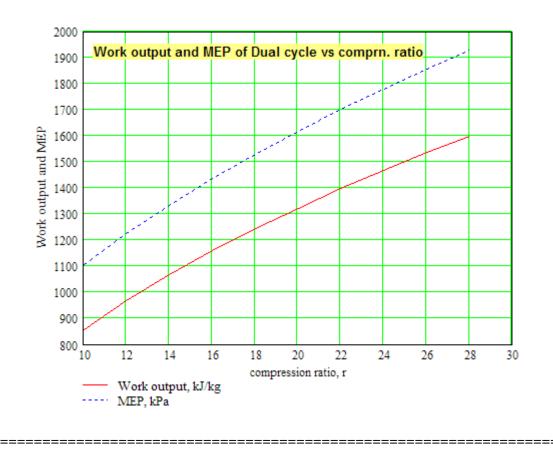




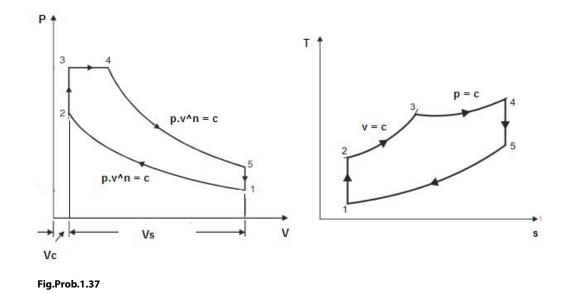


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Prob.1.37. The compression ratio and expansion ratio of an oil engine working on the dual cycle are 9 and 5 respectively. The initial pressure and temp of air are 1 bar and 30 C. The heat liberated at const. pressure is twice the heat liberated at 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]



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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 := 9comprn. ratio
 re := 5 ...expansion ratio = v5/v4

 P1 := 1 bar
 T1 := 303 K
 n := 1.25 $\gamma := 1.4$ R := 287 J/kg.K

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:

$$V_s := \frac{\pi \cdot D^2}{4} \cdot L \qquad \text{ i.e. } V_s = 0.02 \qquad \text{m^3.... stroke volume}$$
$$V_c := \frac{V_s}{r-1} \qquad \text{ i.e. } V_c = 2.454 \times 10^{-3} \qquad \text{m^3.... clearance volume}$$

Also: V3 := Vc V2 := V3

$$V1 := r \cdot V_c$$
 i.e. $V1 = 0.022$ m^A3

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.
$$T3 := \frac{T2}{0.44}$$



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i.e.
$$T3 = 1.193 \times 10^3$$
 K....Ans.

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 × 10³ K....Ans.

$$P5 := \frac{P4}{re^n}$$
 i.e. $P5 = 4.738$ bar....Ans.

Work output:

W = area 12345

Therefore:

$$W := \left[P3 \cdot (V4 - V3) + \frac{(P4 \cdot V4 - P5 \cdot V5)}{n - 1} - \frac{(P2 \cdot V2 - P1 \cdot V1)}{n - 1} \right] \cdot 100 \quad kJ$$

Mean Effective Pressure:

mep :=
$$\frac{W}{V_s}$$
 i.e. mep = 1.081×10^3 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:

$$\eta := \frac{W \cdot 10^3}{Q_s}$$
 i.e. $\eta = 0.581 = 58.1 \%$ Ans.

Power developed when no. of cycles is 8 per sec.:

Power := W-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]

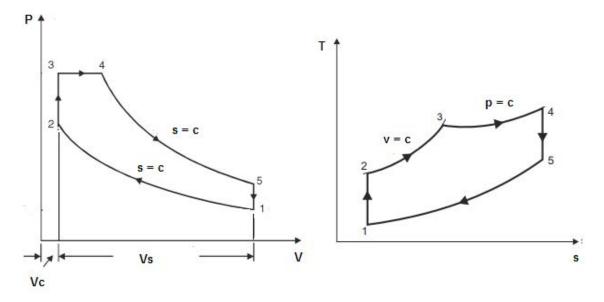


Fig.Prob.1.38

Mathcad Solution:

Data:

P1 := 1 bar T1 := 300 K r := 15 P4 := 70 bar T4 := 3000 K P3 := P4 R := 0.287 kJ/kg.K γ := 1.4

 $cv:=\frac{R}{\gamma-1} \quad i.e \quad cv=0.718 \quad kJ/kg.K \qquad cp:=\frac{R\cdot\gamma}{\gamma-1} \qquad i.e. \ cp=1.005 \quad kJ/kg.K$

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:

$$T3 := \frac{P3}{P2} \cdot T2$$
 i.e $T3 = 1.4 \times 10^3$ K

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

Gas Power Cycles

Process 4-5:

T5 := T4
$$\left(\frac{1}{r}, \frac{T4}{T3}\right)^{\gamma-1}$$
 i.e T5 = 1.377 × 10³ 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^A3

Therefore:

mep :=
$$\frac{W \cdot 10^{5}}{V1 \cdot \left(1 - \frac{1}{r}\right)}$$
 i.e. mep = 1.497×10^{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 = 2.143cut off ratio $rp := \frac{P3}{P2}$ i.e. rp = 1.58 ...pressure ratio V1 = 0.861 m^A3

We have the Mathcad Functions:

$$W(\mathbf{r}, \mathbf{rc}, \mathbf{rp}, \mathbf{p1}, \mathbf{v1}, \gamma) := \frac{\mathbf{p1} \cdot \mathbf{v1} \cdot \left[\mathbf{rp} \cdot \gamma \cdot (\mathbf{rc} - 1) \cdot \mathbf{r}^{\gamma - 1} + (\mathbf{rp} - 1) \cdot \mathbf{r}^{\gamma - 1} - \left(\mathbf{rp} \cdot \mathbf{rc}^{\gamma} - 1 \right) \right]}{\gamma - 1}$$
$$\eta_{\text{th}}(\mathbf{r}, \mathbf{rc}, \mathbf{rp}, \gamma) := 1 - \frac{1}{\mathbf{r}^{\gamma - 1}} \cdot \left[\frac{\mathbf{rp} \cdot \mathbf{rc}^{\gamma} - 1}{(\mathbf{rp} - 1) + \gamma \cdot \mathbf{rp} \cdot (\mathbf{rc} - 1)} \right]$$

$$MEP(\mathbf{r}, \mathbf{rc}, \mathbf{rp}, \gamma, \mathbf{p1}) := \frac{\mathbf{p1}}{(\mathbf{r}-1)\cdot(\gamma-1)} \cdot \left[\mathbf{r}^{\gamma} \cdot \left[\mathbf{rp} \cdot \gamma \cdot (\mathbf{rc}-1) + (\mathbf{rp}-1)\right] - \mathbf{r} \cdot \left(\mathbf{rp} \cdot \mathbf{rc}^{\gamma} - 1\right)\right]$$

Therefore:

$$\begin{split} & W(r, rc, rp, P1 \cdot 100, V1, \gamma) = 1.203 \times 10^{3} \quad \text{kJ/kg....Ans.} \\ & \eta_{th}(r, rc, rp, \gamma) = 0.609 \ = 60.9 \ \text{\%...Ans.} \\ & \text{MEP}(r, rc, rp, \gamma, P1) = 14.967 \quad \text{bar...Ans.} \end{split}$$

Note that the results with Mathcad Functions match very well with the results obtained above.

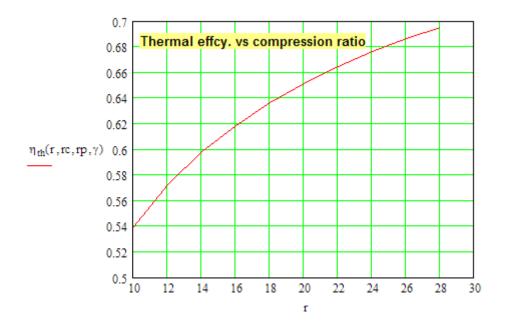
(b) Plot the variation of efficiency, work output and MEP as compression ratio varies from 10 to 28, other conditions remaining the same:

With the use of these Functions, it is very easy to plot the graphs:

r := 10,12..28define r as a range variable

f =	$W(r, rc, rp, P1 \cdot 100, V1, \gamma)$	$\eta_{th}(r, rc, rp, \gamma)$	$MEP(r, rc, rp, \gamma, P1)$
10	906.916	0.54	11.704
12	1.034·10 ³	0.572	13.101
14	1.149·10 ³	0.598	14.371
16	1.254·10 ³	0.619	15.54
18	1.352·10 ³	0.636	16.629
20	1.444·10 ³	0.651	17.65
22	1.53·10 ³	0.664	18.614
24	1.611·10 ³	0.676	19.529
26	1.689·10 ³	0.686	20.401
28	1.763·10 ³	0.695	21.235

Now, plot the graphs:





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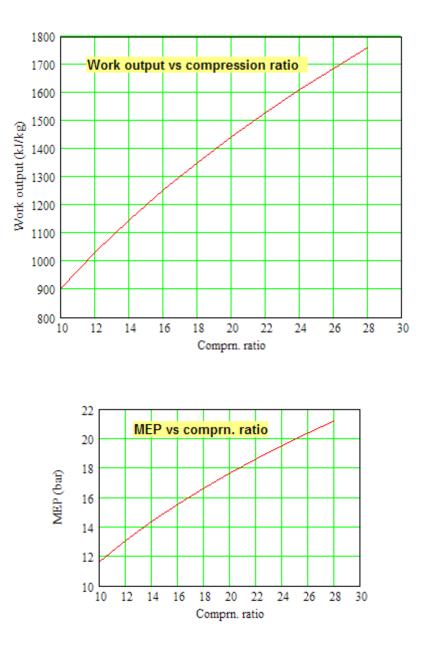
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Prob.1.39. An engine working on air standard dual cycle has a compression ratio of 10. The cylinder diameter is 25 cm and stroke, 30 cm. P and T at the beginning of compression are 1 bar and 27 C. Pressure at the end of const. vol. heat addition is 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]

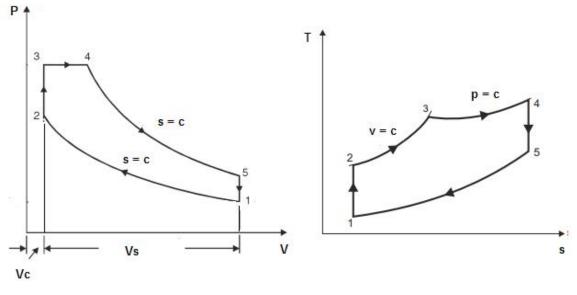


Fig.Prob.1.39

Mathcad Solution:

Data:

r := 10 T1 := 300 K P1 := 1 bar $P3 := 50 bar P4 := P3 D := 0.25 mtext{ m} L := 0.3 mtext{ m}$ $\gamma = 1.401 R := 0.287 kJ/kg.K$ $cp := <math>\frac{R \cdot \gamma}{\gamma - 1}$ 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^A3....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

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

Gas Power Cycles

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^A3

$$V1 := V_s + V_c$$
 i.e. $V1 = 0.016$ m^A3

 ${\rm V4} := {\rm V_c} + 0.05 {\rm \cdot V_s} \qquad i.e. \quad {\rm V4} = 2.373 \times 10^{-3} \qquad m^{\rm A}3$

T4 := T3
$$\cdot \frac{V4}{V_c}$$
 i.e. T4 = 2.175 $\times 10^3$ K

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Process 4-5: P4 := P3

T5 :=
$$T4 \cdot \left(\frac{T4}{T3} \cdot \frac{1}{r}\right)^{\gamma-1}$$
 T5 = 1.004×10^3 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. η = 0.584 = 58.4 %....Ans.

Mean Effective Pressure:

MEP :=
$$\frac{W \cdot 10^3}{V_s}$$
 i.e. MEP = 9.129×10^5 Pa = 9.129 bar Ans.

