2.61 Final solution
Problem 1

isooctane / air : $\underbrace{C_8H_{18}}_{1\text{ mole} = 114\text{ gm}} + \underbrace{12.5(O_2 + 3.773 N_2)}_{\substack{12.5 \times 4.773 = 59.66 \text{ mole} \\ = 1728.42 \text{ gm}}} \longrightarrow 8CO_2 + 9H_2O + 12.5 \times 3.773 N_2$

Average molecular wt $W_1 = \dfrac{114 + 1728.42}{1 + 12.5 \times 4.773} = 30.37$; $Q_{LHV} = 2.75$ MJ/kg mixture (from table D-4)

isooctane / air N_2O mixture : To have 30% by volume of N_2O, the representation of the air / N_2O mixture is $O_2 + 3.773 N_2 + y N_2O$

where $\dfrac{y}{4.773 + y} = 0.3 \Rightarrow y = 2.05$

Reaction : $\underbrace{C_8H_{18}}_{1\text{ mole, } 114\text{ gm}} + \underbrace{\left(\frac{25}{2 + 2.05}\right)\left[O_2 + 3.773 N_2 + 2.05 N_2O\right]}_{42.12\text{ mole, mass} = 1410.33\text{ gm}} \rightarrow 8CO_2 + 9H_2O + \frac{25}{4.05} \times 3.773 N_2$

Average molecular weight $= \dfrac{1410.33 + 114}{1 + 42.12} = 35.35$

Power ratio $= \dfrac{m_2 Q_2}{m_1 Q_1}$

m = mass of charge

Q = Heating value per unit mass of charge.

To calculate the heating value per unit mass of the mixture for C_8H_{18} / air / N_2O :

For the above reaction as written, the $Q = \left(\sum \Delta\tilde{h}^o_{f_i} n_i\right)_{product} - (\quad)_{reactant}$ (negative value means exothermic)

$\Delta\tilde{h}^o_f$ (From table D2)

CO_2	-393.5 KJ/mol	C_8H_{18} (liquid)	-259.28
H_2O	-241.8		
N_2O	+82.05		
N_2	0		
O_2	0		

$Q = \left[8(-393.5) + 9(-241.8)\right] - \left[(-259.28) + \left(82.05 \times \frac{25}{4.05} \times 2.05\right)\right]$

$= -6103.21$ kJ

Therefore the heating value of the mixture is $Q_2 = \dfrac{6103.21 \text{ kJ}}{(114 + 1410.33)\text{ gm}} = 4.0$ MJ/kg

The power ratio $\dfrac{P_2}{P_1} = \dfrac{m_2}{m_1}\dfrac{Q_2}{Q_1} = \dfrac{\left(p_i V_T / \frac{\tilde{R}}{MW_2} T_i\right)}{\left(p_i V_T / \frac{\tilde{R}}{MW_1} T_i\right)} \dfrac{Q_2}{Q_1} = \dfrac{MW_2}{MW_1}\dfrac{Q_2}{Q_1}$

(molecular weight)

$= \underbrace{\left(\frac{35.35}{30.37}\right)}_{1.16} \times \underbrace{\left(\frac{4.0}{2.75}\right)}_{1.45} = \underline{1.69}$

The 69% increase in power comes from 16% because of a denser mixture, and 45% because of the combustion effect (more oxygen available so that more fuel is burned and heating value of N_2O)

Problem 2

(a) The EXPAD technology will reduce the piston sliding friction power consumption. Because of the high piston speed, the mid stroke is in the hydrodynamic lubrication regime. The rubber pad provides insulation of the liner from the coolant so that the mid-section of the liner runs hotter. The viscosity of the lubrication oil decreases exponentially with temperature. The hydrodynamic friction is reduced with the lower viscosity. For the top and bottom part of the liner where the piston speed is low, the liner is not insulated by the EXPAD. So the temperature is controlled by the coolant, and the viscosity is kept high with the lower temperature to minimize mixed and boundary lubrication.

(b) For high BMEP engine with large bore (B), the force on the piston is very high (force $\propto$ BMEP*B^2). Also the wall temperature will be high because of the high load; the viscosity of the lubricant on the liner will correspondingly be low. For a normal piston arrangement, the high side force will break through the oil film (with low viscosity) for a substantial range of the stroke, resulting in high wear and high friction.

With a cross head, because the connecting rod is normal to the combustion chamber piston face, the side force of the piston is small. So even with the low lubricant viscosity in the combustion chamber due to the high temperature, the lubrication film will be able to support the piston for a substantial part of the stroke. For the driving piston, the side force is high. However, the lubrication film is now outside the combustion chamber so that the temperature is low; correspondingly the viscosity is much higher. Then the oil film will be able to support the high side force of the piston.

