Solutions Manual

Engineering Fundamentals of the Internal Combustion Engine

Second Edition

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Contents

CHAPTER 1

(1-1)

SI engines use spark plugs.
CI engines use self-ignition.

SI engines intake an air-fuel mixture.
CI engines intake air only.

SI engines have combustion at about constant volume.
CI engines have some combustion at about constant pressure.

SI engines use gasoline fuel.
CI engines use diesel oil fuel.

SI engines use carburetors or fuel injectors in the intake system.
CI engines have fuel injectors in the combustion chamber.

(1-2)

Two stroke cycle engines have no exhaust stroke. Excess exhaust must be pushed out of cylinder (scavenged) by the intake air-fuel mixture (or intake air in CI engines). This requires that the intake mixture be at a higher pressure than the exhaust residual.

(1-3)

Advantages of two stroke cycle:

Smoother cycle with a power stroke from every cylinder on every revolution.
Do not need mechanical valves.
More power from same weight engine.

Advantages of four stroke cycle:

Can operate without an intake pressure boost.
Cleaner operation with less exhaust pollution.
Can use crankcase for oil reservoir.

(4-17)

(a) stoichiometric combustion equation

$H_2 + \frac{1}{2} O_2 + \frac{1}{2}(3.76) N_2 \rightarrow H_2O + \frac{1}{2}(3.76) N_2$

$(AF)_{stoich} = [(\frac{1}{2})(4.76)(29)]/[(1)(2)] = 34.51$

Eq.(2-57)

$\phi = (AF)_{stoich}/(AF)_{act} = (34.51)/(30) \underline{= 1.15}$

(b) Eq.(2-58)

$\lambda = 1/\phi = (1)/(1.15) \underline{= 0.869}$

(c) at AF = 30

$H_2 + x\ O_2 + x(3.76)\ N_2 \rightarrow$ products

$AF = [x(4.76)(29)]/[(1)(2)] = 30 \qquad x = 0.4347$

actual reaction equation

$H_2 + 0.4347O_2 + (0.4347)(3.76)N_2 \rightarrow 0.8694H_2O + (0.4347)(3.76)N_2 + 0.1306H_2$

Eq.(4-5) with enthalpy values from reference [90]

$Q = \Sigma_{PROD} N_i h_i - \Sigma_{REACT} N_i h_i$

$= (0.8694)[(-241,826)-(0)] + (0.4347)(3.76)[(0)+(0)]$
$+ (0.1306)[(0)+(0)] - (1)[(0)+(0)] - (0.4347)[(0)+(0)]$
$- (0.4347)(3.76)[(0)+(0)] \underline{= 210,244\ kJ}$

(4-18)

(a) stoichiometric reaction for one mole of fuel

$\frac{1}{2}CH_3OH + \frac{1}{2}C_4H_8 + (15/4)O_2 + (15/4)(3.76)N_2 \rightarrow (5/2)CO_2 + 3H_2O + (15/4)(3.76)N_2$

$AF = [(15/4)(4.76)(29)]/[(\frac{1}{2})(32)+(\frac{1}{2})(56)] \underline{= 11.76}$

(b) find mass percents

methanol $m = (\frac{1}{2})(32) = 16kg$ mass % $(16/44) = 0.364$

butene-1 $m = (\frac{1}{2})(56) = \underline{28kg}$ $(28/44) = 0.636$

44kg

Eq.(4-11)

$ON = (\%\ of\ A)(ON_A) + (\%\ of\ B)(ON_B)$

$RON = (0.364)(106) + (0.636)(99) = 101.55$

$MON = (0.364)(92) + (0.636)(80) = 84.37$

Eq.(4-9)

$AKI = (MON+RON)/2 = [(101.55) + (84.37)]/(2) \underline{= 93.0}$

(4-19)

(a) actual reaction

$H_2 \rightarrow x\ H + 2x\ H_2$

conservation of H

$2 = x + 2x \qquad \underline{x = 0.40}$

(b) Eq.(4-4) with $A = H_2$ and $C = H$ $\qquad B = D = 0$

$K_e = [(x^2)/(2x)][1/(x + 2x)]^{2-1} = 1/6 \underline{= 0.1667}$

(c) $\log_{10}K_e = -0.7781$

by interpolation in Table A-3 for reaction (A) $\underline{T = 3362\ K}$

(10-2)

