Internal combustion engines

Chapter two

OPERATION IC ENGINES

By

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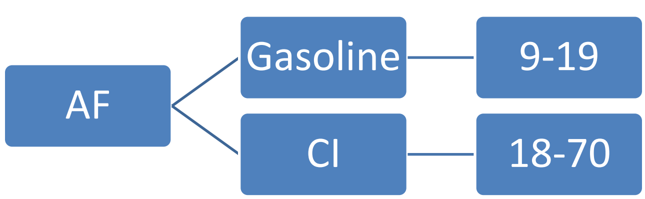
2-6 AIR–FUEL RATIO AND FUEL–AIR RATIO

$$AF = m_a / m_f = \dot{m}_a / \dot{m}_f$$

$$FA = m_f / m_a = \dot{m}_f / \dot{m}_a = 1/AF$$

where: m_a = mass of air
$\dot{m}_a$ = mass flow rate of air
m_f = mass of fuel
$\dot{m}_f$ = mass flow rate of fuel



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Equivalence ratio ϕ

$$\phi = (FA)_{act}/(FA)_{stoich} = (AF)_{stoich}/(AF)_{act} \qquad (2\text{-}57)$$

2-7 SPECIFIC FUEL CONSUMPTION

$$sfc = \dot{m}_f/\dot{W}$$

where: $\dot{m}_f$ = rate of fuel flow into engine
$\dot{W}$ = engine power

brake specific fuel consumption: $bsfc = \dot{m}_f/\dot{W}_b$

indicated specific fuel consumption: $isfc = \dot{m}_f/\dot{W}_i$

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fsfc = friction specific fuel consumption
igsfc = indicated gross specific fuel consumption
insfc = indicated net specific fuel consumption
psfc = pumping specific fuel consumption

$$\eta_m = \dot{W}_b/\dot{W}_i = (\dot{m}_f/\dot{W}_i)/(\dot{m}_f/\dot{W}_b) = (isfc)/(bsfc)$$

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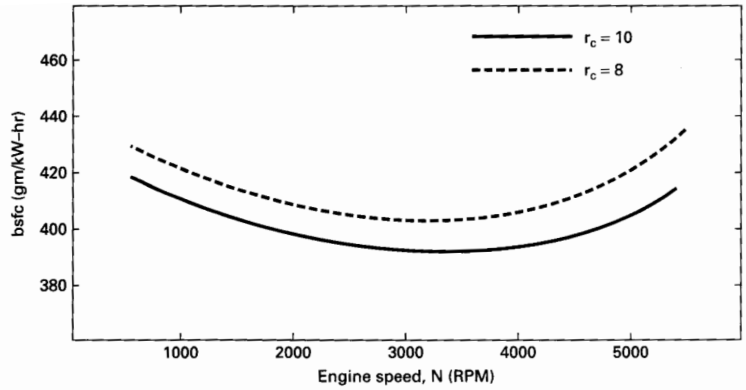

Figure 2-12 Brake specific fuel consumption as a function of engine speed. Fuel consumption decreases as engine speed increases due to the shorter time for heat loss during each cycle. At higher engine speeds fuel consumption again increases because of high friction losses. As compression ratio is increased fuel consumption decreases due to greater thermal efficiency.

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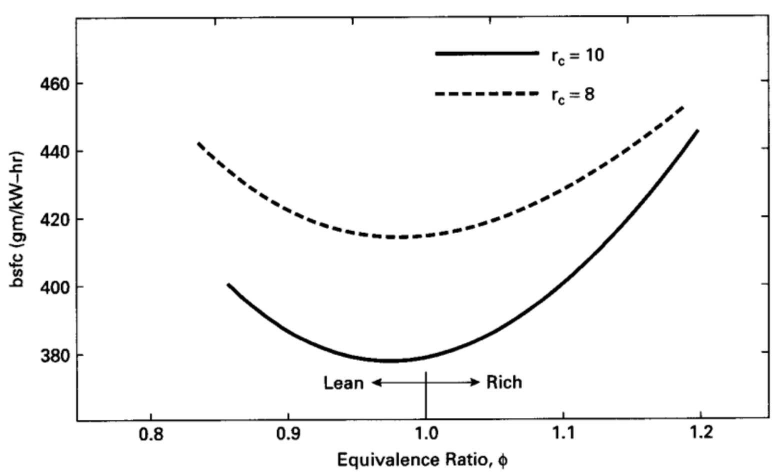

Figure 2-13 Brake specific fuel consumption as a function of fuel equivalence ratio. Consumption is minimum at a slightly lean condition, increasing with both richer and leaner mixtures.

