OPEN ACCESS

International
Journal
Of Modern Engineering Research (IJMER)

Design of Cooling Package of Diesel Genset

AnilkumarSathe[1], Amritkar Swapnil Bapu[2], Mahajan Pratik Balu[3], Urjeet Singh Pawar[4]

[1,2,3,4] *Mechanical Department, Smt. KashibaiNavale College of Engineering, Pune University, India*

Abstract: *Traditional cooling systems have relied on a mechanical coolant pump and an engine mounted radiator fan driven off the engine's crankshaft. The compactness of the system often turned out to be a problem when the generator set and radiator were to be placed separately. The dependence of the pump and fan operations on the engine speed in such cases often leads to a decrease in the overall efficiency. The replacement of traditional mechanical cooling system components with a better and efficient system of components can improve the efficiency of the Generator Set. In this paper a cooling system has been designed so that maximum cooling can be brought about in cases when the radiators are to be placed on tall building terraces.*

I. Introduction

With the power requirement rising steadily the need to have an on-site electricity generation system is also catching pace. Thus the Diesel Generator set becomes an important aspect in almost all type of Industries, Housing Complexes, Shopping Malls etc. On-site electricity generation systems can be classified by type and generating equipment rating. The generating equipment is rated using standby, prime and continuous ratings. The type of on-site generation system and appropriate rating to use is based on application shown in Table I

Table I. Rating and System Types

	Generator Set rating		
	Standby	Prime	Continuous
System Type	Emergency	Prime Power	Base Load
	Legally required	Peak Shaving	Co-Gen
	Optional standby	Rate Curtailment	

Remote radiator systems are often used when sufficient ventilation air for a skid–mounting cooling system cannot be provided in an application. Remote radiators do not eliminate the need for generator set room ventilation, but they will reduce it. If a remote radiator cooling system is required, the first step is to determine what type of remote system is required. This will be determined by calculate on of the static and friction head that will be applied to the engine based on its physical location.

If calculations reveal that the generator set chosen for the application can be plumbed to a remote radiator without exceeding its static and friction head limitations, a simple remote radiator system can be used.

If the friction head is exceeded, but static head is not, a remote radiator system with auxiliary coolant pump can be used.

If both the static and friction head limitations of the engine are exceeded, an isolated cooling system is needed for the generator set. This might include a remote radiator with hot well, or a liquid– to–liquid heat exchanger–based system.

Whichever system is used, application of a remote radiator to cool the engine requires careful design. In general, all the recommendations for skid mounted radiators also apply to remote radiators. For any type of remote radiator system, consider the following:

It is recommended that the radiator and fan be sized on the basis of a maximum radiator top tank temperature of 200 °F(93 °C) and a 115 % cooling capacity to allow for fouling. The lower top tank temperature (lower than described in Engine Cooling) compensates for the heat loss from the engine outlet to the remote radiator top tank.

The radiator top tank or an auxiliary tank must be located at the highest point in the cooling system. It must be equipped with: an appropriate fill/pressure cap, a system fill line to the lowest point in the system (so that the system can be filled from the bottom up), and a vent line from the engine that does not have any dips or traps. (Dips and overhead loops can collect coolant and prevent air from venting when the system is being filled.) The means for filling the system must also be located at the highest point in the system, and a low coolant level alarm switch must be located there.

The capacity of the radiator top tank or auxiliary tank must be equivalent to at least 17 % of the total volume of coolant in the system to provide a coolant "drawdown capacity" (11 %) and space for thermal expansion (6 %). Drawdown capacity is the volume of coolant that can be lost by slow, undetected leaks and the normal relieving of the pressure cap before air is drawn into the coolant pump. Space for thermal expansion is created by the fill neck when a cold system is being filled.

To reduce radiator fin fouling, radiators that have a more open fin spacing (nine fins or less per inch) should be considered for dirty environments.

Coolant friction head external to the engine (pressure loss due to pipe, fitting, and radiator friction) and coolant static head (height of liquid column measured from crankshaft center line) must not exceed the maximum values recommended by the engine manufacturer. If a system configuration cannot be found that allows the engine to operate within static and friction head limitations, another cooling system type should be used.