Gas Power Cycles

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:

$$\begin{split} \mathrm{W}(\mathbf{r},\mathbf{r}\mathbf{c},\mathbf{r}\mathbf{p},\mathbf{p}\mathbf{1},\mathbf{v}\mathbf{1},\gamma) &\coloneqq \frac{\mathbf{p}\mathbf{1}\cdot\mathbf{v}\mathbf{1}\cdot\left[\mathbf{r}\mathbf{p}\cdot\gamma\cdot(\mathbf{r}\mathbf{c}-1)\cdot\mathbf{r}^{\gamma-1}+(\mathbf{r}\mathbf{p}-1)\cdot\mathbf{r}^{\gamma-1}-\left(\mathbf{r}\mathbf{p}\cdot\mathbf{r}\mathbf{c}^{\gamma}-1\right)\right]}{\gamma-1}\\ \eta_{th}(\mathbf{r},\mathbf{r}\mathbf{c},\mathbf{r}\mathbf{p},\gamma) &\coloneqq 1-\frac{1}{\mathbf{r}^{\gamma-1}}\cdot\left[\frac{\mathbf{r}\mathbf{p}\cdot\mathbf{r}\mathbf{c}^{\gamma}-1}{(\mathbf{r}\mathbf{p}-1)+\gamma\cdot\mathbf{r}\mathbf{p}\cdot(\mathbf{r}\mathbf{c}-1)}\right] \end{split}$$

$$\text{MEP}(\mathbf{r}, \mathbf{rc}, \mathbf{rp}, \gamma, \mathbf{p1}) := \frac{\mathbf{p1}}{(\mathbf{r}-1) \cdot (\gamma-1)} \cdot \left[\mathbf{r}^{\gamma} \cdot \left[\mathbf{rp} \cdot \gamma \cdot (\mathbf{rc}-1) + (\mathbf{rp}-1) \right] - \mathbf{r} \cdot \left(\mathbf{rp} \cdot \mathbf{rc}^{\gamma} - 1 \right) \right]$$

Therefore:

$$\begin{split} & W(r, rc, rp, P1 \cdot 100, V1, \gamma) = 13.443 & kJ/kg....Ans. \\ & \eta_{th}(r, rc, rp, \gamma) = 0.584 = 58.4 \ \%....Ans. \\ & MEP(r, rc, rp, \gamma, P1) = 9.129 & bar...Ans. \end{split}$$

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...28define r as a range variable

f =	$W(r, rc, rp, P1 \cdot 100, V1, \gamma)$	$\eta_{th}(r, rc, rp, \gamma)$	$MEP(r, rc, rp, \gamma, P1)$
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

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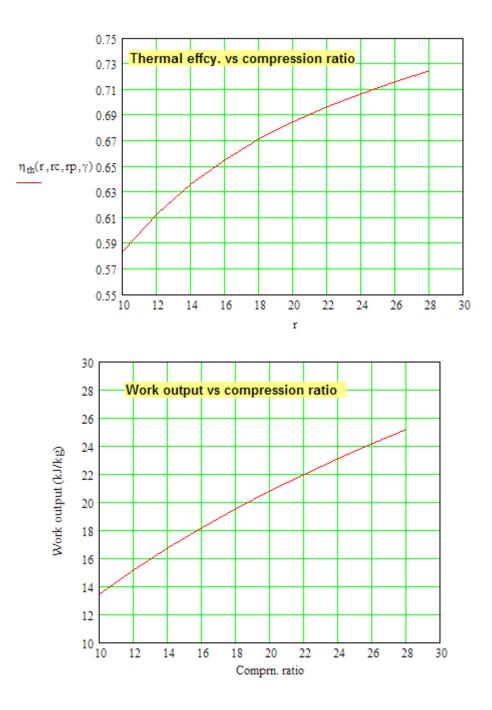
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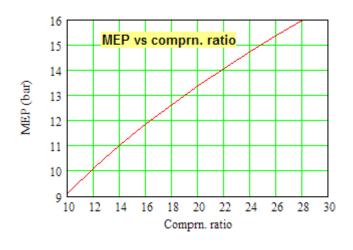




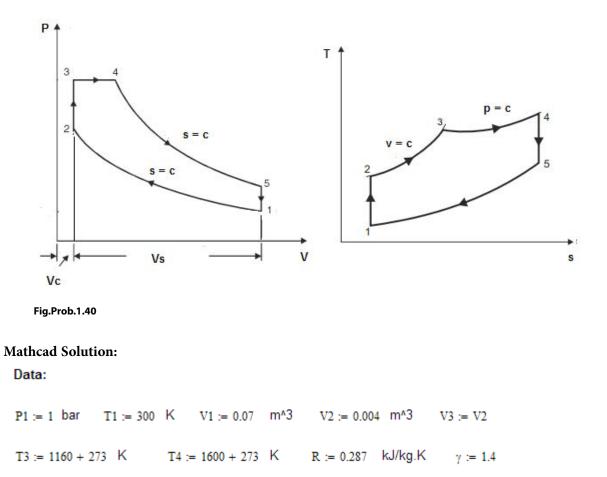
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Now, plot the graphs:





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 m³ to 0.004 m³. 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.]



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

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:

$$\eta_{\text{th}}(\mathbf{r}, \mathbf{rc}, \mathbf{rp}, \gamma) \coloneqq 1 - \frac{1}{r^{\gamma-1}} \cdot \left[\frac{\mathbf{rp} \cdot \mathbf{rc}^{\gamma} - 1}{(\mathbf{rp} - 1) + \gamma \cdot \mathbf{rp} \cdot (\mathbf{rc} - 1)} \right]$$

i.e. $\eta_{\text{th}}(\mathbf{r}, \mathbf{rc}, \mathbf{rp}, \gamma) = 0.671 = 67.2 \%$... Ans.

Mean Effective Pressure:

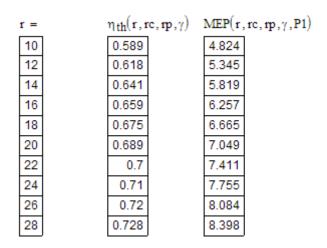
$$MEP(\mathbf{r}, \mathbf{rc}, \mathbf{rp}, \gamma, \mathbf{p1}) := \frac{\mathbf{p1}}{(\mathbf{r}-1)\cdot(\gamma-1)} \cdot \left[\mathbf{r}^{\gamma} \cdot \left[\mathbf{rp} \cdot \gamma \cdot (\mathbf{rc}-1) + (\mathbf{rp}-1)\right] - \mathbf{r} \cdot \left(\mathbf{rp} \cdot \mathbf{rc}^{\gamma} - 1\right)\right]$$

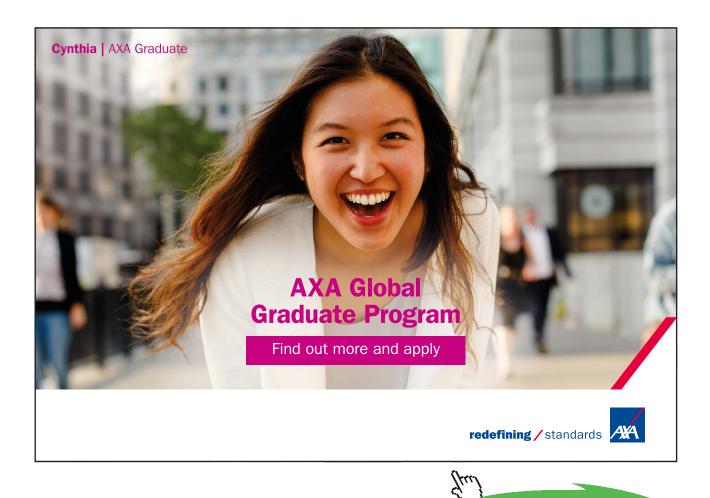
i.e. $MEP(r, rc, rp, \gamma, P1) = 6.566$ barAns.

(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..28define r as a range variable





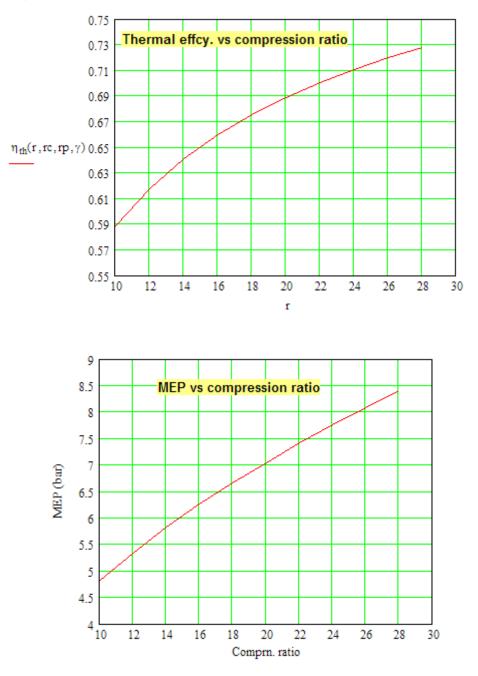
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Now, plot the graphs:

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

Gas Power Cycles

 $W_net_Dual := A * (B + C - D)$

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)



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$MEP_Dual := A * (B + C - D)$

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	∨1 = 0.0164 [m ³]
W _{net} = 13.46 [kJ]			

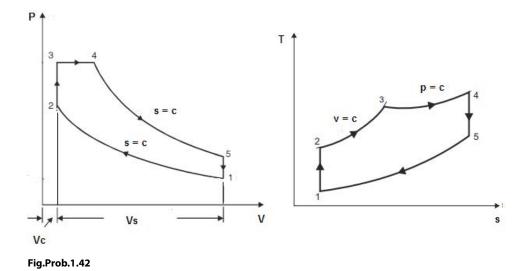
Thus:

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]"



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"

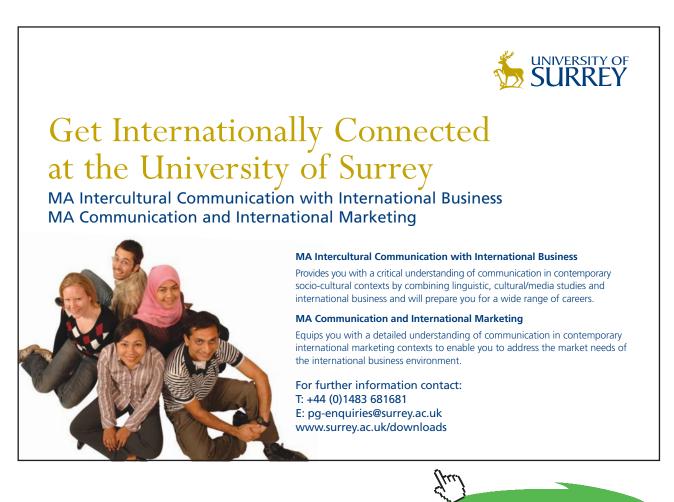
"Calculations:"

"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"



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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	$\eta_{th2} = 0.6057$
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 _{ov} = 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]	∨1 = 0.8983 [m ³]	∨2 = 0.05989 [m ³]	∨3 = 0.05989 [m ³]
∨4 = 0.1284 [m ³]	∨5 =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.

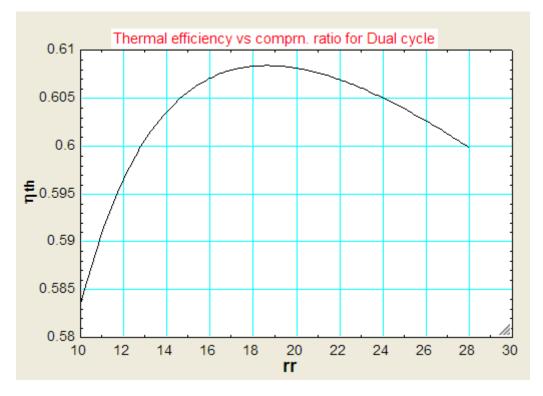
MEP of the cycle = mep = 1210 kPa = 12.1 bar ... Ans.

Note that results calculated with EES Functions, viz. eta_th2, w_net2 and MEP2 match very well with the above results.

