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A Theoretical Investigation of Characteristics of Diesel Engine with Coil Cooler System

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Abstract

Heat exchangers are very essential devices for the industrial applications such as power plant industries, refrigeration and air conditioning systems; and automobiles systems etc. One of the sources to produce electric power is diesel engine with generator called diesel generator. Diesel is a working fluid in this system. In general diesel generators are equipped with radiators or cooling tower systems for cooling the system. For low capacity diesel generators such as ranging from 10 to 500 kW, radiator systems are used for cooling and for high capacity diesel generators ranging from 500 kW to 2 MW, cooling tower systems are used for cooling the system. Integrating the cooling tower system in high capacity diesel generator to cool the system results in various problems such as water pump failure, fan-belt failure, air locking etc. Moreover, pressure drop, huge quantity of water requirement and scale formation on heat transfer tube etc. due to secondary circuit were also taken into account. In this paper, cooling tower system is replaced by coil cooler system for 1 MW diesel generator and the characteristics of diesel engine with coil cooler system were observed. The results showed better results than existing systems such as effective heat transfer rates, high efficiency, low pressure drop, minimizing the raw water requirement, power saving, maintenance and trouble free etc.

Keywords: *Diesel engine, combustion, cooling, heat exchangers*

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INTRODUCTION

Necessity of Cooling

In diesel engines during the process of converting thermal energy to mechanical energy, high temperatures are produced in the cylinders of the engine as a result of the combustion process. A large portion of the heat from the gases of combustion is transferred to the head and walls, piston and valves. Unless this excess heat is carried away and these parts are adequately cooled, the engine will be damaged.

Need to Use Air Cooled Fluid Cooler

There is acute scarcity of water in various parts of our country. The cooling towers require running water in large quantities which is not available at all. The industry therefore uses tube well water for cooling towers. The tube well water being hard needed treatment such as softening plants or adding of chemicals for its utilization. The water treatment is necessary to prevent scaling in the heat exchangers. Moreover this process requires constant monitoring and heavy maintenance. In some areas the water is available from rivers but that also involves laying of long distance piping and its installation and running costs. The users have therefore been facing big problem in the old system of cooling towers. To overcome the said problem, high efficiency "American technology" air-cooled fluid coolers were introduced [1–3].

The air-cooled fluid cooler system is a closed circuit system, which does not require running water, and as such it eliminates the requirement of large quantity of water and the problem of scaling in the heat exchangers. In the Middle East countries almost 100% installations of DG sets are with the air cooled system (air-cooled fluid coolers) which saves 100% water for diesel engine gen. sets in operation. The cooling media is only-free air.

INTRODUCTION TO EXPERIMENT

Integrating the cooling tower system in high capacity diesel generator to cool the system results in various problems such as water pump failure, fan-belt failure, air locking etc. Moreover, pressure drop, huge requirement of water and scale formation on heat transfer tube etc., due to secondary circuit were also observed.

In the present experiment, cooling tower system is replaced by coil cooler system (air cooled fluid cooler) for 1 MW diesel generator, and observed the characteristics of diesel engine with coil cooler system. Obtained good results than the existing system; such as effective heat transfer rates, high efficiency; low pressure drop, minimizing the raw water requirement, power saving, maintenance and also trouble free etc.

DIESEL ENGINGES' CHARACTERISTICS: CONSTANT-PRESSURE HEAT ADDITION - IDEAL DIESEL CYCLE

The air standard diesel cycle is the idealized cycle used in CI or diesel engines. The diesel cycle, illustrated by the *P* - *V* diagram in Figure 1, consists of the following processes: 1-2 isentropic compression from the maximum to the minimum cycle volume, 2-3 constant-pressure heat addition during an accompanying increase in volume to V_3, 3-4 isentropic expansion to the maximum cycle volume, and 4-1 constant-volume heat rejection[2–5].

Actual diesel engines approximate constant-volume heat addition by injecting fuel for a finite duration which continues to burn and release heat at a rate that tends to maintain the pressure in the cylinder over a period of time during the expansion stroke. The efficiency of the ideal diesel cycle is given by:

$$\eta = 1 - \frac{1}{r^{\gamma-1}}\left[\frac{r_c^{\gamma}-1}{\gamma(r_c-1)}\right] \quad (1)$$

The efficiency of the ideal diesel cycle depends not only on the compression ratio, *r*, but also on the cut-off ratio, $r_c = V_3/V_2$, the ratio of the volume when heat addition ends to the volume when it begins.