NOTE: Excessive coolant static head (pressure) can cause the coolant pump shaft seal to leak. Excessive coolant friction head (pressure loss) will result in insufficient engine cooling.

Radiator hose 6 to 18 inches (152 to 457 mm) long, complying with SAE 20R1, or an equivalent standard, should be used to connect coolant piping to the engine to take up generator set movement and vibration.

It is highly recommended that the radiator hoses be clamped with two premium grade "constant–torque" hose clamps at each end to reduce the risk of sudden loss of engine coolant due to a hose slipping off under pressure. Major damage can occur to an engine if it is run without coolant in the block for just a few seconds. A drain valve should be located at the lowest part of the system.

Ball or gate valves (globe valves are too restrictive) are recommended for isolating the engine so that the entire system does not have to be drained to service the engine.

Remember that the generator set must electrically drive remote radiator fan, ventilating fans, coolant pumps, and other accessories required for operation in remote cooling applications. So, the kW capacity gained by not driving a mechanical fan is generally consumed by the addition of electrical devices necessary in the remote cooling system. Remember to add these electrical loads to the total load requirement for the generator set.

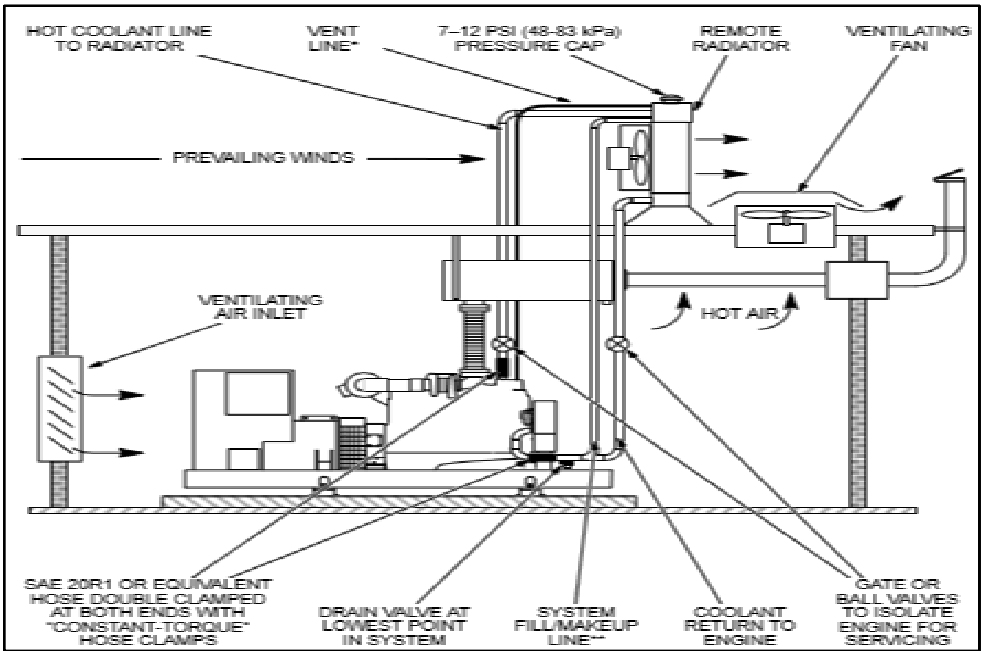

Figure I. Remote Radiator

I.1 Remote Radiator with Auxiliary Coolant Pump

A remote radiator with an auxiliary coolant pump can be used if coolant friction exceeds the engine manufacturer's maximum commended value, and static head is within specifications. In addition to the considerations under Remote Radiators, consider the following:

An auxiliary pump and motor must be sized for the coolant flow recommended by the engine manufacturer and develop enough pressure to overcome the excess coolant friction head.