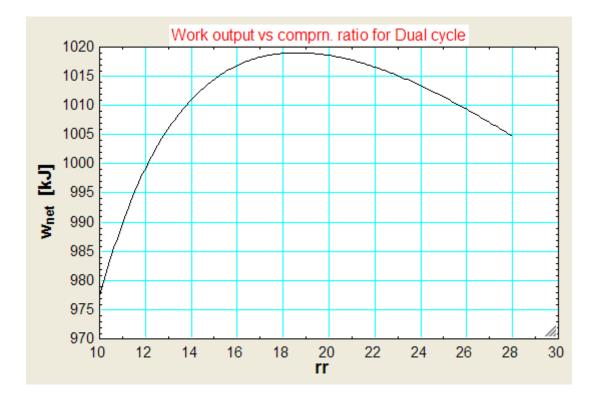
(b) In addition, plot eta_th, W_net and MEP as compression ratio varies from 10 to 28, other conditions remaining the same:

110	1 TT	2 Σ η _{th}	3 ▼ W _{net} [kJ]	₄
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:



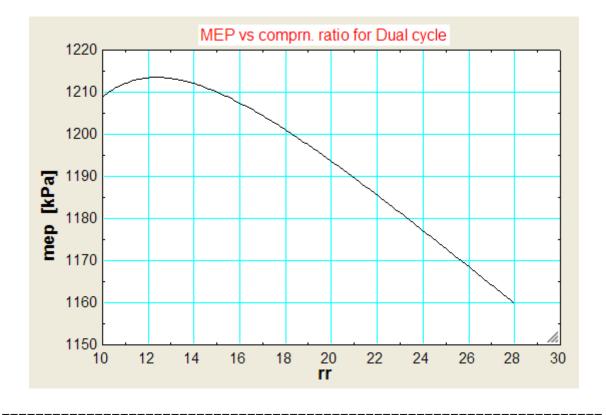
Gas Power Cycles



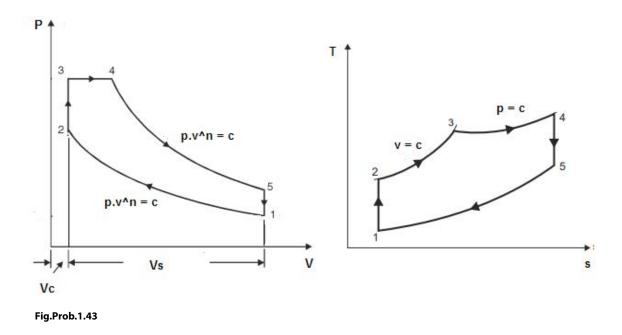




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Prob.1.43. The compression ratio and expansion ratio of an oil engine working on the dual cycle are 9 and 5 respectively. The initial pressure and temp of air are 1 bar and 30 C. The heat liberated at const. pressure is twice the heat liberated at 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]



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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 = 1.4rr=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:"

 $V_s = pi * L * D^2 / 4 \text{ "m^3 stroke volume"}$ $V2 = V_s / (rr -1) \text{ "...finds V2"}$ rc = rr / re "...cut off ratio" **"Process 1-2:"** P1 * V1 = m * R * T1 "finds m, kg" $P2 / P1 = rr^n \text{"finds P2, Pa"}$ $T2 / T1 = rr^n (n - 1) \text{"finds T2, K"}$ **"Process 2-3:"** V3 = V2 P3 / T3 = P2 / T2 "finds T3, K" $q_cv = m * cv * (T3 - T2) \text{ "kJ ... heat supplied during const. vol. process 2-3"}$ $q_cp = 2 * q_cv \text{ "..heat liberated at const. pressure is twice that at const. vol."}$

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

"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"



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Results:

Unit Settings: SI C Pa J mass deg

cp = 1.005 [kJ/kg-K]	ov = 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 _{op} = 24.36 [kJ]	q _{ov} = 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]	∨1 = 0.02209 [m ³]	√2 = 0.002454 [m ³]	∨3 = 0.002454 [m ³]
∨4 = 0.004418 [m ³]	∨5 = 0.02209 [m ³]	∨ _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 baginning of the compression process. The terms of air at the and of constant process heat addition

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]"

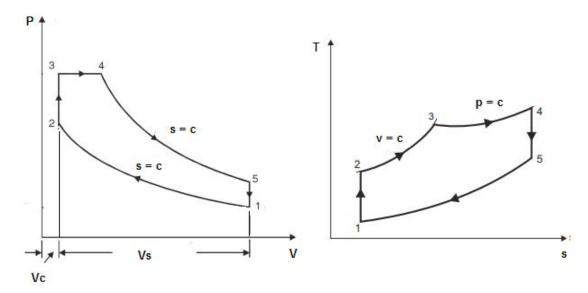


Fig.Prob.1.44

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"

Gas Power Cycles

"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"

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"



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Results:

Unit Settings: SI C Pa J n	nass deg	
cp = 1.005 [kJ/kg-K]	cv = 0.7179 [J/kg-K]	$\eta_{th} = 0.5615$
$\eta_{th2} = 0.5615$	γ = 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 _{ev} = 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 <mark>[K]</mark>
∨1 = 0.861 [m ³]	∨2 = 0.1076 [m ³]	∨3 = 0.1076 [m ³]
V4 = 0.1211 [m ³]	∨5 = 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:

	14	0.51					d Process, (1000			
	thermo	fluids	.net	 Daemo 	ns • Syst	ems	 Closed P 	rocess	• Spe	CIFIC	 Recipr 	ocating Cycle	25 .	PG Model		
Mixed	C SI C I	Englis	sh	< ©Ca	se-0 💙 >		🗸 Help Message	s On	Super-	Itera	te S	uper-Calculate		Load	Super-Initiali	ize
	State Panel				Proces	s Pa	inel	1		Cycl	e Panel			1/0 Pa	nel	
< ©State	<mark>-1 ×</mark> >		Calcu	ilate	No-Plots	~	Initialize		Formati	on Er	nthalpy:	🔿 No 💿 Yes	ł	Air	×	-
🖌 p1			1	T1	1000		v1				u1			h1		
100.0	kPa	~	27.0		deg-C	~	0.86139	m^3/kg	~	-84	.13202	kJ/kg	×	2.00699	kJ/kg	~
s1			1	Vel1			🖌 z1				e1			j1		
6.0934	kJ/kg.K	~	0.0		m/a	~	0.0	m	~	-04	13202	kJ/kg	¥	2.00699	kJ/kg	~
phi1			рзі	1			🖌 m1				Vol1			MM1		
	kJ/kg	~			kJ/kg	~	1.0	kg	~	0.8	6139	m*3	Y	28.97	kg/kmol	٧
R1			c_)	o1			c_v1			+	c1					
0.28699	kJ/kg.K	~	1.003	49	kJ/kg.K	¥	0.71651	kJ/kg.K	~	1.4	0054	UnilLess	¥			

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:

• Mixed •	SI C En	glish	< ©Ca	se-0 ♥ >	F	₹ Hel	p Messages	On	Super-	Iterate	Super-Calculate		Load	Super-Initia	lize
Sta	te Panel			Proces	s Pa	nel				Cycle Panel			I/O P	anel	
< ©State-2	v >	C	alculate	No-Plots	~		Initialize		Formati	on Enthalpy:	ONo •Yes		Air		~
p2			T2			<	v2			u2			h2		
4437.694	kPa	× 88	7.98254	К	v	=V1/1	15	m^3/kg	*	337.05438	kJ/kg	×	591.89343	kJ/kg	1
✓ s2		1	Vel2			-	22			e2			j2		
=s1	kJ/kg.K	۲ 0.	0	m/s	۷	0.0		m	*	337.05438	kJ/kg	۷	591.89343	kJ/kg	
phi2			psi2			1	m2			Vol2			MM2		
	k.l/kg	*		k.l/kg	*	=m1		kg	*	0.05743	m^3	۷	28.97	kg/kmol	1
R2			റ_p2			G_	v2			k?					
0.28699	kJ/kg.K	× 1.	00349	kJ/kg.K	¥	0.710	851	kJ/kg.K	*	1.40054	UnitLess	*			

Here, p2 = 4437.694 kPa, T2 = 887.98 KAns.

7. Similarly, for State 3: Enter $p_3 = 5500$ kPa, $v_3 = v_2$, and $m_3 = m_1$. Hit Enter, and we get:

Mixed CSI CE	nglish	< ©Ca	se-0 ♥ >	₩ He	lp Messages C	On Super	-Iterate	Super-Calculate		Load	Super-Initiali	ize
State Panel			Process	s Panel			Cycle Panel			I/O Pa	nel	
< <mark>©State-3 v</mark> >	Ca	alculate	No-Plots	~	Initialize	Formati	on Enthalpy:	ONO •Yes	4	Air	N	/
p.3		T.3		1	v.3		113			h.3		
500.0 kPa	× 11	00.55	к	✓ =v2	1	n°3/kg 💌	489.36057	kJ/kg	~ 8	305.2036	kJ/kg	
s3	1	Ve/3		-	zJ		e3			j3		
.04717 kJ/kg.K	× 0.0)	m/s	₩ 0.0		m 💙	489.36057	kJ/kg	~ 8	305.2036	kJ/kg	1
phi3		psi3		1	m3		Vol3	3		ММЗ		
kJ/kg	~		kJ/kg	✓ =m1		ka 💌	0.05743	m^3	¥ 2	8 97	kg/kmol	

Note that T3 = 1100.55 K ... Ans.

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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:

Cycle Panel I/O Panel
Formation Enthalpy: ONo OYes Air
u4 🖌 h4
g 🜱 <mark>543.7348 kJ/kg 🛩 =h3+(u3-u2)/2</mark> kJ/kg
e4 j4
✓ 543.7348 kJ/kg ✓ 881.3567 kJ/kg
Vol4 MM4
✓ 0 06139 m ² 3 ✓ 28.97 kg/kmol

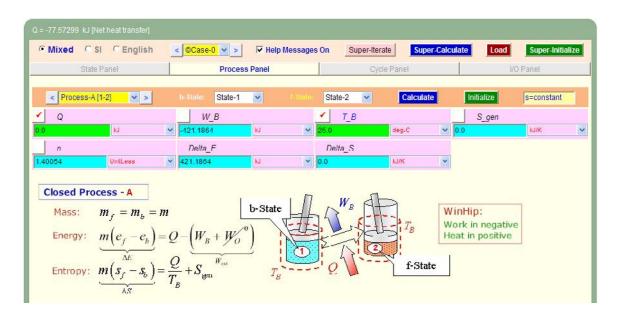
Note that T4 = 1176.44 K....Ans. And, s4 = 7.11408 kJ/kg.K.