(a)

use Eq. (2-55) for fuel flow rate
$\dot{m}_f = \dot{m}_a/(AF) = (0.0289\ kg/sec)/14.6 = 0.00198\ kg/sec$

$\dot{Q}_{evap} = \dot{m}_f h_{fg}(\%\ evaporated) = (0.00198\ kg/sec)(307\ kJ/kg)(0.40) = 0.2431\ kJ/sec$

this cools the air-fuel mixture (use low temp value of c_p)
$\dot{Q}_{evap} = \dot{m}_m c_p \Delta T = (0.0289 + 0.00198)kg/sec(1.005\ kJ/kg\text{-}K)\Delta T$

$\Delta T = 7.8°\ C$

$T_{entering} = 32.2° - \Delta T = 32.2° - 7.8° \underline{= 24.4°\ C}$

(b)

$\dot{m}_f = (0.0289\ kg/sec)/9 = 0.00321\ kg/sec$

$\dot{Q}_{evap} = (0.00321\ kg/sec)(873\ kJ/kg)(0.40) = 1.121\ kJ/sec$
$= (0.0289 + 0.00321)kg/sec(1.005\ kJ/kg\text{-}K)\Delta T$

$\Delta T = 34.7°\ C$

$T_{entering} = 32.2° - 34.7° \underline{= -2.5°\ C}$

(10-3)

Eq. (2-8) for 1 cylinder
$V_d = 0.0011\ m^3 = (\pi/4)B^2S = (\pi/4)B^2(0.9\ B)$

$B = 0.1159\ m = 11.59\ cm$

Eq. (2-15) gives area of piston face
$A_p = (\pi/4)B^2 = (\pi/4)(0.1159\ m)^2 = 0.01055\ m^2$

Eq. (10-7) using viscosity value from Ref. [63]
$Re = [(\dot{m}_a + \dot{m}_f)B]/(A_p\mu_g)$
$= [(0.0289 + 0.00321)(0.1159)]/[(0.01055)(1.846 \times 10^{-5})] \underline{= 19,109}$

(10-4)

assume $\Delta T = (T_{in} - T_{out}) = 100°$ C

average bulk temperature
$T_{bulk} = (477° + 377°)/2 = 427°$ C = 700 K

air property values from Ref. [63] at average bulk temperature:

density	$\rho = 0.5030$ kg/m^3
kinematic viscosity	$\nu = 66.25 \times 10^{-6}$ m^2/sec
thermal conductivity	k = 0.05230 W/m-K
specific heat	$c_p = 1075.2$ J/kg-K
Prandtl number	Pr = 0.684

mass flow rate of exhaust for entire engine
$\dot{m}_{ex} = \dot{m}_a + \dot{m}_f = 0.0289 + 0.00321 = (0.03211 \text{ kg/sec})(6 \text{ cyl}) = 0.19266$ kg/sec

$\text{Vel} = \dot{m}_{ex}/\rho A = (0.19266 \text{ kg/sec})/(0.5030 \text{ kg/m}^3)[(\pi/4)(0.065 \text{ m})^2] = 115.4$ m/sec

Reynolds number
$\text{Re} = (\text{Vel})d/\nu = (115.4 \text{ m/sec})(0.065 \text{ m})/(66.25 \times 10^{-6}) = 113{,}223$

Nusselt number using Dittus-Boelter equation from Ref. [63]
$\text{Nu} = 0.023\ \text{Re}^{0.8}\text{Pr}^{0.3} = (0.023)(113{,}223)^{0.8}(0.684)^{0.3} = 226.6$

this is increased by a factor of 2 due to pulsed flow of exhaust
$\text{Nu} = (226.6)(2) = 453.2 = hd/k$

convection heat transfer coefficient
$h = (\text{Nu})k/d = (453.2)(0.05230 \text{ W/m-K})/(0.065 \text{ m}) = 364.7$ W/m^2-K

convection heat transfer
$\dot{Q} = h(\text{surface area})(T_{bulk} - T_{wall})$
$= (364.7 \text{ W/m}^2\text{-K})[\pi(0.065 \text{ m})(1.5 \text{ m})](700-500)\text{K} = 22{,}342 \text{ W} = \dot{m}_{ex} c_p \Delta T$
$= (0.19266 \text{ kg/sec})(1075.2 \text{ J/kg-K})\Delta T$

