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Fouling effect in vacuum pump cooler replacing in plate type heat exchanger improves sealing water temperature and effectiveness

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ABSTRACT

Water Cooler is used widely in many systems in power plant for heat recovery or cooling purposes. A cooler is a device that allows heat energy in one process water to pass to process water in a controlled manner whose purpose is either to remove heat from water (cooling) or to add heat to raw water. Cooler are used in various systems and processes that involve the transfer of heat energy. Improper design, operation and maintenance of a cooler may result in degradation of the components due to scaling and fouling, performance of the system or unit. This paper evaluates the effects of fouling on shell and tube type in a thermal power plant. Cooler Data were obtained through steady state monitoring and direct measurements from the plant reading. The Cooler data were analyzed to determine the overall heat transfer, temperature and pressure range of hot and cold raw waters and effectiveness. The result shows that for the pump around cooler, the overall heat transfer was less than the design value. This was traceable to increased fouling that has affected the reduce effectiveness of cooler and increase temperature of sealing water. This was due to variation in temperature difference between cooler data and design value in the hot water side of the exchanger which has also affected the pressure drop. The results also show an increase the fouling factor over the design which also affected the effectiveness and capacity ratio of the cooler.

Keywords: Heat, Fouling, Energy, Efficiency, PHE, sealing water, temperature, Cost Optimization

I. INTRODUCTION

Fouling in cooler is not a new problem. In fact, fouling has been recognized for a long time and research on cooler fouling. Water cooler fouling remains today one of the major unresolved problems in Thermal Science, and prevention or mitigation of the fouling problem is still an ongoing process. The major cause of reduction in cooler performance is the effect of fouling .Fouling in cooler is a general term that includes any kind of deposit of extraneous materials that appears upon the heat transfer surface during the lifetime of cooler. It occurs during normal operation, when the tubes surface gets covered or blocked by deposits of dirt, oil and scales. Whatever the cause or exact nature of the deposit, additional resistances to heat transfer is introduced and the operational capability of the cooler is correspondingly reduced. In many cases, the deposit is heavy enough to significantly interfere with the water flow and increase the pressure drop required to maintain the flow rate through the cooler. Major detrimental effects of fouling include loss of heat transfer as indicated by charge outlet temperature decrease and pressure drop increase. Other detrimental effects of fouling may also include blocked tube bundle, under-deposit corrosion and pollution. Where the heat flux is high, as in heat exchanger, fouling can lead to local hot spots resulting ultimately in mechanical failure of the heat transfer surface. Such effects lead in most cases to production losses and increased maintenance costs.

The unexpected failure of equipment such as cooler in thermal power plant is always undesirable and when these equipments are critical, they may lead to drop in overall profit. It is therefore with a view to averting down time, reduction in overall heat transfer, lost production and costly repair, that it is necessary to carry out periodic evaluation of the cooler performance in the plant in order to maintain them at high efficiency level. This paper presents a performance analysis on plate type heat exchanger in power plant and compare with shell and tube type cooler to predict the effect of degradation due to fouling. This enables maintenance period to be predicted in order to eliminate the menace of fouling which increases the thermal resistance of cooler and consequently lowers the overall heat transfer.

II. PROBLEM FORMULATION

The thermal performance of a water cooler depends upon so many factors. Some of them are thermal conductivities of involved cooling water and materials, velocity of flow, turbulence etc. To make any exact prediction about the performance of water cooler under a set of loading conditions is always a tough job.

Fouling is generally defined as the deposition and accumulation of unwanted materials such as scale, algae, suspended solids and insoluble salts on the internal or external surfaces of processing equipment including cooler. Cooler are process equipment in which heat is continuously or semi-continuously transferred from a hot to cold raw water directly or indirectly through a heat transfer surface that separates the two waters. Cooler consist primarily of bundles of pipes, tubes or plate coils.