9. Now, for State 5: Enter v5 = v1, s5 = s4, m5 = m1, and hit Enter. We get:

Mixed C SI C Er	nglis	h <mark><©Ca</mark>	se-0 ♥ >		✓ Hel	p Messages On	Super	-Iterate	Super-Calculate		Load	Super-Initial	ize
State Panel			Proces	s Pa	anel			Cycle Panel			1/0 Pa	anel	
< <mark>©State-5</mark> 💙 >		Calculate	No-Plots	¥		Initialize	Formati	ion Enthalpy:	ONo •Yes		Air		/
p5		T5			1	v5		115			h5	-	
36.07043 kPa	~	408.41544	к	٧	=v 1	m*3	/kg 💌	-0.55903	kJ/kg	~	110.6507	kJ/kg	
\$5		Vel5			-	z5		e5			<i>j</i> 5		
s4 kJ/kg.K	*	0.0	m/s	۷	0.0	m	*	-6.55903	kJ/kg	~	110.6507	kJ/kg	
phib		psib			-	mb		Vol5			MM5		
kJ/kg	~		kJ/kg	Y	=m1	kg	*	0 86139	m^3	~	28.97	kg/kmol	

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:

Mixed CSI CEnglish	< ©Case-0 ∨ >	Ip Messages On Super-Ite	erate Super-Calcul	ate Load Su	per-Initiali
State Panel	Process Panel	0	ycle Panel	I/O Panel	
	- 24	1040			
< Process-B [2-3] 💉 >	b-State: State-2 💌	GSING State-3 💌	Calculate	Initialize Vol=	constant
0	WB	✓ TB		S gen	
Q kJ	W_B	✓ T_B ✓ 25.0	deg-C 💉	S_gen	të

12. And, similarly for Process 3-4:

• Mixed C SI C English	< ©Case-0 ▼ > F	Help Messages On Sur	per-Iterate Super-Cale	culate Load	Super-Initialize
State Panel	Process Pa	nel	Cycle Panel	V	0 Panel
< Process-C [3-4] V >	h-State: State-3	fiState-4	✓ Calculate	Initialize	p=constant
	and the second sec				
Q	W B				
	<i>W_B</i> ✓ 21.77882	✓ T_B	deg-C 🗸	S_gen	kJ/K

13. Again, for Process 4-5:

	elp Messages On Super-I	< ©Case-0 ▼ > ▼ He	• Mixed C SI C English
Cycle Panel I/O Panel		Process Panel	State Panel
Calculate Initialize s=constant	f-State: State-5 💌	b-State: State-4 💌	< Process-D [4-5] 💙 >
S gen	✓ T_B	W B	Q
			n kJ
deg-C V 0.0 kJ/K	25.0	✓ 550 2939 kJ	10 No.
	× 25.0		0.0 kJ

14. And, for Process 5-1:

Q = 0.0 kJ [Net heat transfer]			
• Mixed C SI C English	< Case-0 > Felp Message	es On Super-Iterate Super-Calc	culate Load Super-Initialize
State Panel	Process Panel	Cycle Panel	I/O Panel
< Process-E [5-1] V	h-State: State-5 💌 f-State	State-1 Calculate	Initialize Vol=constant
Q -77.57299 kJ	W_B ❤ <mark>0.0 kJ ❤</mark>	✓ T_B 25.0 deg-C ✓	S_gcn 0.03949 kJ/K V
n	Delta_E	Delta_S	
Infinity Unit ess	✓ -77.57299 kl ✓	-0.22069 k.I/K 📡	

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

*

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

Gas Power Cycles

Note that:

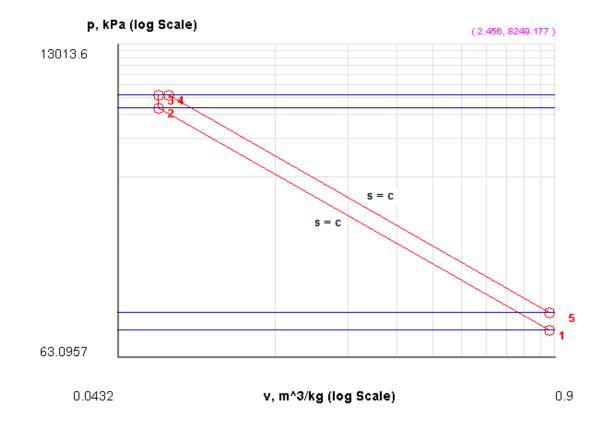
Air standard efficiency = eta_th = 66.05% Ans.

MEP = 187.68 kPa = 1.877 bar ... Ans.

Cut off ratio = v4/v3 = 1.069.... Ans.

Explosion ratio = p3/p2 = 1.239... Ans.

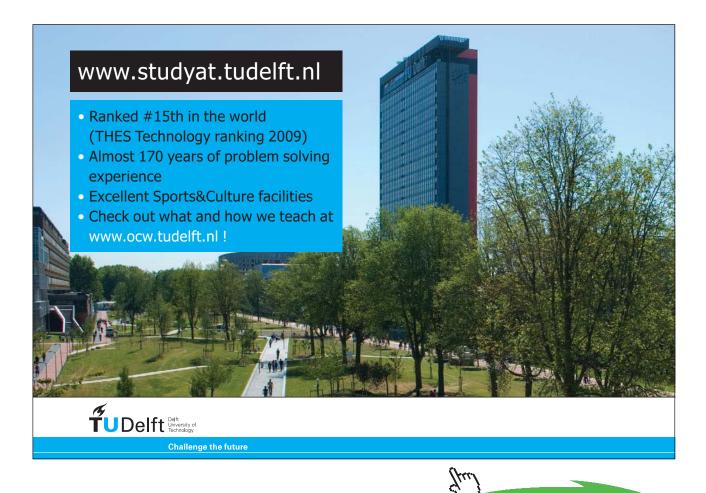
16. Get the p-v plot from the Plots widget:

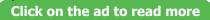


17. And get the TEST code etc from the I/O panel:

#~~~~~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)
               100.0
                          300.2
                                     0.8614
                                                 -84.13
                                                             2.01
                                                                          6.893
#
       1
#
       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 \text{ 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 \text{ 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	
$p_3/p_2 = 1.2393824892196206Ans.$	





(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:

$$\frac{\mathbf{p}_2}{\mathbf{p}_1} = \frac{\mathbf{p}_{\mathbf{r}2}}{\mathbf{p}_{\mathbf{r}1}} \quad \text{and}$$
$$\frac{\mathbf{v}^2}{\mathbf{v}1} = \frac{\mathbf{v}_{\mathbf{r}2}}{\mathbf{v}_{\mathbf{r}1}}$$

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.

				when a	$\Delta s = 0^1$					when A	u = 0
Т	h	и	50	Pr	v,	T	h	и	sa	Pr	vr
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
2.30	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	96.9
330	330.34	235.61	1.79783	1.9352	489.4	630	638.63	457.78	2.46048	19.84	92.8
3-40	340.42	242.82	1.82790	2.149	454.1	640	649.22	465.50	2.47716	20.64	88.9
350	350.49	250.02	1.85708	2.379	422.2	650	659.84	473.25	2.49364	21.86	85.3
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	78.6
380	380.77	271,69	1.94001	3.176	343.4	680	691.82	496.62	2.54175	25.85	75.5
390	390.88	278.93	1.96633	3.481	321.5	690	702.52	504.45	2.55731	27.29	72.5
400	400.98	286.16	1.99194	3.806	301.6	700	713.27	512.33	2.57277	28.80	69.7
410	411.12	293.43	2.01699	4.153	283.3	710	724.04	520.23	2.58810	30.38	67.0
420	421.26	300.69	2.04142	4.522	266.6	720	734.82	528.14	2.60319	32.02	64.5
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	59.8

TABLE A-22 Ideal Gas Properties of Air

1. p, and v, data for use with Eqs. 6.43 and 6.44, respectively.

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				$T(\mathbf{K})$, h and u(kJ/	kg), 5° (1	kJ/kg · K)				
				when .	$\Delta x = 0^1$					when .	$\Delta s = 0$
T	h	и	s°	Pr	v,	Т	h	ш	50	Pr	v,
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	7.80
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	7.15
920	955.38	691.28	2.87324	82.05	32.18	1520	1660.23	1223.87	3.46120	636.5	6.85
940	977.92	708.08	2.89748	89.28	30.22	1540	1684.51	1242.43	3.47712	672.8	6.56
960	1000.55	725.02	2.92128	97.00	28.40	1560	1708.82	1260.99	3.49276	710.5	6.30
980	1023.25	741.98	2.94468	105.2	26.73	1580	1733.17	1279.65	3.50829	750.0	6.046
000	1046.04	758.94	2.96770	114.0	25.17	1600	1757.57	1298.30	3.52364	791.2	5.804
020	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
100	1161.07	845.33	3.07732	167.1	18.896	1700	1880.1	1392.7	3.5979	1025	4,76
120	1184.28	862.79	3.09825	179.7	17.886	1750	1941.6	1439.8	3.6336	1161	4.321
140	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
200	1277.79	933.33	3.17888	238.0	14.470	1950	2189.7	1630.6	3.7677	1852	3.022
220	1301.31	951.09	3.19834	254.7	13.747	2000	2252.1	1678.7	3.7994	2068	2.776
240	1324.93	968.95	3.21751	272.3	13.069	2050	2314.6	1726.8	3.8303	2303	2.55
260	1348.55	986.90	3.23638	290.8	12.435	2100	2377.4	1775.3	3.8605	2559	2.356
280	1372.24	1004.76	3.25510	310.4	11.835	2150	2440.3	1823.8	3.8901	2837	2.17
						2200	2503.2	1872.4	3.9191	3138	2.01
						2250	2566.4	1921.3	3.9474	3464	1.86

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:

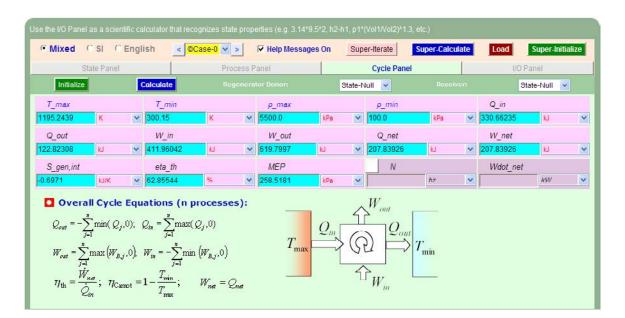
- a) Just choose Ideal Gas (IG) model, instead of PG model. In IG model, variation of sp. heat with temp is taken in to account.
- b) Select air as working substance, and copy the TEST code to the I/O panel
- c) Click on Load to load this TEST code.

chermonulds.ne	t · Daemons · Systems · Closed · Pro	cess · Specific · Reciprocating (Cycles • IG Model
Mixed CSI CEnglish	< Case-0 🐱 > 🔽 Help Messages O	n Super-Iterate Super Calcu	ulate Load Super Initializ
State Panel	Process Panel	Cycle Panel	I/O Panel
******		*****	and on a more the
Start of TEST-Codes			
ites {			
State-1: Air:			
Given: { p1= 100.0 kPa; 1	1= 27.0 deg-C; Vel1= 0.0 m/s; z1= 0.0 m; m1= 1	1.0 kg; }	
		Contract of the second s	
State-2: Air;			
	g; s2= "s1" kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; n	n2= "m1" kg; }	
Given: {v2= "v1/15" m*3/kg	g; s2= "s1" kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; n	n2= "m1" kg; }	
Given: {v2="v1/15" m*3/kg State-3: Air;			
Given: {v2="v1/15" m*3/kg State-3: Air;	g; s2="s1" kJ/kg.K; Vel2= 0.0 m/s; z2= 0.0 m; n V3="V2" m*3/kg; Vel3= 0.0 m/s; z3= 0.0 m; m3=		
Given: {v2="v1/15" m*3/kj State-3: Air; Given: {p3= 5500.0 kPa;			
Given: {v2="v1/15" m*3/k State-3: Air; Given: {p3= 5500.0 kPa; State-4: Air;	√3= "√2" m^3/kg; Vel3= 0.0 m/s; z3= 0.0 m; m3=	"m1" kg; }	
Given: {v2="v1/15" m*3/k State-3: Air; Given: {p3= 5500.0 kPa; State-4: Air;		"m1" kg; }	
Given: {v2="v1/15" m*3/kg State-3: Air; Given: {p3= 5500.0 kPa; State-4: Air; Given: {p4= "p3" kPa; h4	√3= "√2" m^3/kg; Vel3= 0.0 m/s; z3= 0.0 m; m3=	"m1" kg; }	
Given: {v2="v1/15" m*3/kg State-3: Air; Given: {p3= 5500.0 kPa; State-4: Air; Given: {p4= "p3" kPa; h4 State-5: Air;	v3= "v2" m*3/kg; Vel3= 0.0 m/s; z3= 0.0 m; m3= = "h3+(u3-u2)/2" kJ/kg; Vel4= 0.0 m/s; z4= 0.0 m;	"m1" kg; } m4= "m1" kg; }	
Given: {v2="v1/15" m*3/kg State-3: Air; Given: {p3= 5500.0 kPa; State-4: Air; Given: {p4= "p3" kPa; h4 State-5: Air;	√3= "√2" m^3/kg; Vel3= 0.0 m/s; z3= 0.0 m; m3=	"m1" kg; } m4= "m1" kg; }	
Given: {v2="v1/15" m*3/kg State-3: Air; Given: {p3= 5500,0 kPa; State-4: Air; Given: {p4= "p3" kPa; h4 State-5: Air;	v3= "v2" m*3/kg; Vel3= 0.0 m/s; z3= 0.0 m; m3= = "h3+(u3-u2)/2" kJ/kg; Vel4= 0.0 m/s; z4= 0.0 m;	"m1" kg; } m4= "m1" kg; }	
Given: {v2="v1/15" m*3/kg State-3: Air; Given: {p3= 5500.0 kPa; State-4: Air; Given: {p4= "p3" kPa; h4 State-5: Air;	v3= "v2" m*3/kg; Vel3= 0.0 m/s; z3= 0.0 m; m3= = "h3+(u3-u2)/2" kJ/kg; Vel4= 0.0 m/s; z4= 0.0 m;	"m1" kg; } m4= "m1" kg; }	

d) Now, click on SuperCalculate, and immediately, all calculations are up-dated.