$\Delta T = 108°$

temperature of exhaust entering catalytic converter
$T_{ex} = 477°\text{C} - \Delta T = 477°\text{C} - 108° = 369°\text{C} = 642\text{K}$

2nd iteration using $\Delta T = 108°C$ to get better bulk temperature:

average bulk temperature	T_{bulk} = 696 K
density	ρ = 0.5056 kg/m^3
kinematic viscosity	ν = $65.63 \times 10^{-6} m^2/sec$
thermal conductivity	k = 0.05199 W/m-K
specific heat	c_p = 1074.3 J/kg-K
Prandtl number	Pr = 0.684
velocity	Vel = 114.8 m/sec
Reynolds number	Re = 113,698
Nusselt number	Nu = 454.8
convection heat transfer coefficient	h = 363.8 W/m^2-K
heat transfer	$\dot{Q}$ = 21,841 W
change in temperature	ΔT = 106°C
exhaust temperature entering catalytic converter	$\underline{T_{ex} = 371°C = 644\ K}$

these values are close enough so a 3rd iteration is not needed

(10-5)

(a)

using Fig. 10-1 at 2000 RPM

$\dot{Q}_{ex} \approx \dot{W}_b \underline{= 20\ kW}$

(b)

$\dot{Q}_{friction} \approx ¼\ \dot{W}_b = ¼(20\ kW) \underline{= 5\ kW}$

(c)

$\dot{Q}_{coolant} \approx 1.3\ \dot{W}_b = 1.3(20\ kW) \underline{= 26\ kW}$

(10-6)

(a) using Fig. 10-1 at 2500 RPM $\dot{Q}_{coolant} \approx 1.11\ \dot{W}_b = 1.11(30hp) = 33.3hp$

mass flow rate of coolant flow
$\dot{m}_c = (25\ gal/min)(60\ min/hr)(62.4\ lbm/ft^3)/(7.481\ gal/ft^3) = 12{,}512\ lbm/hr$

$\dot{Q}_{coolant} = \dot{m}_c c_p \Delta T = (33.3\ hp)(2545\ BTU/hr/hp) = (12{,}512\ lbm/hr)(1\ BTU/lbm\text{-}^\circ R)\Delta T$
$\Delta T = 7^\circ\ F$

$T_{exit} = T_{in} + \Delta T = 220^\circ + 7^\circ$ $\underline{= 227^\circ\ F}$

(b) velocity of air through radiator
$Vel = [(30\ miles/hr)(5280\ ft/mile)/(3600\ sec/hr)](1.1) = 48.4\ ft/sec$

mass flow of air
$\dot{m}_a = \rho(Vel)A = (0.0739\ lbm/ft^3)(48.4\ ft/sec)(4.5\ ft^2) = 16.1\ lbm/sec$

33.3 hp must be dissipated
$\dot{Q}_{radiator} = \dot{m}_a c_p \Delta T$
$(33.3\ hp)(2545/3600\ BTU/sec/hp) = (16.1\ lbm/sec)(0.240\ BTU/lbm\text{-}^\circ R)\Delta T$
$\Delta T = 6^\circ\ F$

$T_{exit} = T_{in} + \Delta T = 75^\circ + 6^\circ$ $\underline{= 81^\circ\ F}$

(10-7)

approximate ratio of cylinder volumes
$R_{vol} = 320/290 = 1.103$
approximate ratio of linear dimensions
$R_{lin} = (1.103)^{1/3} = 1.033$
approximate ratio of area dimensions
$R_{area} = (1.033)^2 = 1.068$

(a) $\dot{Q}_{in}$ will be proportional to cylinder volume for each engine
heat losses will be proportional to cylinder surface area
$(\eta_t)_{320}/(\eta_t)_{290} \approx R_{vol}/R_{area} = 1.103/1.068 = 1.033$

<u>3.3% greater indicated thermal efficiency in larger engine</u>

(b) if all temperatures are the same, heat transfer
to coolant will be proportional to surface area
$\dot{Q}_{320} \approx 1.068\ \dot{Q}_{290}$

<u>6.8% greater heat flow to coolant in larger engine</u>