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Cooling System Design for 1974cc Gray Cast Iron Alloy Engine

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Abstract: The cooling system is necessary in any internal combustion engine. If no cooling system is provided, parts would melt from the heat of burning fuel and the piston would expand so much they could not move in the burning. In this paper, the design engine is made of the cast iron alloy and it can be studied on engine water cooling system. The cast iron engine head can get over heat at high temperature because the thermal conductivity of cast iron is not good. So, the design engine head is necessary of increasing the cooling efficiency and it must be also needed to increase water tube and cooling fins more than original radiator. The rate of circulation of water coolant, is determined from the quantity of heat received by the cooling system. In the radiator design calculation, design amount of heat to the coolant, heat dissipation surface areas, radiator face area and radiator design selection are described.

Keywords: water flow rate, water velocity, water jacket length, heat dissipation surface, Auto CAD, Master cam

1. INTRODUCTION

When the engine rotates the coolant pump, an impeller is driven within the housing crating low pressure at its inlet, usually located at or closed to the center of impeller. When the cooling system pressure at the inlet to the coolant pump is at its lowest ,boiling will always occur at this location first. This will vary rapidly accelerate the overheating condition as the pump impeller will be acting on vapor. Coolant pumps are main reason that engine coolants should have some lubricating properties because they are vulnerable to abrasion damage when the coolant dissolved solids levels are high.[7]

2. CALCULATION OF WATER FLOW RATE AND WATER VELOCITY

The simplest and most familiar closed cooling system is used in the automobile field. In this system, the coolant circulates through the until it reaches the operating temperature at which point the thermostat at opens and coolant passes through the radiator carries away the excess heat, which prevents engine overheating. It is designed with force circulating of the water and with one or two regulation system controlling of the temperature of the water and the air.[2] To calculate the heat which is lost to the cooling system after first calculating the heat input, 35% of the available heat of the fuel is disposed to the cooling system [1].

Fuel consumption per hour is 13.06 kg / hr.

$Q_{cool} = 35\%\ Q_{total}$ (1)

$Q_{total} = C.V \times m^{\circ}_{f}$ (2)

The design amount of heat is increased by 10%.

$Q_{des} = 56.66$ kW

The rate of circulation of water is determined the quality of heat received by cooling system.

$v_w = Q_{des} / (C_w \times \Delta t_w \times \rho_w)$ (3)

where,

C_w = Specific heat of water = 4.19 kj/kg ˚C

Δt_w = Drop in water temperature in radiator ≥ 7 to 8 ˚C [3]

ρ_w = Density of coolant = 998 kg / m^3

V_ω = 7.214 m^3 / hr

The required water velocity is calculated from

$v_w = V_\omega / (A_{\omega j} \times n)$ (4)

v_w = water velocity, m/s

$A_{\omega j}$ = Area of water jacket inlet pipe, m^2

n = Number of cylinder

v_w = 2.8 m / s

2.1 Amount of water passed through the engine

The quality of water that must be circulated depend upon the initial temperature and the atmospheric conditions, either directly as in marine engine ,or indirectly if recooling system is used and the water is circulated over and over again. In order to avoid excessive heat stresses, the temperature different between the incoming and out going must not excess 20^{o}C in small and medium size engine and less down to 10^{o}C large engine. The heat rejected to the cooling medium through the cylinder walls and head, the piston and its ring when an engine is cooled by water can be found following equation 4[2].

$Q_{cool} = m^{\circ}_{w} \times C_w\ (t_{out} - t_{in})$ (5)

m°_{w} =Amount of water passed through the engine kg/s

C_w =Specific heat of water J/kg

t_{out} = Temperature of water flowing outlet of the engine ˚C

t_{in} = Temperature of water flowing into the engine ˚C

m°_{w} =1.8182 kg/s

The amount of heat rejected to the cooling system is circulated by using equation (5) and the result is shown figure (1) to (4).

