Exercise A)

DATA :

Cylinders	: 4
Engine total volume (4-stroke)	: 2 L
Fuel	: natural gas (34 MJ / m^3)
Air-fuel ratio (**volume**)	: 9 (A/F-vol)
Compression ratio	: 10
Brake power	: 50 kW (=effective)
Indicated thermal efficiency	: 35% (fuel energy => piston energy)
Mechanical efficiency	: 80% (piston=>crankshaft) i.e. minus the friction losses
Volumetric efficiency	: 70% (real air intake vs. theor. displacement volume)

QUESTION :

Find the engine speed (rpm) under these conditions

SOLUTION

Volume for 1 cylinder = 2000 mL / 4 = 500 mL

Compression ratio = 10 = $(V_u + V_o) / V_o$
=> $V_u = 9\,V_o$, with $V_u + V_o = 500$ mL
Displacement volume Vu for 1 cylinder = (9/10) * 500 mL = 450 mL
(dead volume V_o = 50 ml)

Fresh air intake for 1 cycle
= volumetric efficiency * displacement volume = 0.7 * 450 = 315 mL

Fuel intake for 1 cycle = air intake / A/F-vol = 315 mL / 9 = 35 mL

Energy input, per cylinder and per cycle
= fuel (vol) * energy density (34 MJ/m^3) = 35.10^{-6} m^3*34.10^6 = 1.19 kJ

Energy input per second?
Brake power = 50 kW = 50 kJ/s
= effective available power at the crankshaft, after friction loss

Indicated power = brake power / mechanical efficiency = 50 / 0.8 = 62.5 kW
= the power given to the 4 pistons
Hence friction loss can be derived to be = 62.5 – 50 = 12.5 kW

Thermal input power = indicated power / indicated thermal efficiency
= 62.5 / 0.35 = 178.57 kW
= the fuel input (LHV * fuel flow)

To 1 cylinder = 178.57 kW / 4 = 44.64 kW = 44.64 kJ/s

The engine speed is then 44.64 kJ/s divided by 1.19 kJ/cycle = 37.5 cycles/s
One cycle is 2 revolutions ! (4-stroke)

Thus in rpm the engine speed is = 37.5 * 2 * 60 s/min = **4500 rpm**

Let's see how we could relate this to a more usual fuel consumption figure (in L or kg / 100 km).

In the example, natural gas fuel intake is 35 ml per cycle per cylinder.
We have 37.5 cycles per second and 4 cylinders, thus the fuel intake is
0.035 L * 37.5 * 4 = 5.25 L /s = 315 L / min = 18.9 m^3 / h (13.2 kg / h with natural gas density of 0.7).
With a LHV of 34 MJ / m^3, the consumption is then 18.9 * 34 = 642.6 MJ / h.
Compared to gasoline with an energy content of ≈ 32 MJ / L, the equivalent gasoline consumption would then be 642.6 MJ / 32 = 20 L /h.
At a brake power of 50 kW and 4500 rpm, the 2 L engine is running at (very) high load and we may estimate the vehicle speed at probably ≈ 150 km/h.
Finally the equivalent gasoline consumption under these load conditions is then
20 L /h / 150 km/h = 13.3 L / 100 km.
<u>Average</u> consumption of a 2 L gasoline car is around 8-9 L / 100 km.
As the engine runs here at <u>high speed and load</u> (4500 rpm, 50 kW), fuel consumption is logically higher, therefore we see that the calculated values are plausible.

Exercise B)

DATA :

Cylinders	:	4
Fuel LHV (diesel)	:	42 MJ / kg
Bore	:	120 mm
Stroke	:	100 mm
Air density	:	1.15 kg/m^3
Air-fuel ratio (**mass**)	:	15 (A/F-mass)
Engine speed	:	2000 rpm
Brake power	:	60 kW
Brake thermal efficiency	:	30%
Mechanical efficiency	:	80%

<u>QUESTIONS :</u>

Calculate

1) Fuel consumption (kg/s)
2) Air consumption (m^3 / s)
3) Volumetric efficiency (%)
4) Brake mean effective pressure (bar)
5) Mean piston speed (m/s)

Brake power (60 kW)
= fuel consumption (g/s) * fuel LHV (42 MJ/kg) * brake thermal efficiency (0.3)
=> <u>fuel consumption</u> = 60 kW / (0.3 * 42 MJ/kg) = **4.762 g / s**

Air consumption
= fuel consumption * A/F-mass ratio = 4.762 * 15 = 71.43 g/s
With air density of 1.15g/L, the <u>air consumption</u> in volume is 71.73 / 1.15 = **62.1 L / s**

Air flow rate for 1 cylinder = 62.1 / 4 = **15.53 L / s**

Volumetric efficiency
= actual air flow per cylinder / theoretical air flow for swept volume displacement
Theoretical swept volume for 1 cylinder = π * (0.12/2)^2 * (0.1) per cycle = 1.13 L / cycle
Engine speed = 2000 rpm = 2000 / 60 = 33.33 rps
2 revolutions for 1 cycle ! (4-stroke) => the engine performs 16.67 injection cycles/s
=> theoretical air flow per s for 1 cylinder = 1.13 L/cycle * 16.67 cycles /s = **18.833 L/s**

Hence <u>volumetric efficiency</u> = **15.53 / 18.833** = **82.4%**

Energy (J) = Pressure x Volume
Power (J/s) = Pressure x (Vol/s)
The effective mean pressure P that results from this fundamental equation, when taking the effective brake power, is the brake mean effective pressure BMEP (bar).

BMEP (bar)
= brake power (60 kW) / theoretical air volume flow of the engine

The theoretical air volume flow of the engine = 18.833 L/s (1 cylinder) * 4 (cylinders) = 75.332 L/s = 0.075332 m^3/s

Then the BMEP = 60'000 J/s / 0.075332 m^3/s = 796'474 J/m^3 = 796.5 kN/m^2 = **7.96 bar**

Mean piston speed
= twice the stroke length (L) * number of revolutions per second
= 2 * 0.1 * 33.33 rps = **6.67 m/s**

Also here let's see how we could relate this to a more usual fuel consumption figure (in L or kg / 100 km).
The fuel consumption is 4.762 g/s = 285.7 g/ min = 17.14 kg / h.
The swept volume is 1.13 L per cycle for 1 cylinder, hence 4.5 L for the 4 cylinders.
With these data and the rather low engine speed of 2000 rpm we can safely conclude we deal with a diesel engine of a Jeep or similar (buses and trucks are more like 7 to 15 L engines). Diesel fuel density is 0.85 L / kg, so the consumption would be
17.14 / 0.85 = 20.16 L/h. At a brake power of 60 kW it may be driving at ≈120 km/h, thus the fuel consumption for 100 km would be 20.16 L/h / 120 km/h = 16.8 L / 100 km.
Which is not surprising for a 4.5 L Jeep.