ISSN 2229-5518

Performance Evaluation of Novel Energy Efficient Water Cooler

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Abstract- The continuously increasing imbalance between the energy demand and supply, together with escalating cost of the conventional energy resources as well as growing environmental pollution are forcing people to invent newer methods either to reduce energy demands or to find alternative energy resources. In refrigeration and air- conditioning systems, the compressor is the largest consumer of electricity, in most of the cases consuming about 70% of total electricity. It is well known fact that water cooling is always effective than air cooling. Water cooler provides an opportunity to use water cooled condenser being always installed near water source. An in-house facility is developed by modifying the existing water cooler system to use the water as cooling medium instead of the air as cooling medium. Accordingly, a water cooled condenser system is designed and developed for existing water cooler with the facility to use of waste water from the water cooler, available relatively at low temperature in significant amount. Experiments were conducted at various operating conditions. It is observed that the COP is higher with water cooled condenser in comparison with air cooled condenser due to saving in power. However, cooling capacity is obtained low for water cooled condenser due to reduction in condenser pressure. High flow rate of cooling water in water cooled condenser system gives better performance when compared to low and medium flow rates of cooling water at condenser. High flow rate of cooling water offer better performance at the cost of water. Waste water utilization of the water cooler with low flow rate brings the system COP almost similar to medium flow which saves the water.

Index Terms— water cooled condenser, compressor, water cooler, rotameter, flow control valve, refrigerant,heat exchanger

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1 Introduction

Energy is an important entity for the economic development of any country. The rapid industrial and economic growths in India and China where one third population of the world live, have increased the need for energy rapidly in the recent years. Considering the environmental protection and also in the context of great uncertainty over future energy supplies, attention is concentrated on the utilization of sustainable energy sources and the energy conservation methodologies.

Today world's 15% of total electrical energy is used for refrigeration and air- conditioning applications (As per US Department of energy). In refrigeration and air- conditioning systems, the compressor is the largest consumer of electricity, in most of the cases consuming about 70% of total electricity. Refrigeration and air conditioning systems tend to underperform in extremely hot climatic conditions as prevailed in South-East-Asian nations. Generally an air cooled condenser is employed to reject heat from conditioned space to outdoors. The reason being to make the system as simple as possible without any need to the water connection line and other equipments. This idea seems quite reasonable as far as the air temperature in summer is moderate and not too high, say about 35–37 0C. However, summer temperature in South-East-Asian often exceeds this range.

Temperature of air-cooled condenser directly depends on the ambient air temperature, therefore, in the area with very hot weather temperature in summer; the condenser temperature and pressure are increased considerably which consequently increases the power consumption of the refrigeration system due to the increase in the pressure ratio. Increasing condenser temperature also decreases cooling capacity of the cycle due to the reduction of liquid content in the evaporator. These two effects decrease performance of the system considerably in the area with very hot weather temperatures prevailing summer. Thus, water cooler turns out to be the major contributors to the summer peak electrical demands in most of the nations. Therefore, it is important to have a refrigeration system which can decrease the energy demands and also improve the COP [1].

Compressor Power

As mentioned above compressor is the main consumer of electricity in the refrigeration and air conditioning systems. Hence to have an energy efficient system we need to reduce compressor power. One of the factor on which compressor power depends is the temperature of heat rejection at the condenser. If the temperature of heat rejection at condenser is high, correspondingly compressor consumes relatively more power in order to bring refrigerant temperature higher than that of cooling medium temperature. It is always beneficial in terms of energy conservation to reduce temperature of heat rejection by employing proper method of heat rejection at condenser side [2].

A lot depends on condenser design or its operating temperature and pressure. Either the condenser needs to be redesigned, altering its length and/or diameter or by adopting techniques like internal grooving, optimizing external fins, fin length, fin spacing etc. or the other option is to reduce the operating temperature and pressure of existing condenser design by some means. if the condenser temperature and pressure is reduced, the compressor work is reduced whereas the refrigeration effect is increased. This indicates that by improving the condenser cooling to reduce it temperature and pressure, the system performance can be enhanced.