Fouling on process equipment surfaces can have a significant, negative impact on the operational efficiency of the unit. On most power plants today, a major economic drain may be caused by fouling. The total fouling related costs for major industrialized nations. One estimate puts the losses due to fouling of cooler in industrialized nations around 30%. According to 25% of the maintenance costs of a process plant can be attributed to cooler and of this, half is probably caused by fouling. Costs associated with cooler fouling include production losses due to efficiency deterioration and to loss of production during planned or unplanned shutdowns due to fouling, and maintenance costs resulting from the removal of fouling deposits with chemicals and/or mechanical antifouling devices or the replacement of corroded or plugged equipment. Typically, cleaning costs are in the range of Rs 50,000 per cooler per cooling.

Figure 1. Vacuum pump cooler found outside corrosion on outer surface and inside tubes

Loss of heat transfer and subsequent charge outlet temperature decrease is a result of the low thermal conductivity of the fouling layer or layers which is generally lower than the thermal conductivity of the waters or conduction wall. As a result of this lower thermal conductivity, the overall thermal resistance to heat transfer is increased and the effectiveness and thermal efficiency of cooler are reduced. All these and other factors that may affect fouling need to be considered and taken into account in order to be able to prevent fouling if possible or to predict the rate of fouling or fouling factor prior to taking the necessary steps for fouling mitigation, control and removal.

III. MAJOR FOULING DEPOSITION AND STAGES

Fouling can be divided into a number of distinctively different depositions. Generally speaking, several of this fouling deposition occurs at the same time and each requires a different prevention technique. Of this different deposition some represent different stages in the process of fouling. The major fouling deposition or stages include:

1. Particulate fouling and particle formation, aggregation and flocculation.
2. Mass transport and migration of foulants to the fouling sites.
3. Phase separation and deposition involving nucleation or initiation of fouling sites and attachment leading to deposit formation.
4. Growth, aging and hardening and the increase of deposits strength or auto-retardation, erosion and removal.

Detailed analysis of deposits from the cooler may provide an excellent clue to fouling deposition. It can be used to identify and provide valuable information about such deposition. The deposits consist primarily of organic material that is predominantly asphaltenic in nature, with some inorganic deposits, mainly iron salts such as iron sulphide. The inorganic content of the deposits is relatively consistent in most cases at 22-26%. In general, high turbulence, absence of stagnant areas, uniform water flow and smooth surfaces reduce fouling and the need for frequent cleaning. In addition, designers of cooler must consider the effects of fouling upon cooler performance during the desired operational lifetime of the cooler. The factors that need to be considered in the designs include the extra surface required to ensure that the cooler will meet process specifications up to shut down for cleaning, the additional pressure drop expected due to fouling.

Figure 2. vacuum pump cooler tubes fouling with corrosion on cooler dome

Deposits on tube of calcium and magnesium salts as the total dissolved solid of water 1400-1800 PPM. It is soluble with anti scaling because of protection and coatings of mild steel dome. The iron oxide layer get corroded. When it reacts with high amount of salt, through corrosion inhibitor is there in water but due to restriction of flow reduced that point or area inhibitor get exhausted. Same condition we found when in return line tubes and domes shown in picture above.

Corrosion-type fouling can also be minimized by the choice of a construction material which does not readily corrode or produce voluminous deposits of corrosion. A wide range of corrosion resistant materials based on stainless steel is now available in market. Noncorrosive but expensive materials such as titanium and nickel based alloys may be used sometimes to prevent corrosion. If one of the waters is more corrosive, it may be convenient to send it through the tube side because the shell can then be built with a lower-quality and cheaper material. The construction material selected must also be resistant to attack by the cleaning solutions in situations where chemical removal of the fouling deposit is planned. For water allocation, it is usually preferred to allocate the most fouling water to the tube side as it is easier to clean the tube interiors than the exteriors.

IV. FOULING DEPOSITION REMOVAL TECHNIQUES

Several techniques may be used for the control of fouling as part of power plant maintenance. Some of these techniques are designed to prevent or mitigate fouling. Various strategies and devices for the continuous mitigation and reduction of fouling have been proposed such as periodical reversal of flow direction for the removal of weakly adherent deposits, raising flow velocity or by increasing turbulence level. In order to enhance the removal of the fouling deposits, velocities in tubes should in general be above 2 m/s and about 1 m/s on the shell side.