• Mixed	C SI C En	glish < <mark>©</mark>	Case-0 ♥ >	Help Messages On	Super-Iterate	Super-Calculate	Load	Super-Initialize
	State Panel	1	Process	Panel	Cycle Par	iel	V	O Panel
	OLJTPL	T OF SUPER-CAL		TION FROM THE LOADE	D TEST-CODE~~~~~	~~~~~~		
******ANAL	YST: Dr. Muliya; T	EST License: Profe	ssional******					
Solu	tion logged at: Ma	ay 25, 2014 6:11:26	PM					
*****TEST	code: To save th	e solution, copy the	codes generate	ed below into a text file. To	reproduce the solutio	n at a later time. launch		
				ST-code at the bottom of				
Dee	non Dath: Quatan	nos Classeds Brasse		warOualas IC Hadali y 10 a	-00			
Dae	non Fain. System	IS-CIUSEU-FIOCES	sespecificerov	verCycle>IG-Model; v-10.c	300			
	Start of TEST-o	ode			73			
States {								
	e-1: Air:							
Give	n: {p1= 100.0	kPa; T1= 27.0 de	g-C; Vel1= 0.0	m/s; z1= 0.0 m; m1= 1.	D kg; }			
Stat	e-2: Air;							
Give	n: {v2= "v1/15	" m^3/kg; s2= "s1	"kJ/kg.K; Vel2=	= 0.0 m/s; z2= 0.0 m; m2	2= "m1" kg; }			
Stat	e-3: Air;							

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

Gas Power Cycles

```
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 -----
```

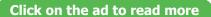


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#	Prope	rty spread	lsheet sta	arts:			
##	State	p(kPa)	T(K)	v(m^3/kg)	u(kJ/kg)	h(kJ/kg)	s(kJ/kg)
#	1	100.0	300.2	0.8614	-84.12	2.02	6.893
#	2	4193.16	839.1	0.0574	327.84	568.64	6.893
#	3	5500.0	1100.6	0.0574	548.29	864.13	7.122
#	4	5500.0	1195.2	0.0624	631.33	974.35	7.218
#	5	156.04	468.3	0.8614	38.71	173.12	7.218
#	Prope	rty spread	sheet end	ls			
# Cycl	e Analy	sis Result	s:				
#		Calculat	ted: T_m	ax= 1195.243	9 K; T_mi	n= 300.15 K	; p_max= 5500.0 kPa;
#			p_min=	100.0 kPa; Q_	_in= 330.6	6235 kJ; Q_0	out= 122.82308 kJ;
#			W_in= 4	11.96042 kJ;	W_out= 6	19.7997 kJ; (Q_net= 207.83926 kJ;
#			W_net=	207.83926 kj	J; S_gen,in	t= -0.6971 k	J/K; eta_th= 62.85544 %;
#			MEP= 2	58.5181 kPa;			
#							
#****	*CALCU	JLATE VA	ARIABLE	S: Type in an	expression	n starting wi	th an '=' sign ('= mdot1*(h2-h1)',
'= sqrt	t(4*A1/I	PI)', etc.) a	nd press t	the Enter key)******		
#Cut o	off ratio	:					
v4/v3	= 1.086	04228128	93336	. Ans.			
#Expl	osion ra	tio:					
p3/p2	= 1.311	66001540	84803,	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:

	thermo	fluide	net	Daemo	ne . Svet	ome	. (locod . Di	rocese	. Sne	rific	. Recipi	rocating Cycle	ac .	DG Model		
								Josed - Pi	locess	· oper	anc	Recipi	ocating cyci	50	ForModer		
ove mouse ove	er a variable ti	o dispi	lay its v	alue with n	nore precisio	on.	-										
• Mixed	C SI CE	Ingli	sh	< ©Ca	se-0 🗙 >		₩ He	lp Messages	s On	Super-	Itera	ate	uper-Calculate	9	Load	Super-Initiali	ize
3	State Panel				Proces	ss Pa	anel				Cycl	le Panel			I/O Pa	nel	
< @State	-1 🗸 >		Calcu	late	No-Plots	~		Initialize		Formatio	on F	nthalpy:	⊙No •Yes		Air	~	•
🖌 p1			1	T1				vt	_			u1			h1		
100.0	kPa	*	30.0		deg-C	~	0.87	6	m*3/kg	~	-81	1.9825	kJ/kg	۷	5.01/4/	kJ/kg	1
51			-	Vel1			-	21				ef			jt		
6.90338	kJ/kg.K	*	0.0		m/s	~	0.0		m	*	-81	1.9825	kJ/kg	۷	5.01747	kJ/kg	
phi1			psi	1			-	m1				Vol1			MM1		
	kJ/kg	۷			kJ/kg	*	10		kg	~	0.8	17	m^3	۷	28.97	kg/kmol	1
R1			c_0	51			c	_v1				k1					
0.28699	kJ/kg.K	~	1.003	49	kJ/kg.K	~	0.71	1651	kJ/kg.K	*	1.4	0054	UnitLess	~	1		

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:

• Mixed	SI CE	nglis	sh < ©C	ase-0 💙 >	١	✓ Help	p Messages	On	Super-	Iterate	Super-Calculate		Load	Super-Initial	lize
St	ate Panel			Proces	s Pa	inel				Cycle Panel			I/O Pa	nel	
< OState-2	v >		Calculate	No-Plots	-		Initialize	i.	Formatic	on Enthalpy:	ONo •Yes		Air	ŀ	~
p2			T2				v2			112			h2		
3828.8853	kPa	~	859.7975	К	۲	0.064	144	nr*3/kg	*	316.85956	kJ/kg	*	563.60986	kJ/kg	
✓ 32			✓ Vel2			1	z2			e2			j2		
=s1	kJ/kg.K	~	0.0	m/s	۷	0.0		m	~	316.85956	kJ/kg	۷	563.60986	kJ/kg	
phi2			psi2			*	m2			✓ Vol2			MM2		
	kJ/kg	~		kJ/kg	۷	=m1		kq	*	=0.08*Vol1/1	.08 m^3	۷	28.97	kq/kmol	1
R2			c p2			с	v2			k2					
0.28699	kJ/kg.K	¥	1.00349	kJ/kg.K	~	0.716	651	kJ/kg.K	~	1.40054	UnitLees	~			

Here, p2 = 3828.89 kPa, T2 = 859.8 KAns.

7. Similarly, for State 3: Enter p3 = 7000 kPa, Vol3 = Vol2, and m3 = m2. Hit Enter, and we get:

• Mixed	C SI C E	ngli	sh	< ©Cas	e-0 💙 >	V	Help Messages	s On	Super-	Itera	te Su	per-Calculat	e	Load	Super-Initial	ize
	State Panel				Process	Pan	el			Cycle	e Panel			I/O P	anel	
< ©State	e-3 💙 >		Calcula	ate	No-Plots	~	Initialize		Formati	on En	nthalpy:	No •Yes		Air		~
🖌 рЗ				ТЗ			v3				u3			h3		
7000.0	kPa	~	1571.8	889	К	~	0.06444	m°0/kg	~	827	7.07837	kJ/kg	~	1278.1893	kJ/kg	1
e3			1	Vol3			✓ z3				03			j3		
7.33567	kJ/kg.K	*	0.0		m/s	~).0	m	*	827	7.07837	kJ/kg	*	1278.1893	kJ/kg	1
phi3			psi3				 m3 			1	Vol3			ММЗ		
	kJ/kg	~			kJ/kg	~	=m2	kg	~	=Vo	012	m^3	~	28.97	kg/kmol	1
R3) с_р3				c_v3				k3					
0.28699	kJ/kg.K	~	1.0034	9	kJ/kg.K	~).71651	kJ/kg.K	~	1.4	0054	UnitLess	~			

Note that T3 = 1571.89 K ... Ans.



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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:

Mixed C SI C English	h < ©Case-0	✓ > ▼	Help Messages (On Super-I	terate Super	-Calculate	Load Su	per-Initialize
State Panel		Process Pane	el	C	lycle Panel		I/O Pane	1
< ©State-4 v >	Calculate N	lo-Plots 🔽	Initialize	Formatio	n Enthalpy: 🛛 🖗 N	lo 🔹 Yes	Air	~
p4	T4		v4		<i>u</i> 4		h4	
p3 kPa 💙 3	3536.75 K	¥ 0	. 145	m*3/kg 💌	2234.916	kJ/kg 💌	3249.9158	kJ/kg
s4	✓ Vel4		z4		e4		j4	
14944 kJ/kg.K 🛛 🖌	D.0 m/s	· 🖌 🛛	0.0	m 💙	2234.916	kJ/kg 💌	3249.9158	kJ/kg
phi4	psi4		m4		✓ Vol4		MM4	
kJ/kg 🗸	KJ/	kg 💉 😑	:m3	kg 🗸	=Val3+0 1*(Val1-\	m^3 🗸	28.97	kg/kmol

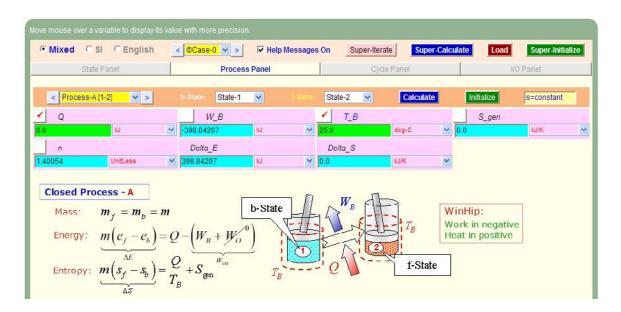
Note that T4 = 3536.75 K....Ans. And, s4 = 7.11408 kJ/kg.K.

