INTERNAL COMBUSTION ENGINES

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Lecture # 3 (Operating Characteristics Problems)

9. VOLUMETRIC EFFICIENCY

- Amount of air required for combustion is critical for producing power
- Ideally, the amount of air ingested in each cycle should be

mass of air = (the density of atmospheric air) x (displacement volume of the cylinder)

- However, less than ideally amount of air is ingested because:
  1. the short cycle time available
  2. the flow restrictions presented by the air cleaner
  3. carburetor (if any)
  4. intake manifold, and intake valve(s)

VOLUMETRIC EFFICIENCY

$$\eta_v = m_a/\rho_a V_d$$
$$\eta_v = n\dot{m}_a/\rho_a V_d N$$

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

9. VOLUMETRIC EFFICIENCY

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

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

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

$$\rho_a = P_o/RT_o \tag{72}$$

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

At standard conditions, the density of air $\rho_a = 1.181 \text{ kg/m}^3 = 0.0739 \text{ lbm/ft}^3$.

10. EMISSIONS

- The four main engine exhaust emissions that must be controlled are
  1. oxides of nitrogen (NOx)
  2. carbon monoxide (CO)
  3. hydrocarbons (HC)
  4. solid particulates (part)

- Two common methods of measuring the amounts of these pollutants are
  1. specific emissions (SE)
  2. emissions index (EI)

10. EMISSIONS

Specific Emissions:

$$
\begin{aligned}
(\mathrm{SE})_{\mathrm{NOx}} &= \dot{m}_{\mathrm{NOx}}/\dot{W}_b \\
(\mathrm{SE})_{\mathrm{CO}} &= \dot{m}_{\mathrm{CO}}/\dot{W}_b \\
(\mathrm{SE})_{\mathrm{HC}} &= \dot{m}_{\mathrm{HC}}/\dot{W}_b \\
(\mathrm{SE})_{\mathrm{part}} &= \dot{m}_{\mathrm{part}}/\dot{W}_b
\end{aligned}
\tag{73}
$$

where

$\dot{m}$ = flow rate of emissions in gm/hr

$\dot{W}_{\mathrm{b}}$ = brake power

10. EMISSIONS

Emissions Index:

$$
\begin{aligned}
(\mathrm{EI})_{\mathrm{NOx}} &= \dot{m}_{\mathrm{NOx}}[\mathrm{gm/sec}]/\dot{m}_f[\mathrm{kg/sec}] \\
(\mathrm{EI})_{\mathrm{CO}} &= \dot{m}_{\mathrm{CO}}[\mathrm{gm/sec}]/\dot{m}_f[\mathrm{kg/sec}] \\
(\mathrm{EI})_{\mathrm{HC}} &= \dot{m}_{\mathrm{HC}}[\mathrm{gm/sec}]/\dot{m}_f[\mathrm{kg/sec}] \\
(\mathrm{EI})_{\mathrm{part}} &= \dot{m}_{\mathrm{part}}[\mathrm{gm/sec}]/\dot{m}_f[\mathrm{kg/sec}]
\end{aligned}
\tag{74}
$$

PROBLEM 1

Example Problem 1

John's automobile has a three-liter SI V6 engine that operates on a four-stroke cycle at 3600 RPM. The compression ratio is 9.5, the length of the connecting rods is 16.6 cm, and the engine is square $(B = S)$. At this speed, combustion ends at 20° aTDC.
Calculate:

1. cylinder bore and stroke length
2. average piston speed
3. clearance volume of one cylinder
4. piston speed at the end of combustion
5. distance the piston has traveled from TDC at the end of combustion
6. volume in the combustion chamber at the end of combustion

PROBLEM 2

Example Problem 2

The engine in Example Problem 1 is connected to a dynamometer which gives a brake output torque reading of 205 N-m at 3600 RPM. At this speed air enters the cylinders at 85 kPa and 60°C, and the mechanical efficiency of the engine is 85%.

Calculate:

1. brake power
2. indicated power
3. brake mean effective pressure
4. indicated mean effective pressure
5. friction mean effective pressure
6. power lost to friction
7. brake work per unit mass of gas in the cylinder
8. brake specific power
9. brake output per displacement
10. engine specific volume

PROBLEM 3

Example Problem 3

When a three-cylinder, four-stroke cycle, SI engine, operating at 4000 RPM is connected to an eddy current dynamometer, 70.4 kW of power is dissipated by the dynamometer. The engine has a total displacement volume of 2.4 liters and a mechanical efficiency of 82% at 4000 RPM. Because of heat and mechanical losses, the dynamometer has an efficiency of 93%. $\eta_{\text{dyno}} =$ (power recorded by dynamometer)/(actual power from engine).

Calculate:

1. power lost to friction in engine
2. brake mean effective pressure
3. engine torque at 4000 RPM
4. engine specific volume

PROBLEM 4

Example Problem 4

The engine in Example Problem 2 is running with an air–fuel ratio AF = 15, a fuel heating value of 44,000 kJ/kg, and a combustion efficiency of 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

PROBLEM 5

Example Problem 5

A 12-cylinder, two-stroke cycle CI engine produces 2440 kW of brake power at 550 RPM using stoichiometric light diesel fuel. The engine has bore of 24 cm, stroke of 32 cm, volumetric efficiency of 97%, mechanical efficiency of 88%, and combustion efficiency of 98%. Calculate:

1. mass flow rate of fuel into engine
2. brake specific fuel consumption
3. indicated specific fuel consumption
4. specific emissions of hydrocarbons due to unburned fuel
5. emissions index of hydrocarbons due to unburned fuel

END OF THE LECTURE