A bypass gate valve (globe valves are too restrictive) must be plumbed in parallel with the auxiliary pump, for the following reasons:

To allow adjustment of the head developed by the auxiliary pump (the valve is adjusted to a partially–open position to recirculate some of the flow back through the pump).

To allow operation of the generator set under partial load if the auxiliary pump fails (the valve is adjusted to a fully open position).

Coolant pressure at the inlet to the engine coolant pump, measured while the engine is running at rated speed, must not exceed the maximum allowable static head shown on the recommended generator set Specification Sheet. Also, for de-aeration type cooling systems (230/200 kW and larger generator sets), auxiliary pump head must not force coolant through the make–up line into the radiator top tank or auxiliary tank. In either case, the pump bypass valve must be adjusted to reduce pump head to an acceptable level.

Since the engine of the generator set does not have to mechanically drive a radiator fan, there may be additional kW capacity on the output of the generator set. To obtain the net power available from the generator set, add the fan load indicated on the generator set Specification Sheet to the power rating of the set. Remember that the generator set must electrically drive the remote radiator fan, ventilating fans, coolant pumps, and other accessories required for the set to run for remote radiator applications. So, the kW capacity gained by not driving a mechanical fan is generally consumed by the addition of electrical devices necessary in the remote cooling system.

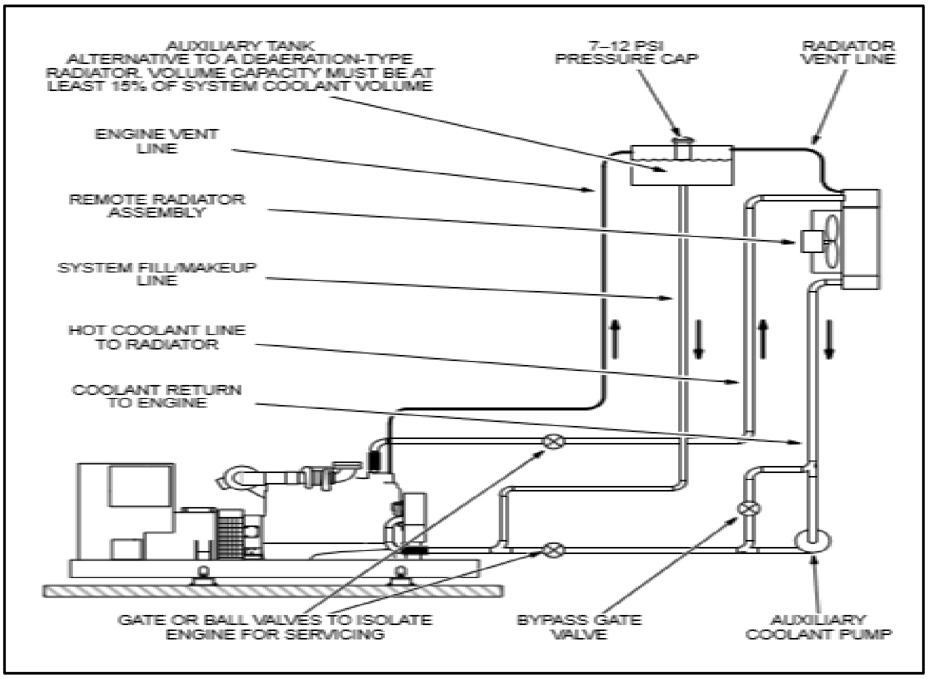

Figure II. Remote Radiator with Auxiliary Pump

I.2 Remote Radiator with Hot Well

A remote radiator with a hot wellcan be used if the elevation of the radiator abovethe crankshaft centerline exceeds the allowablecoolant static head on the recommended generator set Specification Sheet. In a hot well system, the engine coolant pump circulates coolantbetween engine and hot well and an auxiliarypump circulates coolant between hot well andradiator. A hot well system requires carefuldesign.
In addition to the considerations under RemoteRadiator, consider the following:

The liquid holding capacity of the hot wellshould not be less than the sum of the following volumes:
¼ of the coolant volume pumped per minute through the engine (e.g., 25 gallons if the flow is 100 gpm) (100 liters ifthe flow is 400 l/min), plus¼ of the coolant volume pumped per minute through the radiator (e.g., 25 gallons if the flow is 100 gpm) (100 liters ifthe flow is 400 l/min), plus
Volume required to fill the radiator andpiping, plus 5 percent of total system volume for thermal expansion.