(c) To have the turbine extracting much of the charge energy, the exhaust valve is opened early so that the high pressure cylinder charge is discharged through the turbine. Since the extraction of work via the turbine and that via the piston are the same thermodynamic process, there is no material difference in the output work in principle. Note that the turbine exit pressures for both the regular configuration and the one with the extra power turbine are the same. With the same work going to drive the compressor, the combine work extraction with the power turbine and the limited expansion stroke is the same as that with the normal expansion stroke.

In practice, however, the flow loss through the valve is much higher because of the higher density exhaust with the early EVO.

The heat transfer loss is also much higher due to the higher temperature high speed flow through the valve and port. Because high surface area of the blade surfaces, the heat transfer loss in the power turbine is much larger than that in a piston engine.

The overall fuel conversion efficiency will be lower than the regular engine, and the cost will be higher because of the extra hardware.

(d) When the combustion is retarded, the expansion will take less work out of the charge and the exhaust gas will be hotter.

With the combustion retard, to maintain the same torque output to overcome engine friction in the idle process, the throughput of the engine has to increase. Thus the exhaust gas mass flow rate increases.

Both effects (higher temperature and higher gas flow rate) accelerate the catalyst light off.

(e) The longer expansion stroke extracts more work out of the charge. The fuel conversion efficiency improves.

The shorter compression stroke implies that less charge is trapped. So the torque output decreases.

(f) With some of the cylinders deactivated, the remaining cylinders operate at a higher load for the same total output torque. Thus the pumping loss is reduced.

The deactivated cylinders should have the valves closed. Then heat transfer and friction are the only significant losses. These losses are much less than the pumping loss of the gas flowing in and out of the cylinder if the valves are not closed.

Problem 3 soluiton

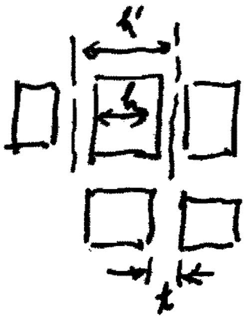
Catalyst flow: At the catalyst exit $\frac{c(L)}{c(0)} = \exp\left(-\frac{4\,Sh}{h^2/D}\,\frac{L}{U}\right) = 1-\underbrace{\eta_{cat}}_{\text{catalyst efficiency}}$

Thus the length

$$L = \left[-\log_e(1-\eta_{cat})\right]\cdot\frac{h^2/D}{4\,Sh}\cdot U \qquad \text{——— (1)}$$

The power of the engine is $P = \dot m_f\, LHV\, \eta_f = \frac{\dot m}{(1+A/F)}\, LHV\, \eta_f$

Thus the mass flow rate is $\dot m = \frac{P\,(1+A/F)}{\eta_f\, LHV}$ ——— (2)



The cell size is $h' = \left(\frac{25.4\text{ mm}}{\sqrt{cpsi}}\right) = 1.037\times10^{-3}\text{ m} = \underline{\underline{1.037\text{ mm}}}$

The channel heigh $h = h' - t = \underline{\underline{0.837\text{ mm}}}$

The void fraction $\zeta = (h/h')^2$ ——— (3) $\zeta = \underline{\underline{0.6515}}$

Thus the flow velocity $U = \frac{\dot m}{\rho A \zeta}$ where A is the frontal area ——— (4)

(a) The catalyst cost $\$ \propto \underbrace{(4hL)}_{\text{surface area of 1 channel}}\cdot\underbrace{\left(\frac{A}{h'^2}\right)}_{\text{no. of channels}}$

From (1) for const. catalyst efficiency

$$\$ \propto h\cdot\underbrace{h^2\,U}_{\propto L}\left(\frac{A}{h^2}\right) \propto h\left(\overbrace{\frac{\dot m}{\rho\zeta}}^{UA}\right) \underline{\underline{\propto h}} \qquad \underline{\underline{\$ \propto h}}.$$

want small h.

(b) From (2) $\dot m = \frac{120\times10^3\,(1+14.6)}{0.32\times44\times10^6} = \underline{\underline{0.133\text{ Kg/s}}}$

(c) From (4): $\rho = \frac{pW}{RT} = \frac{10^5\times29}{8314\times800} = 0.442\text{ Kg/m}^3$; $U = \frac{\dot m}{\rho A\zeta} = \frac{0.133}{0.442\times117.8_{-4}\times0.6515} = \underline{\underline{39.2\text{ m/s}}}$

(d) From (1) $L = \left(-\log_e 3\times10^{-3}\right)\frac{(0.837_{-3})^2}{5.63_{-5}}\cdot\frac{1}{4\times4}\times39.2 = 0.177\text{ m} = \underline{\underline{17.7\text{ cm}}}$

(e) $Re = \rho U h/\mu = \underline{\underline{402.8}}$; $\Delta p = \frac{1}{2}\rho U^2 f\left(\frac{L}{h}\right) = \frac{1}{2}\rho U^2\left(\frac{64}{Re}\right)\left(\frac{L}{h}\right) = \underline{\underline{1.14\times10^4\text{ Pa}}} = \underline{\underline{0.114\text{ bar}}}$

2.61 Internal Combustion Engines
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