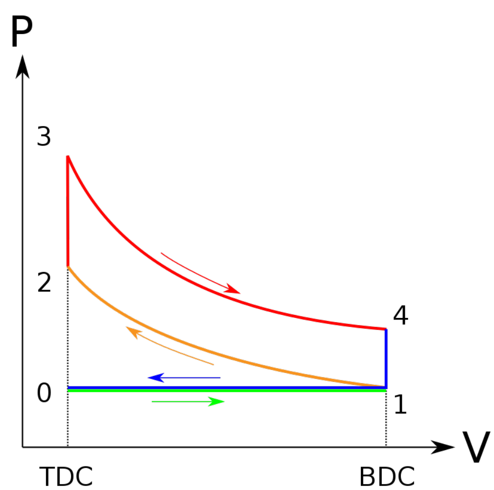
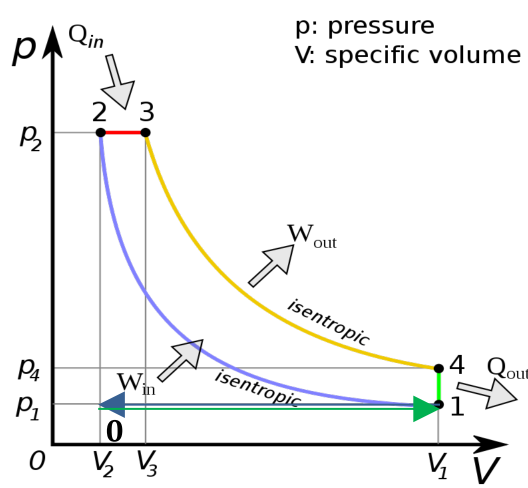
Chemical Engineering Thermodynamics
Quiz 2 January 21, 2021

The Diesel Cycle is a model engine to study unmixed fuel/air mixture engines typical for trucks. Diesel engines operate at a much higher compression ratio, about $V_1/V_2 = 20$, compared to a gas engine following the premixed (carburated/fuel injected) Otto Cycle. Consider one cylinder of a four-stroke diesel engine with each cylinder having a $V_{TDC} = V_1 = 583\ \text{cm}^3$ (6 cylinders are 3.5L). The stages are:

0-1 Intake	Isobaric
1-2 Compression	Adiabatic
2-3 Ignition	Isobaric
3-4 Power stroke	Adiabatic
4-1 Blowdown	Isochoric
1-0 Exhaust	Isobaric

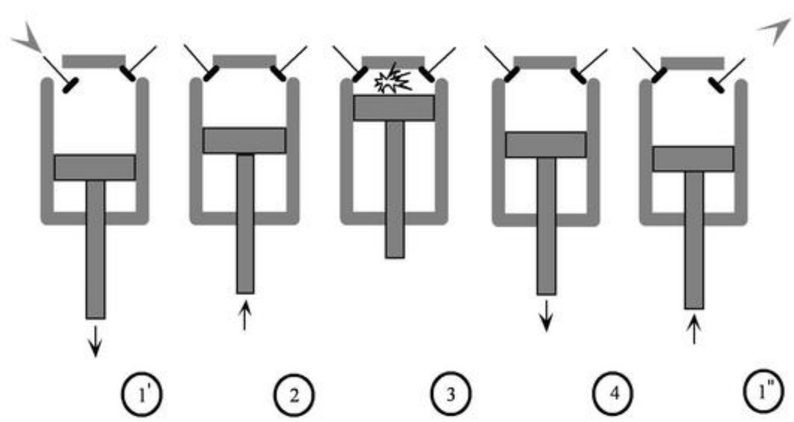


Four Stroke Otto Cycle (**not used**)



Four Stroke Diesel Cycle (***Used Here***)

(Both figures from Wikipedia)



https://web.mit.edu/16.unified/www/FALL/thermodynamics/notes/node26.html

Consider that the material in the cylinder is 2 mole percent isooctane in air with **C_p = 3.89R for the mixture with a combustion enthalpy for pure octane of 5,470 kJ/mole (109 kJ/mole for the mixture).**

Assume an ideal gas throughout the calculations.

