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Thermal Calculation for Converted CNG Engine (Radiator)

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Abstract: Natural gas has been considered as one of the most promising alternative fuel for Transportation due to its ability to reduce regulated pollutants, cost and as safe as other fuels like gasoline and diesel. This thesis expresses about cooling system of converted CNG engine. In converted CNG engine, the engine cooling system has been increased because a medium working temperature has been increased. Engine cooling system is closely related with overall performances of an engine, including reduction of fuel consumption, decrease of air pollution, and increase of engine life. Radiator is the heart of cooling system. Compact heat exchangers have been widely used in various applications in thermal fluid systems including automotive thermal management systems. Radiators for engine cooling systems, evaporators and condensers for heating ventilation and air conditioning (HVAC) systems, oil coolers, and intercoolers are typical examples of the compact heat exchangers that can be found in ground vehicle. Among the different types of heat exchangers for engine cooling applications, cross flow compact heat exchangers with flat tube and flat plate fins are of special interest because of their higher rejection rate capability with the lower flow resistance.

Keywords: Converted CNG Engine, Water Cooling system, Thermal calculation, Radiator, Fin

1. INTRODUCTION

Natural Gas Vehicle (NGVs) that operate on compressed natural gas (CNG) fuel expected to find widespread use from the standpoint of promoting global environment protection and effective utilization of energy resources. This is because NGVs can be effective in preventing air pollution and global warming and also in coping with the future depletion of oil resources.

The union of Myanmar is endowed with plenty of natural resources. Petroleum and natural gas are among the rich terrestrial and aquatic resources and there lie a large deposit of them inland a well a off-shore. At such a time like this, it is good news that there is an abundant reserve of natural gas and that CNG engines can be used in place of petrol and diesel engines. Myanmar possesses many natural gas fields.As Myanmar can produce enough gas for vehicles, the CNG substitution plan is in accord with the nation's requirements.

CNG as an alternative fuel in an engine could be divided into three main types; Dual Fuel (Diesel-CNG), Bi-Fuel (Gasoline-CNG) and Dedicated/Mono Fuel. In our country, the dedicated conversion system is more useful. In converted CNG engine, cooling system has been increased because a medium working temperature has been increased.

As shown in **figure (1)** the CNG fuelled operation generated higher coolant temperature for all engine speeds compared to that of gasoline engine. These results demonstrated that CNG generated higher heat load into the cooling system compared to that of gasoline for all engine speeds. The higher coolant temperature of the CNG occurred presumably due to the higher auto ignition temperature. The CNG has 630ºC of auto ignition temperature compared to that of gasoline in the value of 315.60ºC. At engine speed 1500 rpm, the coolant temperature for the CNG operation is 84.50ºC compared to the gasoline with 83.40ºC. The similar condition occurred at 3500 rpm of engine speed, coolant temperature for CNG operation can goes up until 90.50 ºC compared to that of gasoline at 89.10 ºC.

2. OVERVIEW OF COOLING SYSTEM

All internal combustion engines are equipped with some type of cooling system because of the high temperatures they generate during operation. Fuel burning engines produce enormous amounts of heat; temperatures can reach up to 4,000 degrees F when the air-fuel mixture burns. However, normal operating temperature is about 2,000 degrees F. The cooling system removes about one-third of the heat produced in the combustion chamber. The purpose of the engine's cooling system is to remove excess heat from the engine, to keep the engine operating at its most efficient temperature, and to get the engine up to the correct temperature as soon as possible after starting. Ideally, the cooling system keeps the engine running at its most efficient temperature no matter what the operating conditions are.

As fuel is burned in the engine, about one-third of the energy in the fuel is converted into power. Another third goes out the exhaust pipe unused, and the remaining third becomes heat energy. A cooling system of some kind is necessary in any internal combustion engine. If no cooling system were provided, parts would melt from the heat of the burning fuel, and the pistons would expand so much they could not move in the cylinders called seize.

On the other hand, if an engine runs at too low a temperature, it is inefficient, the oil gets dirty (adding wear and subtracting horsepower), deposits form, and fuel mileage is poor-- not to mention exhaust emissions! For these reasons, the cooling system is designed to stay out of the action until the engine is warmed up.

