Energy Auditing in Cooling Tower

R. K. Kiruthika
Assistant Professor
Department of Electrical & Electronics Engineering
CK College of Engineering & Technology, India

Abstract— The aim of this project is to do energy auditing in sugar factory and identify areas in which energy saving opportunities can be made. Cooling tower which is a device used to cool the cold fluid from the condenser, condensation ability depends on the performance of cooling tower, which handles water at a large quantity and at high temperatures which is being cooled by circulation of air into the tower. The performance of the cooling tower can be improved by analyzing various parameters range, approach, effectiveness etc., the energy auditing is focused on cooling tower. Effective utilization of lighting systems, implementing new technology to reduce the cost of the electricity. Study of opportunities to recover the waste heat available in the flue gas of boiler. Calculating the energy savings by implementation of energy saving measures, investment required for such implementation and payback period for each energy saving measures.

Key words: Cooling Tower, Energy Auditing

I. INTRODUCTION

There are two types of cooling towers used (a) Counter Flow (b) Cross Flow .In the counter flow type the air is forced from the downward direction, while the water flows from the upward direction. Whereas in the cross flow type the air flows through the cross sides. There are 4 cells in which three cells are counter flow & one is Cross flow. This is a very essential device which is being used in most of the industries to cool the hot fluid. The cooling tower consists of drift eliminators, Fills and ID Fan.

The drift eliminators [1]are used to reduce the water loss by air. There are six ways by which the drift eliminators are placed, The arrangements are in a Zigzag manner, Honeycomb and in a Rhomboidal shape. The distance & the angle between the eliminators are changed and the losses are calculated by comparing with the actual data. The losses are reduced to 0.005 -0.004%.

The validity of the model[2] has been verified or checked by experiments. The performance of the cooling tower is calculated by using a computerised model (i.e) a flowchart is used to calculate the performance by continuous checking of the parameters until they obtain the reasonable value. The result is that the mass flow rate is varied by having the surface area unchanged by which the performance or the range is increased to give a better effectiveness.

An experimental set up [3]from which the mathematical model is calculated by varying the parameters such as mass flow rate of air & water, Outlet temperature of cooling tower. Comparison between the predicted & theoretical values are formulated & verified. The cooling rate or the heat taken up by the air is calculated that is the heat & Mass transfer characteristics are determined.

II. AUDITING

The auditing on cooling tower of a cogeneration plant is conducted and the various parameters are observed:

- Air circulation rate
- Mass Flow rate of cooling tower
- Range
- Approach
- Effectiveness
- Evaporation losses
- Blow down rate
- Mass flow rate of Makeup water

The steam from the turbine enters into the condenser where the steam is condensed and sent into the hot well then to the deaerator and finally to the Boiler and the process is continued. The process has been explained by the help of a diagram:

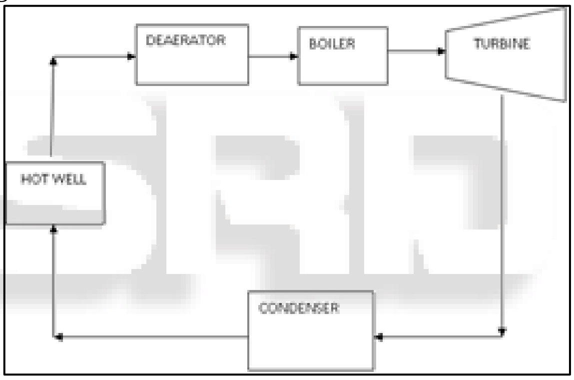
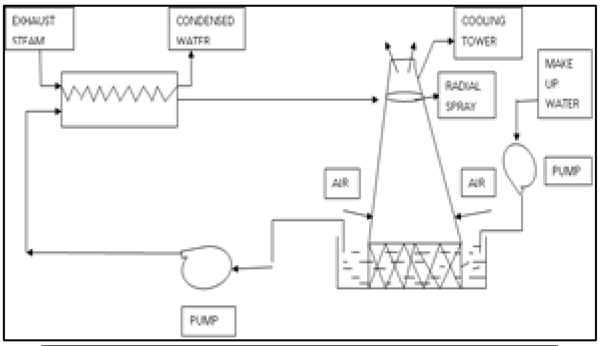


Fig. 1: Process Layout

The condenser which is a shell & tube type in which the cold water from the cooling tower outlet is sent through the tubes and the heat is transferred from the steam to the water in the condenser tubes. The hot water from the condenser tubes is sent to the inlet of the cooling tower. Pump is being used to pump the water to the cooling tower and to the condenser tubes. The following diagram represents the operation of cooling tower.

