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Experimental Investigation for Improving Efficiency of Natural Draft Cooling Tower

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Abstract - In this experiment, the main element of the cooling system is a natural draft cooling tower. The basic parts of the tower can easily be described and understood; the processes of heat and mass transfer are very complex. In natural draft cooling towers, a process of counter flow heat transfer, in which the water is cooled by air. Between the water and the air, a boundary layer is established, which is considered to be saturated air at the same temperature as the water. In the heat transfer process more than two-thirds of the heat is transferred by evaporation and the rest being transferred by convection. An improved cooling tower performance is the result of an optimum mass flow rate of cooling water with respect to the power plants operating conditions. For this kind of operation, pumps with a variable speed, which is unusual for today's cooling systems with large water mass flow rates, are required. Besides eliminating local anomalies in the temperature and velocity fields, it is also possible to improve conditions with a proper distribution of water across the cooling towers plane area.

Considering the cooling air measurements, it is possible to distribute the water in such a way it ensures the homogeneity of the heat transfer and a reduction of entropy generation, thus minimizing the amount of exergy lost. The velocity and temperature fields of the air flow were measured at an arbitrary point above the spray zone over the entire plane area of the cooling tower. The structures of the moist air velocity profiles and the temperature profiles above the spray zone were used as input data for optimum water distribution. Optimum water distribution system is applied with minimum possible alterations in existing system to ensure the minimum expenditure. Further, the experiment is carried out to evaluate the cooling tower performance with optimal water distribution system.

Keywords - *Natural Draft Cooling Tower, Wet bulb temperature, Psychrometer, Flow measurement, Efficiency, Approach, Range.*

I. INTRODUCTION

Cooling towers are heat removal devices used to transfer process waste heat to the atmosphere. Cooling towers may either use the evaporation of water to remove process heat and cool the working fluid to near the wet-bulb air temperature or, in the case of closed circuit dry cooling towers, rely solely on air to cool the working fluid to near the dry-bulb air temperature.

HISTORY OF COOLING TOWER

Cooling towers originated out of the development in the 19th century of condensers for use with the steam engine. Condensers use relatively cool water, via various means, to condense the steam coming out of the pistons or turbines. This reduces the back pressure, which in turn reduces the steam consumption, and thus the fuel consumption, while at same time increasing power and recycling boiler-water. However the condensers require an ample supply of cooling water, without which they are impractical the cost of the water exceeds the savings on fuel. While this was not an issue with marine engines, it formed a significant limitation for many land-based systems. A hyperboloid cooling tower was patented by the Dutch engineers Frederik van Iterson and Gerard Kuypers in 1918. The first hyperboloid cooling towers were built in 1918 near Heerlen. The first ones in the United Kingdom were built prior to 1930 in Liverpool, England to cool water used at a coal-fired electrical power station.

II. LITERATURE SURVEY

Performance of existing Natural Draft Cooling Tower is improved either by optimization of operation method or by employing some innovative ideas.

Georgia F.Cortinovis, José L. Paiva (1) worked on optimization model for the operation of cooling tower system and concluded that in the most economical operation of the cooling water system, the temperature of water that leaves the tower must be maintained at the highest value possible, provided the thermal requirements are achieved. When there is an increase of thermal demand of the process without a simultaneous requirement of a lower water outlet temperature from the cooling tower, the optimal solution prescribes increasing the flow rate of circulating water through the system, keeping the other operational conditions constant. In situations when cooler water is needed to fulfill the process thermal demand, and its availability is reached (i.e., increase of water flow rate), the most economical expenditure is to increase the air flow rate through the cooling tower.

M. Goodarzi, R. Keimanesh (2) experimented on radiator type wind breaker for enhancement of heat rejection through Natural Draft Cooling Tower. They concluded that Regardless of increasing the initial and fabrication costs, radiator type windbreakers improve the cooling efficiency more than solid windbreakers do. In fact, the radiator type windbreakers use the cooling potential of the blowing wind in addition to the velocity deceleration characteristic. They even improve cooling efficiency under normal condition.

The water particles that are carried away with saturated exit air are called as drift. This drift is a huge evaporation loss that needs to be eliminated.

Manuel Lucas, Javier Ruiz (3) investigated the thermal performance of cooling tower with drift eliminator. The presence of an eliminator does not necessarily worsen the performance of cooling tower as expected by the additional pressure loss incorporated into the air flow. Further, the performance of Natural Draft Cooling Tower will be improved by using the munters media (4) of PVC as a cooling media.

But all above ideas are costly to execute and difficult also. Then we reached to next research paper that presents a good option.i.e. Improving the efficiency of Natural Draft Cooling Tower researched by J. Smrekar, J. Oman (5).