Mechanical cleaning is generally preferred over chemical cleaning because it can be a more environmentally-friendly alternative, whereas chemical cleaning causes environmental problems through the handling, application, storage and disposal of chemicals. However, mechanical cleaning may damage the equipment, particularly tubes, and it does not produce a chemically clean surface. Furthermore, chemical cleaning may be the only alternative if uniform or complete cleaning is required and for cleaning inaccessible areas. The shell side in particular can only be chemically cleaned. The tubes on the other hand can be mechanically cleaning is required for one of the waters, the usual practice is to put that water in the tube side.

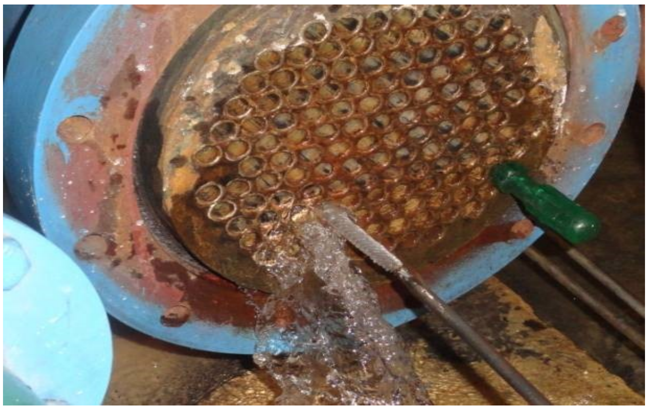

Figure 3. vacuum pump cooler cleaning by high pressure jet and mechanical brush cleaning

Mechanical techniques for the removal of fouling include for tightly plugged tubes, generally known as bullet cleaning, may be employed and for lightly plugged tubes roding is employed. In cases where biofouling occurs it may be removed by mechanical brushing processes. Particularly weakly adherent deposits may be mechanically removed by applying high velocity water jets. Jet cleaning can be used mostly on external surfaces where there is an easy accessibility for passing the high pressure jet shown in above pictures. For the chemical removal of fouling material, weak acids and special solvents or detergents are normally used. Chlorination may be used for the removal of carbonate deposits. The effect of fouling, as has been noted above all condition affected the vacuum pump performance.

V. EFFECT OF SEALING WATER TEMPERATURE IN VACUUM PUMP

Water Ring (WR) type vacuum pumps are subject to several possible operating conditions that can cause insufficient vacuum the most common of which are:

1. Sealing water vapor pressure is too high
2. Incorrect sealing water flow rate being supplied
3. Process contamination of the sealing water

Water Ring (WR) pumps utilize a sealing water which is most commonly DM water however; Generally, the lower the temperature of the sealing water, the lower its vapor pressure and results in increased pumping capacity and deep vacuum performance. In addition, as the process vacuum level approaches the sealing water's vapor pressure the sealing water will begin to flash from the water to the vapor phase (cavitation), subsequently displacing the pump's capacity. As a rule of thumb, to avoid pump cavitation when selecting sealing water, the vapor pressure (Pv) of the sealing water at operating temperature should be less than half of the required vacuum level (P1) as measured at the pump inlet. For instance, the vapor pressure of water at operating the vacuum pump's suction pressure below this level will result in cavitation of the water within the pump and can ultimately damage the pump's impeller rotor. High water temperature supplied to the pump directly as sealing water or indirectly as coolant to the cooler of a full sealing water recovery system will increase the vapor pressure of the sealing water. As the vapor pressure increases this value may approach the vacuum level of the pump and cause the sealing water to flash and reduce the pumping capacity. In many cases the use of cooling tower water used in cooler. When operating the pump at higher temperature due to scaling and fouling in shell and tube type cooler.

