

# Solutions Manual

## Engineering Fundamentals of the Internal Combustion Engine Second Edition

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## **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:**

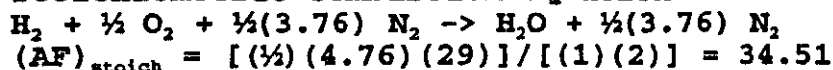
**Smoother cycle with a power stroke from every cylinder on every revolution.  
Do not need mechanical valves.  
More power from same weight engine.**

**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



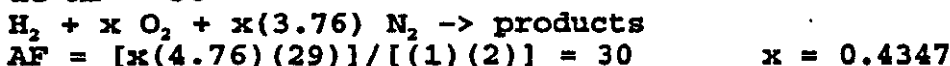
Eq. (2-57)

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

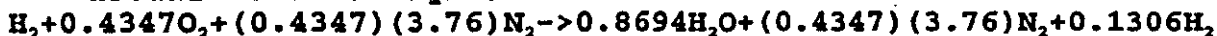
(b) Eq. (2-58)

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

(c) at  $\text{AF} = 30$



actual reaction equation



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

$$Q = \sum_{\text{PROD}} N_i h_i - \sum_{\text{REACT}} N_i h_i$$

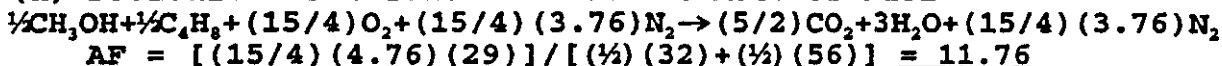
$$= (0.8694)[(-241,826) - (0)] + (0.4347)(3.76)[(0) + (0)]$$

$$+ (0.1306)[(0) + (0)] - (1)[(0) + (0)] - (0.4347)[(0) + (0)]$$

$$- (0.4347)(3.76)[(0) + (0)] = \underline{210,244 \text{ kJ}}$$

(4-18)

(a) stoichiometric reaction for one mole of fuel



(b) find mass percents

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

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

$$44 \text{ kg}$$

Eq. (4-11)

$$\text{ON} = (\% \text{ of A})(\text{ON}_A) + (\% \text{ of B})(\text{ON}_B)$$

$$\text{RON} = (0.364)(106) + (0.636)(99) = 101.55$$

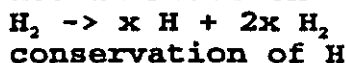
$$\text{MON} = (0.364)(92) + (0.636)(80) = 84.37$$

Eq. (4-9)

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

(4-19)

(a) actual reaction



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

(b) Eq. (4-4) with  $A = \text{H}_2$  and  $C = \text{H}$

$$B = D = 0$$

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

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

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

**(10-2)**

**(a)**

use Eq. (2-55) for fuel flow rate

$$\dot{m}_f = \dot{m}_a / (AF) = (0.0289 \text{ kg/sec}) / 14.6 = 0.00198 \text{ kg/sec}$$

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

this cools the air-fuel mixture (use low temp value of  $c_p$ )

$$\dot{Q}_{\text{evap}} = \dot{m}_m c_p \Delta T = (0.0289 + 0.00198) \text{ kg/sec} (1.005 \text{ kJ/kg-K}) \Delta T$$

$$\Delta T = 7.8^\circ \text{C}$$

$$T_{\text{entering}} = 32.2^\circ - \Delta T = 32.2^\circ - 7.8^\circ = \underline{24.4^\circ \text{C}}$$

**(b)**

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

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

$$\Delta T = 34.7^\circ \text{C}$$

$$T_{\text{entering}} = 32.2^\circ - 34.7^\circ = \underline{-2.5^\circ \text{C}}$$