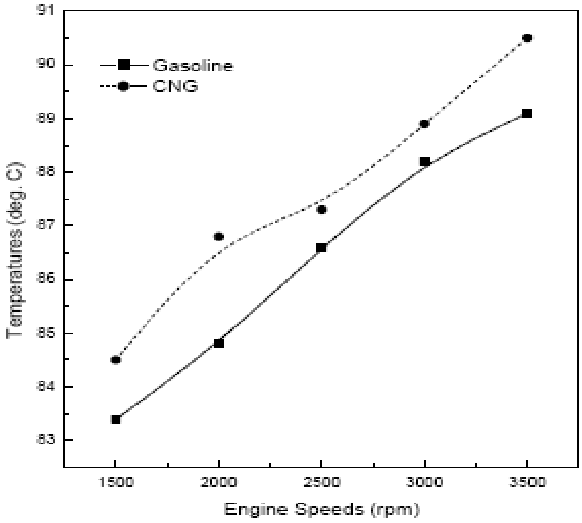

Fig (1) Cooling temperature profile for all speeds

2.1 Heat transfer

Heat transfer occurs when a temperature difference exists. As a result of combustion, high temperatures are produced, inside the engine cylinder. Considerable heat flow occurs from gases to the surrounding metal walls. However, the heat transfer on this account is quite small. Hence, the cylinder wall must be adequately cooled to maintain safe operating temperatures in order to maintain the quality of the lubricating oil.

Heat transfer from gases to the cylinder wall may occur predominantly by convection and radiation whereas the heat transfer through the cylinder wall occurs only by conduction. Heat is ultimately transferred to the cooling medium by all the three modes of heat transfer.

The cooling system works on the principle of heat transfer. Heat will always travel from a hotter to cooler object. Heat transfer is in three ways

1. Conduction
2. Convection
3. Radiation

2.2 Method of Heat Removal

When fuel is burned in an engine, a great deal amount of heat is produce. The rest of heat, the excess heat, must be removed to prevent engine damage from overheating. Excess heat is removed from engine in three ways.

1. Some heat leaves the cylinders with the hot exhaust gases. These are the burned and unburned gases that remain after combustion.
2. Some heat is removed by lubricating oil. After the hot oil drops down into the oil pan, the oil gives up some of its heat to the air passing under the oil pan.
3. The remaining heat is removed by the engine cooling system. This is about one-third of the heat produced in the combustion chambers by the burning fuel.

2.3 The Purpose of Cooling System

The cooling system keeps the engine at its most efficient temperature at all speeds and operation conditions. Burning fuel in the engine produces heat. Some of this heat is taken away before damages engine parts. This is one of the three jobs performed by the cooling system. It also helps bring the engine up to normal operating temperature as quickly as possible.

3. THERMAL CALCULATION

Thermal calculation of a spark ignition engine to be calculated in 2L Converted CNG engine is given bellow.

Initial data;

the rate power	$N_b = 70$ hp
the crankshaft speed	n = 4200 rpm
the number cylinder	i = 4
the compression ratio	ε = 10:1

Physical constant; composition of CNG –fuel

(By volume) CH_4=90.6

C_2H_6=5.4 %

C_3H_8=1.52 %

C_4H_{10}=1.6 %

C_5H_{12}=0.88 %

(By mass) C = 75%

H = 25%

Higher heating value H_H = 50 MJ/kg

Lower heating value H_L = 45 MJ/kg

3.1 Design Consideration

In internal combustion engines, the oxygen necessary for combustion is contained in the air introduced into the cylinder during admission. Since there is about 23 per cent oxygen in the air by mass and 21 per cent by volume, we obtain correspondingly the theoretical amount of required for the combustion of one kilogram of fuel.