9. Now, for State 5: Enter Vol5 = Vol1, s5 = s4, m5 = m4, and hit Enter. We get:

• Mixed	SI CE	nglis	sh <mark>< ©Ca</mark>	se-0 ♥ >		✓ Hel	p Messages	s On	Super-	-Iterate	Super-Calculat	e	Load	Super-Initial	lize
Sta	ite Panel			Proces	s Pa	anel				Cycle Panel			I/O P	anel	
< ©State-5	v >		Calculate	No-Plots	*		Initialize	1	Formati	on Enthalpy:	ONO • Yes		Air		~
p5			T5				v5			u5			h5		
569.20636	kPa	Y	1725.5491	К	Y	0.87		m^3/kg	×	937.17706	kJ/kg	×	1432.3864	kJ/kg	
 ✓ 85 			 Vel5 			1	∠5			e5			j5		
=\$4	kJ/kg.K	~	0.0	m/s	~	0.0		m	~	937.17706	kJ/kg	~	1432.3864	kJ/kg	2
phi5			psi5			1	m5			✓ Vol5			MM5		
	kJ/kg	~		kJ/kg	~	-m4		kg	~	-Vol1	m^3	×	28.97	kg/kmol	
R5			c_p5			c_	v5			k5					
0.28699	KJ/Kg.K	~	1.00349	kJ/kg.K	v	0.71	651	KJ/Kg.K	v	1.40054	UnitLess	v	1		

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:

Mixed C SI C English	< ©Case-0 v > V	Help Messages On Sup	er-Iterate Super-Cal	Load	Super-Initialize
State Panel	Process Pan	el	Cycle Panel	1	IO Panel
< Process-B [2-3] >	b-State: State-2 💉	FState-3	✓ Calculate	Initialize	User Defined
< Process-B [2-3] >	b-State: State-2 V W_B	i-State: State-3 ✓ I_B	Calculate	Initialize S_gen	User Defined
Q		✓ I_B	Calculate	S_gen	User Defined
Q	✓ w_B	✓ I_B		S_gen	

12. And, similarly for Process 3-4:

Mixed C SI C English	< ©Case-0 🛩 >	Help Messages C	Super-Iterate	Super-Calculate	Load Super-Init	tialize
State Panel	Process	s Panel	Cycle Pan	nel	I/O Panel	
						_
Process C 13.41	h.State: State-3	v LStater	State-1	Calculate	Initialize	+
< Process-C [3-4] >	b-State: State-3	• EState:	State-1 💌	Calculate	Initialize p-constant	t
< Process-C [3-4] >	b-State: State-3	• 6-Stite:	State-1 💌	Calculate	Initialize p-constant	t
						t

13. Again, for Process 4-5:

• Mixed C SI C English	< ©Case-0 v >	Help Messages On Super-	Iterate Super-Calculat	e Load Super-Initia
State Panel	Process Par	nel	Cycle Panel	I/O Panel
< Process-D [4-5] 🗸 >	h-State: State-4 🗸	f-State: State-5 🗸	Calculate	Initialize s=constant
C Hocesser [4-5]	June 4	otate-o e	Carculate	s=constant
Q	W_B	🖌 T_B		S_gcn
́] Q 0 кі	W_B ▼ 1297.739 kJ	✓ T_B ✓ 25.0	deg-C 💙 0.1	

14. And, for Process 5-1:

• Move mouse over a variable to display its v	alue with more precision.		
• Mixed C SI C English	< ©Case-0 ▼ > F Help Message	es On Super-Iterate Super-Calcula	te Load Super-Initialize
State Panel	Process Panel	Cycle Panel	I/O Panel
< Process-E (5-1) V >	b-State: State-5 💌 f-State	State-1 V Calculate	Initialize User Defined
Q	✓ W_B	✓ T_B 25.0 deg-C ✓ 2	S_gen
n	Delta_F	Delta_S	TT RELE
UnitLess	✓ -1019.15955 N ✓	-1.24606 kJ/K 🛩	



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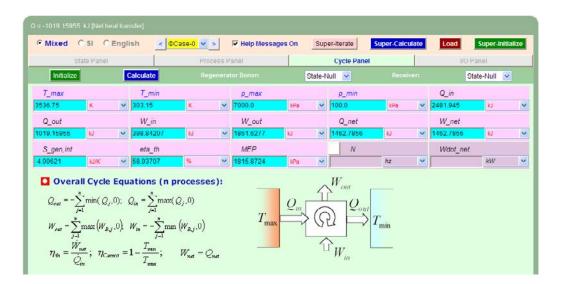
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264 Download free eBooks at bookboon.com 15. Now, go to Cycle Panel, Click on Calculate and SuperCalculate. All calculations are available here:

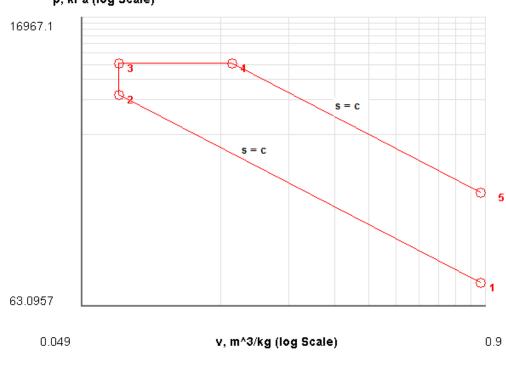


Note that:

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:



p, kPa (log Scale)

17. And get the TEST code etc from the I/O panel:

#~~~~	~~~~~	~~~~~~	~~~OUTP	UT OF SUPE	R-CALCULA	ΔТЕ	
#	Daemo	n Path: Sys	tems>Clos	ed>Process>	Specific>Pow	erCycle>PG-M	odel; v-10.ca08
#		Start of	TEST-code				
States	{						
	State-1:	Air;					
	Given:	{ p1= 100.0	kPa; T1= 3	0.0 deg-C; Ve	el1= 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"kF	Pa; Vel4=0.0	0 m/s; z4 = 0.01	m; m4= "m3" l	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; }
	}						
Analys	sis {						
	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= 2	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= 2	25.0 deg-C; }			
	}						
#		End of	TEST-cod	e			
#	Propert	ty spreadshe	eet 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
#	Propert	ty spreadshe	et 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:

	Specific, Closed Process, Cycle Daem	
Select a material mode	thermofluids.net · Daemons · Systems · Closed · to launch the closed (reciprocating) cycle daemon.	Process - Specific - Reciprocating Cycles
Navigation Map		Gas Models Gas Models Gas Mixture Models





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:

			ſ	Specific, (Close	ed Process,	Cycle I	Daem	on: IG	Model				
	therm	ofluic	ls.net • Da	emons • Sy	stems	· Closed ·	Process	• Spe	cific • Re	ciprocating Cycle	s .	IG Model		
		Densi												
Mixed Ø	C SI C	Engl	ish <	SCase-0 💌	-	🔽 Help Message	s On	Super-	Iterate	Super-Calculate		Load	Super-Initia	alize
St	ate Panel			Proc	ess Pa	anel			Cycle Pane	1		1/0 P	anel	
< ©State-1	1 ¥ >		Calculate	No-Plo	ts 💌	Initialize		Formati	on Enthalpy	ONO OYes		Air		~
🖌 p1			🖌 T1			tho1			vt			u1		
100.0	kPa	~	30.0	deg-C	*	1.14943	kg/m^3	*	0.87	m^3/kg	~	81.96466	kJ/kg	*
h1			s1			✓ Vel1			¥ z1			e1		
5.0353	kJ/kg	~	6.90339	kJ/kg.K	*	0.0	m/e	~	0.0	m	~	81.96466	kJ/kg	~
j1 .			phi1			peit			< m1	1		Vol1		
5.0353	kJ/kg	*		kJ/kg	~		kJ/kg	~	1.0	kg	*).87	m^3	٧
MM1			R1			c_p1								
20.97	kg/kmol	~	0.20699	kJ/kg.K	~	1.00424	kJ/kg.K	~						

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:

• Mixed C SI C	English	< ©Case-0 v >	Help Messages	On Super	-Iterate Su	per-Calculate	Load	uper-Initialize
State Panel		Proces	is Panel	1	Cycle Panel		I/O Pan	el
< <mark>©State-2 v</mark> >	Calcu	late No-Plots	✓ Initialize	Formati	ion Enthalpy:	⊖No •Yes	Air	~
p2		T2	rho2		🖌 v2	a)	u2	
815.1011 kPa	* 820.11	865 K	₩ 16.09196	kg/m*3 😽	-v1/14	m°3/kg 🛩	317.2909	kJ/kg
h2	1	32	✓ Vel2		✓ z2		e2	
54.38184 kJ/kg	✓ =s1	kJ/kg.K	♥ 0.0	m/s 💙	0.0	m 🗸	317.2969	kJ/kg
j2	phi2		psi2		🖌 m2		Vol2	
54.38184 kJ/kg	~	kJ/kg	~	kJ/kg 💙	1.0	kg 💉	0.06214	m^3

Here, p2 = 3815.16 kPa, T2 = 826.12 KAns.

7. Similarly, for State 3: Enter T3 = 1200 C, v3 = v2, and m3 = 1 kg. Hit Enter, and we get:

• Mixed C SI C	Eng	ish < ©C	ase-0 💙 >	✓ Help Messages	On Super-	-Iterate Sup	per-Calculate	Load	uper-Initialize
State Panel			Process P	anel	1	Cycle Panel		I/O Pan	el
< CState-3 V >		Calculate	No-Plots 💌	Initialize	Formati	on Enthalpy: 🛛	No • Yes	Air	~
p3		🖌 ТЗ		rho3		🖌 v3		u3	-
803.2656 kPa	¥	1200.0	deg-C 💙	16.09196	kg/m^3 💉	=v2	m^3/kg 💉	883.4264	kJ/kg 💊
h3		s3		✓ Vel3		✓ z3		e3	
306.2006 k.l/kg	¥	7.4063	k l/kg K 🛛 👻	0.0	m/s 🗸	0.0	m 🗸	883.4264	k.l/kg
j3		phi3		psi3		🖌 m3		Vol3	
306.2006 kJ/kg	~		kJ/kg 💙		kJ/kg 😽	1.0	kg 🛩	0.06214	m^3

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:

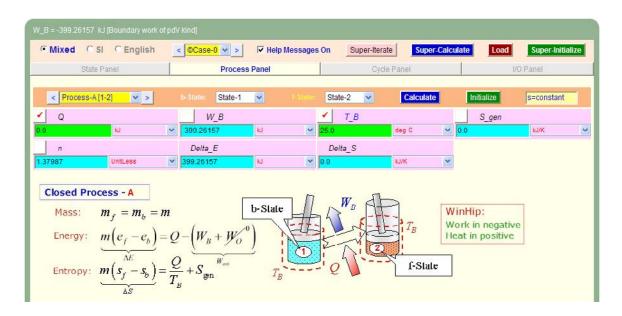
v4 u4 kg/m ² 3 ♥ 0.0748 m ² 3/kg ♥ 1165.0662 kJ/kg ♥ ✓ z4 e4 m/s ♥ 0.0 m ♥ 1105.0602 kJ/kg ♥ ✓ m4 Vo/4	• Mixed C SI	CEnglis	sh <mark>< ©Ca</mark>	ase-0 💙 >	✓ Help Messages	On Super-	Iterate	Super-Calculate	Load	uper-Initialize
v4 U4 kg/m²3 ♥ 0.0748 m²3kg ♥ 1165.0662 kJ/kg N ✓ z4 e4 m/s ♥ 0.0 m ♥ 1105.0602 kJ/kg N ✓ m4 Vo/4	State Pan	el		Process F	Panel		Cycle Panel		I/O Pan	el
kg/m*3 Ø.0748 m*3/kg 1165.0662 kJ/kg KJ/kg ✓ Z4 e4 e4 e4 m/s Ø.0 m 1105.0602 kJ/kg kJ/kg ✓ m4 Vol4 Vol4 Vol4	< OState-4 😽 >		Calculate	No-Plots 👻	Initialize	Formati	on Entholpy:	No •Yes	Air	~
✓ z4 e4 m/s ✓ 0.0 m ✓ 1105.0062 kJ/kg × ✓ m4 Vol4	✓ p4		T 4		rho4		v4		u4	
m/s ♥ 0.0 m ♥ 1105.0662 kJ/kg N ✔ m4 Vol4	=p3 kPa	× 1	500.0	deg-C 💉	13.36935	kg/m^3 💉	0.0748	m^3/kg 💉	1165.0662	kJ/kg 🔊
✓ m4 Vol4	h4		s4		✓ Vel4		🖌 z4		e4	
	1073.9304 kJ/kg	~ 7	.03345	kJ/kg.K 😽	0.0	m/s 🗠	0.0	m 🛩	1105.0662	kJ/kg
	j4		phi4		pai4		✓ m4		Vol4	
Ku/kg Y 1:0 kg Y 0.0748 m ⁻³	1673.9364 kJ/kg	~		kJ/kg 💙		kJ/kg 💙	1.0	kg 💉	0.0748	m*3 *
	j4				рзі4		✓ m4		Vol4	

