Chapter Three

Methodology

3.1 Introduction

In this research the methodology was used to state the thermodynamics and kinetics equations which were used to calculate the engine parameters.

3.2 Engine Specifications:-

- Number of cylinders : 4
- Compression ratio (R_C) : 16.5:1
- Crankshaft rotation speed (N) : 4000 rpm
- Power output (N_o): 103 kW

3.3 thermodynamic equations

Can get with thermodynamic the pressure and temperature in the end of each stroke:

3.3.1 Engine parameters:-

a. The sufficient amount of air for burning 1 kg of fuel:-

$L_o = \frac{1}{0.208}\left(\frac{C}{12} + \frac{H}{4} - \frac{O}{32}\right) \text{kmol}_{\text{air}} \,/\, \text{kg}_{\text{fuel}}$ …………………………………. (3.1) [11]

$l_o = \frac{1}{0.23}\left(\frac{8\times C}{3} + 8 \times H - O\right) \text{kg}_{\text{air}} \,/\, \text{kg}_{\text{fuel}}$ ………………………...…... (3.2) [11]

b. Amount of air charge:-

$M_1 = \alpha \times L_o$, Take ($\alpha = 1.4$) ………………………………….……. (3.3) [11]

$\alpha > 1$ Always in diesel engines

For the engine without turbocharger will be taken as 1.4

And for the engine with turbocharger will be taken as 1.8

c. Content of exhaust gas:-

$M_{H_2O} = \frac{H}{2}\ \mathrm{kmol_{H_2O}/kg_{fuel}}$ Amount of H_2o …………………………….……… (3.4)

$M_{CO_2} = \frac{C}{12}\ \mathrm{kmol_{co_2}/kg_{fuel}}$ Amount of CO_2 ………………………………… (3.5)

$M_{O_2} \quad = 0.208 \times Lo \times (\alpha - 1)\ \mathrm{kmol_{o_2}/kg_{fuel}}$ Amount of O_2 …………..… (3.6)

$M_{N_2} \quad = 0.792 \times M1\ \mathrm{kmol_{N_2}/kg_{fuel}}$ Amount of N_2……….…………….….…… (3.7)

d. Amount of exhaust gas:-

$M_2 = M_{CO_2} + M_{H_2O} + M_{O_2} + M_{N_2}$ ……………………………………….……….. (3.8)

e. Ambient conditions:-

Ambient Temperature (T_o) = 300 K.

Atmospheric pressure (P_o) = 0.1 MPa.

Exhaust Pressure (P_{ex}) = 0.105 MPa.

$\Delta T = 15 \sim 20$°C Assume ($\Delta T = 20$°C)

3.3.2 Intake stroke

a. Air density at the cylinder inlet

$\rho_o = P_o \times \frac{10^6}{\mathrm{R \times T_o}}$……………………………………………………… (3.9)

b. Air Pressure at the end of intake stroke

During intake stroke, a drop in pressure occurs through the manifold and valves holes. It could be found using the following relation.

$\Delta P_a = \left(\beta^2 + {\xi_{in}}^2\right) \times {w_{in}}^2 \times \frac{\rho_o}{2}$ ……………………………..…..... (3.10)

We will take $\left(\beta^2 + {\xi_{in}}^2\right) = 2.7$, and $w_{in} = 110\ \mathrm{m/s}$ form past experimental

c. Volumetric efficiency

$$\eta_v = \frac{T_o*(R_c \times P_a - P_r)}{P_a(T+\Delta T)(R_c-1)}$$ ………………………………...………….. (3.11) [1]

d. Coefficient of residual burned gas

$$\gamma_r = \frac{(T_o+\Delta T)}{T_r} \times \frac{P_r}{R_c \times P_a - P_r}$$ ……………………………...……….. (3.12) [1]

e. Temperature at the end of intake stroke

$$T_a = \frac{T_o+\Delta T+\gamma_r \times T_r}{1+\gamma_r}$$ …………………………………………….……...…. (3.13) [1]

