1) a) Flammability limits are the limits in equivalence ratio (also fuel to air ratio) between which a mixture can sustain a self-propagating flame. The lean limit is the smallest possible fuel to air ratio. The existence of the lean flammability limit is due to the low flame temperature as the mixture becomes leaner, which leads to the dominance of chain-terminating reaction over chain-propagating reaction. For hydrocarbon flames at ~~atmos~~ atmospheric pressure this occurs at around 1500 K.

(b) Energy balance for the heat exchange between inflowing reactant mixture and outgoing products is, at steady state,

$$\dot{m}\, c_p (T_R - T_{in}) = \dot{m}\, c_p (T_f - T_{out}) \quad \text{— (1)}$$

Energy balance across the flame (lower heating value)

$$\dot{m} c_p (T_f - T_R) = \dot{m}\, Y_f\, Q \quad \text{— (2)}$$

$T_f = 1600$, $T_{in} = 300$, $T_{out} = 1000$ K

Eq. (1) $\Rightarrow$ $\boxed{T_R = 900\text{K}}$

Eq. (2) $\Rightarrow$ $1.2\,(1600 - 900) = Y_f \; 50\times10^3$

$$\Rightarrow \boxed{Y_f = 0.0168}$$

Equivalence ratio $\phi = \dfrac{(m_f/m_{air})}{(m_f/m_{air})_{st}} = \dfrac{Y_f/(1-Y_f)}{\left[Y_f/(1-Y_f)\right]_{st}}$

To find $Y_{f,st}$

$$CH_4 + \frac{2}{0.21}\left(0.21O_2 + 0.79N_2\right) \longrightarrow CO_2 + 2H_2O + \frac{2*0.79}{0.21}N_2$$

$$\Rightarrow Y_{f,st} = \frac{16}{2*32 + 2\times3.76\times28} = 0.0583$$

$$\Rightarrow \phi = \frac{0.0168/(1-0.0168)}{\left[0.0583/(1-0.0583)\right]} = 0.276$$

$$\boxed{\phi = 0.276}$$

(c) At these low temperature, thermal NO is expected to be small. There is no fuel bound NO, because CH_4 is used. Thus, there is only <u>prompt NO</u>.

2) (a) For well-stirred reactor, the energy balance gives

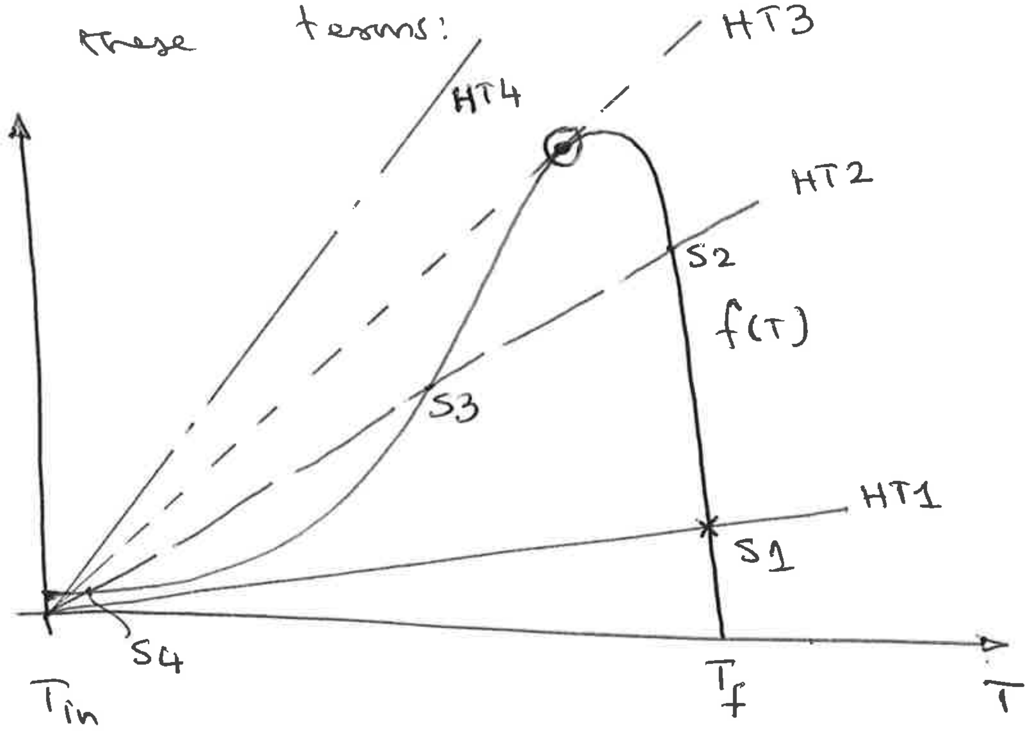
$$\frac{\dot{m}}{\rho V}(T - T_{in}) = -\dot{\omega}_f = c\,f(T) \quad \text{— (1)}$$