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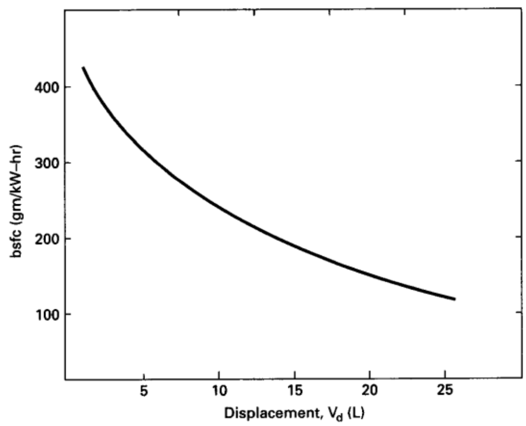

Figure 2-14 Brake specific fuel consumption as a function of engine displacement. Generally, average fuel consumption is less with larger engines. One reason for this is less heat loss due to the higher volume to surface area ratio of the combustion chamber in a large engine. Also, larger engines operate at lower speeds which reduces friction losses. Adapted from [123].

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2-8 ENGINE EFFICIENCIES

combustion efficiency, η_c

$$Q_{in} = m_f Q_{HV} \eta_c$$

$$\dot{Q}_{in} = \dot{m}_f Q_{HV} \eta_c$$

Thermal Efficiency, η_t

$$\eta_t = W / Q_{in} = \dot{W} / \dot{Q}_{in} = \dot{W} / \dot{m}_f Q_{HV} \eta_c = \eta_f / \eta_c$$

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2-9 VOLUMETRIC EFFICIENCY

$$\eta_v = m_a / \rho_a V_d \quad (2\text{-}69)$$

$$\eta_v = n\dot{m}_a / \rho_a V_d N \quad (2\text{-}70)$$

where: m_a = mass of air into the engine (or cylinder) for one cycle
$\dot{m}_a$ = steady-state flow of air into the engine
ρ_a = air density evaluated at atmospheric conditions outside the engine
V_d = displacement volume
N = engine speed
n = number of revolutions per cycle

Unless better values are known, standard values of surrounding air pressure and temperature can be used to find density:

$$P_o\text{(standard)} = 101\text{ kPa} = 14.7\text{ psia}$$

$$T_o\text{(standard)} = 298\text{ K} = 25°\text{C} = 537°\text{R} = 77°\text{F}$$

$$\rho_a = P_o / RT_o \quad (2\text{-}71)$$

where: P_o = pressure of surrounding air
T_o = temperature of surrounding air
R = gas constant for air = 0.287 kJ/kg-K
= 53.33 ft-lbf/lbm-°R

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At standard conditions, the density of air ρ_a = 1.181 kg/m³ = 0.0739 lbm/ft³.

EXAMPLE PROBLEM 2-3

The engine in Example Problem 2-2 is running with an air-fuel ratio AF = 15, a fuel heating value of 44,000kJ/kg, and a combustion efficiencyof 97%. Calculate:

1. rate of fuel flow into engine
2. brake thermal efficiency
3. indicated thermal efficiency
4. volumetric efficiency
5. brake specific fuel consumption

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1) From Example Problem 2-2, the mass of air in one cylinder for one cycle is m_a = 0.00050 kg. Then:

$$m_f = m_a / \text{AF} = 0.00050/15 = 0.000033 \text{ kg of fuel per cylinder per cycle}$$

Therefore, the rate of fuel flow into the engine is:

$$\dot{m}_f = (0.000033 \text{ kg/cyl-cycle})(6 \text{ cyl})(3600/60 \text{ rev/sec})(1 \text{ cycle/2 rev})$$
$$= 0.0060 \text{ kg/sec} = 0.0132 \text{ lbm/sec}$$

2) Using Eq. (2-64) to find brake thermal efficiency:

$$(\eta_t)_b = \dot{W}_b / \dot{m}_f Q_{HV} \eta_c = (77.3 \text{ kW})/(0.0060 \text{ kg/sec})(44{,}000 \text{ kJ/kg})(0.97)$$
$$= 0.302 = 30.2\%$$

Or, using Eq. (2-68) for one cycle of one cylinder:

$$(\eta_t)_b = W_b / m_f Q_{HV} \eta_c = (0.43 \text{ kJ})/(0.000033 \text{ kg})(44{,}000 \text{ kJ/kg})(0.97)$$
$$= 0.302$$

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3) Indicated thermal efficiency using Eq. (2-65):

$$(\eta_t)_i = (\eta_t)_b / \eta_m = 0.302/0.85 = 0.355 = 35.5\%$$

4) Using Eq. (2-69) with standard air density for volumetric efficiency:

$$\eta_v = m_a / \rho_a V_d = (0.00050 \text{ kg})/(1.181 \text{ kg/m}^3)(0.0005 \text{ m}^3)$$
$$= 0.847 = 84.7\%$$

5) Using Eq. (2-59) for brake specific fuel consumption:

$$\text{bsfc} = \dot{m}_f / \dot{W}_b = (0.0060 \text{ kg/sec})/(77.3 \text{ kW})$$
$$= 7.76 \times 10^{-5} \text{ kg/kW-sec} = 279 \text{ gm/kW-hr} = 0.459 \text{ lbm/hp-hr}$$