3.3.3 Compression stroke

a. Pressure at the end of compression

$$P_c = P_a(R_c)^n$$ …………………………………………………….……...….. (3.14) [7]

Take polytropic coefficient (n) 1.35

b. Temperature at the end of compression

$$T_c = T_a(R_c)^{n-1}$$ ……………………...……………………………………….. (3.15) [7]

c. Mean molar heat capacity

$$(m\,C_v) = \frac{1}{M_2}\Big(\big(M_{CO_2} \times (m\,C_v)_{CO_2}\big) + \big(M_{H_2O} \times (m\,C_v)_{H_2O}\big) + \big(M_{O_2} \times (m\,C_v)_{O_2}\big) + \big(M_{N_2} \times (m\,C_v)_{N_2}\big)\Big)$$ ……………………………………… (3.16) [7]

The specific heat was determined from thermodynamic tables as a function of the temperature.

3.3.4 Combustion Stroke

a. Fuel mixing ratio

$$\mu_o = \frac{M_2}{M_1}$$ ……………………………………………………..……. (3.17) [1]

$$\mu = \frac{\mu_o \times \gamma_r}{1+\gamma_r}$$ The ratio of changing work body in diesel ……..............… (3.18) [1]

c. Heat of combustion

$$H_{mix} = \frac{H_u}{M_1(1+\gamma_r)} \quad \text{……………………………………..………...……. (3.19) [14]}$$

$$H_{mix} = (m\,C_v) \times T_z - (m\,C_v) \times T_c \quad \text{……………………..………..…. (3.20) [7]}$$

$$\lambda = \frac{T_z}{T_c} \quad \text{…………………………………………………….....……. (3.21)}$$

$P_z = P_c \times \lambda$ The increases of pressure cusses the combustion ……………… (3.22)

3.3.5 Expansion Stroke

a. Expansion coefficient

$$\delta = \frac{R_c}{\mu} \quad \text{…………………………………………………………...…. (3.23) [7]}$$

b. Pressure at the end of expansion

$$P_b = \frac{P_z}{\delta^n} \text{……………………………………………………….………. (3.24) [7]}$$

c. Temperature at the end of expansion

$$T_b = \frac{T_z}{\delta^{n-1}} \quad \text{…………………………………………………….………. (3.25) [10]}$$

$$T_r = \frac{T_b}{\sqrt[3]{\frac{P_b}{P_r}}} \text{…………………………………………………….........…. (3.26) [10]}$$

$$Error = \frac{T_{r_{act}} - T_{r_{assum}}}{T_{r_{act}}} \text{……………………….……………………………...... (3.27)}$$

3.3.6 Indicated parameters

a. Theoretical mean Indicted pressure

$$P_i{}' = \frac{P_c}{R_c - 1}\left(\lambda(\rho - 1) + \frac{\lambda \times \rho}{n-1}\left(1 - \frac{1}{\delta^{n-1}}\right) - \left(\frac{1}{\gamma - 1}\right)\left(1 - \frac{1}{Rc^{n1-1}}\right)\right) \text{……. (3.28)}$$

b. Mean indicated pressure considering the losses:-

$$P_i = P_i{}' \times \varphi \text{…………………………………………………………. (3.29) [6]}$$

c. Indicated efficiency:-

$$\eta_i = \frac{P_i \times l_o \times \alpha}{H_u \times \rho \times \eta_v} \text{ .... (3.30) [8]}$$

d. Indicated fuel consumption:-

$$g_i = \frac{3600}{H_u \times \eta_i} \text{ .... (3.31) [1]}$$

3.3.7 Effective parameters

a. Mechanical losses

$$P_m = P_i - 0.85 \times P_i \text{ .... (3.32) [4]}$$

b. Effective mean pressure

$$P_e = P_i - P_m \text{ .... (3.33) [8]}$$

c. Mechanical efficiency

$$\eta_m = \frac{P_e}{P_i} \text{ .... (3.34) [8]}$$

d. Effective efficiency

$$\eta_e = \eta_i \times \eta_m \text{ .... (3.35) [8]}$$

d. Effective fuel consumption

$$g_e = \frac{3600}{H_u \times \eta_e} \text{ .... (3.36) [1]}$$

3.3.8 Main parameters

a. Displacement

$$V_{liter} = \frac{60 \times \tau \times N_o}{P_e \times N} \text{ .... (3.37) [4]}$$