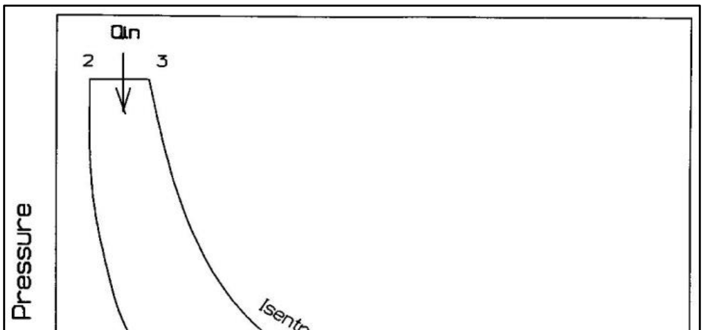

Fig. 1: *Schematic Pressure-Volume Diagram of Ideal Diesel Cycle.*

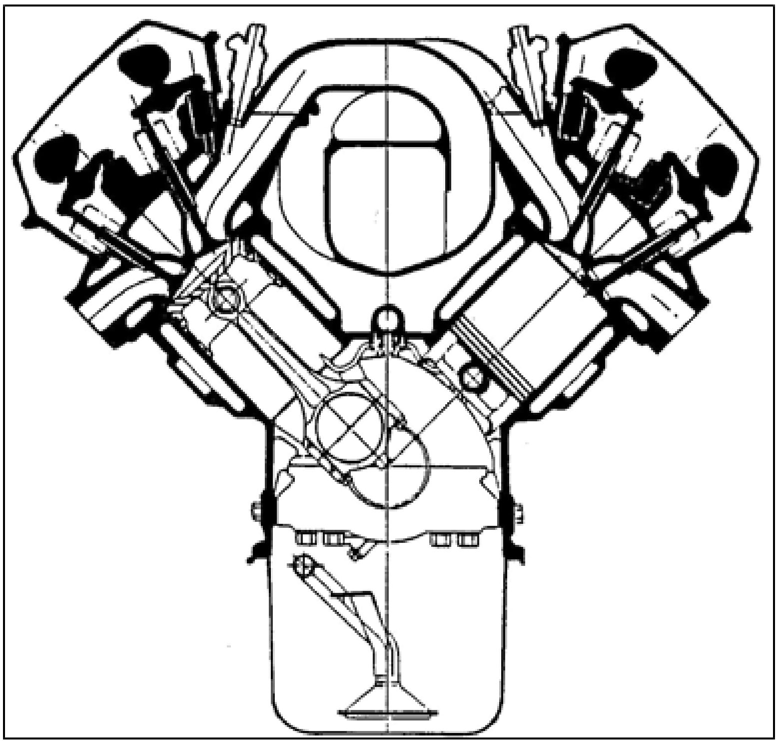

Fig. 2: *V-16 CI Engine.*

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Indicated Mean Effective Pressure (imep)

The specified work performed per cycle can be calculated by taking the integral of PdV for the complete cycle. The imep i.e., indicated mean effective pressure, is well-defined as the ratio between the net indicated work outputs to the displacement volume [4–6].

$$\text{imep} = \frac{\text{indicated work output per cycle}}{\text{displacement volume}}$$

Brake Power (B.P)

Brake work or power, as measured by a dynamometer, is the definite work or power, produced at the output shaft of an engine. Due to friction losses and any parasitic power requirements for oil pumps, water pumps, etc., the brake work will be less than the indicated work. Break Power (shaft power) is defined as that can be developed at shaft, it is calculated from:

$$\text{B.P} = \frac{2\Pi NT}{60X1000}\ \text{kw}$$

Where;
Π = Constant.
N = Speed in rpm (revolutions per minute).
T = Torque in Newton-meter.

Indicated Power

Indicated Power is maximum power that can be developed in engine. It is from:

$$\text{I.P} = \frac{\text{Pim LAnK}}{60X1000}\ \text{kw}$$

Where:
P_{im} = Indicated mean effective pressure (N/m^2).
L = Length of the stroke (m).
A = Area of the piston (m^2).
N = Speed in rpm.
N = Number of power strokes
N/2 for 4 stroke and N for 2 stroke engines.