**(10-3)**

Eq. (2-8) for 1 cylinder

$$V_d = 0.0011 \text{ m}^3 = (\pi/4) B^2 S = (\pi/4) B^2 (0.9 \text{ B})$$

$$B = 0.1159 \text{ m} = 11.59 \text{ cm}$$

Eq. (2-15) gives area of piston face

$$A_p = (\pi/4) B^2 = (\pi/4) (0.1159 \text{ m})^2 = 0.01055 \text{ m}^2$$

Eq. (10-7) using viscosity value from Ref. [63]

$$\begin{aligned} \text{Re} &= [(\dot{m}_a + \dot{m}_f) B] / (A_p \mu_f) \\ &= [(0.0289 + 0.00321) (0.1159)] / [(0.01055) (1.846 \times 10^{-5})] = \underline{19,109} \end{aligned}$$

(10-4)

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

average bulk temperature

$$T_{bulk} = (477^\circ + 377^\circ)/2 = 427^\circ \text{C} = 700 \text{ K}$$

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

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

mass flow rate of exhaust for entire engine

$$\dot{m}_{ex} = \dot{m}_a + \dot{m}_f = 0.0289 + 0.00321 = (0.03211 \text{ kg/sec})(6 \text{ cyl}) = 0.19266 \text{ kg/sec}$$

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

Reynolds number

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

Nusselt number using Dittus-Boelter equation from Ref. [63]

$$Nu = 0.023 Re^{0.8} Pr^{0.3} = (0.023)(113,223)^{0.8}(0.684)^{0.3} = 226.6$$

this is increased by a factor of 2 due to pulsed flow of exhaust

$$Nu = (226.6)(2) = 453.2 = hd/k$$

convection heat transfer coefficient

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

convection heat transfer

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

$$\Delta T = 108^\circ$$

temperature of exhaust entering catalytic converter

$$T_{ex} = 477^\circ\text{C} - \Delta T = 477^\circ\text{C} - 108^\circ = 369^\circ\text{C} = 642\text{K}$$



2nd iteration using  $\Delta T = 108^\circ\text{C}$  to get better bulk temperature:

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

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

(10-5)

(a)

using Fig. 10-1 at 2000 RPM

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

(b)

$$\dot{Q}_{\text{friction}} \approx \frac{1}{4} \dot{W}_b = \frac{1}{4}(20 \text{ kW}) = \underline{5 \text{ kW}}$$

(c)

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

**(10-6)**

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

mass flow rate of coolant flow

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

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

$$\Delta T = 7^\circ \text{ F}$$

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

(b) velocity of air through radiator

$$\text{Vel} = [(30 \text{ miles/hr})(5280 \text{ ft/mile})/(3600 \text{ sec/hr})](1.1) = 48.4 \text{ ft/sec}$$

mass flow of air

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

33.3 hp must be dissipated

$$\dot{Q}_{\text{radiator}} = \dot{m}_a c_p \Delta T$$

$$(33.3 \text{ hp})(2545/3600 \text{ BTU/sec/hp}) = (16.1 \text{ lbm/sec})(0.240 \text{ BTU/lbm} \cdot ^\circ\text{R}) \Delta T$$

$$\Delta T = 6^\circ \text{ F}$$

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

**(10-7)**

approximate ratio of cylinder volumes

$$R_{\text{vol}} = 320/290 = 1.103$$

approximate ratio of linear dimensions

$$R_{\text{lin}} = (1.103)^{1/3} = 1.033$$

approximate ratio of area dimensions

$$R_{\text{area}} = (1.033)^2 = 1.068$$

- (a)  $\dot{Q}_{\text{in}}$  will be proportional to cylinder volume for each engine  
 heat losses will be proportional to cylinder surface area  
 $(\eta)_320/(\eta)_290 \approx R_{\text{vol}}/R_{\text{area}} = 1.103/1.068 = 1.033$

3.3% greater indicated thermal efficiency in larger engine

- (b) if all temperatures are the same, heat transfer to coolant will be proportional to surface area

$$\dot{Q}_{320} \approx 1.068 \dot{Q}_{290}$$

6.8% greater heat flow to coolant in larger engine