Figure 4 .vacuum pump impeller rotor damages due to cavitation

Above all problems facing in vacuum pump due to higher sealing water temperature maintain and cooler tube heavily fouling observed. This reason Turbine maintenance team decided the existing shell and tube cooler replaced by new plate type heat exchanger for vacuum pump.

VI. NEW DESIGN OF PHE FOR VACUUM PUMP

A plate type heat exchanger is uses a pack of corrugated metal plates with port holes for the passage to transfer heat between two waters. This has a major advantage over a conventional cooler in that the waters are exposed to a much larger surface area because the waters spread out over the plates. This facilitates the transfer of heat, and greatly increases the speed of the temperature change. The plate type heat exchanger (PHE) is a specialized design well suited to transferring heat between medium- and low-pressure waters. The hot water flows in one direction in alternating chambers while the cold raw water flows in true counter-current flow in the other alternating chambers. The heat transfer surface consists of a number of thin corrugated plates pressed out of a high grade metal. The pressed pattern on each plate surface induces turbulence and minimizes stagnant areas and fouling. Unlike shell and tube cooler, which can be custom-built to meet almost any capacity and operating conditions, the plates for plate and frame cooler are mass-produced using expensive dies and presses. In this paper we designed the PHE for the required operating conditions. In the design we calculated the overall heat transfer coefficient of PHE. The heat transfer rate and the number of plates required for the PHE were also calculated. Cost optimization of the designed PHE was carried out and it has been found that there is a considerable drop in the cost of the heat exchanger.

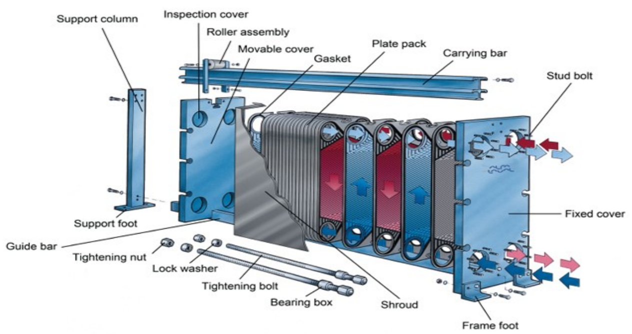

Figure 5. vacuum pump cooler replaced by cross section of Plate heat exchanger

VII. RESULTS AND DISCUSSIONS

The data collection was carried out through direct measurements from the equipment in the plant. Also data from the operational log book from September 2016 to October, 2017 were considered. Field investigation and observation of the various cooler units were also done. More data were obtained from the design data sheet and field operator's log book. In the analysis and treatment of the data, mean values of daily parameters were computed using statistical methods. This was followed by daily, monthly and the overall average for the period the research was carried out. From this, such parameter as vacuum pump sealing water temperature was determined.

Table 1 shows the vacuum pump sealing water temperature compared with shell and tube type cooler with plate type heat exchanger.

Vacuum pump sealing water temperature					
vacuum pump	**ACW inlet temperature**	**shell and tube type cooler**			**Plate type heat exchanger**
		Before cooler	After cooler	Before cooler	After cooler
2A	33.64	53	47.6	53	47.1
	30.91	49	44	53	47.1
2B	30.97	48	43.2	41.3	31.3
	29.3	46	41.6	43	31

The advantages of using PHE were investigated experimentally. The main results are listed as follows:

1. The Sealing water temperature was reduced from 43°C to 32°C.
2. A considerable increase of raw water cooling temperature from 30°C to 31.5°C was observed.
3. The observations on temperature of the newly plate type heat exchanger gives more cooling effect than existing shell and tube type cooler.

Table 2 shows the vacuum pump compared parameter such as condenser vacuum, sealing water temperature, hotwell temperature, suction temperature of pump, motor current etc.