K = Number of cylinders.
Friction power is defined as:
F.P = I.P – B.P

The brake mean effective pressure, bmep, is defined as:

$$\text{bmep} = \frac{\text{brake work output per cycle}}{\text{displacement volume}}$$

Mechanical Efficiency

Mechanical efficiency can be defined as the ratio of the break power to the indicated power.

$$\eta_m = \frac{\text{brake work (power)}}{\text{indicated work (power)}} = \frac{\text{bmep}}{\text{imep}}$$

Engine Thermal Efficiency

Engine thermal efficiency can be determined from the ratio of power output to rate of fuel energy input.

$$\eta_t = \frac{\text{Power}}{m_f Q_c}$$

mf is the rate of fuel consumption.
Qc is the heat of combustion per unit mass of fuel.

Volumetric Efficiency

Volumetric efficiency (η_v) is an important performance parameter for four-stroke engines defined as the ratio of mass of charge actually inducted to the mass of charge represented by swept volume at ambient temperature and pressure.

$$\eta_v = \frac{m_{\text{actual}}}{m_d}$$

Where; m_{actual} is the mass of intake mixture per cycle at inlet conditions (pressure and temperature near the inlet port) and m_d is the mass of mixture contained in the displacement volume at inlet conditions.

COOLING SYSTEMS OF DIESEL ENGINE

Introduction

A normal diesel engine can convert 40% of the total fuel supplied into mechanical power or output; hence its very necessary to provide a very good cooling system.

Parameters Affecting Engine Heat Transfer

1. Fuel-Air Ratio.
2. Compression Ratio.
3. Engine Output.
4. Cylinder Wall Temperature.

Characteristics of an Efficient Cooling System

The following are the two main characteristics desired of an efficient cooling system:

(1) It should be capable of removing about 30% of heat generated in the combustion chamber while maintaining the optimum temperature of the engine under all operating conditions of the engine. (2). It should remove heat at a faster rate when engine is hot. However, during starting of the engine the cooling should bel ow, so that the working parts of the engine reach their operating temperatures in a short time [3–6].

Types of Cooling System

In order to cool the engine a cooling medium is required. This can be either air or a liquid. Accordingly there are two types of systems in general used for cooling the IC engines. They are:

(1) Liquid or indirect cooling system.
(2) Air or direct cooling system.

Conventional Cooling System-Cooling Towers

Systems are designed for ambient temperature of 50°C. Water used in cooling system should have properties as mentioned in Table 1. If properties are outside the limits then it can result in:
Scale formation, Overheating, Corrosion.

Table 1: Water Properties.

Hardness as CaCO3	<170 ppm
P^H - Raw water	6.5–7.5
P^H - Engine water	5.0–9.0
Chlorides	<40 ppm
TDS	<400 ppm
Sulphates	<100 ppm

Water softening/de mineralizing plants should be used, if raw water quality is not acceptable.

Table 2 represents the coolants to be used in various engine models.

Table 2: Coolant for Various Engines.

B/S/X Series	50–50 Water and Ethylene glycol
C Series	AL Plus (DCA4) Premix
All other engines (Including N14)	CAC (DCA2)+Water

Different Types of Cooling Towers

1. A natural-draft counter-flow cooling tower.
2. A mechanical draft cross-flow cooling tower.
3. A natural-draft cross-flow cooling tower.