$\dot{m}$ – mass flow rate

ρ – density

V – Volume of the reactor.

Plotting these terms:



$f(T)$ – heat generation by chemical reaction

HT – LHS of Eq. (1)
with slope representing $(\dot{m}/\rho V) = \frac{1}{t_{res}}$.

$\Rightarrow$ larger the slope smaller the residence time, t_{res}.

For HT1 – large residence time
Stable reactor, or flame @ S1

HT2 – intermediate residence time
if T is large, stable flame @ S2

if T is low then no reaction/flame @ S4.

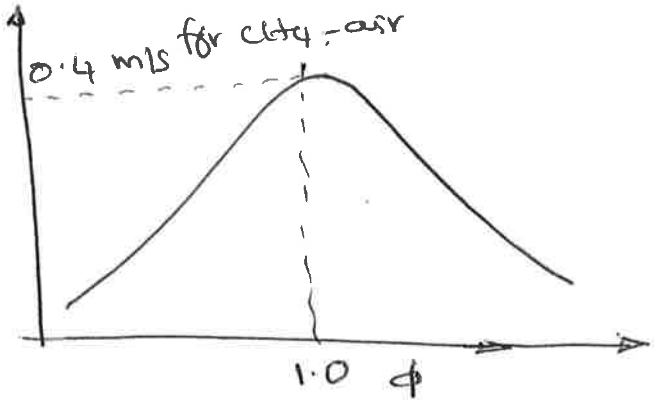
S3 - is unstable or unphysical.

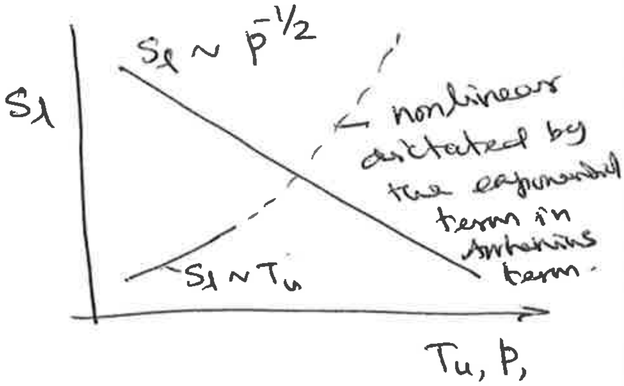
HT3 - has Critical residence time

Any small increase in $\dot{m}$ or decrease in t_{res} will extinguish the flame leading to flame blow-off. This strongly depends on reactant temperature, equivalence ratio, and pressure. This results because of competing effects of heat release rate (chemical time scale) and heat loss (t_{res}).

HT4 - residence time is too short for chemical reaction to occur.

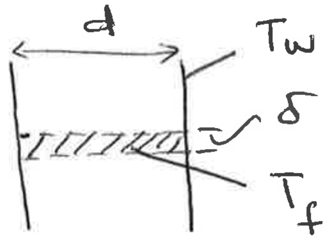
(b)





$S_l \uparrow$ as $\phi \uparrow$, and reaches maximum around $\phi = 1.1$ and then drops.

(c) Just before quenching the flame is inside the hole as shown below



Now the energy balance:

Generation = loss by conduction

$$\dot{\omega}_f \, LHV \left(\delta \frac{\pi d^2}{4}\right) = (\pi d \delta) \lambda \frac{(T_f - T_w) 2}{d}$$

$$\dot{\omega}_f \sim \rho_u \frac{S_L}{\delta} \; ; \qquad LHV \sim c_p (T_f - T_u)$$

$$\Rightarrow \rho_u \frac{S_L}{\delta} c_p (T_f - T_u) d^2 = 8 \lambda (T_f - T_w)$$

$$d = \sqrt{8 \frac{\lambda}{\rho_u c_p} \frac{\delta}{S_L} \frac{(T_f - T_w)}{(T_f - T_u)}}$$

~~Just before~~

when quenching occurs $T_w \approx T_u$,

Generation < loss.

$$\Rightarrow d \le \sqrt{8 \alpha \tau_{ch}} = \sqrt{8 \delta^2}$$

$$\Rightarrow \boxed{d \le 2\sqrt{2} \, \delta}$$

(d) $d \sim \delta$ from c.

