Design of heat recovery device to elevate coefficient of performance of water cooler by circulating drain water

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Abstract - *In water coolers water is cool by either refrigerants or thermoelectric cooling, both of which consumes electric power. However most of the time the cold water gets wasted in varying amount, which directly implies that electric energy gets wasted. This research deals with the design of heat recovery device equipped externally which facilitates precooling of intake water by recirculation of the drain water. Thus the heat from intake water is extracted by the relatively cool drain water, without use of any external work for circulation of drain water by designing the precooler in accordance with the available potential head of tank.*

*Key Words***: Heat recovery device, water cooler, drain water, improve performance, efficient water cooler.**

1. INTRODUCTION :

Energy conservation refers to efforts made to reduce water consumption. energy conservation can be achieved through increased efficient energy used in conjunction with decreased energy consumption. energy conservation can result in increased financial capital, environmental quality and reduce energy crisis.

Nnowadays we have witnessed a significant increase in the use of water coolers mostly in public places like offices, colleges and many more. according to survey, on an average nearly when every individual drinks water 20 to 25% of cold water gets wasted from him.

Our vision is to effectively make use of this waste cold drain water in order to reduce the temperature of incoming water to the cooler, thus reducing the power consumed by the water cooler to attain the same temperature from relatively cool water. The main challenge was the recirculation of drain water through heat recovery device and bypassing the incoming water simultaneously without use of any energy consuming device such as pump. This was overcome by providing suitable head and accordingly design of the heat recovery coil and its placement.

2. LITERATURE REVIEW:

The heat recovery device basically comprises of a heat exchanger whose performance affects the efficiency of the water cooler. Hence it is very important to employ the most suitable and efficient heat exchanger type for application. Efforts were made to sort out the best type of heat exchanger from previously carried out research work.

Helically coil tubes are superior to straight tubes employed in heat transfer applications. In the coiled tubes, the modification of the flow is due to the centrifugal forces caused by the curvature of the tube which produces a second flow field which is a circulatory motion pushing in the fluid particles towards the core region of the tube. A natural convection shell and coil heat exchanger consists of cylindrical shell which with helical coils place inside it. Helical coils are widely used as heat exchangers due to the high heat transfer coefficients.

Helical coiled exchangers offer certain advantages. Compact size provides distinct benefit, Higher film coefficients - the rate at which heat is transferred through the wall from one fluid to another and more effective use of available pressure drop result in efficient and less expensive designs. True counter-current flow fully utilize is available LMTD (Logarithmic mean temperature difference). Helical geometry permits handling of high temperatures and extreme temperature differential without High induced stresses or costly expansion joints.

Due to curvature of the tubes, as fluid flows through curved tubes, centrifugal force is generated. A secondary flow induced by the centrifugal force has significant ability to enhance the heat transfer rate. Single-phase heat transfer characteristics in the helical coil tubes have been widely studied by researchers both experimental and theoretically.

3. DESIGN:

The dimensions of coil are calculated as per the available head of the tank so as to facilitate natural calculation of incoming water without incorporating any other power absorbing devices such as pump.

3.1 Selection parameters for heat exchanger:

It is the most crucial part as far as performance is concerned. Heat transfer rate is the most important parameter for achieving desired temperature change, hence it should have sufficiently high heat transfer rate. Shell and coil heat exchanger is used because of its high performance, high heat transfer rate, compact and lightweight, low maintenance cost, high temperature difference, low pressure drop, easy installation and flexible design. Material is also one of the most important parameters, selection of optimum material with high thermal conductivity and low thermal expansion improve efficiency of unit, hence copper is used.

3.2 Methodology selection:

The heat exchanger are designed by two methods first one is the Log mean temperature difference (LMTD) and the second one is effectiveness- NTU method. LMTD is more reliable when inlet and outlet temperature of hot and cold fluids are known or can be found out by energy balance equation. Therefore LMTD method is very suitable for determining the size of heat exchanger to realize prescribed outlet temperature when the mass flow rate and inlet and outlet temperature are specified.
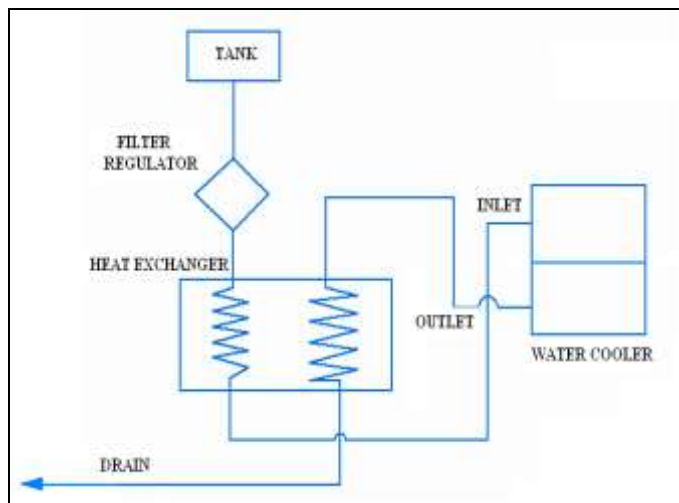

Fig-1 : Block diagram of setup.

