ME 200 – Thermodynamics, L. Liebenberg

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Quiz 5 (Total: 40 points)

Due back on Wed. Feb. 22 at 10 p.m., in Canvas

- *Assignments will only be graded if the honor code statement is completed and signed.*
- *Save your entire assignment as one **PDF document** and upload it in the appropriate assignment folder on Canvas.*

Honor Code Statement

ME 200, Quiz 5

Being a student of high standards, I pledge to embody the principles of *academic integrity*.

This quiz is my own work. I did not seek (or get) outside help or collaboration with any of the questions and their solutions. I did not post any of the questions on an electronic platform (like Chegg) nor did I solicit answers or solutions from any electronic platform (like Chegg). I also did not offer my solutions or answers to any other student.

I understand that this quiz is "open book" and "open notes" which means that I was permitted to use my prescribed textbook and lecture notes when addressing any of the questions. I have properly cited any other resources, with full cognizance of the regulations pertaining to plagiarism, copyright infringement, academic cheating, etc., as stipulated in the Student Code.

I acknowledge that academic violations will be dealt with according to the UIUC Student Code, Article 1, Part 4.

Student's signature:

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Date: 2/21/23

A citybus engine has the following characteristics:
Engine displacement: 12.9 liters
6 cylinders, in-line placement;
Fuel: Diesel
Compression ratio: 18.5:1
Cut-off ratio: 2.5
The engine's inlet conditions are 20ºC and 1 bar
Maximum engine pressure: 5 MPa


12.9-liter DAF diesel engine, courtesy of *DAF/Paccar Trucks*
https://www.dafcomponents.com/en/products/paccar-daf-engines

Using an ideal air-standard Diesel cycle, calculate the following and remember to show all your calculations:

a. the temperature and pressure at state points 1, 2, 3, and 4. (15)

b. the heat and work transferred in each of the four processes. (20)

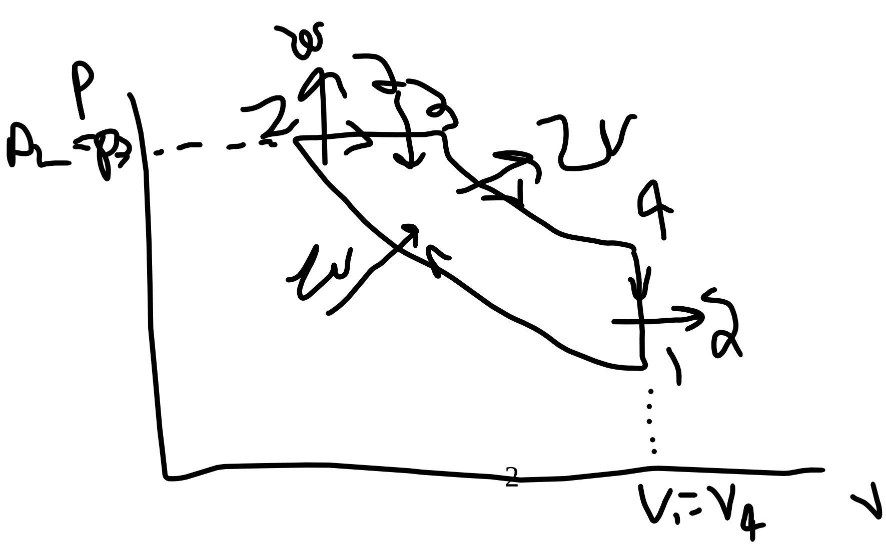
c. The cycle's thermal efficiency.

η = 55.9%(5)

Summarize your calculated values of temperature, pressure, heat, work, and change in internal energy. (-5 points if tables are not completed.)

Process	***q* (kJ/kg)**	***w* (kJ/kg)**	**Δ*u* (kJ/kg)**
1 – 2	0	−422.35	422.35
2 – 3	1344.22	344.15	1000.07
3 – 4	0	829.80	-829.80
4 – 1	-592.62	0	-592.62
Cycle:	q_{net} = 751.6	w_{net} = 751.6	0

State point	***T* (K)**	***p* (kPa)**
1	293 (given)	100 (given)
2	799.42	5000 (given)
3	1998.55	5000 (given)
4	1003.58	338.95