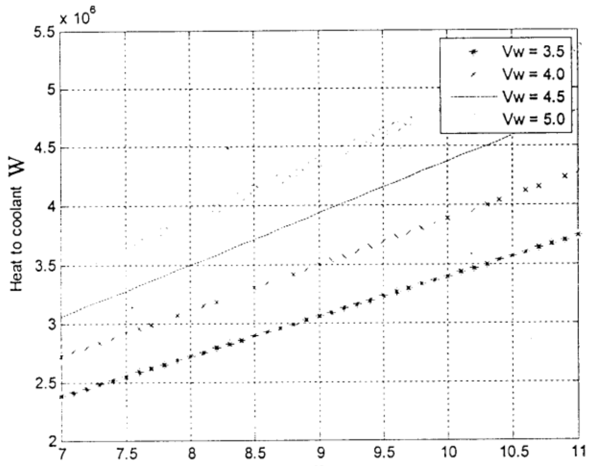

Figure 1.Amount of Heat Reject to The cooling System

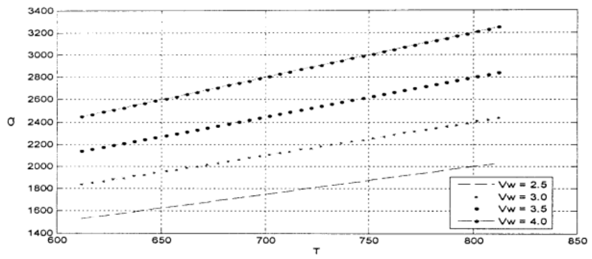

Figure 2.Heat Flux at the Exhaust Channel with Various Water velocity

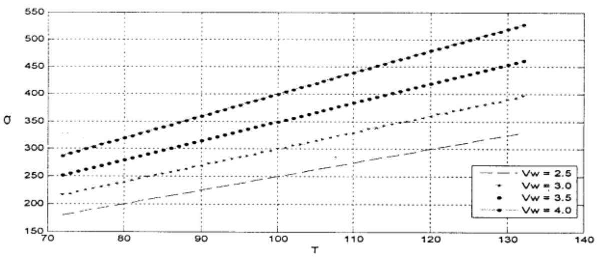

Figure 3.Heat Flux at the Cylinder wall near the Cylinder with Various Water velocity

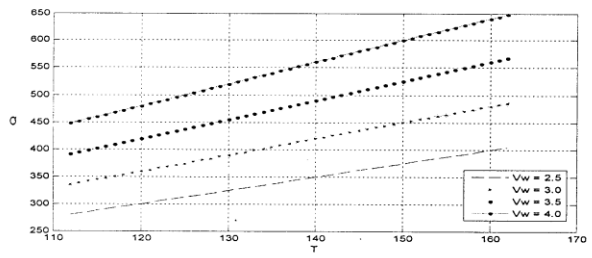

Figure 4.Heat Flux at the Cylinder Head with Various Water velocity

2.2 Determination of water jacket

An adequate cooling system must be designed to keep the engine at a temperature that lubrication is not destroyed. In this way, engine parts will not have been heated to such a degree that expansion has not caused clearances to be materially reduced. It is necessary that the water jacket to be sufficient size with an adequate supply of coolant.[10]The amount of heat absorbed by the engine head varies with the load form (11 to 19) % of the total head supplied with fuel.[4]

For one cylinder

$Q_H' = (11 \text{ to } 19) \text{ of } Q_t$ (6)

$Q_H' = 19\% \ Q_t$

For one cylinder,

$Q_H'' = 723\text{kW}$

The water jacket in most present day engine are cast as integral part of the cylinder block and cylinder head, and provide water passages around the cylinders and valves for the circulation of water. The water passages must allow an unrestricted flow of water around the cylinder and valves. As the coolant passes the hot metal part, some of the heat transfers to the lower temperature coolant. This cools the metal parts and heat the coolant. The circulation then carried the heat to the radiator. [8] The average length of the water jacket is determined by