Ignore the increase in number of moles with combustion.

a) Solve for P_f and T_f for the 1-2 stroke.
(Fill in your answers in the table for each calculation. The table should be filled out by the end of the quiz. Include a sheet showing your work.)

b) Solve for V_f in the 2-3 stroke.

c) Solve for P_f and T_f for the 3-4 stroke.

d) Calculate W_{EC}, Q, the internal energy changes, ΔU, and enthalpy changes, ΔH, using C_V and C_P for all of the strokes that are not greyed out in the table. ***Keep in mind that R is in units of Joules not kJ.*** A Joule is equal to MPa cm^3.

e) Calculate the efficiency of this engine (net work/enthalpy input) if the fuel/air mixture had a combustion enthalpy of **5,470 kJ/mole * 0.02 = 109 kJ/mole** of the mixed gas in the engine (accounting for 2% isooctane in air). ***Keep in mind that R is in units of Joules not kJ.*** A Joule is equal to MPa cm^3.

You can use the attached excel sheet for your answers and calculations. Make sure you write out your calculations on a separate sheet of paper so that I can follow your work. Remember to use 3 significant digits and put units on every number you write down or put in the excel sheet (where possible).

	Intake (Mass Changes)	Compression	Combustion	Expansion (power stroke)	Blowdown (Mass Changes)	Exhaust (Mass Changes)
	isobaric	adibatic, rev	isobaric	adibatic, rev	isochoric	isobaric
Stage	0-1	1-2	2-3	3-4	4-1	1-0
Ti K	298	298		2900		298
Tf K	298		2900		298	298
Pi MPa	0.101	0.101				0.101
Pf Mpa	0.101				0.101	0.101
Vi cm3	29.1	583	29.1		583	583
Vf cm3	583	29.1		583	583	29.1
moles i						
moles f						
W_{EC} kJ/mole						
ΔH kJ/mole						
ΔU kJ/mole						
Q kJ/mole						

1 atmosphere is 14.7 psi, 1.01 bar, 0.101 MPa, 760 mmHg, 29.9 inHg

Gas Constant, R

= 8.31447 J/mole-K = 8.31447 cm^3-MPa/mole-K = 8.31447 m^3-Pa/mole-K

= 8,314.47 cm^3-kPa/mole-K = 83.1447 cm^3-bar/mole-K = 1.9859 Btu/lbmole-R(see note 1)

= 82.057 cm^3-atm/mole-K = 1.9872 cal/mole-K(see note 2) = 10.731 ft^3-psia/lbmole-R

Process Type	Work Formula (ig)
Isothermal	$W_{EC} = -\int P dV = -RT\int \frac{dV}{V} = -RT\ln\frac{V_2}{V_1}$ (ig)
Isobaric	$W_{EC} = -\int P dV = -P(V_2 - V_1)$ (ig)
Adiabatic and reversible	$W_{EC} = -\int P dV = -\int \text{const}\frac{dV}{V^{(C_P/C_V)}}$ (*ig) or $\Delta U = C_V(T_2 - T_1) = W_{EC}$ (*ig) $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{(R/C_P)} = \left(\frac{V_1}{V_2}\right)^{(R/C_V)}$ (*ig)

$Q_{rev} = \Delta U$ for isochoric (constant volume) 4.17

$dU = C_v \, dT$ for isochoric (constant volume)

$C_p = C_v + R$ (exact for ideal gas)

$\Delta H = \Delta U + \Delta(PV) = \Delta U + R(\Delta T)$ (exact for ideal gas)

ANSWERS: Chemical Engineering Thermodynamics
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	Intake (Mass Changes)	Compression	Combustion	Expansion (power stroke)	Blowdown (Mass Changes)	Exhaust (Mass Changes)
	isobaric	adibatic, rev	isobaric	adibatic, rev	isochoric	isobaric
Stage	0-1	1-2	2-3	3-4	4-1	1-0
T i K	298	298	**841**	2900	**1580**	298
T f K	298	**841**	2900	**1580**	298	298
P i MPa	0.101	0.101	**5.71**	**5.71**	**0.532**	0.101
P f Mpa	0.101	**5.71**	**5.71**	**0.532**	0.101	0.101
V ¡ cm3	29.1	583	29.1	**100**	583	583
V f cm3	583	29.1	**100**	583	583	29.1
moles i		**0.0238**	**0.0238**	**0.0238**	**0.0238**	
moles f	**0.0238**	**0.0238**	**0.0238**	**0.0238**		
W_{EC} kJ/mole		**13.0**	**-17.0**	**-31.7**		
ΔH kJ/mole		**17.5**	**66.6**	**-42.7**		
ΔU kJ/mole		**13.0**	**49.5**	**-31.7**		
Q kJ/mole		**0**	**66.5**	**0**		