The cooling tower consists of fills, Drift Eliminators, Nozzles for spraying water & the induced fan to take the hot air out. The fills are in a Zigzag manner so that the contact time between the water and the air is more. There are nearly 6 sets of fills each set has 4 layers of fills with the thickness of 25 mm. The air is passed from the downward direction since it is a counter flow type. The inner arrangement of cooling tower is showed in the following figure.



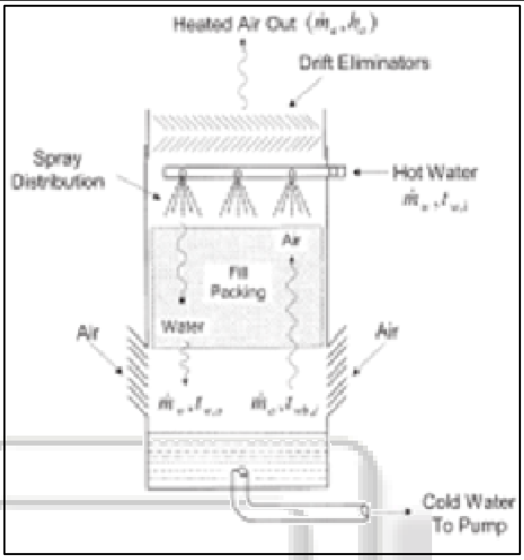


Fig. 3: Inner Arrangement of CT

The dimensions of the cooling tower are mentioned in the following table:

Width	M	7.92
Length	M	23.78
Height	M	10.34
Fill Dimension	mm	1200 x 300
Nozzle diameter	inch	1
No of Fill layer	Nos	4
No.of Fills	Nos	648
Fill Height(1 Layer)	mm	25
Pack Height	M	1.2
Cooling Tower Inlet Temperature	ºC	42
Cooling Tower Outlet Temperature	ºC	32
Ambient wet bulb temperature	ºC	27
No.of Branch pipes in each cell	Nos	72
No.of Nozzles in each pipe	Nos	8
No.of Nozzles per cell	Nos	576
Flow through each Nozzle	m³/Hr	1.7
Condenser inlet temperature	ºC	38

Table 1.1: Specification

III. Calculations

The calculations regarding the present study is analysed and the losses are being evaluated:

Data:

CT water flow /cell, m³/Hr - 1000

CT fan air flow, m³/Hr - 648319

Inlet temp. of water at CT ° C (Tw)in - 47.4

Outlet temp. of water at CT ° C (Tw)out ° C - 38

Wet bulb temp of air ° C - 27

Range = (Tw) in - (Tw)out

= 47.4 -38

=9.4 ° C

Approach = (Tw) out - wet bulb temp

= 38 -27 =11 ° C

Effectiveness =Range/(Range+ Approach)

= 9.4 / (9.4 +11)

=0.46

Cooling duty handled /cell in Kcal =Flow * Temp diff *1000

=1000 *9.4 *1000

=14100 *10³KCal/hr

Evaporation losses =0.00085 *1.8 *Circulation rate *((Tw) in - (Tw)out)

=0.00085 *1.8 *1000 *9.4 =21.573m³/hr per cell

% Evaporation losses= (Evaporation loss /Flow rate)*100 =(21.573/1000)*100

=2.15 %

Cycles of concentration: The amount of dissolved solids in the cooling tower is calculated and the unit is ppm.