$L_{wj} = Q_H''/[\alpha_1(T_{wc}-T_{coolant})\pi D_{wj}]$ (7)

α_1=The heat exchange between metal wall and water ,4340W/m^2 ˚C

T_{wc} = Engine head average wall temperature at the coolant side ˚C=190 ˚C

$T_{coolant}$ = Temperature of coolant ˚C

= 86 to 91

D_{wj} =Average diameter of water jacket

=15 mm

L_{wj} = 348.5 mm

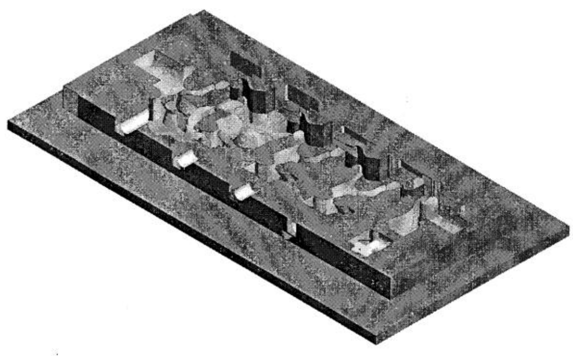

Figure 5. The pattern of water jacket for1974cc Gray Cast Iron Alloy Engine head

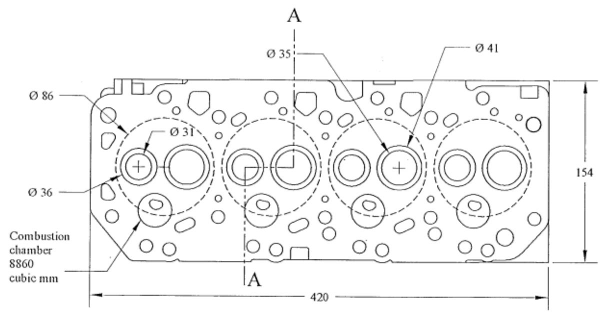

Figure 6. The lower view of 1974cc Gray Cast Iron Alloy Engine head

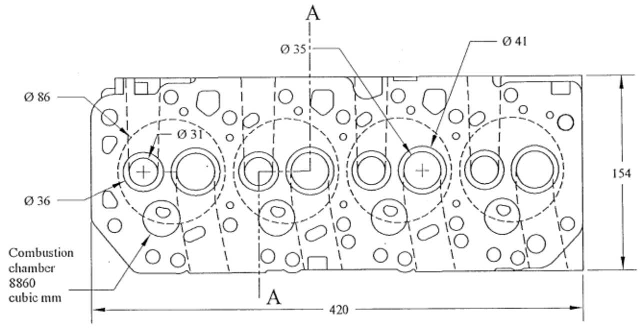

Figure 7. The lower view of1974cc Gray Cast Iron Alloy Engine head with the exhaust and Inlet Passage

3. RADIATOR DESIGN

In the radiator design calculation, design amount of heat to the coolant, heat dissipation surface area, radiator face area and radiator design selection are described. It is assumed that all of the heat rejected to the cooling system should be dissipated by radiator surface.

The amount heat for an engine operation at rotated power is Q_{des} = 58.66kW.

The relation between the design amount of heat Q_{rad} and the heat dissipation surface A_t of the radiator is,

$Q_{rad} = C_h \times \Delta t_{wa} \times A_t$

where,

A_t = Heat dissipation surface

C_h = Heat transfer coefficient

$$C_h = \frac{1}{\frac{\varepsilon}{\alpha_1} + \frac{\varepsilon \times \delta}{\lambda} + \frac{1}{\alpha_2}} \quad (8)$$

α_1 = Heat transfer coefficient from the coolant to the metal of the tube = 4340 W/m^2 ˚C

α_2= Heat transfer coefficient from the wall of the tube to the air = 100 W/ m^2 ˚C

$\boldsymbol{\lambda}$ = Heat conductivity coefficient for copper
= 330 W/ m^2 ˚C [5]