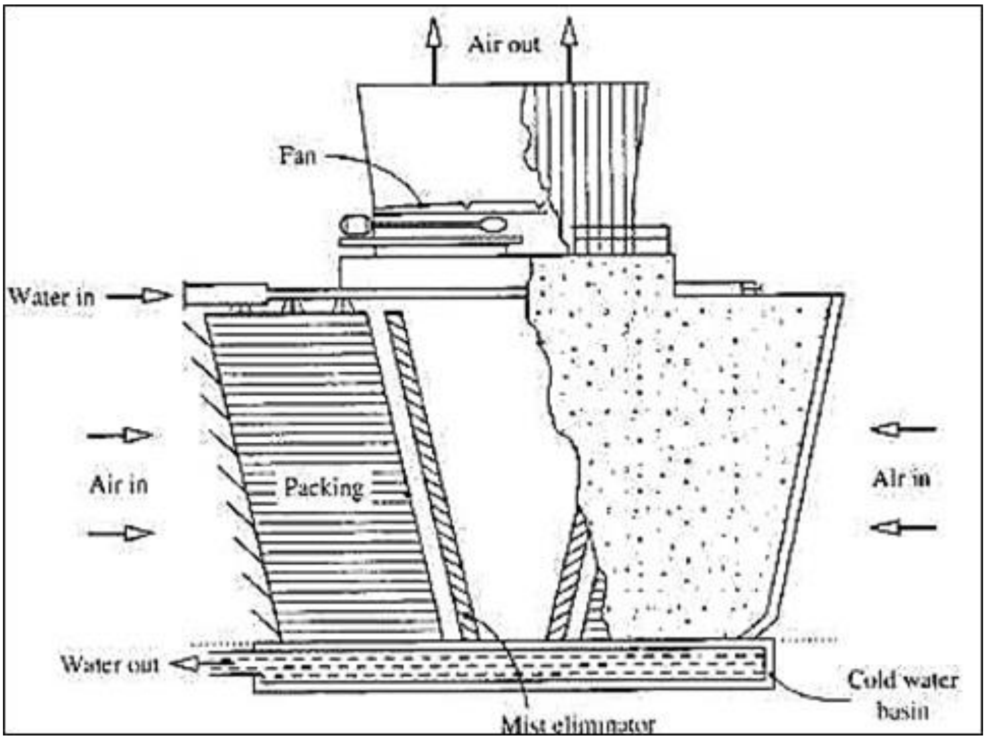

Fig. 3: *Mechanical Draft Cross Flow Cooling Tower.*

HEAT EXCHANGERS

Introduction

A heat exchanger is a device to provide for transfer of internal thermal energy (enthalpy) between two or more fluids, between a solid surface and a fluid, or between solid particulates and a fluid, in thermal contact without external heat and work interactions. The fluids may be single compounds or mixtures. Figure 1