b. Displacement per cylinder

$$V_h = \frac{V_{liter}}{4} \text{ .... (3.38)}$$

c. Cylinder measurements

Cylinder bore and stork

$$D = S = 100 * \sqrt[3]{\frac{4*V_h}{\pi*1}} \quad (3.39)\ [8]$$

d. Mean piston velocity

$$V_{pm} = \frac{S \times N}{30 \times 10^3} \quad (3.40)$$

e. Piston cross section area

$$A_p = \frac{\pi D^2}{4} \quad (3.41)$$

f. Effective torque

$$M_e = 3 \times 10^4 \times \frac{N_e}{\pi N} \quad (3.42)$$

g. Total fuel consumption

$$G_f = N_e \times g_e \quad (3.43)$$

h. Volumetric power

$$N_{liter} = \frac{N_e}{V_{liter}} \quad (3.44)$$

3.4 adding the turbocharger

3.4.1 Pressure and temperature after the turbocharger:

$$T_{o2} = T_{o1} \times {R_{c_{turbo}}}^{n-1}\ K \quad (3.45)\ [13]$$

$$P_{o2} = P_{o1} * {R_{c_{turbo}}}^{n}\ MPa \quad (3.46)[13]$$

The thermodynamic calculations can be done by the equations above

3.5 Kinematics equations

3.5.1 The displacement of the piston

$S_x = \frac{S}{2} * ((1 - cos\theta) + \frac{\zeta}{4} * (1 - cos2\theta))$... (3.47) [21]

Where:-

S = the diameter of the crankshaft

ζ = Ratio between the crankshaft radius and the connecting rod length

θ = Crank angle

3.5.2 Piston velocity

$\omega = \frac{2*\pi*N}{60}$ ………………………………………………………….. (3.48) [13]

$V_x = \frac{S}{2} * \omega * ((1 - sin\theta) + \frac{\zeta}{4} * (1 - sin2\theta))$ ………………………… (3.49) [21]

3.5.3 Piston acceleration

$a_x = \frac{S}{2} * \omega^2 * ((1 - sin\theta) + \frac{\zeta}{4} * (1 - sin2\theta))$ ………………….…….. (3.50) [21]

3.6 Dynamic calculations

3.6.1 Inertia force

$F_1 = m * a_x$ ………………………………………………………….…… (3.51) [21]

Where:

$m = m_p + m_c$ …………………………………………………….….... (3.52) [21]

m_p = piston mass

m_c = connecting rod mass that have a liner velocity

3.6.2 Torque

$M = F_T * r$ ……………………………………………………...…… (3.53) [21]

Where:

M = torque

F_T = total force acting in crankshaft

r = the crank shaft radios

$F_T = F_g + F_1$ ……………………………………………………...…… (3.54) [21]

F_g = Gas force N

F_1 =Indicator force

All Kinematics equations was applied using MATLAB.

And the mass of the parts was determined by SOLIDWORKS.