The theoretical amount of air required for the combustion of one mole or one cubic meter of gaseous fuel.

$$a_{th} = \frac{1}{0.23}\left[\frac{8}{3}C + 8H - O_r\right] \quad (1)$$

$$A_{th} = \frac{1}{0.21}\sum\left(m + \frac{n}{4} - \frac{r}{2}\right) C_nH_mO_r \quad (2)$$

The number of moles of fresh mixture is determined by:

$$M_1 = 1 + \alpha A_{th} \quad (3)$$

The lack of oxygen causes some of carbon to burn to CO. The amount of individual components of the combustion products are determined by the following equations:

$$M_{CO_2} = \sum n\,(C_nH_mO_r) \quad (4)$$

$$M_2 = M_{CO_2} + M_{H_2O} + M_{O_2} + M_{N_2} \quad (5)$$

The theoretical coefficient of molar change is

$$\mu_{th} = \frac{M_2}{M_1}$$

$$\eta_v = \frac{\varepsilon P_a T_0}{(\varepsilon - 1)P_0(1+\gamma_{res})T_a} \quad (7)$$

There are two parameters we have to find for the compression. The first parameter is the pressure at the end of compression, P_c and the second parameter is the temperature at the end of compression, T_c.

$$P_c = P_a\,\varepsilon^{n_1} \quad (8)$$

$$T_c = T_a\,\varepsilon^{n_1 - 1} \quad (9)$$

3.2 Combustion Parameters

The actual coefficient of molar change, we use the following equation:

$$\mu_{act} = \frac{M_2 + \gamma_{res} M_1}{M_1(1+\gamma_{res})} \quad (10)$$

The maximum design pressure at the end of the combustion,

$$P_z = \mu_{act} \times \frac{T_z}{T_c} \times P_c \quad (11)$$

$$P_z' = 0.85\,P_z \quad (12)$$

For CNG engine, the pressure at the end of expansion, P_b is determined by the following equation:

$$P_e = \frac{P_z}{\varepsilon^{n_2}} \quad (13)$$

The temperature at the end of expansion can be calculated from the equation:

$$T_e = \frac{T_z}{\varepsilon^{n_2 - 1}} \quad (14)$$

4. RADIATOR

A radiator is a heat exchanger that removes heat from coolant passing through it, thereby maintaining the engine temperature. This is done by heat transfer from hot coolant coming from engine cooling jacket, flowing into the tubes via the Inlet tank. Heat rejected from coolant to the tube is transferred to the ram air (ambient) flowing over the fins.

The radiator is the most important element of the cooling system and has the critical function of reducing temperature of the passing coolant. The **"cooled"** coolant continues recirculating throughout the engine, removing heat waste. The coolant carrying the heat waste from the engine moves into the radiator core via the inlet hose.

In **Fig (3),** the automotive radiator has three main parts. These are a radiator core and inlet and outlet tanks. In the past, the entire radiator was made of copper. Now the cores are

usually made of aluminum while the tanks may be made of plastic or metal.

The radiator core has two sets of passage, a set of tubes and a set of fins attached to the tubes. The tubes run from the inlet tank to the outlet tank. Coolant flows through the tubes and air flows between the fins. Heat transfers from the hot coolant, through the tubes, to the fins. The outside air passing between the fins picks up and carries away the heat. This lowers the temperature of the coolant.

This process is called heat exchange in this cease, heat is exchanged from the coolant, to air, this is called a liquid to air heat exchanger, note that the coolant flows through the tubes and air flows through the air fins.

Radiators are classified by the direction in which the tubing is assembled in the core; two types of radiators are commonly used in the automobile.

- Down flow radiator
- Cross-flow radiator

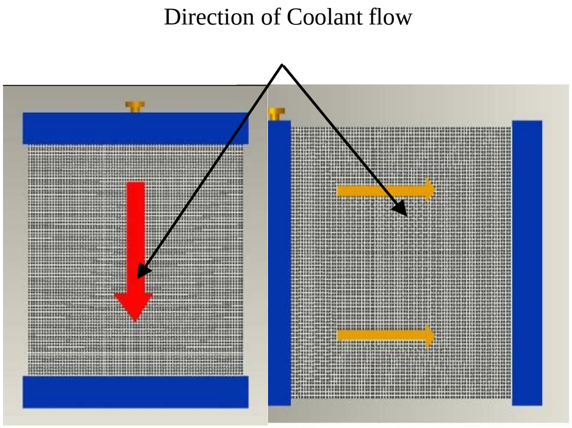

Fig (3) Down flow radiator and Cross flow radiator

4.1. Calculation of Heat Dissipation Surface of Radiator

Calculation of a radiator consists in determining the heat dissipation surface for the selected design of the radiator, as well as the velocities of the water and the air. It is assumed that all the heat rejected to the cooling system should be dissipated by the radiator surface.