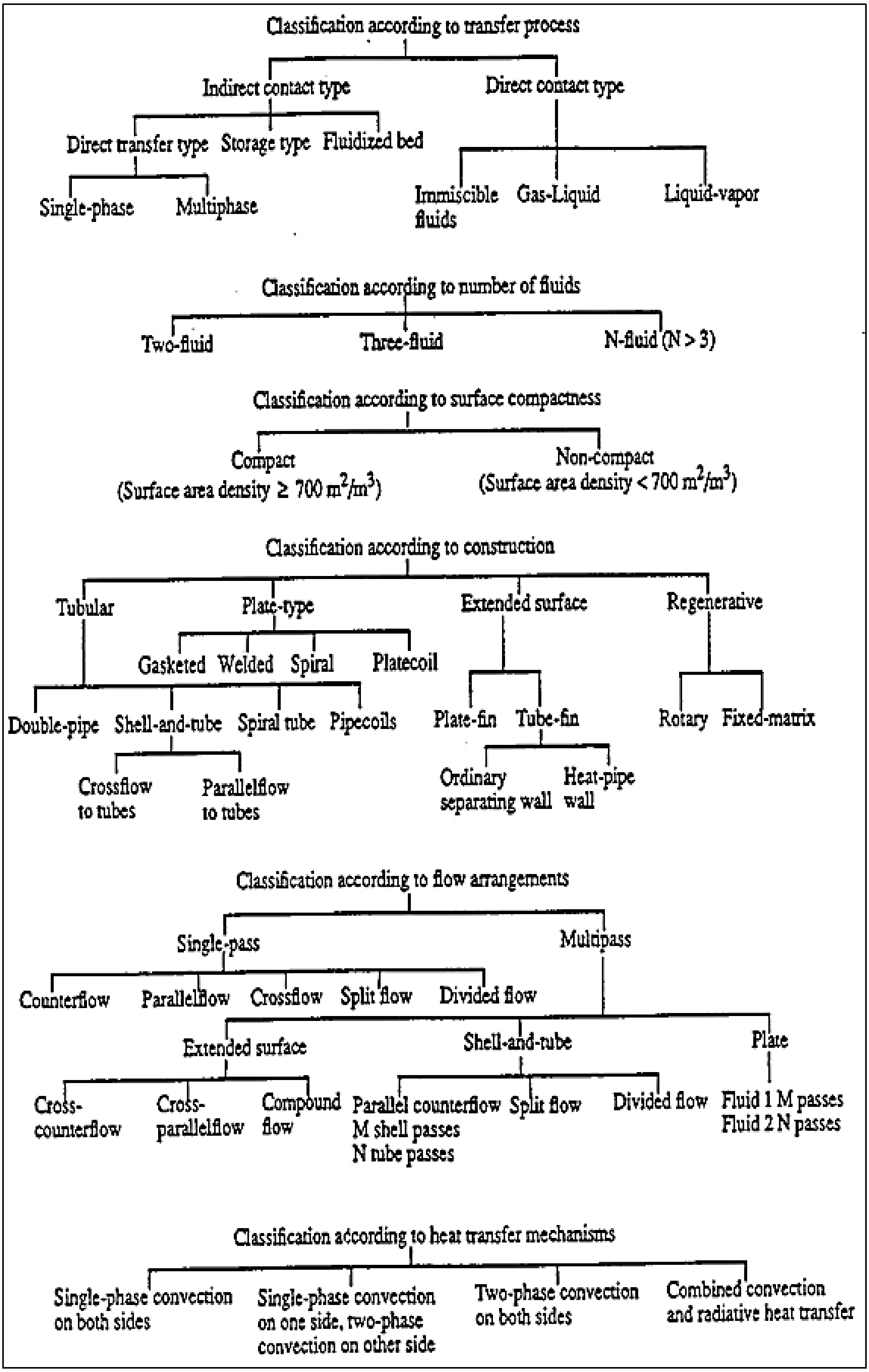

Fig. 4: *Classification of Heat Exchangers.*

Table 3: *Dimensions for ACFC FCW Model.*

Engine Capacity (KVA)	Model No.	Length (A)	Width (B)	Width (C)	(D)	(E)	(F)	Motor		Fan	
								Qty	H.P.	Qty	Dia (mm)
1000	FCW-100										
	(LT+HT)	3135	2030	2495	2125	1460	2655	2	7.5	2	1050
1250	FCW-120										
	(LT+HT)	3645	2030	2495	2125	1460	3165	2	7.5	2	1200
1500	FCW-140										
	(LT+HT)	4155	2030	2520	2150	1460	3670	2	10		1200

Note: *1. All dimensions are in mm. 2. Tolerance % P 10 mm.*

Types of Air Cooled Fluid Coolers

W-Type (320 KVA and Above)

- Induced draft type system.
- Compact in design.
- Easy maintenance

H-Type (100 to 1500 KVA)

- Induced/Force draft system.

W - Type (320 KVA and Above)

- Horizontal coil bundle.
- Low noise level

S-Type (75 to 285 KVA)

- Induced/Forced draft type.
- Vertical coil bundle.
- Suitable for smaller capacity DG sets.

Fig. 5: *W-Type Air Cooled Fluid Cooler.*

Technical Information

Heat Transfer Coils

The coils are made of seamless copper/steel tubes and high efficiency sine wave aluminum fins which are being produced in our most modern coil manufacturing plant of international standards. The excellent tube-to-fin expansion equipment which ultimately makes high efficiency heat transfer coils.

Casing

Casing is made of electrostatic powder coated G-I sheet; which is available in various shades.

Motors

Motors are totally enclosed fan cooled type (TEFC), to protection against dust/moisture with class F installation and 415 ± 10 V/3 ph/50 HZ.

Headers

Headers are made of heavy duty steel pipe and are complete with mating flangs and air purging valves.

Power Supply Requirements

The air cooled fluid cooler is factory wired up to the electrical junction box which is located at the back of air cooled fluid cooler. The wiring from the electrical junction box to starter is to be done in accordance with national and local electric codes.

It is important to use proper size of wire to bring the electrical power to air cooled fluid cooler. The voltage drop in feeder line should not be more than 3%. MCB/MPCBs are recommended to be used for the protection of fan motors under any overloading or short-circuiting. Cable to be used from the junction box to panel is generally 4 crore aluminium cable of size 10 mm^2.

There must be a remote fused disconnect switch installed for the air cooled fluid cooler main power supply and no other load should be connected to this switch.

1. All the motors used in air cooled fluid cooler are of 3 phase/415 V/50 Hz. Motors are totally enclosed fan cooled motors with class F insulation and class B temperature limits.
2. When line voltages are not exactly the same on all phases, unbalanced current will flow in the stator winding. A small voltage unbalance can increase the temperature rise and current, at operating speed, by 6 to 10 times the voltage unbalance.

Location of Air Cooled Fluid Cooler

The proper location of air cooled fluid cooler is very essential for their successful and efficient operation. In this the cooling media is ambient air. So in order to obtain maximum efficiency from the cooler it is necessary to get fresh air in its surrounding.