Assumptions,

Working hours of water cooler = 8 hrs.

Working hours of heat exchanger = 7 hrs.

Total strength of workers = 360

Total strength of company staff = 40

Therefore total 400 persons use the water cooler. After two hours there is   recess and on an average one person take one glass (250 ml) of water.

Total quantity of water utilized = 400 * 250 ml = 100000 ml = 100 litre per two hour. Therefore per hour 50 liter water is utilized.

We assume that every person 15 to 20 % of water.

Wastage of water = 0.20 * 50 = 10 liter. So 10 liter of cold water per hour is available for heat exchanger. Neglecting the pressure losses in the copper tube.
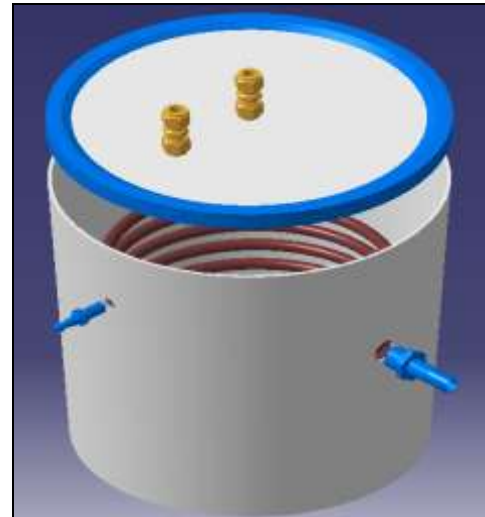

Fig-2: 3D Model

4. OBSERVATION:

The head available for water cooler from water tank is 15 m. Now pressure is given by

$P = \rho * g * h$

$= 1000 * 9.81 * 20$ $= 1.962$ bar

Table-1: Observation table

Sr.No.	Description	Value	Unit
1.	Hot water inlet (T_{hi})	35	℃
2.	Hot water outlet (T_{ho})	30	℃
3.	Cold water inlet (T_{ci})	17	℃
4.	Cold water outlet (T_{co})	X	℃
5.	Mass flow rate of hot water (m_h)	3.75	kg/min
6.	Mass flow rate of cold water (m_c)	2.0682	kg/min

X = To be found out analytically and verified experimentally
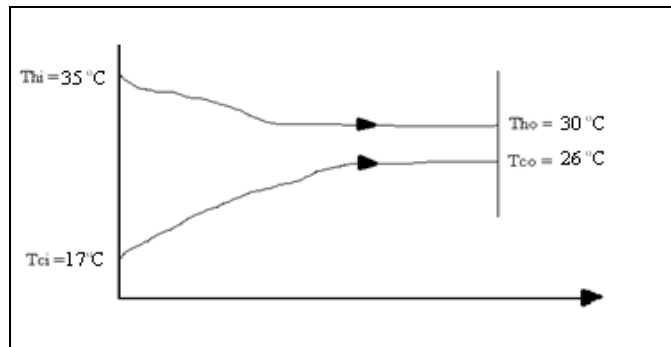
5. CALCULATIONS:

Assuming parallel flow : -

Heat balance equation

Energy given by hot water = Energy taken by cold water

$m_h*C_{ph}*(T_{hi}-T_{ho}) = m_c*C_{pc}*(T_{co}-T_{ci})$

$(3.75/60)*4186*(35-30) = (2.0682/60)*4179*(T_{co}-17)$

$T_{co} = 26$ °C.

Fig-3 : LMTD for parallel flow

5.1 For parallel flow:

In order to develop a relation for equivalent average temperature average between the t wo fluids, consider parallel flow heat exchanger. In comparison with counter flow heat exchanger the dimensions for this heat exchanger are more. So considering the safe design we go for parallel flow type heat exchanger.

Log Mean Temperature Difference (LMTD)

$\Delta T_1 = T_{hi}-T_{ci}$ $\Delta T_2 = T_{he}-T_{co}$

= 35-17   = 30-2

= 18 °C   = 4 °C

LMTD = $(\Delta T1-\Delta T2)/(\ln(\Delta T1/\Delta T2))$

= (18-4)/ln(18/4)

LMTD = 9.308

Overall heat transfer coefficient (U) = 1377.3466 w/m² K.

In water to water type of heat exchanger, the values of overall heat transfer coefficient lies between 850 – 1700 W/m² ° C.

6. DESIGN OF COIL :

Total length of copper tube (L_T) = 6 m.