Careful design of the inlet and outlet connections and baffles is required to minimize coolant turbulence, allow free deaeration and maximize blending of engine and radiator coolant flows. Coolant must be pumped to the bottom tankof the radiator and returned from the top tank, otherwise the pump will not be able to completely fill the radiator.

The auxiliary pump must be lower than thelow level of coolant in the hot well so that it will always be primed. The radiator should have a vacuum relief check valve to allow drain down to the hot well. The hot well should have a high volume breather cap to allow the coolant level to fall as the auxiliary pump fills the radiator and piping. The bottom of the hot well should be above the engine coolant outlet.

Coolant flow through the hot well/radiator circuit should be approximately the same ascoolant flow through the engine. The radiatorand the auxiliary pump must be sized accordingly. Pump head must be sufficient to overcome the sum of the static and friction heads in the hot well/radiator circuit.

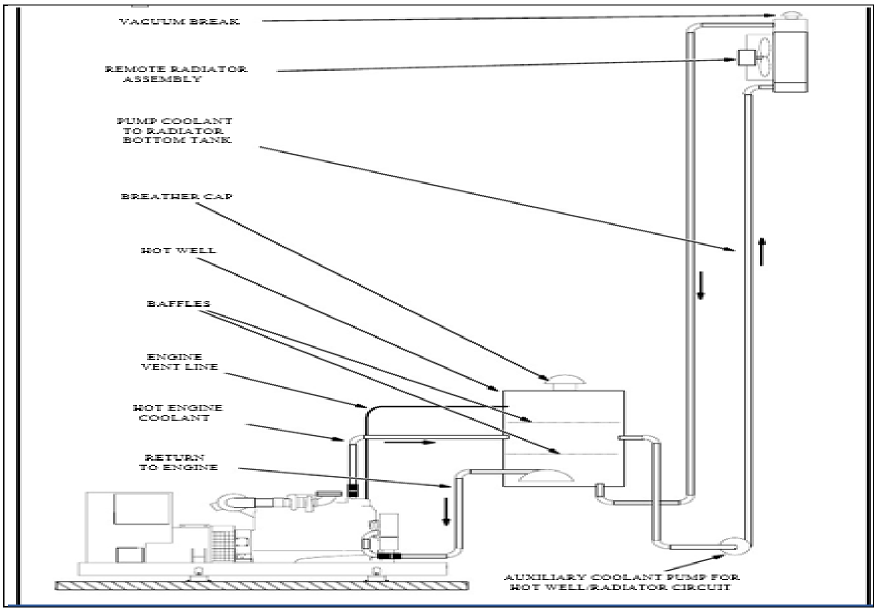

Figure III. Remote Radiator with Hot Well and Auxiliary Pump

II. Design Procedure

The design procedure for radiator and pump in case of all the three types of remote radiators is same but in case of remote radiator with hot well the liquid to liquid plate heat exchanger has to designed.
Its procedure is as mentioned below:

2.1 Design of Heat Exchanger (Plate Heat Exchanger)

Temperature at the inlet (hot side) = T_1 K
Temperature at the outlet (hot side) = T_2 K
Temperature at the inlet (cold side) = T_3 K
Temperature at the outlet (cold side) = T_4 K
Knowing the heat duty(Q) we can calculate the mass flow rate;
(1)$Q = \dot{m}\, Cp\, \Delta T$
Converting mass flow rate into volumetric flow rate we get,
(2)Volumetric flow rate = $\dot{m}/\rho \times 3600$
Using LMTD (LOG MEAN TEMPERATURE DIFFERENCE METHOD) method;
(3)LMTD = $(\Delta T_1 - \Delta T_2)/ \ln(\Delta T_{1/} \Delta T_2)$
Finding the overall Heat transfer Co-efficient;
(4) $\frac{1}{U} = \frac{1}{\alpha 1} + \frac{1}{\alpha 2} + \frac{\delta}{\lambda} + \mathrm{Rf}$
Now calculating the required area by using the equation;
(5)Q = UA (LMTD)
Calculating $\Delta T_{m;}$
(6)Effective plate area is given by = L × W
Calculating no. of plates required;
(7)No. of plates = Total area/ Effective area