4.1.1The amount of heat received by cooling water,

$$Q_w = \eta_w H_l G_f \quad \text{J/hr} \tag{15}$$

Where Q_w =Amount of heat received by cooling water, J/hr

H_l = Lower heating value of fuel, J/kg

ρ_w = Percentage of heat going to cooling water (Assume ρ_w= 25%)

G_f = Consumption of fuel, kg/hr.

The design amount of heat dissipated by the radiator surface,

To allow for reduction of the heat transfer coefficient a as result of clogging of the radiator face and of scale deposits on the internal surfaces of the tubes, and for deviations of the data used in the calculations from actual conditions, the design amount of the heat is increased by 10 percent, and

$$Q_{rad} = 1.1\, Q_w \tag{16}$$

Where Q_{rad} = the design amount of heat dissipated by the radiator surface

4.1.2 Flow rate of Cooling water

$$G_w = Q_w / (C_w \rho_w / \Delta T_w) \tag{17}$$

where, G_w= Volume flow rate of cooling water, m^3/sec

ΔT_w = drop in water temperature in the radiator,

= 6-12 K

C_w = specific heat capacity of water, 4187 J/kg.K

ρ_w =density of water, 1000 kg/m^3

4.1.3 Velocity of Coolant water

$$v_w = G_w / A = 1.5662 \text{ m/sec} \tag{18}$$

$$A = \frac{\pi}{4} D^2_{inw} = 0.000792 \text{ m}^2 \tag{19}$$

Where, D_{inw}= Water pump outlet diameter, (D_{inw}=1.25 in or 0.03175m)

V_w= velocity of coolant water, m/sec

4.1.4 Calculation of Hydraulic diameter of Cool side and Hot side

(i) Calculating the water stream hydraulic diameter of a tube

Wetted circumference a single tube is calculate by this equation,

$$P_{tw} = 2\pi(r_t - x_{twt}) + 2(x_{tw} - x_{tt}) \tag{20}$$

Where, P_{tw}= wetted circumference of a single tube

r_t= tube outer radius

x_{tw}=width of tube

x_{tt}=thickness of tube

x_{tw}t=tube wall thickness

Area of water cross section in tube,

$$A_{tcs} = \pi(r_t - x_{twt})^2 + (x_{tw} - x_{tt})(x_{tt} - 2x_{twt}) \tag{21}$$

=28.731mm^2

Hydraulic Diameter of Tube,

$$D_{hw} = \frac{4A_{tcs}}{P_{tw}} \tag{22}$$

=2.31 mm

(ii)Calculating the air stream hydraulic diameter of a tube

External Tube Surface Area,

$$A_{teu} = [2\pi r_t + 2(x_{tw} - x_{tt})]x_{fp} \tag{23}$$

= 156.85 mm^2

The unit fin surface area for four surface,

$$A_{feu} = 4(x_{ful})\sqrt{\left(\frac{x_{fp}}{2}\right)^2 + (x_{fw})^2} \quad (24)$$

$= 647.3\ \text{mm}^2$

The total area exposed to air stream is,

$$A_{au} = A_{teu} + A_{feu} \quad (25)$$

$=804.15\ \text{mm}^2$

Where, x_{fp} = Fin pitch

x_{ful}=Fin unit length

x_{fw}=Fin width of a unit cell

x_{tp}=tube pitch

The wetted Perimeter of external tube,

$$P_{aw} = x_{fp} + 2\sqrt{\left(\frac{x_{fp}}{2}\right)^2 + (x_{fw})^2} \quad (26)$$

$= 13.44$ mm

Unit Fin Cross section Area,

$$A_{acs} = \frac{x_{fp}}{2} \times x_{fw} = 7.5\ \text{mm}^2 \quad (27)$$

Hydraulic diameter of the air channel

$$D_{hz} = \frac{4A_{acs}}{P_{aw}} = 2.2324\ \text{mm} \quad (28)$$

4.1.5 Air temperature raise given by heat transfer

D_{fan}=0.4 m

$$A_{fan} = \frac{\pi}{4} D^2{}_{fan} = 0.126\ \text{m}^2 \quad (29)$$

$$m^{\bullet}{}_a = v_a \times A \times \rho_a = 1.8588\ \text{kg/sec} \quad (30)$$

$$\Delta T_a = \frac{Q_{rad}}{m_a{}^{\bullet} c_{pa}} = 27.75\ \text{K} \quad (31)$$