Adiabatic $(q = 0)$	**Isochoric** $(\cancel{V} = \text{constant})$	**Isobaric** $(p = \text{constant})$	**Isothermal** $(T = \text{constant})$
$\left(\frac{pv}{T}\right)_1 = \left(\frac{pv}{T}\right)_2$	$\left(\frac{p\cancel{v}}{T}\right)_1 = \left(\frac{p\cancel{v}}{T}\right)_2$	$\left(\frac{\cancel{p}v}{T}\right)_1 = \left(\frac{\cancel{p}v}{T}\right)_2$	$\left(\frac{pv}{\cancel{T}}\right)_1 = \left(\frac{pv}{\cancel{T}}\right)_2$
$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1}$			
$\frac{p_2}{p_1} = \left(\frac{v_1}{v_2}\right)^{\gamma}$			
$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}}$			
First Law for a closed cycle: $\Delta u = \cancel{q} - w$ $\therefore w = -\Delta u \equiv -c_v\,\Delta T$	First Law for a closed cycle: $\Delta u = q - w = q - p\,\cancel{\Delta v}$ $\therefore q = \Delta u \equiv c_v\,\Delta T$	First Law for a closed cycle: $\Delta u = q - w = q - p\,\Delta v$ $\therefore q = \Delta u + p\,\Delta v$ but $\Delta h = \Delta u + p\,\Delta v$ $\therefore q = \Delta h \equiv c_p\,\Delta T$	First Law for a closed cycle: $\Delta u = q - w = q - p\,\Delta v$ $\equiv c_v\,\cancel{\Delta T} = 0$ $\therefore q = w \equiv p\,\Delta v$
First Law for an open cycle: $\Delta h = \cancel{q} - w$ $\therefore w = -\Delta h \equiv -c_p\,\Delta T$	First Law for an open cycle: $\Delta h = q - w = q - p\,\cancel{\Delta v}$ $\therefore q = \Delta h \equiv c_p\,\Delta T$	First Law for an open cycle: $\Delta h = q - w = q - p\,\Delta v \equiv c_p\,\Delta T$	First Law for an open cycle: $\Delta h = q - w = q - p\,\Delta v \equiv c_p\,\cancel{\Delta T}$ $\therefore q = w \equiv p\,\Delta v$

Relevant Information For all Processes:

This is taken from Table A-20. The assumed temperature is 900*K

- c_v = .834
- c_p = 1.121
- k = 1.344

1-2: Adiabatic Compression

- Compression Ratio = 18.5:1 = V_1 / V_2
- Initial Temp = 20*C = 293*K
- Initial Pressure = P_1 = 1 bar = 100 kPa
- Max Pressure = P_2 = 5 MPa = 5000 kPa
- V_1 = 12.9 Litres

Since this is an adiabatic process,

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{k-1} => T_2 = T_1 * (18.5)^{.344} = 293K * 2.665 = 799.42K$$

Since this is a adiabatic process in a closed cycle, q=0 and…

$$w = -\Delta u = -c_v * \Delta T = -.834 * (799.42 - 293) = -422.35\,\frac{kJ}{kg}$$

This also means that Δu = -w = -422.35 kJ/kg

2-3: Constant Pressure Heat Injection

- Max Pressure = P_2 = P_3 = 50 bar = 5000 kPa
- Cut-off Ratio = V_2 / V_3 = 2.5

Since this is a constant pressure process…

$$\frac{v_2}{T_2} = \frac{v_3}{T_3} => T_3 = \frac{v_3}{v_2} * T_2 = 2.5 * T_2 = 2.5 * 799.42K = 1998.55K$$

We also know that in a closed system with constant pressure, so

$$q = \Delta\mathrm{h} = \mathrm{c_p} * \Delta\mathrm{T} = 1.121 \frac{\mathrm{kJ}}{\mathrm{kg} * \mathrm{K}} * (1998.55\mathrm{K} - 799.42\mathrm{K}) = 1344.22 \frac{\mathrm{kJ}}{\mathrm{kg}}$$

From the first law, we know that w = q – Δu, so

$$w = \mathrm{q} - \mathrm{c_p} * \Delta\mathrm{T} = 1344.22 \frac{\mathrm{kJ}}{\mathrm{kg}} - .834 \frac{\mathrm{kJ}}{\mathrm{kg} * \mathrm{K}} (1998.55K - 799.42K) = 344.15 \frac{kJ}{kg}$$

$$u = q - w = 1000.07 \frac{kJ}{kg}$$

3-4: Adiabatic Expansion

- P_4 / P_3 = (P_4 / P_2) / (P_3 / P_2) = Compression Ratio / Cut-Off Ratio = 7.4
- P_3 / P_4 = 1 / 7.4 = .135
- P_3 = Max Pressure = 50 bar
- V_4 = V_1 = 12.9 Litres

We know this is an adiabatic process, so we can use the equations,

$$p_4 = p_3 * (.135)^k = 5000kPa * (.135)^{1.344} = 338.95kPa$$

$$T_4 = T_3 * (.135)^{k-1} = 1998.55K * (.135)^{.344} = 1003.58K$$

Since this is an adiabatic process,

$$\Delta\mathrm{u} = -\mathrm{w} = \mathrm{c_v} * \Delta\mathrm{T} = .834\,\frac{\mathrm{kJ}}{\mathrm{kg} * \mathrm{K}} * (1003.58K - 1998.55K) = -829.80\,\frac{\mathrm{kJ}}{\mathrm{kg}}$$

$$\therefore w = 829.80\,\frac{\mathrm{kJ}}{\mathrm{kg}}$$

We also know that work is -Δu, ∴ Δu = -829.80 kJ/kg

4-1: Constant Volume Heat Rejection

- V_1 = V_4 = 12.9 Liters

Since the volume is the same, we know work is 0.

$$\Delta \mathrm{u} = \mathrm{q} = \mathrm{c_v}\Delta \mathrm{T} = .834\,\frac{\mathrm{kJ}}{\mathrm{kg} * \mathrm{K}}(293K - 1003.58K) = -592.62\,\frac{\mathrm{kJ}}{\mathrm{kg}}$$

To find η, we apply the following formula,

$$\eta = \frac{\mathrm{w_{net}}}{q_{in}} * 100 = \frac{751.6}{1344.22} * 100 = 55.9\%$$