J.Smerkar ,J.Oman (5) measured the velocity and temperature across the periphery of Natural Draft Cooling Tower.

Using the results of the velocity and temperature measurements of the cooling tower, three-dimensional topological structure diagrams of the velocity and temperature data were obtained. Because the air mappings completely characterize the water/air interface across the plane area of the cooling tower, problems with the water distribution and the fill system can be identified in the mappings and successfully solved.

The analyzed cooling tower had the same type of nozzles across the plane area of the cooling tower. The water distribution system with flow channels is exposed to atmospheric pressure, which means that with the correct operation of the nozzles and channels, the water distribution across the plane area would be uniform. At the edge of the analyzed plane area, there is a relatively extensive region of high air velocities and low air temperatures. These represent the areas with a high entropy generation.

If ambient difference and operational irregularities of the water distribution system, then CT packing and the nozzles are not taken into account, we can only focus on improving the operation of the cooling tower. This kind of improvement involves determining the optimal water/air mass flow ratio on a local basis across the plane area of the cooling tower. It is also clear that because of the specific hyperbolic shape of the cooling tower, the air velocity de- creases from the edge of the tower to the interior. Because of the uniform inlet water temperatures and uniform mass flow rates of water across the plane area and because of the different air mass flow rates, the outlet water temperatures are different, which results in increased entropy generation in the cooling tower. With a constant water/air mass flow ratio, the same amount of air per unit of water is ensured, which results in the same outlet water temperatures across the plane area of the cooling tower and smaller entropy generation. To achieve a constant water/air mass flow ratio then there has to be a variable mass flow rate of water that is adapted to the mass flow rate of the air across the plane area. Because of a lower total entropy generation, a lower outlet water temperature is achieved and, thus, a better overall cooling tower efficiency is ensured. A suitable distribution of water relative to the air flow can be achieved by regulation of the water distribution system or by different sizes of nozzles across the plane area of the cooling tower.

Sr. No.	Location	Temp(°C)	Velocity(m/s)
1	Avg. Of location A@120 m	36.5	3.43
2	Avg. Of location B@70 m	39.9	2.43
3	Avg. of location C@20 m	40.5	1.90

Table 2.1- Temperature & Velocity

The scheme can be used to explain the reduction in entropy generation where we distributed the same amount of water with respect to the mass flow rate of air. It could happen that in some regions, the air does not become saturated along the fill system, which represents unused potential for evaporation and, thus, less transferred heat. In the interior of the cooling tower, we can see the opposite state where the water/air mass flow ratio is too high. In this case, the condition of the air approaches saturation in the lower part of the CT packing, while the upper part of the CT packing is not so effectively used for the process of evaporation. Both examples show non-optimal usage, depending on the air flow distribution across the plane area. Consequently, there are large non-homogeneities, which contribute to the generation of entropy.

From the above discussion it can be concluded that the analysis shows that we should distribute water from interior of cooling towers, where we have more water relative to the air flow comparing to the cooling towers of exterior pattern. Thus we will obtain the best possible results for the given operating conditions when we have the optimal distribution of water across the plane area of the cooling tower.

III. OBJECTIVE

EXISTING WATER DISTRIBUTION SYSTEM				PURPOSED WATER DISTRIBUTION SYSTEM			
Dia. (mm)	Flow (m3/hr)	Qty. (Nos)	Total flow (m3/hr	Dia (mm)	Flow (m3/hr)	Qty. (Nos)	Total flow (m3/hr)
				21	4	2956	11824
25	6	11083	66500	25	6	6651	39906
				32	10	1477	14770
Total flow		11083	66500	Total flow		11083	66500

Table 3.1- Comparison of existing and proposed water distribution system

n1=2956
q1=4cum/hr

n2=39906 q2=6 cum/hr
n3=14770 q3=10 cum/hr

Above discussion shows that we should distribute water from the cooling towers interior, to the cooling towers exterior. It means the water flow must be maximized at the edges of Natural Draft Cooling Tower and minimized near the interior of cooling tower. It is decided to optimize the water distribution but with minimum possible alteration to minimize the expenditure. It is possible by using a larger diameter nozzles at the edges and shorter diameter nozzles at interior of natural draft cooling tower.

DESIGN OF OPTIMAL WATER DISTRIBUTION SYSTEM

Total water flow of cooling tower is 66500 cubic meter per hour and it is distributed through 25 NB nozzle in the existing water distribution system of cooling tower.

By using relation, q=A.V

Nozzle has flow of 6 cubic meter per hour. Q=N.q

Total 11083 numbers of nozzles are used in existing water distribution system. This nozzles should be distributed such that, they should satisfy following condition.