Length of Straight copper tube from one end (L_1)= 0.3 m.

Length of Straight copper tube from other end (L_2)= 0.13 m.

Required length of copper coil (L_R) = $L_T – (L_1 + L_2)$.

= 6 –(0.3+0.13)

= 5.57 m.

Diameter of copper tube (d_o) = 10mm

Diameter of copper coil (D_C) =210mm

Total surface area of copper tube (A_T)= π * d_o * L

= π * (10*10⁻³) * 6

= 0.1885 m²

Length of one coil (L_{1C}) = π * D_C

= π * 0.21

= 0.65973 m.

Surface Area of one coil (A_{1C}) = π * L_{1C} * d_0

= π * 0.65973 * 10 * 10⁻³ = 0.02073 m².

Surface Area of required copper coil (A_r) = π * d_0 * L_R
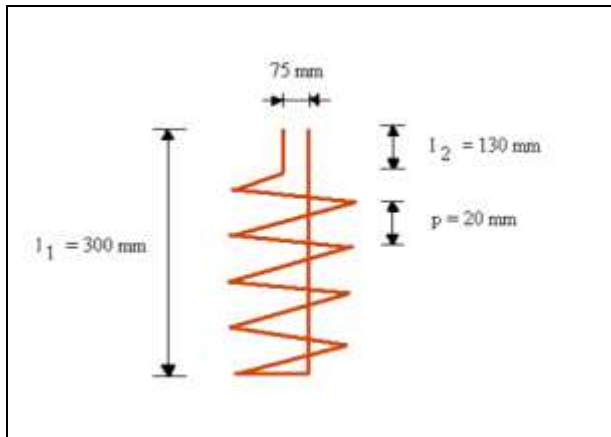
= π * (10*10⁻³) * 5.57

=0.175 m².

Surface Area of required copper coil (A_r) = n * Surface Area of one coil (A_{1C})

0.175 = n * 0.02073

n = 8.44

i.e. No. of turns of copper coil (n) = 8 $\frac{1}{2}$ turns.

6.1 Inlet & outlet port consideration:

n = No of turns = 8.5

Height of coil = 8.5 * 20

= 170 mm

Clearance of coil from base of shell = 10 mm.

Total height of coil from base = 170 + 10

= 180 mm.

Therefore the total height of coil from base is 180 mm.

Considering the available surface area and quantity of water, the position of inlet and outlet ports are designed. Therefore the total length of coil available is 180 mm.

According to the pipe size i.e. inlet pipe to shell and outlet pipe from shell the holes are drills. The inlet pipe diameter is 20 mm and it is drilled 160 mm above the base. The outlet pipe diameter is 10 mm and it is drilled 200 mm above the base.

For the complete use of cold water for heat exchange, the coil is completely dipped in the cold water.

The other important parameters while considering ports position is head available to inlet port of shell. The available head at inlet from drain collector is not sufficient so the height of water cooler is increased. Hence the back flow of water is avoided. So the position of inlet and outlet port is adjusted.

6.2 Theoretical efficiency:

Energy required to cool the water without heat exchanger

$= m_h * C_{ph} * (T_{hi} - T_{ci})$

$= (3.6 / 60) * 4180 * (35 - 16)$

= 4765.2 W.

Energy required to cool the water with heat exchanger

$= m_h * C_{ph} * (T_{hi} - T_{ho})$

$= (3.6 / 60) * 4186 * (30 - 16)$

= 3516.24 W.

Theoretical Efficiency increased by

(1 – (Energy required to cool the water with heat exchanger) / Energy required to cool the water without heat exchanger))

$$= 1 - \frac{3516.2}{4765.2}$$

= 0.2621

= 26.21 %

Therefore the theoretical efficiency is 26.21%.

Total energy saved per year

$Q_{max} = m_c * C_{pc} * \Delta T$

$= (3.6 / 60) * 4.186 * (35 - 30)$

= 1255.8 W.

Assume that heat exchanger will recover 25% of available heat in cold water.

$Q = \varepsilon * Q_{max}$

$= 0.25 * 1255.8$

= 313.95 W.

Considering heat exchanger will operate 7 hr a day.

Operation hours in year = 7 * 365

= 2555 hrs per year.

Energy saved per year = Heat transfer rate * Operation hours

= 313.95 * 2555

= 802.14225 kW per year

So, according to this

energy saved per day = 1.5 to 2.5 Units of energy meter.

6.3 Energy consumption calculation

For 10 revolution of energy meter time required is 53 seconds.

Therefore for 1 revolution time required is 5.3 seconds.

For energy meter to complete 1200 revolution i.e. 1 kW hr of energy consumption of cooler is : -

Time required for 1 kW hr energy consumption = (1200 * 5.3) / 3600 = 1 hr 46 sec.