2.2 Design of Radiator

(8) Total Heat rejected to radiator = heat rejected to engine jacket radiator

Calculating heat dissipated in radiator making allowance for dirtying process in radiator surface

(9)Q_{water} = 1.1 × Heat rejection to engine jacket radiator

Also,

(10)$Q_{water} = Q_{air}$

Calculating the temp of incoming water and air with the help of thermostat valve

Calculating the temp of outgoing fluid with help of effectiveness of heat exchanger:

For design of radiator;

Effectiveness (ϵ) is 60 % (Design Data Book)

(11)$\epsilon = \frac{(Th1 - Th2)}{(Th1 - Tc1)}$

Finding Volumetric air flow through radiator core;

(12)$V_{air} = Q_{air} / (C_{air} \times \rho_{air} \times \Delta T_{air})$

Similarly,

Volumetric water flow through radiator core;

(13)$V_{water} = Q_{water} / (C_{water} \times \rho_{water} \times \Delta T_{water})$

Finding mean water and air temperature in radiator;

(14)$T_{water\_m} = T_{h1} - (\Delta T_{water}/2)$

(15)$T_{air\_m} = T_{c1} + (\Delta T_{air}/2)$

Required radiator surface area;

(16)$F_{rad} = 10^3 \times Q_{water} / (U_{water} \times (T_{water\_m} - T_{air\_m}))$

Design of Radiator fan:

The major factors to be considered in the design of fan include static pressure rise P_{air} (Pa) and volumetric air flow rate V_{air}(m^3/s)

Fan tip speed is given by;

(17)$u = \psi_{air} \times \sqrt{(P_{air} / \rho_{air})}$

Where,

ψ_{air}= 2.2 to 2.9 for curved blades

2.8 to 3.5 for straight blades

P_{air} = 600 to 1450 Pa Depending on application

ρ_{air}= 1.127 kg/m^3

(18)$u = 2.8\sqrt{(600/1.127)}$

Determining Fan diameter:

Volumetric efficiency of fan is given by;

(19)$\eta_v = (60 \times u) / (\pi \times D_v)$

Now,

(20)$D_v = 1.3\sqrt{(V_{air}/\nu_{air})}$

Frontal surface area of radiator core;

(21)$F_{fr} = V_{air} / \nu_{air}$

Length of radiator;

(22)$L_{rad} = F_{rad} / (F_{fr} \times \phi)$

Where,

Φ = Ranging from 0.6 to 1.8 mm^{-1}

Assuming the volumetric factor (Φ) to be 0.6 mm^{-1}

Cross sectional area of tubes

(23)L_{rad} = (minimum number of tubes used) × (space between two tubes) + c/s area of each tube