1. Design requirement- Maximum flow at edges and minimum flow near the interior of cooling tower.

2. Minimum Cost requirement-Only nozzles will be replaced i.e. same AC pipes with same number of holes are used.

3. Same Discharge- Discharge should remain same to avoid head loss.

We know that, for parallel pipes the total discharge is some of individual discharge.

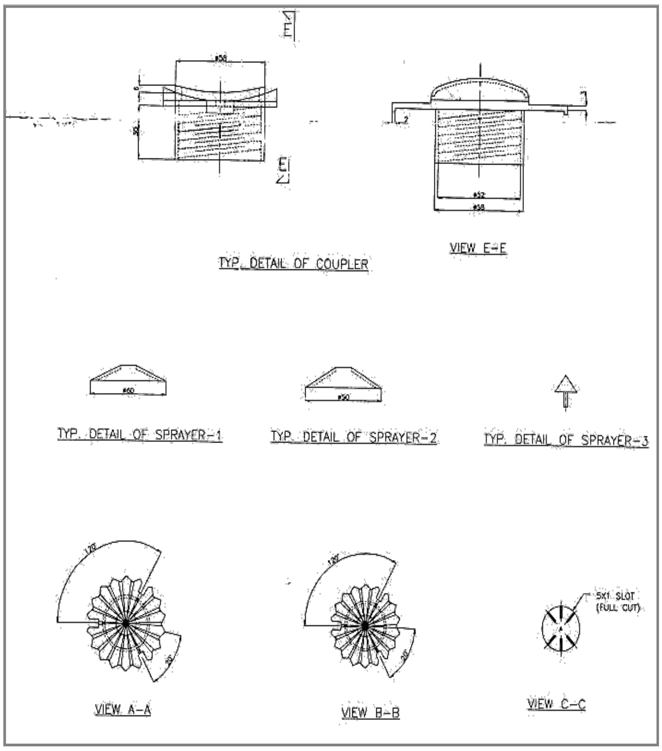
Q=Q1+Q2+Q3………1

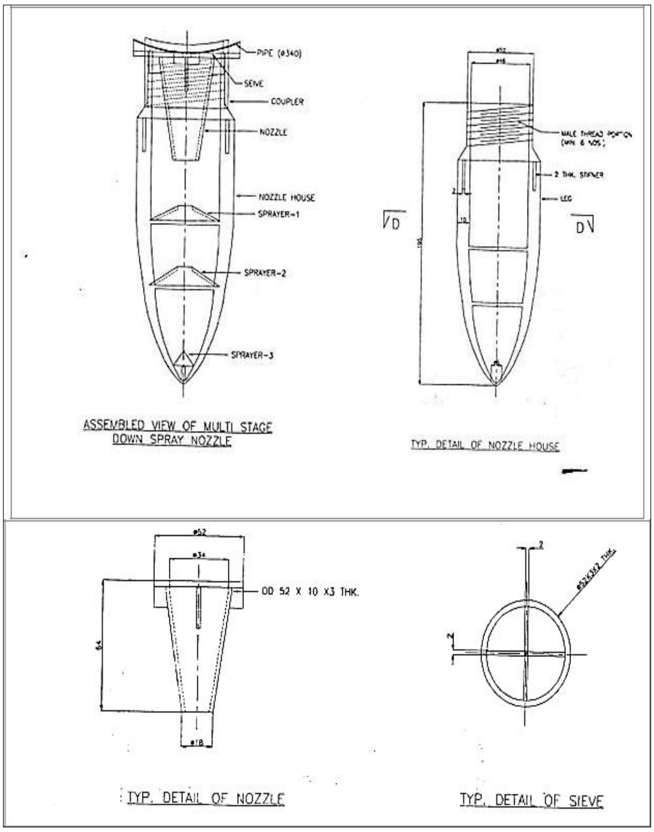
N.q=n1.q1+n2.q2+n3.q3 ……….2

After performing number of iterations, it is decided to replace 60% of 25 NB nozzles with 26.67% of 21 NB nozzle & 13.33% of 32 NB nozzles.

EXISTING AND PROPOSED DISTRIBUTION

In this way, we can use this nozzle by keeping same discharge and with same number of nozzles.Only thing we have to do is to replace the nozzles or nozzle diameter. But the nozzle used here are 3 stage spray type nozzle. This nozzles diameter will be cut to the desire size, on site also. The minimum diameter of supplied nozzles is 18 mm and it is easily cut to 21 mm and 32 mm on site also.