Blow down requirement for site COC =evaporation loss /(COC -1)

=21.573/(3.5 -1)

=8.62 m³/hr

Make up water required /cell in m³/hr =Evaporation loss + Blow down loss

=21.573 + 8.62

=30.20 m³/hr

The theoretical calculations to find the maximum effectiveness, Range, approach etc. are calculated by varying the mass flow rate of water & the outlet temperature of water.

Cogen 3 cell (Counter flow)		
CT water flow /cell	m³/Hr	1000
CT fan air flow	m³/Hr	648319

Table 1.2

The table shown below is calculated by varying the outlet temperature of water from 38 to 27°C by having inlet temperature of water & the wet bulb temperature of air is maintained constant.

Mass flow rate of water	Effectiveness
m³/Hr	
1020	0.49
1040	0.54
1060	0.59
1080	0.63
2000	0.68
2020	0.73
2040	0.78
2060	0.82
2080	0.87
3000	0.92
3020	0.97
3040	1.00

Table 1.3

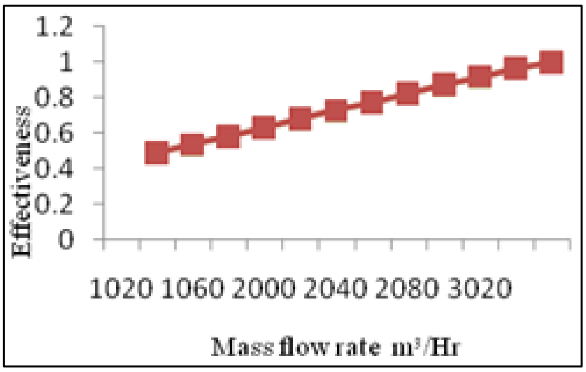


Fig. 4:

In this the maximum effectiveness is obtained at the maximum flow rate of 3040 m³/Hr .But this cannot be obtained practically. The obtainable value of effectiveness is 0.78 at the mass flow rate of 2040 m³/Hr which is taken from the graph. This can be achieved so that the thermal performance be improved in a better manner.

S.No	Range ° C	Mass flow rate of water m³/Hr	Q KJ/s
1	10	1020	12198.63
2	11	1040	13645.38
3	12	1060	15138.57
4	13	1080	16678.2
5	14	2000	33207.78
6	15	2020	35885.3
7	16	2040	38609.27
8	17	2060	41379.68
9	18	2080	44196.53
10	19	3000	67228.33
11	20	3020	71183.08
12	21	3040	74125.33

Table 1.4

The above table shows the heat flow from 1020 m³/Hr to 3040 m³/Hr mass flow rate of water. For the minimum (1020 m³/Hr) mass flow rate the heat flow is calculated as 12198.6 KJ/s. For the maximum flow rate (3040 m³/Hr) the heat flow is 74125.33 KJ/s. For the acceptable effectiveness of mass flow rate of water of 2040 m³/Hr the heat flow obtained is 38609.27 KJ/s.

Mass flow rate of water	Evaporation losses /cell	Blow down reqd.
m³/Hr	m³/Hr	m³/Hr
1020	16.07	6.43
1040	17.98	7.19
1060	19.95	7.98
1080	21.98	8.79
2000	43.76	17.50
2020	47.29	18.91
2040	50.88	20.35
2060	54.53	21.81
2080	58.24	23.30
3000	88.59	35.43
3020	93.80	37.52
3040	97.68	39.07

Table 5.1

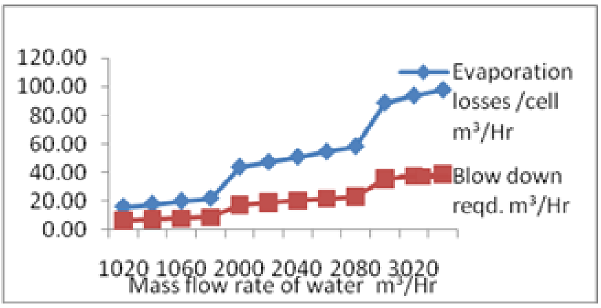


Fig. 5:

Mass flow rate of water	Range	Approach
m³/Hr	° C	° C
1020	10	11
1040	11	10
1060	12	9
1080	13	8
2000	14	7
2020	15	6
2040	16	5
2060	17	4
2080	18	3
3000	19	2
3020	20	1
3040	21	0

Table 1.6

From the above table the evaporation losses & the blow down rate is determined by varying the outlet temperature of water. The obtainable value of the losses and the blow down rates are 50.88m³/Hr & &20.35m³/Hr respectively .This is obtained for the corresponding mass flow rate where the obtainable effectiveness is calculated. Here both the losses and the blow down rate are increased with the increase in the mass flow rates. The evaporation losses are increased gradually from lower value to the higher value. There is a steep increase after the mass flow rate reaches 2000 m³/Hr. The blow down rate is increased to a maximum value of 39.07 m³/Hr with an increase in the flow rate of water.

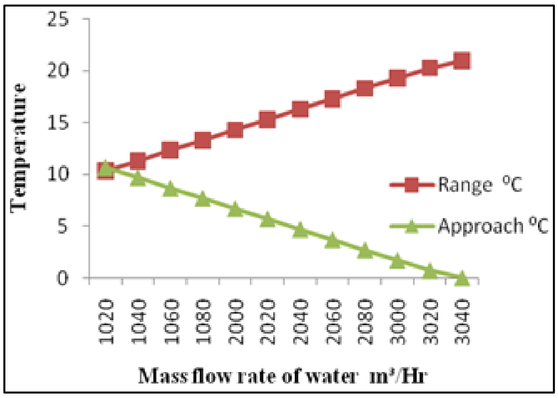


Fig. 6

The graph explains the variation in the Approach & Range with the variations of mass flow rate of water. As the Range increases the Approach is decreased with the increase in the mass flow rate of water. The obtainable value of Range & Approach are 16 **° C** & 5 ° C respectively for the mass flow rate of 2040 m³/Hr. This range results in the improvement of thermal performance and the better effectiveness can be obtained .

COGEN (4 CELL) cross flow		
CT FLOW RATE	m³/Hr	2000

Table 1.7

The below table is drawn by varying the outlet temperature of water keeping wet bulb temperature of air & the inlet temperature of water as constant.

Mass flow rate of water	Range	Approach
m³/Hr	° C	° C
1960	9	4
1980	10	3
2000	11	2
2020	12	1
2040	13	0

Table 1.8:

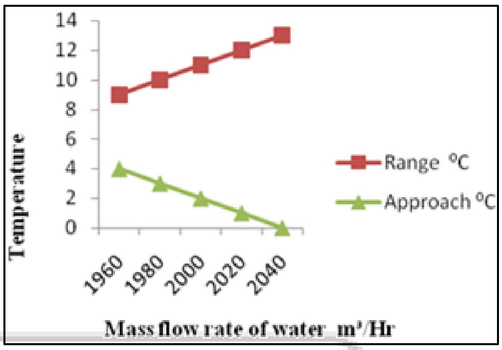


Fig. 7:

In the above graph the range & approach increases & decreases respectively with the increase in mass flow rate of water. For the graph the acceptable temperature for mass flow rate of 2000 m³/Hr the range & approach is 11 ° C & 2 ° C respectively.

S.No	Range	Mass flow rate	Q
	° C	m³/Hr	KJ/s
1	11	1960	25033.56
2	12	1980	27588
3	13	2000	30188.89
4	14	2020	32836.22
5	15	2040	35530

Table 2.7:

Table represents the heat flow for the various mass flow rate of water from 1960 m³/Hr to 2040 m³/Hr. The maximum heat flow of 35530 KJ/s be obtained at a mass flow rate of 2040 m³/Hr whereas the minimum heat flow for 1960 m³/Hr is 25033.56 KJ/s is obtained. The obtainable heat flow rate for 2000 m³/Hr is 30188.89 KJ/s.