9. Now, for State 5: Enter v5 = v1, s5 = s4, m5 = 1 kg, and hit Enter. We get:

• Mixed	C SI C	Engl	ish	< @Cas	se-0 v >	F	Help Messages	s On	Super-	Iterate		Super-Calculate	2	I oad	Super-Initia	lize
S	tate Panel				Proces	ss Par	iel			Cycle F	anel			I/O Pa	inel	
< <mark>©State-</mark>	5 🗙 >		Calcul	ale	No-Plots	~	Initialize		Formati	on Enti	alpy:	CN0 €Yes	2	Air		~
p5	1.1			T5			rho5			*	v5			u5		
263 4921	kPa	~	798 776	37	К	× [1 14943	kg/m^3	~	=v1		m^3/kg	۷	295 10837	kJ/kg	~
h5			< s	5			✓ Vel5			1	75			e5		
524.34644	kJ/kg	~	=\$4		kJ/kg.K	~).0	m/s	~	0.0		m	۷	295.10837	kJ/kg	Y
<i>j</i> 5			phi5				psi5			1	<i>m5</i>			Vol5		
524.34644	kJ/kg	*			kJ/kg	× [kJ/kg	Y	1.0		kq	۷	0.87	m^3	~
MM5			R5				c_p5									
28.97	kg/kmol	*	0.28699		kJ/kg.K	~	1.09572	kJ/kg.K	*							

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:

State Panel Process Panel Ovde Panel I/O Panel	• Mixed CSI CEnglish	< ©Case-0 v > F	Help Messages On	Super-Iterate Sup	er-Calculate Load	Super-Initializ
	State Panel	Process Pa	inel	Cycle Panel	1	I/O Panel
	Shave r dilet	Processing	liter	wycie r dilei		no callel
		-				-
Process-B (2-3) V > b-State: State-2 V 6-State: State-3 V Calculate Initialize User De	< Process-B [2-3] × >	b-State: State-2	State State	e-3 V Calcula	ite Initialize	User Defined
			Stat			User Defined
		<u>✓</u> w_o	<u> </u>	т_0	S_gen	

12. And, similarly for Process 3-4:

Q = 566.12946 kJ [Net heat transfer]		
• Mixed C SI C English	< Case-0 > F Help Messages On Supe	er-Iterate Super-Calculate Load Super-Initialize
State Panel	Process Panel	Cycle Panel I/O Panel
< Process C [3 4]	b State: State 3 🔹 f State: State 4	Calculate Initialize p=constant
Q	W_B T_B	S_gen
367.73578 kJ	✓ 86.09596 kJ ✓ 25.0	deg-C ✓ <mark>-1.00625 kJ/K ✓</mark>
n	Delta_E Delta_S	
0.0 UnitLess	✓ 281.03983 kJ ✓ 0.22715	kJ/K 🛩

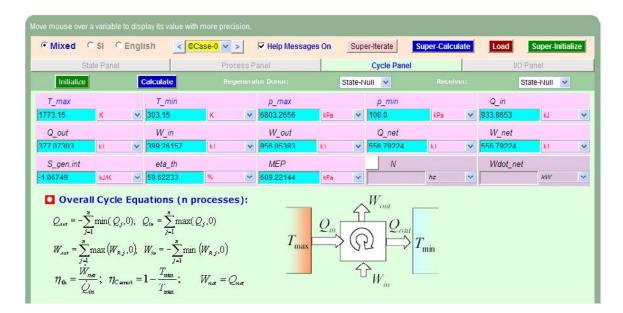
13. Again, for Process 4-5:

			Calculate Load Super-Initializ
State Panel	Process Panel	Cycle Panel	I/O Panel
< Process D [4 6]	b State: State 4 💌	f State: State 5 😪 Calculate	Initialize s=constant
0	W B	✓ T_B	S gen
l kJ	✓ 869.9579 kJ	✓ 25.0 deg-C	✓ 0.0 kJ/K

14. And, for Process 5-1:

• Mixed C SI C English	< ©Case-0 v >	Help Messages	On Super-Iterate	Super-Calculate	Load Super-Initialize
State Panel	Process	Panel	Cycle Panel		I/O Panel
< Process-E (5-1) V >	b-State: State-5	▼ PSinta	State-1 V	Iculate Initi	alize User Defined
	✓ W B		✓ T_B		S_gen
77 07303 kJ	✓ 0.0	kJ 💙	25.0 deg-C		Contraction of the second s
n	Delta E		Delta S		

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.

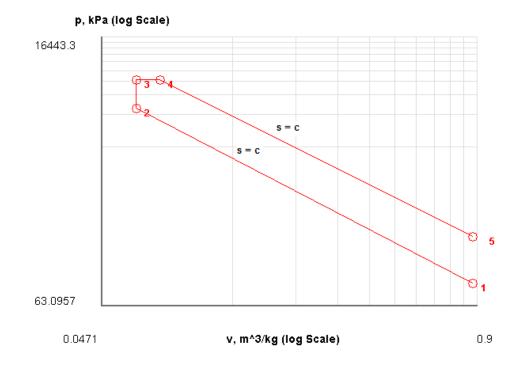
Heat rejected = Q_out = 377.07 kJ Ans.

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:





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

#~~~~	~~~~~	~~~~~~	~~~~OU	TPUT OF SU	JPER-CAL	CULATE	
#	Daem	on Path: Sy	ystems>C	losed>Proces	ss>Specific	:>PowerCyc	cle>IG-Model; v-10.ca08
<i>#</i>		Start o	of TEST-co	de			
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	2: Air;					
	Given:	{ v2= "v1/	14"m^3/k	g; s2= "s1"kJ	/kg.K; Vel2	2= 0.0 m/s; z	z2= 0.0 m; m2= 1.0 kg; }
	State-3	: Air;					
	Given:	{ T3= 120	0.0 deg-C;	v3= "v2"m^	3/kg; Vel3=	= 0.0 m/s; z	3= 0.0 m; m3= 1.0 kg; }
	State-4	: Air;					
	Given:	{ p4= "p3"	'kPa; T4=	1500.0 deg-0	C; Vel4= 0.0	0 m/s; z4= 0	0.0 m; m4= 1.0 kg; }
	State-5	: Air;					
	Given:	{ v5= "v1"	²m^3/kg; s	5= "s4"kJ/kg	.K; Vel5= (0.0 m/s; z5=	0.0 m; m5= 1.0 kg; }
	}						
Analys	is {						
	Proces	s-A: b-Stat	e = State-1	l; f-State = St	ate-2;		
	Given:	{ Q= 0.0 k	J; T_B= 2	5.0 deg-C; }			
	Proces	s-B: b-State	e = State-2	; f-State = St	ate-3;		
	Given:	{ W_B= 0	.0 kJ; T_B	= 25.0 deg-C	;		
	Proces	s-C: b-Stat	e = State - 3	3; f-State = St	ate-4;		
	Given:	{ T_B= 25	.0 deg-C;	}			
	Proces	s-D: b-Stat	e = State-4	4; f-State = St	ate-5;		
	Given:	$\{ Q = 0.0 k$	⟨J; T_B= 2	5.0 deg-C; }			
	Proces	s-E: b-State	e = State-5	; f-State = State	ate-1;		
	Given:	{ W_B= 0	.0 kJ; T_B	= 25.0 deg-C	;		
	}						
ŧ		End	of TEST-c	ode			
<i>‡</i>	Prope	rty spreads	heet 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
ŧ	2	3815.16	826.1	0.0621	317.3	554.38	6.903
<i>‡</i>	3	6803.27	1473.2	0.0621	883.43	1306.2	7.406
<i>‡</i>	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
<i>‡</i>	Prope	rty spreads	heet 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:

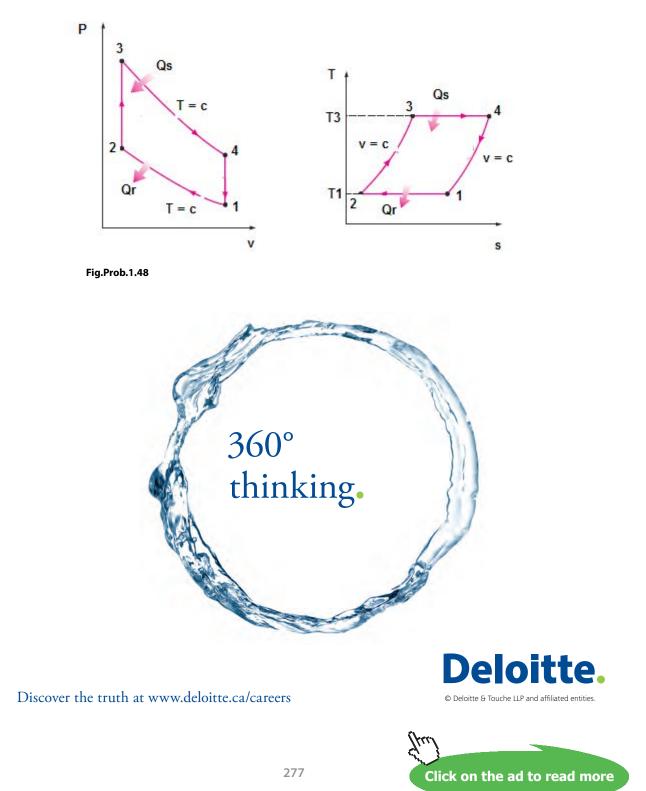
#	Calculated: T_max= 1773.15 K; T_min= 303.15 K; p_max= 6803.2656 kPa;
#	p_min= 100.0 kPa; Q_in= 933.8653 kJ; Q_out= 377.07303 kJ;
#	W_in= 399.26157 kJ; W_out= 956.05383 kJ; Q_net= 556.79224 kJ;
#	W_net= 556.79224 kJ; S_gen,int= -1.86749 kJ/K; eta_th= 59.62233 %;
#	MEP= 689.22144 kPa;

Gas Power Cycles

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 m³ 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]



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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:

	thermo	fluids	.net •	Daemon	s · Syste	ems	Closed P	rocess	• Spec	cific • Reci	procating Cycl	es ·	 PG Model 		
ove mouse ove	r a variable tr	l disol	av ite va	lue with m	ore precisio	n									
				-					Marrie Contra						
• Mixed	C SI CE	ngii	sn	< @Cas	e-0 v >	IV.	Help Messages	Con	Super-	Iterate	Super-Calculat	e	load	Super-Initialia	ze
9	tate Panel		1		Proces	s Par	iel		(Cycle Panel			I/O Par	nel	
< ©State	-1 🛩 >		Calcul	ate	No-Plots	-	Initialize		Formatic	on Enthalpy:	⊙No ⊙Yes		Air	~	
pt			1	T1			vt			ut			ht		
00.0	kPa	×	30.0		deg-C	~	0.87	m*3/kg	~	-81.9825	kJ/kg	~	5.01747	kJ/kg	
s1			-	Vel1			✓ z1			et			i1		
.00338	kJ/kg.K	~	0.0		m/e	~	0.0	m	~	81.0825	kJ/kg	~	5.01747	kJ/kg	
phi1			psi1				m1			Vol	1		MM1		
	kJ/kg	~			kJ/kg	~	0.05747	kg	*	0.05	m^3	*	28.97	kg/kmol	
R1			ср	1			c v1			k1					
0 28699	kJ/kg.K	~	1 0034		kJ/kg.K		-	kJ/kg.K		1 40054	UnitLess	~	1		

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:

Mixed CSI CI	Englis	h <mark>< @C</mark> ;	ase-0 v >	F	Help Messag	es On	Super-	Iterate	Super-Calculate		load	Super-Initial	i7e
State Panel			Process	Pa	nel			Cycle Panel			I/O Pa	anel	
< OState-2 V >		Calculate	No-Plots	~	Initialize	•	Formati	on Enthalpy:	ONO 🖲 Yes		Air		•
p2		✓ T2			v2			u2	1.01		h2		
000.0 kPa	~	-T1	deg-C	~	0.087	m^3/kg	~	-81.9825	kJ/kg	~	5.01747	kJ/kg	
\$2		✓ Vel2			1 22			e2			j2		
.24257 kJ/kg.K	×	0.0	m/s	¥	0.0	m	~	-81.9825	kJ/kg	×	5.01747	kJ/kg	
phi?		psi2		Π	✓ m2			Vol.	2		MM2		
kJ/kg	×		kJ/kg	~	=m1	kg	V	=0:1*V0I1	m^3	~	28.97	kg/kmol	1

Here, we get $p_2 = 1000$ kPa.