3.7 Dimensional design of the engine:-

An already existed parameters in engines was used

3.7.1 Theoretical design piston:-

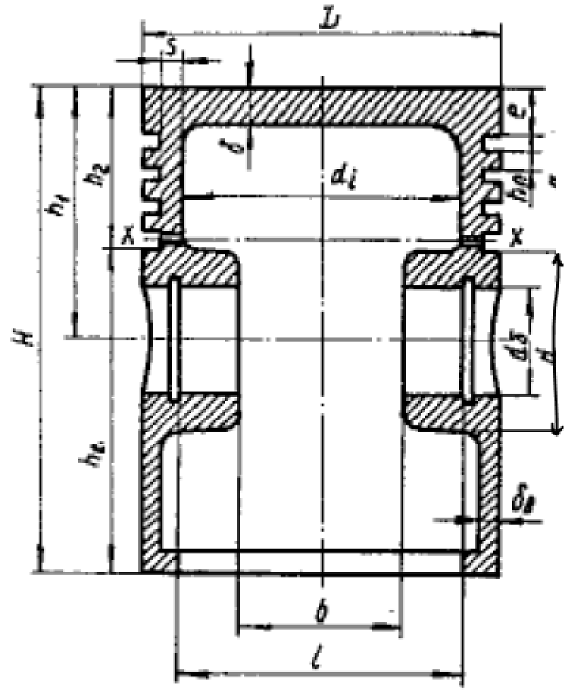

Figure (3.1): The main structural dimension of piston

a. Thickness of piston crown

$$T_c = \sqrt{\frac{3 \times Pz \times D^2}{16 \times \sigma_t}} \quad \text{……… (3.55) [9]}$$

b. Height of the piston

$H =$ (0.8~1.3) × D ……… (3.56) [8]

c. Distance from the front to the axis of piston pin

h_1 = (0.45~0.47) × D ……… (3.57) [8]

e. Size

$b =$ (0.3~0.5) × D ……… (3.58) [8]

f. Wall thickness of leading part

T_L=(1.5~4.5) ……………………………………………………..……… (3.59) [8]

g. Thickness of the sealing part

$s = (0.03 \sim 0.08) \times D$ …………………………..…………………… (3.60) [8]

h. Distance from the front to the first ring channel

$e = (0.06 \sim 0.12) \times D$ …………………………………………..…… (3.61) [8]

i. Wall thickness between channels

$h_n = (0.03 \sim 0.05) \times D$ ………………………............................. (3.62) [8]

j. Hole diameter of piston pin

$d_\delta = (0.22 \sim 0.28) \times D$ ………………………………………...…….. (3.63) [8]

k. Height of the leading part

$h_\delta = (0.6 \sim 0.8) \times D$ …………………………………………………….. (3.64) [8]

l. Inner diameter of the blot

$d_i = (0.65 \sim 0.75) \times d_\delta$ …………………………………………….… (3.65) [8]

m. Length of the bolt

$l = (0.88 \sim 0.93) \times D$ ………………………………………………….… (3.66) [8]

