Engine Performance Modeling (with Short Equations)

Orientation:

You are strongly encouraged to apply the engineering problem solving rubric we studied in week #1 in your solutions to quantitative problems in this course. This activity is intended to consolidate your understanding of the 'short' equations for engine performance modeling that we have studied in the last two class periods and strengthen your engineering documentation skills.

Learning Outcomes:

1. Translate a problem statement analogous to those you will see in HW 3 into knowns and unknowns, giving the correct units and accurate parameter values for all the knowns.
2. Assemble a complete set of governing equations that can be implemented in an EES solution.
3. Obtain and validate your solution (in terms of units as well as magnitude).
4. Write two reflections about this exercise and your solution that will attract interest of others in the class and add value in future combustion engine problem solving.

Targeted Skills:

Integrating – combining parts into a new whole (esp. engine design and performance relations)
Using Tools – identifying relevant equations and applying software to find valid solutions
Generalizing Solutions – modifying solutions for reuse and broader applicability

Task:

A 4-stroke SI engine with 3.0 liters of displacement and a 8.9:1compression ratio has an output torque of 236 Nm at 3000 RPM. At this operating point, the brake specific fuel consumption is measured as .090 MJ/kg. The volumetric flowrate of air is .068 m^3/s and the inlet conditions of 20 C and 1 bar. The heating value of the fuel used in the engine is 44 MJ/kg. Find the volumetric efficiency, the mass flow rate of air, the mass flow rate of fuel, the air/fuel ratio, the arbitrary efficiency, and the ideal otto cycle efficiency.

Working with a partner, generate documentation for the following dimensions in the engineering problem solving rubric: (1) system description, (2) knowns/unknowns (units and assumed values), (3) governing equations/solution method, (4) validated answer, and (5) reflection on results/solution process.

Knowns

$N_R = 2$ (4-stroke engine)

$V_d = 3\ L = .003\ m^3$

$R_c = \frac{8.9}{1}$

$T = 236\ N \cdot m$

$RPM = 3,000$

$BSFC = .090\ \frac{MJ}{kg}$

$Q_{HV} = 44\ \frac{MJ}{kg}$

Air at inlet conditions

$\dot{V}_a = .068\ \frac{m^3}{s}$

$T_i = 20°C$

$P_i = 1\ bar$

Find

a.) Volumetric efficiency
b.) mass flow rate of air
c.) AF
d.) arbitrary efficiency
e.) ideal otto cycle efficiency

① Mass flow rate of air

$\dot{m}_a = \rho_i \dot{V}$; ρ_i is defined by T_i, P_i

② Volumetric efficiency

$\eta_v = \frac{2 \dot{m}_a}{\rho_i V_d N}$ (2.27b) ; all variables are known

③ Air Fuel Ratio

$P = 2\pi N T$ (2.13a) ; all known ✓

$BSFC = \frac{\dot{m}_f}{P}$ (2.21) ; solve for $\dot{m}_f$ ✓

$AF = \frac{\dot{m}_a}{\dot{m}_f}$

④ Arbitrary Efficiency

$\eta_o = \frac{1}{BSFC * Q_{HV}}$; book lists as fuel conversion efficiency ✓ all known

④ Otto efficiency

$\eta_{otto} = 1 - \frac{1}{R_c^{K-1}}$ ✓ ; all known

Convert $.09 \frac{kg}{MJ}$ to $\frac{g}{kW\text{-}h}$

$$.09 \frac{kg}{MJ} \times \frac{1000\ g}{kg} \times \frac{1\ MJ}{1000\ kJ} \times \frac{1\ J}{W \cdot s} \times \frac{3600\ s}{h} = \boxed{324 \frac{g}{kW\text{-}h}}$$

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"PROBLEM STATEMENT"
"A 4-stroke SI engine with 3.0 liters of displacement and a 8.9:1compression ratio"
"has an output torque of 236 Nm at 3000 RPM.  At this operating point, the brake"
"specific fuel consumption is measured as .090 MJ/kg.  The volumetric flowrate of"
"air is .068 m^3/s and the inlet conditions of 20 C and 1 bar.  The heating value of"
"the fuel used in the engine is 44 MJ/kg.  Find the volumetric efficiency, the mass"
"flow rate of air, the mass flow rate of fuel, the air/fuel ratio, the arbitrary efficiency,"
"and the ideal otto cycle efficiency."


"KNOWNS"
nr        = 2[dim]
Vs        = 3000E-6[m^3]
T         = 236[N-m]
Bsfc      = .09[kg/MJ]*1/convert(MJ,kJ)
Vdot_air = .068[m^3/s]
rc        = 8.9[dim]
T_in      = 293[K]
P_in      = 101[kPa]
Q_HV      = 44E3[kJ/kg]
N         =50[1/s]
R         = .286[kJ/kg-K]
k         =1.4[dim]


"EQUATIONS"
P            = T*2*pi*N
P            = bmep*Vs*N/nr

eta_o        = 1/(Bsfc*Q_HV)
eta_otto     = 1-1/(rc)^(k-1)
eta_v        = Vdot_air/(Vs*N/nr)

rho_in       = P_in/(R*T_in)
mdot_air  = Vdot_air*rho_in*convert(kg/s, g/s)
mdot_fuel = Bsfc*P
A_F          = mdot_air/mdot_fuel
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SOLUTION

Unit Settings: SI C kPa kJ mass deg

A_F = 12.28 [dim]	bmep = 988554 [Pa]	Bsfc = 0.00009 [kg/kJ]
η_o = 0.2525 [dim]	η_{otto} = 0.5829 [dim]	η_v = 0.9067 [dim]
k = 1.4 [dim]	$mdot_{air}$ = 81.96 [g/s]	$mdot_{fuel}$ = 6.673 [g/s]
N = 50 [1/s]	nr = 2 [dim]	P = 74142 [w]
P_{in} = 101 [kPa]	Q_{HV} = 44000 [kJ/kg]	R = 0.286 [kJ/kg-K]
rc = 8.9 [dim]	ρ_{in} = 1.205 [kg/m^3]	T = 236 [N-m]
T_{in} = 293 [K]	$Vdot_{air}$ = 0.068 [m^3/s]	Vs = 0.003 [m^3]

No unit problems were detected.

KEY VARIABLES

η_v = 0.9067 [dim] *volumetric efficiency*

$mdot_{air}$ = 81.96 [g/s]	*mass flow rate of air*
$mdot_{fuel}$ = 6.673 [g/s]	*mass flow rate of fuel*
A_F = 12.28 [dim]	*air/fuel ratio*
η_o = 0.2525 [dim]	*arbitrary efficiency*
η_{otto} = 0.5829 [dim]	*otto cycle efficiency*