There should be no restriction at the fan outlet (from where the hot air is going out) such as ceiling.

If the air cooled fluid cooler is connected in primary circuit care should be taken that maximum vertical distance from engine water pump to highest point in cooling system should not exceed 5 m. The maximum horizontal distance of air cooled fluid cooler from engine should not exceed 10 m.

Expansion/Dearating Tank

A suitable expansion/dearation tank must be used along with air cooled fluid cooler (Normally 20% of the system capacity). The tank should be located at the highest point (minimum 0.5 m from radiator top) of entire cooling system.

Water Piping and Connections

The most important factor in the piping layout of air cooled fluid cooler is the size of the pipe. The exact size of pipe is essential so as to get proper flow rate of water and for achieving the pressure drop within prescribed limits. It is advisable to use MS pipe of Schedule 20. It is recommended to use flexible joints in the pipeline close to the DG set.

Piping size should be such that external restriction of piping and air cooled fluid cooler is within limit. The maximum pressure drop allowed in HT and LTA circuit is 0.35 kg/cm^2 (5 psi) and 0.28 kg/cm^2 (4 psi) respectively.

Valves and Fittings

Butterfly valves should be used in the pipe line for isolating the engine so that the entire system does not have to be drained during maintenance in the DG set or air cooled fluid cooler.

Coolant Treatment

To avoid scaling and corrosion in the cooling closed circuit, the first filling and make up water shall be of convenient quality. It is always recommended to provide good quality water/coolant.

Trouble Shooting:

Symptom	Cause	Remedy
Engine temperature shooting up the designed range.	Coils are choked. Air in the system. Possibility of short cycling of air.	Clean the fins of coils. Purge out the air for purging valves. Avoid any hot source emitting heat near the cooler.
Self-closing dampers are not opened at the top of the fan, while the fluid cooler is running.	Fans are rotating in the opposing direction due to change in phase. Motor is not running.	The fan should run in the direction of marked arrow at the fan tube i.e. the air should come out at the fan outlet. Check the motor.
Abnormal vibration of the cooler.	Loosening of fan blades. Loosing of the bush from the motor shaft.	Stop the fans and check all the nuts and bolts of fan blade assembly. Stop the fans and replace the bush.

Water Quality

water quality shall be as follows:

Table 4: *Quality of Water which is used in Air Cooled Fluid Cooler.*

Hardness as CaCO3	<170 ppm
P^H	<5.0 to 9.0
Chlorides	<40 ppm
TDS	<400 ppm
Sulphates	<100 ppm

Units/lt.: Above 0.6
PH: 8.5–10 (Pink colour)

Comparison between Air Cooled Fluid Cooler and Cooling Tower System

The cooling tower system is a combination of primary (close) and secondary (open) circuits. In the primary circuit water is circulated through engine driven pump. In the secondary pump the water is circulated through external pump. In the secondary pump the water is circulated through external pump (generally termed as 'raw water pump').

When the air-cooled fluid cooler is incorporated with the equipment such as heat exchangers, water softening plant, filtration plant, raw water pump, cooling tower, water reservoir, make up water system for cooling tower is not required.

Therefore the cost of the air cooled system is to be compared with not only the cooling tower alone but with the infrastructure required along with the tower. This will provide a very attractive payback period and result in profits year after year, at the same time eliminates all the associated problems of cooling tower setup.

Applications

1. Diesel Engine Gensets.
2. Steam turbine exhausts steam condensing.
3. Charge air cooling.
4. Lubricating oil cooling.
5. Exhaust steam condensing.
6. Furnace cooling and oil cooling.
7. Hydraulic oil cooling.

CONCLUSION

In this paper, an attempt is made to integrate the cooling tower system in high capacity diesel generator to cool the system results in various problems such as water pump failure, fan-belt failure, air locking. Moreover, pressure drop, huge quantity of water requirement and scale formation on heat transfer tube etc. due to secondary circuit were also taken into account. The cooling tower system is replaced by coil cooler system for 1 MW diesel generator and the characteristics of diesel engine with coil cooler system were observed. The paper also describes a comparative study between air cooled fluid cooler and cooling tower system. The results showed better results than existing systems such as effective heat transfer rates, high efficiency, low pressure drop, minimizing the raw water requirement, power saving, maintenance and trouble free etc.

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