Efficiency	0.328

a) <u>1-2 Stroke</u> adiabatic

$$n = \frac{PV}{RT} = \frac{0.101\,MPa\; 583\,cm^3}{8.31\,\frac{MPa\,cm^3}{K\,mol}\; 298K} = 0.0238\,mole$$

$$P_2 = P_1\left(\frac{V_1}{V_2}\right)^{C_p/C_v} = 0.101\,MPa\left(\frac{583\,cm^3}{29.1\,cm^3}\right)^{\frac{3.89R}{2.89R}}$$

$$= 5.71\,MPa$$

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{R/C_p} = 298K\left(\frac{5.71\,MPa}{0.101\,MPa}\right)^{R/R3.89}$$

$$= 841\,K$$

b) isobaric <u>2-3 stroke</u>

$$V_f = V_i\left(\frac{T_f}{T_i}\right) = 29.1\,cm^3\left(\frac{2900K}{841K}\right) = 100\,cm^3$$

c) <u>3-4 Stroke</u> adiabatic

$$P_f = P_i\left(\frac{V_i}{V_f}\right)^{C_p/C_v} = 5.71\,MPa\left(\frac{100\,cm^3}{583\,cm^3}\right)^{\frac{3.89R}{2.89R}}$$

$$= 0.532\,MPa$$

$$T_f = T_i\left(\frac{P_f}{P_i}\right)^{R/C_p} = 2900K\left(\frac{0.532\,MPa}{\cancel{0.532\,MPa}\;5.71\,MPa}\right)^{R/R3.89}$$

$$= 1580\,K$$

d) <u>1-2 stroke</u> Adiabatic

$Q = 0$

$\Delta U = W_{EC} = C_v(T_f - T_i) = 2.89\left(8.31 \frac{J}{K\,mol}\right)(841K - 298K)/(1000\ J/kJ)$

$= 13.0\ kJ/mole$

$\Delta H = \Delta U \frac{C_p}{C_v} = 13.0 \frac{kJ}{mol}\left(\frac{3.89R}{2.89R}\right) = 16.0\ kJ/mole$

<u>2-3 stroke</u> isobaric

$W_{EC} = -\frac{P\Delta V}{n} = \frac{-5.71\ MPa\,(100\,cm^3 - 29.1\,cm^3)}{0.0238\ mole\ (1000\ MPa\,cm^3/kJ)}$

$= -17.0\ kJ/mole$

$\Delta U = C_v(T_f - T_i) = 2.89\left(8.31\ J/mol\,K\right)(2900K - 841K)/(1000\ J/kJ)$

$= 49.5\ kJ/mole$

$Q = \Delta U - W_{EC}$
$= 66.5 \frac{kJ}{mole}$

$\Delta H = \Delta U\left(\frac{C_p}{C_v}\right) = 49.5 \frac{kJ}{mole}\left(\frac{3.89R}{2.89R}\right) = 66.6\ kJ/mole$

<u>3-4 stroke</u> adiabatic

$Q = 0$

$\Delta U = W_{EC} = C_v(T_f - T_i) = \frac{2.89\left(8.31 \frac{J}{mol\,K}\right)(1580K - 2900K)}{1000\ J/kJ}$

$= -31.7\ kJ/mole$

$\Delta H = \Delta U \frac{C_p}{C_v} = -31.7 \frac{kJ}{mole} \frac{3.89R}{2.89R} = -42.7 \frac{kJ}{mole}$

e) $\text{efficiency} = \frac{-(W_{EC12} + W_{EC23} + W_{EC34})}{109\ kJ/mole} = \frac{-\left(13.0\frac{kJ}{mol} + \left(-17.0\frac{kJ}{mol}\right) + \left(-31.7\frac{kJ}{mol}\right)\right)}{109\ kJ/mole}$

$= 0.328$