$d \sim \alpha / S_l$ $\qquad \alpha = \dfrac{\lambda}{\rho c_p}$

ideal gas mixture.

$\Rightarrow \alpha \sim p^{-1}$

$\therefore d \sim p^{-1} p^{1/2} \Rightarrow \boxed{d \sim p^{-1/2}}$

So, the diameter decreases by a factor of $\left(1/\sqrt{5}\right)$

3(a) IC-engined vehicles:-

(i) Engine downsizing – smaller engines, less friction, less throttling (gasoline)
(ii) Turbocharging – even smaller engines
(iii) Start-stop – especially beneficial for city driving
(iv) Reduced drag coefficient – especially beneficial for motorway driving
(v) Maximum speed limit reduction – drag goes as V^2
(vi) Mechanical CVT – better matching of engine to power requirement – essentially down-speeding
(vii) Electrical CVT "Hybrid" – ditto reasons as (vi), Start-stop easy to include. Series hybrid gives best flexibility, but biggest cost. Parallel ("mild") hybrid more cost-effective, but less potential economy benefit. Prius "power-split" hybrid offers "most of both worlds", at intermediate cost
(viii) Plug-in hybrid permits possibility of most (short, city) journeys to be all-electric, but with a an IC engine "range-extender" to allow journeys outside the AER (all electric range). CO2 benefits depend on "Well-to-tank" CO2

(b) Other prime movers

(i) All electric "BEV". CO2 benefits depend on "Well-to-tank" CO2. Cabin heating/air-con/terrain (hills) big issues affecting range. Battery embodied CO2 relevant
(ii) Fuel cell. SOFCs can use natural gas (purity issues?), PEMs use hydrogen. CO2 emissions used in H2 production non-negligible (!)
(iii) Tram, trolley bus. Infrastructure cost for new installation high. CO2 lies mainly with production mix.

4(a) Air standard cycles offer a simple way of understanding the importance of compression ratio and throttling on engine indicated efficiency, but that is about all – burn duration, knock and heat transfer cannot be modelled.

(b) (i) At intermediate rpm, scavenging of exhaust gases during the valve over-lap period is effective, but pressure losses through the intake system are modest. At high rpm, scavenging is still effective, but pressure losses mean that the cylinder charge is of diminished density, and hence less work per-cycle is delivered.

Power = torque*angular velocity

At the max power condition $T = 61000/(2\pi 5500/60) = 105.9Nm$

At the max torque condition $P = 128(2\pi 3250/60) = 43.6kW$

(ii)

The fuel flow rate will be given by $\dot{m}_{fuel} = 43600/44E6/0.4 = 0.00248kg/s$. The isfc will be given by $isfc = 3.6E6 * 0.00248/43.6E3 = 0.205kg/kWh$

At the higher engine speed, and with increased losses associated with the higher gas velocities, it would be expected that the isfc would be higher at the maximum power condition.

(iii)

The air flow rate is $\dot{m}_{air} = 0.00248 * 14.6 = 0.036kg/s$, thus the engine displacement rate must be $= \frac{\dot{m}_{air}}{\rho_{inlet}\eta_{vol}} = \frac{0.036}{0.9} \bigg/ \left(\frac{1e5}{287 * (20+273)} \right) = 0.0338m^3/s$.

If the bore (and stroke) is ***b***, then the displacement rate is

$= 4\frac{\pi b^2}{4} b.60.\frac{N}{2}$. Equating, this gives $b = 73.5mm$,and an engine displacement of 1.25 litres.

(iv) Reducing the number of cylinders from 4 to 3 raises complex issues. On the +ve side

a. Cheaper, lighter
b. Potentially higher efficiency –due to lower friction, lower heat transfer

On the –ve side

a. Extra balancing shaft may be required
b. Higher efficiency may be compromised by reduced compression ratio