δ = Thickness of the tube wall
= 0.13 to 0.2 mm [7]
= 0.165 mm

ε = Fining coefficient
= 7.5 to 10
=(7.5+10)/2= 8.75

Δt_{wa} = Temperature drop between the mean temperature of the cooling water and air passing through the radiator

$t_{wm} = (t_{w,out} - t_{w,in})/2$ = 86 to 91˚C

$t_{am} = (t_{a,out} - t_{a,in})/2$

Δt_a =20 to 30 ˚C [8]

$t_{am,b}$ = 15˚C = 288K

$t_{a,in} = t_{am,b} + \Delta t_f$

Δt_f = Amount by which the air is heated when pass through the shutter or the face of the oil cooler installed before the cooling system radiator = 3 to 5 ˚C

$t_{a,in}$ = 15+4=19˚C

$t_{a,out} = t_{a,in} + \Delta t_a/2$ = 31.5 ˚C

t_{am} =25.25 ˚C

$\Delta t_{wa} = t_{wm} - t_{am}$= 63.25 ˚C

By substituting in equation (8)

C_h = Heat transfer coefficient = 85.26W/m^{2}C

By substituting in Q_{rad} equation,

A_t = Heat dissipation surface
=10.87m^2

3.1 Radiator Face Area

It is important that temperature variation of the coolant be maintained within closed limits. This is a heat exchanger with two sets of passages. One set is for coolant and the other for outside air. This arrangement allows the radiator to remove heat from the engine coolant by passing through radiator to remove from the engine. The heat transfers from the hot coolant to the cooler outside air that also pass through the radiator.[9] The another formula of heat dissipated surface is

$$A_t = A_f \times l_{rad} \times \phi_{rad} \quad (9)$$

where

A_f = Face area of the radiator, m^2

l_{rad} = radiator depth m = 44mm

ϕ_{rad} = Volumetric coefficient of compactness
= 1100/m

By substituting in equation (9)

A_f = 0.22458 m^2 = radiator width × radiator height

In modern tubular constructions, appearance and provided by the ornamental grille which is now universal in passenger vehicles, and the radiator block can be designed simply as an efficient heat exchanger of the lightest possible weight. The cooling element consists of a nest of copper tubes soldered into brass upper and lower tube plates which are bolted to the top and bottom tanks. This construction is inexpensive and makes for accessibility and ease of repair.[9]

Choose Radiator width, W_R = 550 mm

Radiator width, H_R = 407mm

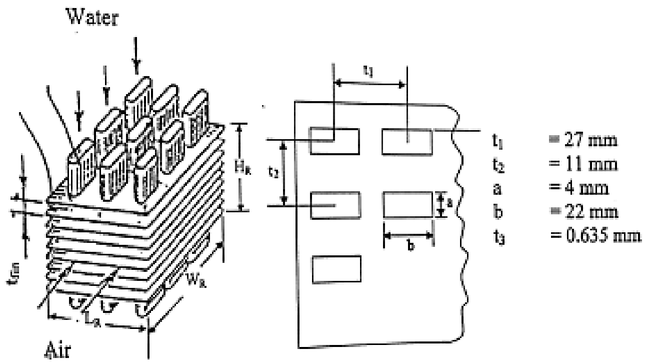

Figure 1. Basic dimensions of radiator

Number of tube row=3

NT=Number of tube in transverse plane,
=Width of radiator /tube pitch in transverse plane
=21

Total Number of Tube =N T x Number of row
= 63

Also heat dissipated surface is determined

$$A_t = 2nf\,(A_{fi} - A_t \times N_t) + N_t P_t (L_f - n_f t_3) \quad (10)$$

where,

A_{fi} = Fin area
A_t = Tube Area
P_t = Tube parameter
t_3 = Fin thickness
n_f = Number of fin
= 195

$$\text{Number of Fin}, n_f = \frac{\text{Height of radiator}}{\text{fin pitch}} \quad (11)$$