Where, D_{fan}= diameter of fan

m_a=mass flow rate of air

ΔT_a=air temperature raise

ρ_a=air density (at 35C)

c_{pa}=specific heat capacity of air (at 35C)

4.1.5 Calculate the overall heat transfer coefficient of radiator

In order to calculate the overall heat transfer coefficient, the thermal resistance concept is employed in this study. As illustrated in Fig., the heat is rejected from the coolant to the air through four major thermal resistances:

(a) Convection from the coolant to the inner surface of the tube

(b) Resistance by fluid impurities, rust formation, or other reactions between the fluid and the wall material, R_f (Fouling factor)

(c) Conduction through the tube wall

(d) Convection from the outer surface of the tube to the air via the fins.

Those thermal resistances are in series as shown in Fig.

$$U=\left(\frac{1}{h_w} + R_f + \frac{t_t}{k_t} + \frac{1}{\eta_o h_a}\right) \quad (32)$$

Where, U = overall heat transfer coefficient of radiator, W/m2 K

h_w = convection heat transfer coefficient for coolant side, W/m2 K

t_t = thickness of tube, m

k_t = thermal conductivity of tube, W/m K

h_a = convection heat transfer coefficient for air side, W/m2 K

η_0 = overall surface efficiency of the fins

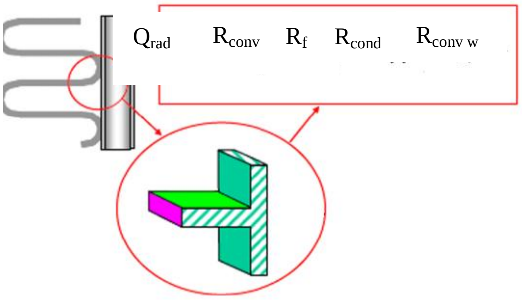

Fig (4) Thermal resistance of in series

(i)Convection Heat Transfer coefficient for the Coolant Side

The convection heat transfer coefficient for the coolant side (hw) is calculated using the following formula:

$$Nu_w = \frac{h_w D_h}{k_w}$$

Where, Nu_w = Nusselt number for coolant side

h_w = convective coefficient of water, W/ m2K

D_h = Hydraulic diameter of tube, m

V_w=velocity of water in tube, 0.7 m/sec (assume)

ρ_w=density of water ,1000 kg/m^3

(ii) Convection Heat Transfer Coefficient for Air side

The air side convective heat transfer coefficient is calculated by this equation,

$$Nu_a = \frac{h_a \times Dh_a}{K_a}$$

$$Nu_a = 0.664 \, \mathrm{Re}^{1/2} P_r^{1/3} \quad \text{(Pr>= 0.6)}$$

=24.72

h_a=297.8 W/m^2 K

(iii)Overall surface efficiency of fin

The overall surface efficiency of the fin

$$\eta_0 = 1 - \frac{A_{feu}}{A_{au}}\left(1 - \eta_f\right)$$

$$\eta_f = \frac{\tanh(mL)}{mL}$$

Fin length,

$$L = \sqrt{\left(\frac{x_{fp}}{2}\right)^2 + x_{fw}^2} = 5.22\text{mm}$$

$$m = \sqrt{\frac{2h_a}{Kt}} = 122.61$$

h_f = 0.8826 =88.26%

h_0 = 0.9055 =90.55%

R_f =fouling factor =0.000175 for engine jacket water

$U_{overall}$=

$$\left[\frac{1}{1564.85} + 0.000175 + \frac{0.4 \times 10^{-3}}{396.2} + \frac{1}{0.9055 \times 297.8}\right]^{-1}$$

=221.07 W/m^2 K

5. CONCLUSION

In this thesis, study on engine cooling system and design of radiator. Engine cooling system is closely related with overall performances of an engine, including reduction of fuel consumption, decrease of air pollution, and increase of engine life. Radiator is the heart of cooling system. Compact heat exchangers have been widely used in various applications in thermal fluid systems including automotive thermal management systems. So, radiator design is calculated by at maximum water temperature flow out from water pump.

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