Mass flow rate of water	Evaporation losses /cell	Blow down reqd.
m³/Hr	m³/Hr	m³/Hr
1960	26.99	10.80
1980	30.29	12.12
2000	33.66	13.46
2020	37.09	14.83
2040	40.58	16.23

Table 1.9:

The considerable losses & the blow down rate are 33.66 m³/Hr &13.46 m³/Hr respectively for the mass flow rate of 2000 m³/Hr. Both increases with the increase in the mass flow rate of water. This shows the improvement in the thermal performance of the cooling tower.

Mass flow rate of water	Effectiveness
m³/Hr	
1960	0.69
1980	0.77
2000	0.85
2020	0.92
2040	1.00

Table 2.0:

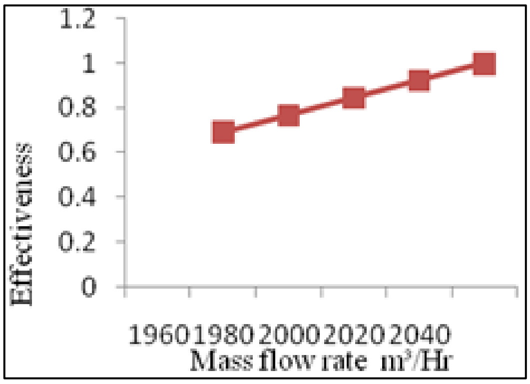


Fig. 9:

The mass flow rate of water is varied from 1960 m³/Hr to 2040 m³/Hr .The maximum effectiveness is obtained at the mass flow rate of 2040 m³/Hr. The effectiveness of 0.85 can be achieved at the mass flow rate of 2000 m³/Hr. The performance of the cooling tower be improved at this effectiveness which is obtained by the graph drawn above. The value of effectiveness is increased as the mass flow rate of water is increased.

(m)air	Outlet temp. of water
Kg/s	° C
1157.24	37.7
1052.03	36.7
964.36	35.7
890.18	34.7
826.60	33.7
771.49	32.7
723.27	31.7
680.73	30.7
642.91	29.7
609.07	28.7
578.62	27.7

Table 2.1:

The graph shows the variation between the Mass flow rate of air & the outlet temperature of water, both decreases simultaneously. The cooling of fluid will be effective when the mass flow rate of air is higher.

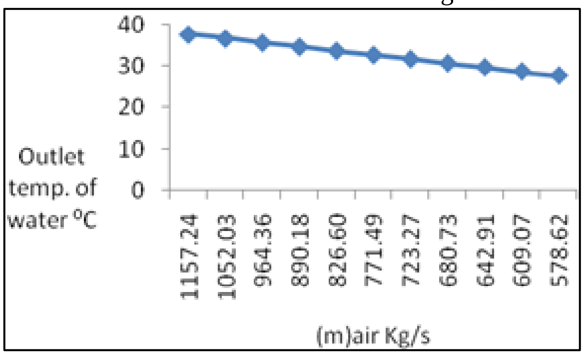


Fig. 10:

(m)air	(dT)air
Kg/s	°C
1157.236	10
1052.033	11
964.3632	12
890.1814	13
826.597	14
771.4905	15
723.2724	16
680.727	17
642.9088	18
609.0715	19
578.6179	20
551.0647	21
526.0163	22
503.146	23
482.1816	24
462.8943	25

Table 2.2:

The table explains how the $(dT)_{air}$ is increased with a reduction of the mass flow rate of air entering the cooling tower. The graph is plotted to show the variations with a steep decrease of mass flow rate of air with respect to temperature difference of air.

IV. Proposed Work

S.No	Consumption & Saving for 1 fan	Unit	20% Power Consumption	30% Power Consumption	Consumption & Saving for 4 fans	
					20% Power Consumption	30% Power Consumption
1	Energy Saved	kWh/Yr	42,120	63,180	1,68,480	2,52,720
2	Amount Saved	Rs/Yr	1,51,632	2,27,448	6,06,528	9,09,792
3	Energy saved after the installation of VFD	kWh/Yr	48, 39,480	48,18,420	1,93,57,920	1,92,73,680
4	Cost saved after the installation of VFD	Rs/Yr	1,74,22,128	1,73,46,312	6,96,88,512	6,93,85,248
5	Pay Back Period	Months	57	38	57	38
6	% Power Consumption	%	0.86	1.29	3.45	5.17