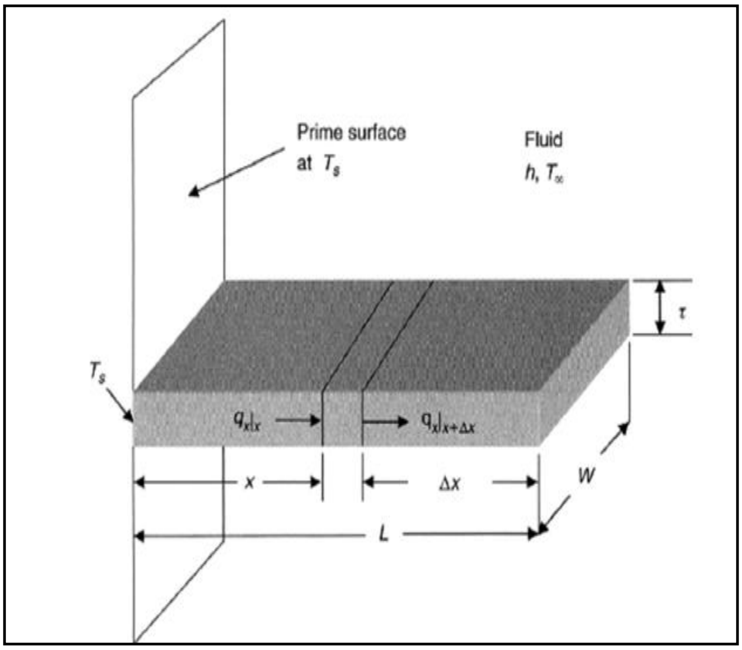

Figure IV. Fin Dimensions

Design of Fin:
Fins with finite length,
Where,
Space between two tube = length of the fin
Width of the tube = (major axis of the tube + thickness of tube)
Thickness of the fin = (assume)
Height of the radiator = as per space availability
Fins used in one tube = (2500/2) = 1250
Number of tubes = (assume)
Therefore,
(24)n = Fins used in one tube * Number of tubes
Ta = atmospheric temperature
(25)One end of fin is in contact with atmosphere and other with the tubes so temperature difference= (T – Ta)
Now we know the equation;

$$(26)m = \sqrt{\frac{(h \times Pf)}{(k \times acs)}}$$

Efficiency of fins;

$$(27)\eta = \frac{tanh(mLf)}{mLf}$$

2.3 Design of Pump

To calculate the pump requirements for the present generator set, we first need to calculate the head losses and the flow rate which are the basic parameters to decide the rating of the pump.
(28)$Q = \dot{m}\, C_{p\,\Delta}T$
Converting mass flow rate into volumetric flow rate:
(29)Volumetric flow rate = $\dot{m}/\rho \times 3600$
Calculating velocity:
(30)$Q = A\, \square_{\mathbf{water}}$
Calculating the frictional head due the piping using the Darcy weisbach equation
(31)$h_f = fL_{eq} x\, \square_{\mathbf{water}}{}^2/2gd_p$
To calculate this we need the equivalent length of pipes in all the section of the flow arrangement.
To calculate the equivalent length we have a standard chart;

Table II. Equivalent Lengths of Pipe Fittings and Valves in Feet

TYPE OF FITTING	NOMINAL INCH (MILLIMETER) PIPE SIZE										
	1/2 (15)	3/4 (20)	1 (25)	1–1/4 (32)	1–1/2 (40)	2 (50)	2–1/2 (65)	3 (80)	4 (100)	5 (125)	6 (150)
90° Std. Elbow or Run of Tee Reduced ½	1.7 (0.5)	2.1 (0.6)	2.6 (0.8)	3.5 (1.1)	4.1 (1.2)	5.2 (1.6)	6.2 (1.9)	7.7 (2.3)	10 (3.0)	13 (4.0)	15 (4.6)
90° Long Sweep Elbow or Straight Run Tee	1.1 (0.3)	1.4 (0.4)	1.8 (0.5)	2.3 (0.7)	2.7 (0.8)	3.5 (1.1)	4.2 (1.3)	5.2 (1.6)	6.8 (2.1)	8.5 (2.6)	10 (3.0)
45° Elbow	0.8 (0.2)	1.0 (0.3)	1.2 (0.4)	1.6 (0.5)	1.9 (0.6)	2.4 (0.7)	2.9 (0.9)	3.6 (1.1)	4.7 (1.4)	5.9 (1.8)	7.1 (2.2)
Close Return Bend	4.1 (1.2)	5.1 (1.6)	6.5 (2.0)	8.5 (2.6)	9.9 (3.0)	13 (4.0)	15 (4.6)	19 (5.8)	25 (7.6)	31 (9.4)	37 (11.3)
TEE, Side Inlet or Outlet	3.3 (1.0)	4.2 (1.3)	5.3 (1.6)	7.0 (2.1)	8.1 (2.5)	10 (3.0)	12 (3.7)	16 (4.9)	20 (6.1)	25 (7.6)	31 (9.4)
Foot Valve and Strainer	3.7 (1.1)	4.9 (1.5)	7.5 (2.3)	8.9 (2.7)	11 (3.4)	15 (4.6)	18 (5.5)	22 (6.7)	29 (8.8)	36 (11.0)	46 (14.0)
Swing Check Valve, Fully Open	4.3 (1.3)	5.3 (1.6)	6.8 (2.1)	8.9 (2.7)	10 (3.0)	13 (4.0)	16 (4.9)	20 (6.1)	26 (7.9)	33 (10.1)	39 (11.9)
Globe Valve, Fully Open	19 (5.8)	23 (7.0)	29 (8.8)	39 (11.9)	45 (13.7)	58 (17.7)	69 (21.0)	86 (26.2)	113 (34.4)	142 (43.3)	170 (51.8)
Angle Valve, Fully Open	9.3 (2.8)	12 (3.7)	15 (4.6)	19 (5.8)	23 (7.0)	29 (8.8)	35 (10.7)	43 (13.1)	57 (17.4)	71 (21.6)	85 (25.9)
Gate Valve, Fully Open	0.8 (0.2)	1.0 (0.3)	1.2 (0.4)	1.6 (0.5)	1.9 (0.6)	2.4 (0.7)	2.9 (0.9)	3.6 (1.1)	4.7 (1.4)	5.9 (1.8)	7.1 (2.2)