3.7.2 Theoretical Design connecting rod:

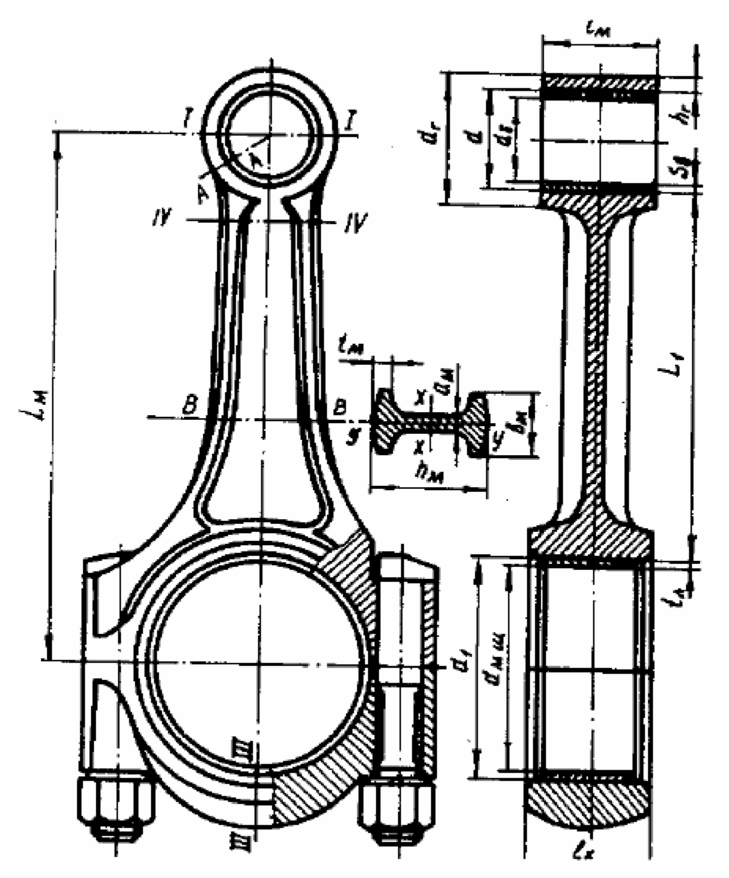

Figure (3.2): connecting rod

a. Length of the upper head of the rod

$l_m = (0.28 \sim 0.38) \times D$ ……………………………………………….... (3.67) [8]

b. Inner diameter of the upper head without sleeve

$d = d_\delta = 27$ mm ………………………………...……………...…… (3.68) [8]

c. Outer diameter of the upper head

$d_o = (1.25 \sim 1.65) \times d$ ……………………………...………………… (3.69) [8]

d. Minimal radial thickness of the upper head

$h_o = (0.16 \sim 0.27) \times d$ ………………………………..……...…...… (3.70) [8]

e. Minimal height of the profile

$h_{m_{min}} = (0.5\sim0.55) \times d$ ………………………………..………..... (3.71) [8]

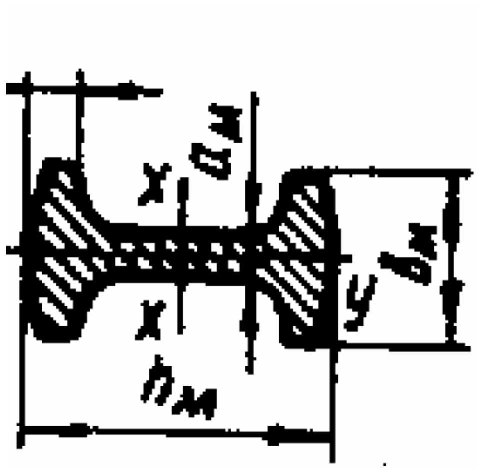

Figure (3.3): Cross-section of the connecting rod

$h_m = (1.2\sim1.4) \times h_{m.min}$ ..……………………………..…...……….. (3.72) [8]

$b_m = (0.5\sim0.6) \times l_m$…………………………………..…..……. (3.73) [8]

$a_m = (2.5\sim6)$ ……………………………………………………… (3.74) [8]

f. Diameter of connecting rod neck

$d_{mu} = (0.56\sim0.75) \times D$ …….………………………….……………..... (3.75) [8]

g. Thickness of the bearing shells

$t_{sh} = (0.03\sim0.05) \times \mathrm{d}_{mu}$ ………………………………….……..…. (3.76) [8]

h. Distance between connecting rod bolts

$C = (1.3\sim1.75) \times d_{mu}$ ….…………………………………………. (3.77) [8]

i. Length of the low head

$l_k = (0.45\sim0.65) \times d_{mu}$ ……………………………………..……… (3.78) [8]

j. Length of the connected rod

$L = \frac{D}{\delta}$ ……………………………………...………………….……... (3.79) [8]

3.7.3 Theoretical Design crankshaft:

a. Distance between the circles of the main journals

$l = (1.1 \sim 1.25) \times D$ …………………..………..………………… (3.80) [8]

b. Diameter of the main journal

$d_{ou} = (0.5 \sim 0.8) \times D$……………………………….……….…..... (3.81) [8]

c. Length of the main journal

$l_{ou} = (0.5 \sim 0.6) \times d_{ou}$ ……………………………..……….…..... (3.82) [8]

d. Diameter of the rod journal

$d_{mu} = 70$ mm

e. Length of the rod journal

$l_{mw} = (0.45 \sim 0.65) \times d_{mw}$ ……………………………………...… (3.83) [8]

f. Thickness of the crank

$h = (0.15 \sim 0.35) \times d_{mu}$ ……………………………………….…..... (3.84) [8]

g. Width if the crank

$b = (1.7 \sim 2.9) \times d_{mu}$ ……………………………...………………… (3.85) [8]

h. Radius of the rounded

$r = (0.06 \sim 0.1) \times d_{mw}$ ……………………………………………..… (3.86) [8]