Table 2.2: Energy Consumed in Cooling Tower fan

V. Results & Discussion

The thermal performance of the cooling tower is performed by analysing the various parameters. The correlation between various parameters are plotted in the graph. The effectiveness of the tower can be improved by increasing the mass flow rate of water and decreasing the outlet temperature. The proposal on installing the VFD would lead to the reduction of power consumption. The graph shows how the parameters such as range, approach etc are varied with respect to mass flow rate of water. The discussions was on the improvement of performance and the energy saving opportunities. Suggestions on replacing the high intensity lamps by energy efficient lamps has been given which reduces the energy consumed.

VI. Conclusion

This paper represents the various opportunities for improving performance of the cooling tower. The power consumed for 8640h/yr is calculated and savings is about 42120Kwh/Yr by the installation of VFD in cooling tower fans. The power saved in Cooling tower pump would be about 279244.8 Kwh/Yr for 20% power consumption. The ranges at which the maximum effectiveness can be obtained. The proposal on the reduction of power consumption has been calculated. Graphs are drawn to show the variations between various parameters and this indicates how the performance can be improved.

There is an energy savings of about 202 W/Fixture during the energy auditing in lighting. Suggestions given for using solar street lightings instead of ordinary street lights. Energy saving lamps are used to reduce the energy or the watts consumed.

The efficiency of the boiler is calculated as 46.5% which can be increased by reducing the heat losses due to moisture in the fuel, unburnt carbon, dry flue gas etc. Efficiency of boiler can be improved by arresting air infiltration and by increasing the thickness of insulation which avoids heat losses to the surroundings.

References

[1] By M. Lucas a,*, P.J. Martínez a, A. Viedma b * Energy Conversion and Management 50 (2009) 490–497.
[2] By Jameel-Ur-Rehman Khan, M. Yaqub, SyedM. Zubair Energy Conversion and Management 44 (2003) 2073–2091
[3] S.S. Kachhwaha, P.L. Dhar, S.R. Kale, Proceedings of the 3rd ISHMT-ASME Heat and Mass Transfer Conference, and 14th National Heat and Mass Transfer Conference, India, 1997 (Dec.), p. 29.
[4] M.M. El-Wakil, Powerplant Technology, McGraw-Hill, Singapore,1985.

[5] Walker WH, Lewis WK, McAdams WH, Gilliland ER. Principles of chemical engineering. 3rd ed. New York:McGraw-Hill Inc; 1923.
[6] J.R. Khan, S.M. Zubir, Trans. ASME 123 (2001) 770.
[7] S.P. Fisenko, A.I. Petruchik, A.D. Solodukhim, Int. J. Heat Mass Transfer 45 (2002) 4683.
[8] S.P. Fisenko, A.A. Brin, A.I. Petruchik, Int. J. Heat Mass Transfer 47 (2004) 165.
[9] M.N.A. Hawlader, B.M. Lui, Appl. Therm. Eng. 22 (2002) 41.
[10] P. Stabat, D. Marchio, Appl. Energy 78 (2004) 433.
[11] M. Prasad, Appl. Therm. Eng. 24 (2004) 579.
[12] T.H. Kuehn, J.W. Ramsey, J.L. Threlkeld, Thermal Environmental Engineering, 3rd ed., Prentice-Hall Inc., New York,1998.
[13] Walker WH, Lewis WK, McAdams WH, Gilliland ER. Principles of chemical engineering. 3rd ed. New York:McGraw-Hill Inc; 1923.
[14] Merkel F. Verdunstungshuhlung. Zeitschrift des Vereines Deutscher Ingenieure (VDI) 1925;70:123–8.
[15] Webb RL. A unifiedtheoretical treatment for thermal analysis of cooling towers, evaporative condensers, andfluid coolers. ASHRAE Trans 1984;90(2):398–415.
[16] Webb RL, Villacres A. Algorithms for performance simulation of cooling towers, evaporative condensers, and fluid coolers. ASHRAE Trans 1984;90(2):416–58.