=2

Table 1. Result Table of Cooling system Design

Item	Design Data
The amount of heat introduced into the engine with fuel, (Q_{total})	152.36 kW
Amount of heat rejected to the cooling system	53.32kW
The water pump capacity V_W	$2.004 \times 10^{-3} m^3/s$
The velocity of water in the pump, v_w	2.8m/s
Amount of heat to the coolant (Q_w)	58.66kW
Heat dissipation area (A_t)	$10.87 m^2$
Radiator Face area (A_f)	$0.22458 m^2$
Width, (W_R)	550mm
Length, (L_R)	44mm
Height, (H_R)	407mm
Number of row	3
Number of table, N_1	21×3 = 63
Number of fin, n	195
Tube shape, (a×b)	In line, rectangular $(22 \times 4) mm^2$
Fin thickness, t_3'	0.635mm
Fin Pitch, t_3	2mm

3.2 Increment of Heat rate by designed radiator

Heat dissipation surface area of the original radiator

$$A_t' = A_f' \times l_{rad}' \times \phi_{rad} \quad (12)$$

$= 7.55\ m^2$

A_t'=original heat dissipated area of radiator of original engine,m^2

A_f'= original face area of radiator, m^2

ϕ_{rad} = original volumetric coefficient of compactness

The amount of heat disorient by the cooling system can be calculated,

$$Q_{des}' = A_t' \times C_h \times \Delta t_a \quad (13)$$

Q_{des}' = amount of heat absorbed by the original cooling system,,kW

C_h = Heat transfer coefficient

= 40.71 kW

Percentage increased by the design radiator,

% increased = $(Q_{rad} - Q_{rad}')/ Q_{rad}'$

= 44%

The amount of heat transfer by the water is circulated from

$$Q_{water} = \alpha_1 \times A \times \Delta T \quad (14)$$

where,

ΔT = Temperature difference of the water at the radiator outlet and inlet = 7˚C

α_1 =Heat transfer coefficient from the metal to the coolant
$=4340 W/m^{2}{}^\circ C$

A =Total coolant passing area through the tube
$= P_t \times N_T \times H_R$
$= 1.339 m^2$

By substituting in equation (14)

Q_{water} = 40.51Kw

3.3 Removal Amount of Heat to the Water and air

The warm water leaved the engine and passed through the radiator tube. The heat of warm water is transferred to the surrounding while it passed along the tube. At the same time, the fan gives cooling air to the radiator. So that engine heat transfer is due to the air and water to the cooling system .The amount of heat transfer by the water is 40.51 kW. Total heat removed amount by the cooling system is 58.66 kW.

Foe the design cooling system

Percentage amount of water removed = 70%

Percentage amount of air removed = 30%.

4. CONCLUSION

In this paper, the design engine is made of gray cast iron alloy and it can be studied on the engine cooling system. In closed type water cooling system the water is running through the passage in the engine (it absorbs the heat from the engine parts) and when it passes through the radiator, it cools. After getting cool again in the radiator, the water comes back through the engine. Therefore, this continues as long as the engine running, with the water absorbing and removing the engine heat and radiator cooling the water.

Cooling system efficiency is usually rated by the different in temperature between the water and surrounding air. Heat transfer analysis to the engine head with various water velocity, water flow rate, water jacket average length and radiator of cooling system for 1974cc gray cast engine head were calculated. In the radiator design, engine heat transfer is due to the air and water of the cooling system. The design water velocity is 2.8m/s. The limit of water velocity is 2.5 to 3 m/s for diesel engine [8].

The original radiator used in aluminum engine head can be released the amount of heat about 30.28 kW but the design radiator is rejected heat about 53.32 kW. In this paper ,the radiator size is changed and then the depth of radiator is increased from 4 mm, the width of radiator increased from 30mm and the height of radiator is increased from 75mm.The radiator size can be large about 75% and the amount of heat removed is increased to 44%. Today the percentage of the removed heat by the water is between 70% to 75%.

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