Now,
(34)Total head loss = h_f + Static Lift
Now using Darcy WeisbachEquation to calculate h_f
(35)$h_f = fL_{eq} x \square_{\mathbf{water}}{}^2/2gd_p$
Also,
(36)$Re = \rho_{water} \square_{\mathbf{water}} d_p / \mu$
From this we calculate the friction factor
f = 0.07
Thus calculate total head.

III. Conclusion

The need for an on-site generation of emergency and standby electricity is usually driven by mandatory installations to meet building code requirements and/or risk of economic loss due to loss of electric power.

Thus with rising power demands the sizes of generator set are increasing with every design and with that increases the heat produced by the set. An efficient cooling system is thus the need of the hour. As the world is fast progressing, things are becoming more compact, hence remote cooling system design is very important and should change itself with the course of demand.

The use of Compact Heat Exchangers is very rapidly increasing and hence should be further studied for newer progress and design.

Acknowledgement

We take the opportunity to express our deep gratitude towards all the people who have helped us in completing this project successfully. Since every project is a team effort, contribution of a lot of people is involved in making it successful.

We would like to thank our company guide**,** Mr. SHAILESH MAHAJAN, Executive Manager Engineering, Cummins, India who has been a constant source of motivation. We thank him for his time, patience, and his constant guidance. Without his help this endeavor would not have been possible. We are highly gratified by his timely and eye opening guidance.

We are thankful to our internal guide ANILKUMAR SATHE, for his encouragement and support that he has extended. His knowledge in this field was the true source of inspiration for this project. Without his support, this project would have never got the look it has.

We extend our heartfelt gratitude toProf. A. S. JOGLEKAR, project coordinator Mechanical Engineering and Prof. A. P. PANDHARE, Head of Department, Mechanical Engineering without whose support, this project would not have been possible. A word of thanks is also in place for entire staff of department of Mechanical Engineering for all they have given us, and a very special thanks to our parents for always believing in us.

AMRITKAR SWAPNIL BAPU
MAHAJAN PRATIK BALU
URJEET SINGH PAWAR

REFERENCES

[1] Heat exchanger design handbook – T. Kuppan
[2] Heat exchangers selection – SadikKakac
[3] Design Analysis and Fabrication of Radiators (Air Cooled Heat Exchanger) – Kanishk Shah
[4] Fundamentals of Heat Exchanger Design – Ramesh K Shah and DusanSekulic
[5] Basics of Air Cooled Heat Exchangers by AMERCOOL