6.4 Without heat exchanger :

Time required for cooler to cool water from 31℃ to 12 ℃ is 2 hrs.

Energy consumption of water cooler =

$$\frac{\text{Total time required for cooling}}{\text{Time required for 1 kW hr reading of energy meter}}$$

= 106 / 106

= 1 unit.

6.5 With heat exchanger:

Time required for water cooler to cool water with heat exchanger is 1 hr 22 min.

Therefore energy consumption = 82 / 106

= 0.7736 unit

Energy saving =

$$\frac{\text{Energy consumption without H. E. } - \text{Energy con. with H. E.}}{\text{Energy consumption without H. E}}$$

= ((1 – 0.7642) / 1) * 100

= 22.64 %

Therefore, energy saved is 22.64 %.

FIG: Actual setup

7. RESULT

A test run was completed on the apparatus. Once all of the components were in place, the system was checked thoroughly for leaks. After fixing the leaks, the apparatus was prepared for testing. Data was recorded every five minutes until the apparatus reached steady state. The apparatus is in working order and ready for use in the industry with a few small exceptions.

In our condition, we consider the cooler is working in steady condition that is it needs 10 revolution of energy meter completes in 53 seconds. The energy meter constant is 1200 that is when 1200 revolution completes the cooler consumes 1 kW hr. The time required for cooler to cool the water from 35 ℃ to 15 ℃ is 1 hr 46 minutes.

Table-2 : Result Table for unit

Sr. No.	Parameter	Cooler without heat exchanger	Cooler with heat exchanger
1.	Energy Consumption(Unit)	1	0.7736
2.	Time (minutes)	106	82

Therefore in 1 hr 0.1443 unit energy saved and in one day water cooler runs for 7 hr so 1.0101 unit energy saves per day. Then in one month (30 days) 30.3 unit energy saved. The total energy consume in 137 units.

Percentage of energy saved per month

= [1 – ((137-30.3) / 137)] * 100 = 22.12 %.

Coefficient of performance of Water Cooler:

Before heat exchanger

$$\text{COP} = \frac{\text{Refrigerant effect (Q2)}}{\text{Net work done (W)}} = \frac{T_{co}}{T_{hi} - T_{co}}$$

= 16 / (35 - 16)

= 0.8421

After heat exchanger

$$\text{COP} = \frac{\text{Refrigerant effect (Q2)}}{\text{Net work done (W)}} = \frac{T_{co}}{T_{ho} - T_{co}}$$

= 16 / (30 - 16)

= 1.143

Now, Net COP = COP $_{\text{After heat exchanger}}$ - COP $_{\text{After heat exchanger}}$
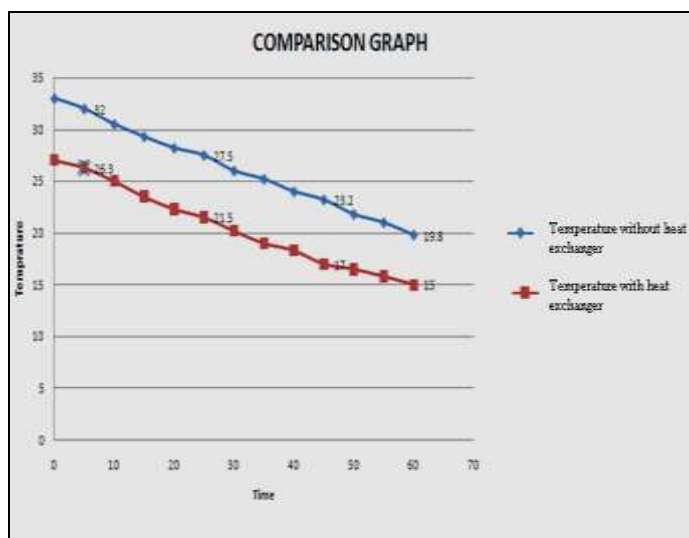
= 1.143 – 0.8421

= 0.301.

Therefore, the COP is increased by 0.301.

Table: Result table for temperature

Sr. No.	Time	Temperature without heat exchanger	Temperature with heat exchanger
1	0	33	27
2	5	32	26.3
3	10	30.5	25
4	15	29.3	23.5
5	20	28.2	22.3
6	25	27.5	21.5
7	30	26	20.2
8	35	25.2	19
9	40	24	18.3
10	45	23.2	17
11	50	21.8	16.5
12	55	21	15.8
13	60	19.8	15

8. CONCLUSION:

The expected energy saved after installing heat exchanger is around 25-28 %. The readings were taken in the month of April and the reading showed that after installing heat exchanger the energy saved is 22.64%. The result varies due to weather conditions, wastage amount of water, etc. The

COP of total system was increased by 0.301. Economically the project cost can be recovered within 9-10 months.

The result achieved after completion of project where highly appreciable in terms of knowledge, quality and with cost reduction.

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