7. Similarly, for State 3: Enter T3 = 700 C, Vol3 = Vol2, and m3 = m1. Hit Enter, and we get:

• Mixed	SI CE	ngli	sh < CC	ase-0 ⊻ >	▼ ⊦	elp Message	s On	Super-	Iterate	Super-Calculate		Load	Super-Initial	ize
Sta	ite Panel			Process	Panel		1		Cycle Panel			I/O Pa	anel	
< ©State-3	* >		Calculate	No-Plots	~	Initialize		Formatie	on Enthalpy:	ONo •Yes		Air	0	~
p3	10		🖌 T3		-	v3	-		U3			h3	2.5	
210.127	kPa	~	700.0	deg-C	~ 0.0	87	m*3/kg	~	398.0775	kJ/kg	~	077.35840	kJ/kg	
33			✓ Vel3		-	z3			e3			j3		
.07824	kJ/kg.K	~	0.0	m/s	۷ 0.		m	*	398.0775	kJ/kg	۷	677.35846	kJ/kg	
phi3			psi3		-	m3			< Vol	3		MM3		
	kJ/kg	~		kJ/kg	~ =r	11	kq	~	=Vol2	m^3	¥	28.97	kq/kmol	

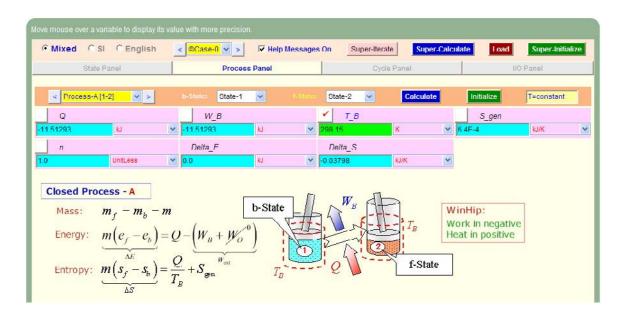
Note that p3 = 3210.13 kPa.

8. Now, for State 4: enter T4 = T3, m4 = m1, and Vol4 =Vol1. Hit Enter. We get:

• Mixed	C SI CI	Ingli	sh	< ©Ca	se-0 ♥ >	F	✓ Help	p Messages	On	Super-	Iterate	Super-Calculate		Load	Super-Initial	lize
	State Panel				Proces	s Pa	inel				Cycle Panel			I/O Pa	nel	
< ©State	-4 💙 >		Calo	ulate	No-Plots	~		Initialize		Formatio	on Enthalpy:	ONo •Yes		Air		~
p4			1	T4	10			v4			114			h4		
321.0127	kPa	*	=T 3		deg-C	۷	0.87		nr*3/kg	*	398.0775	kJ/kg	~	677.35846	kJ/kg	
54			-	Vel4			1	z4			e4			j4		
7.73905	kJ/kg.K	~	0.0		m/s	*	0.0		m	~	398.0775	kJ/kg	~	677.35846	kJ/kg	ľ
phi4			p	514			1	<i>m</i> 4			< Vol	4		MM4		
	kJ/kg	*			kJ/kg	~	=m1		kg	~	=Val1	m^3	~	28 97	kg/kmol	
R4			C_	.p4			C_	v4			k4					
0.20699	kJ/kg.K	~	1.00	349	kJ/kg.K	~	0.716	551	kJ/kg.K	*	1.40054	UnitLcaa	*			

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:

• Mixed C SI C Englis	sh < ©Case-0 >	✓ Help Me	ssages On Super	-Iterate Super-	Calculate Load	Super-Initialize
State Panel	Proce	ess Panel		Cycle Panel		I/O Panel
< Process-B [2-3] >	b-State: State-	2 🗸	State-3	Calculate	Initialize	Vol=constant
< 1100633-D [Z-3]	- Oldies	- MI	Diale-J	Carculate	muanze	Voi-constant
	W B		✓ TB		S gen	
Q 7 58967kJ	<i>W_B</i>	kJ	✓ T_B	ĸ	S_gen	kJ/K

11. And, similarly for Process 3-4:

• Mixed C SI C English	< @Case-0 v >	Help Messages On	Super-Iterate	Super-Calculate	Load Super-Initia	alize
State Panel	Process P	anel	Cycle Panel		I/O Panel	
< Process-C [3-4] V >	D-State: State-3	• 1-State: S	ate-4 💙 Calo	culate Initia	alize T=constant	
< Process-C [3-4] >	D-State: State-3	 1-State: St 	ate-4 💉 Calo		alize T=constant	
Q		v r-State: Si v kl v <mark>290</mark>	ТВ		gen	
Q	W B	kJ 🕑 290	ТВ	s	gen	

12. Again, for Process 4-1:

• Mixed CSI CEnglish	< ©Case-0 v >	Help Messages On Super-Iterat	e Super-Calculate	Load Super-Initialize
State Panel	Process Pan	el Cycle	Panel	I/O Panel
< Process-D [4-1] V >	b-State: State-4 🗸	f-State: State-1 💌	Calculate	alize Vol=constant
	State-4	olate-1	Carculate	Voi-constant
2	W_B	✓ T_B	S	gen
Q	VV D			
] Q 7.58967 kl	✓ 0.0 kl	✓ 298.15	K V 0.04451	

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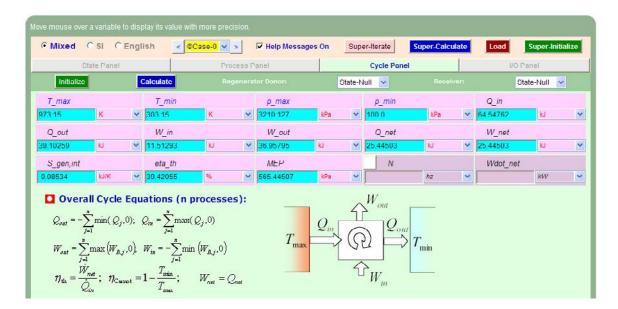


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13. Now, go to Cycle Panel, Click on Calculate and SuperCalculate. All calculations are available here:



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.

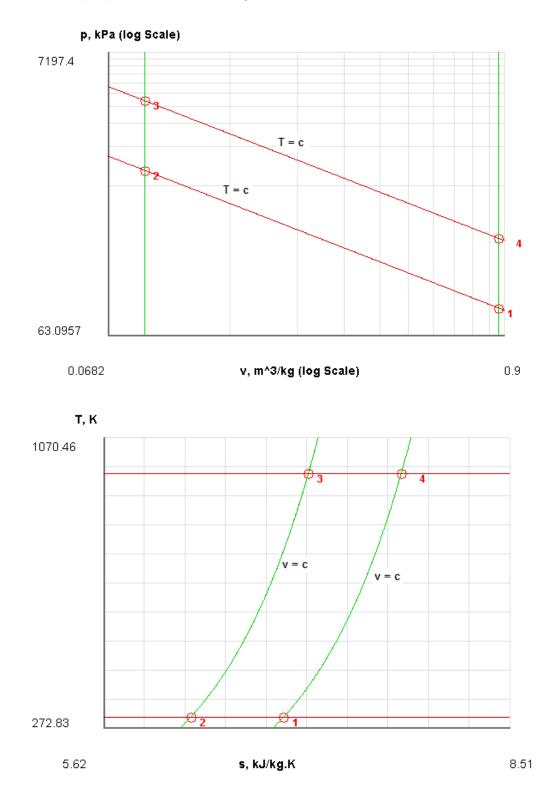
Now: when there is a regenerator with 100% efficiency:

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; }



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```
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)
#
              100.0
                       303.2
                                0.87
                                            -81.98
                                                      5.02
                                                                  6.903
#
      1
      2
              1000.0
                       303.2
                                0.087
                                            -81.98
                                                      5.02
                                                                  6.243
#
      3
              3210.13 973.2
                                0.087
                                            398.08
                                                                  7.078
#
                                                      677.36
              321.01
      4
                       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;
#
```

Gas Power Cycles

#*****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"

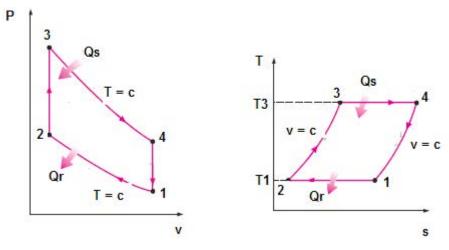


Fig.Prob.1.49

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"

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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]
∨1 = 0.861 [m ³]	∨2 = 0.4305 [m ³]	∨ _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.

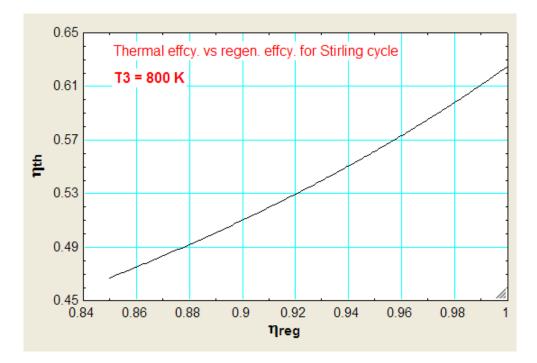
Ideal or Carnot efficiency = eta_ideal = 0.625 = 62.5% Ans.

(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:

116	1 ▼ η _{reg}	2 νth
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		
111	1 T3 [K]	2 Ν _{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

111	1 T3 [K]	2 Σ 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 = 0.9

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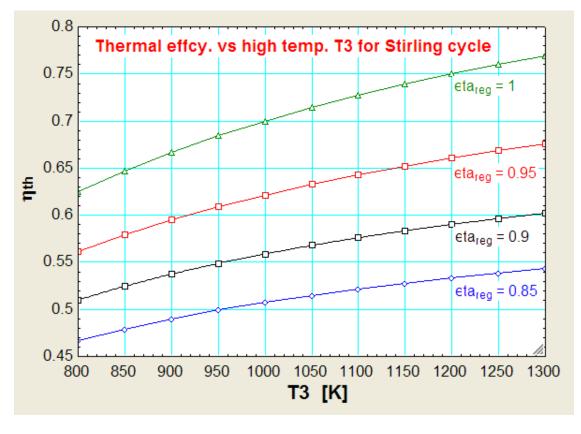
eta_reg	= 0.95
---------	--------



▶ 111	1 T3 [K]	2 Σ 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

111	1 ▼ T3 [K]	2 Ν 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

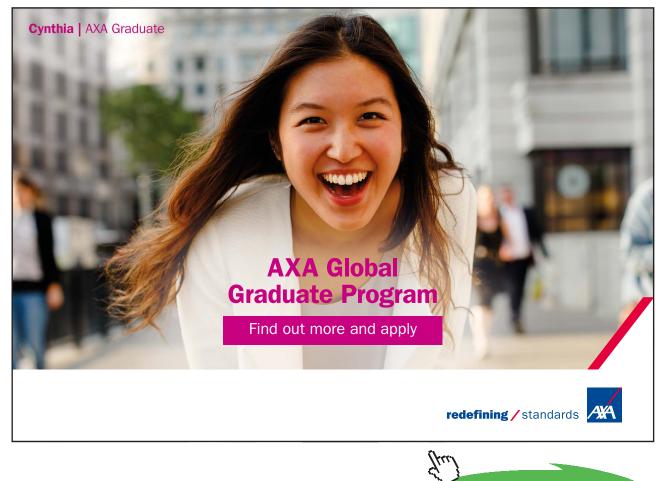
Now, plot the results:





1.6 References

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