3.7.4 Theoretical Design of engine block

3.7.4.1 Cylinders:

a. Allowable tensile stress for aluminum

Use aluminum as a material

$\sigma_{on} = 151.658$ MPa

With factor of safety of 2.25

$$\sigma_{on} = \frac{151.658}{2.25} = 67.4 \text{ MPa} \quad \text{(3.87) [8]}$$

b. The distance between the axis of two cylinders

Take $\frac{L_o}{D} = 1.3$

$$L_o = D \times 1.3 \quad \text{(3.88) [8]}$$

c. The minimum thickness of the cylinder

$$t_{c.min} = 0.5 \times \frac{p_z \times D}{\sigma_{on}} \quad \text{(3.89) [8]}$$

3.7.4.2 Cylinder head

a. Height of cylinder head

$$H_h = (0.95 \sim 1.2) \times D \quad \text{(3.90) [8]}$$

b. The thickness of the lower support wall

$$t_{hl} = 0.09 \times D + 2 \quad \text{(3.91) [8]}$$

c. Thickness of the cooler area of aluminum cylinder heads

$$t_{hc} = 0.03 \times D + 4.2 \quad \text{(3.92) [8]}$$

3.8 Cooling system

The need for a cooling system is to tackle the excess heat from the engine after adding the turbocharger

3.8.1 Cooling water considerations

The engine running stable at temperature between ($90 \sim 95$℃) and the difference between the hot water and the cool water in automobiles is in range of ($6 \sim 12$℃)

$$T_{w_m} = T_{lq_{out}} - \frac{\Delta T_{lq}}{2} \quad \text{(3.93) [3]}$$

3.8.2 Ambient air

Sudan climate was considered in the project.

3.8.3 Heat transfer calculations

$$Q_w = \frac{0.53 \times i \times D^{1+2m} \times N^m}{\alpha} \quad \text{......... (3.94)}$$

Where

D = Piston diameter

m = constant (0.6~0.7)

i = number of sylinders

The water flow rate of the water (the pump capacity)

$$\dot{m}_w = \frac{Q_w}{Cp_w \times \rho_w \times \Delta T_w} \quad \text{......... (3.95)}$$

3.8.4 Radiator calculations

a. Area of radiator

$$A = \frac{Q_w}{U\left[T_{w_m} - \left(T_{a_m} + \frac{\Delta T_a}{2}\right)\right]} \quad \text{......... (3.96)}$$

Where

U = Coefficient of heat transfer for automobile it's in range of
(140~180) kW/(m^2 K)

b. Fan calculation

1. Air flow rate

$$\dot{m}_a = \frac{Q_a}{\rho_a \times cp_a \times \Delta T_a} \quad \text{......... (3.97)}$$

Aerodynamic resistance is in range of (600~1000) Pa

Tack the fan efficiency = (0.32 ~ 0.65) %

2. The power need to run the fan

$$N_{fan} = \frac{\dot{m}_a \times \Delta P_{air\ risestance}}{\eta_{fan} \times 1000} \quad \text{......... (3.98)}$$

3. Fan area

$\omega_a = (6\sim24)\ \text{m/s}$

$$A_{fan} = \frac{\dot{m}_a}{\omega_a} \quad (3.99)$$

3. The diameter of the fan

$$D_{fan} = 2 \times \sqrt{\frac{A_{fan}}{\pi}} \quad (3.100)$$

4. Fan speed

$$u_{fan} = \Psi \times \sqrt{\frac{\Delta P_a}{\rho_a}} \quad (3.101)$$

$\Psi \equiv$ factor Depended on the shape of the fan (2.8~3.5)

The rotary speed of fan

$$n_f = \frac{60 \times u_{fan}}{\pi \times D_{fan}} \quad (3.102)$$