Date and Time	LOAD	COND VACUUM	U#2 Abs Vacuum Pressure trans	Sealing water temperature		HOTWELL TEMP	suction temperature		Motor current	
				VACUUM PUMP A	VACUUM PUMP B		VACUUM PUMP A	VACUUM PUMP B	VACUUM PUMP A	VACUUM PUMP B
	With vacuum pump 2B ON									
10-Feb-18 09:00:00	310.63	-0.8766	78.04	29.90	43.60	46.54	33.59	44.19	0.00	141.10
10-Feb-18 10:00:00	310.75	-0.8773	78.02	29.85	43.58	46.56	31.73	44.18	0.00	140.99
10-Feb-18 11:00:00	310.60	-0.8791	77.19	29.77	43.41	46.32	30.68	43.87	0.00	140.65
10-Feb-18 12:00:00	310.54	-0.8774	77.92	30.02	43.65	46.51	30.41	44.18	0.00	140.86
Avg 2B	**310.63**	**-0.8776**	**77.79**	**29.89**	**43.56**	**46.49**	**31.60**	**44.11**	0.00	**140.90**
	With vacuum pump 2A ON									
11-Feb-18 09:00:00	309.99	-0.8894	72.34	30.23	29.86	44.17	42.56	34.44	151.63	0.00
11-Feb-18 10:00:00	309.92	-0.8896	72.43	30.40	29.93	44.25	42.65	32.49	150.40	0.00
11-Feb-18 11:00:00	310.00	-0.8883	73.09	30.79	30.26	44.51	42.93	31.72	149.50	0.00
11-Feb-18 12:00:00	310.03	-0.8834	74.81	31.62	30.93	45.26	43.72	31.51	148.84	0.00
Avg 2A	**309.99**	**-0.8877**	**73.17**	**30.76**	**30.24**	**44.54**	**42.96**	**32.54**	**150.09**	0.00
Diff between 2A&2B(Avg 2B - Avg 2A)	0.64	0.0101	4.63	-0.87	13.32	1.94	-11.36	11.56	-9.19	

Table 3. shows condenser vacuum pump energy saving impact

Condenser vacuum					
Parameters	**Unit**	**Design values**	**Deviation**	**Heat rate (Kcal/Kwh)**	**Monetary Impact (Rs/day)**
Condenser vacuum	Kg/Cm^2	-0.8713	0.01 kg/cm^2	13	82000

VIII. CONCLUSION

On the basis of above study it is clear that a lot of factors affect the performance of the cooler and the optimization obtained by the formulas depicts the cumulative effect of all the factors over the performance of the heat exchanger. Higher the thermal conductivity of the plate metallurgy higher the heat transfer rate will be achieved. Less is the spacing, higher the heat transfer at the less of the pressure drop. So, while optimization it must be taken care that the advantage in one of the output parameter can affect the other parameters, which can lead to increase in initial or operating cost.

This work has highlighted the deviations of plant operations from actual design values due to fouling of the cooler units. The fouling affected the cooler effectiveness and temperature range of the hot and cold water. This consequently affected the pressure drop and the overall system performance. The parameters used in assessing the efficiency of the cooler and also to check deterioration of the equipment design and operation with time was by steady state monitoring, direct collection of data from the equipment in the plant and analysis of the data compared with the equipment design data. It provided a good method of obtaining the performance of the cooler.

- The plate type heat exchanger is successfully optimized using LMTD with the objective functions of maximizing heat transfer rate and minimizing total cost.
- There is reducing in pressure drop with increase in water flow rate in plate type heat exchanger which reduces pumping power.

This leads to great reduction in space and cost without affecting the heat will transfer efficiency. Initial cost is generally a function of approach temperature. When considering the maintenance costs, the determining factor should be the properties of water involve. When the water has a greater tendency to foul, the plate and frame design offer easier access to heat transfer surface for cleaning. In addition, because of high turbulence, plate type heat exchanger has less of a tendency to scale or foul when compared to a shell and tube design. While the gasket is a weakness in the plate and frame design, the ability to expand or reduce the thermal capacity by adding or reducing plates is a major advantage for the plate and frame heat exchanger. If you want the application may be expanded in the future, a plate cooler is far the easiest and the most economical design. In summary, properly selected, installed and maintained cooler is probably the most trouble free piece of equipment in the system.

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