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IV. EXPERIMENTAL INSTRUMENTATION

All measurements for this test were carried out using calibrated instruments. Long Mercury-in-glass thermometers (0.1ºCgraduations), Swirling Psychrometers with long mercury-in-glass thermometers (0.1 degC) are used for temperature measurements. Vane anemometer with digital display was employed for wind velocity measurements. manometers, for measurement of water flow velocity, indicated as head in the manometers. Ultrasonic flow meter was also used to measure the flow.

PROCEDURE

Hot Water Temperature

Two locations Hot water duct inside the tower were chosen for HWT measurement, and the average of the readings for each one hour duration, is taken for each location. The average from the two locations is considered for calculations.

Cold Water Measurement

Two locations were chosen for CWT measurements and from the average one hour duration for each location, the final average is obtained

DBT/WBT

At properly chosen three locations in the vicinity of the tower, both DBT and WBT were noted, taking care to wet the wick around the mercury bulb of the Wet Bulb Thermometer, and whirling the psychrometer every time a reading is taken, the average of the readings from three locations, for each hour is taken for evaluation purposes.

Wind Velocity

The vane type anemometer is oriented to face the wind flow direction, and kept above the head level, every time a reading is taken.

Flow measurement

Flow is measured by using ultrasonic flow meter. Readings obtained from ultrasonic flow meter are considered for further evaluation. The total flow into the tower is obtained as the sum of the two main flow risers and the two auxiliary flow risers.

Using the Performance curves evaluation is done from the average values for stable one hour for HWT and CWT, Range R is obtained, and likewise RH from DBT and WBT average values. Temperature readings of hot water and cold water between time periods 12.00 to 13.00 hr are more consistent. Load was constant besides fairly good values of range, WBT which are closer to design values. Summary of readings has been tabulated in table 4.1.

Parameter	Average
HWT	41.44
CWT	32.15
Range	9.29
DBT	34.93
WBT	27.82
RH	58
Wind Velocity	15

Table 4.1 - Temp & wind velocity measurement

V. CALCULATION

The calculations are performed to compare the present performance of NDCT (with optimal water distribution) with previous performance of NDCT (with uniform water distribution). The past record of NDCT available with company is as follows.

PREVIOUS PERFORMANCE (WITH UNIFORM WATER DISTRIBUTION)

Flow: 66250 cum/hr WBT: 28 ºC
HWT: 41.44 ºC RH: 60%
Wind velocity=15 km/h CWT: 33.15 ºC
Range = HWT-CWT
= 8.29^{0}C
Approach = CWT-DBT
=5.35^{0}C
Efficiency = Approach / (Range + Approach)
= 60.77%

CURRENT PERFORMANCE (WITH OPTIMAL WATER DISTRIBUTION)

Flow: 65372 cum/hr WBT: 27.8 ºC
HWT: 41.44 ºC RH: 58
Wind velocity=15 km/h CWT=33.15 ºC

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Range = HWT-CWT
= 9.29^{0}C
Approach =CWT-DBT=4.35^{0}C
Efficiency = 68.10%

Sr. No.	Parameter	Previous	Current
1	Range	8.29	9.29
2	Approach	5.35	4.35
3	Efficiency	60.77	68.10

Table 5.1 - Comparison of actual and predicted performance of NDCT

Present CWT is less than past cold water temperature. Thus we obtained a lower water outlet temperature from cooling tower which is 1°C lower than with a uniform water distribution system. This results in improvement in efficiency by @7%.

VI. CONCLUSION

Measurements of the temperature and velocity fields in a cooling tower were performed for the given power plant parameters, cooling tower constructional characteristics and ambient air velocity conditions in the vicinity of the cooling tower. The last two parameters influence the homogeneity of the heat transfer, from which we can see the anomalies in the cooling towers operation. Homogeneity in the heat transfer could not only be achieved with fault free construction characteristics but also with a proper distribution of water across the plane area of the cooling tower.

In this study, we have analyzed the water distribution across the plane area of the cooling tower. We have adjusted the amount of water to suit the air flow conditions, which cannot be influenced with natural draft cooling towers. In this way, the optimal moistening of the cooling tower packing is ensured, which results in a more effective heat transfer. With a optimal water distribution, a constant local water outlet temperature is obtained, which decreases the entropy generation and the exergy lost from the cooling tower.

The result is lower outlet water temperature from the cooling tower and, thus, from the condenser, which results in greater efficiency of the power plant.

VII. FUTURE SCOPE
VIII.

1. Same study can be carried out by using computer software and can be compared with experimental data.

2. Alternate method for flow optimization can be used, such as using different combination of nozzle.

3. Efficiency can be improved by different methods such as using drift eliminator or by varying the size and shape of packing media.

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