ISSN 2229-5518

2 DESIGN AND DEVLOPEMENT

2.1 Design Data

Thermal design of the heat exchanger is carried out based on the following considerations:

Flow rates of both fluids; inlet temperature of cooling water, power consumed by compressor, cooling capacity, mass of water to be cooled, velocity of cooling water are required.

Fouling resistances for both streams are to be furnished, the designer should adopt values specified in the standards or based on past experience.

Physical and thermal properties of both streams include viscosity, thermal conductivity, density, specific heat and prandtl number, preferably at both inlet and outlet temperatures. Viscosity data must be supplied at inlet and outlet temperatures, especially for liquids, since the variation with temperature may be considerable and is irregular.

Condenser line sizes are desirable to match nozzle sizes with existing line sizes to avoid expanders or reducers.

Preferred tube sizes are designated as I.D., O.D., thickness and length. Some plant owners have a preferred I.D., O.D., thickness (usually based upon inventory considerations) and the available plot area will determine the maximum tube length. Many plant owners prefer to standardize all four dimensions, again based upon inventory considerations.

Materials of construction, for maximum heat transfer on refrigerant side copper is used and for outer side cast steel is used [16].

2.2 Design Methodology

Heat exchanger is designed for water cooler having following specifications:

Power consumption - 575 W
Refrigerant - R-134a, 600gm
Storage tank - 20 liters Cooling capacity
Compressor - 1/6 HP(300litre)
Pipe material -PVC (3/4 Inch dia)
Copper tube dia -(1/4 inch)

Cooling water at temperature tcw1 enters outer pipe of condenser and leaves the condenser at temperature tcw2 as shown in Fig. 3.1. At the same time refrigerant enters the inner tube of condenser in at temperature tsup1 and leaves the condenser at temperature t4.

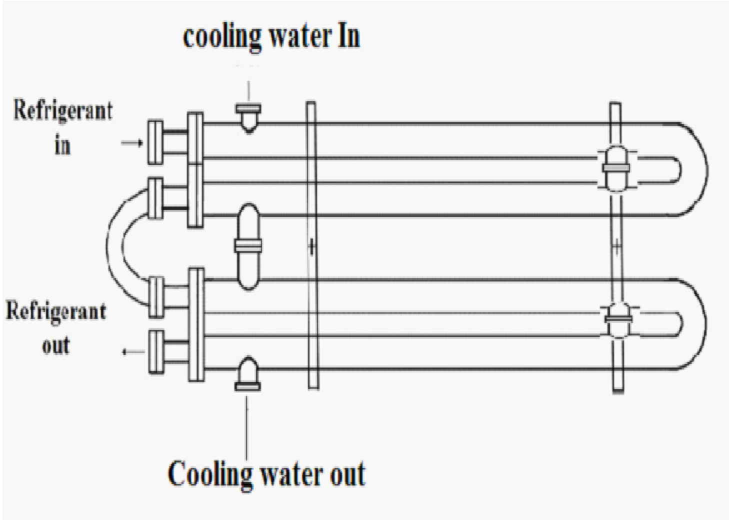


Fig. Heat Exchangr

The refrigerant enters the condenser in a superheated state. It is first de-superheated and then condensed by rejecting heat to an external medium. Here, it is assumed that refrigerant leaves the condenser as a sub cooled liquid. 3.2, the heat rejection process is represented by 2-3 Process is the condensation process, during which the temperature of the refrigerant remains constant as it undergoes a phase change process. Process 3-4 is a sensible, sub cooling process, during which the refrigerant temperature drops from T3 to T4. It is also assumed that during evaporation process refrigerant gets superheated and enters the compressor in the super heated state .

During its path through condenser, the refrigerant coexists in three phases. Refrigerant enters a gaseous state, goes through a two-phase state and finally leaves the condenser in a liquid state as shown in Fig. 3.3. Generally during designing of condenser or odeling, three zones are considered as one lumped two-phase zone, where only one global heat transfer coefficient is calculated or identified as we have done above in our designing. But we have to consider a more detailed model which distinguishes between the different zones and identifies a specific heat transfer coefficient for each zone. This approach allows us to verify the separate influences of gaseous, two-phase and liquid zones on the heat exchanger performance.

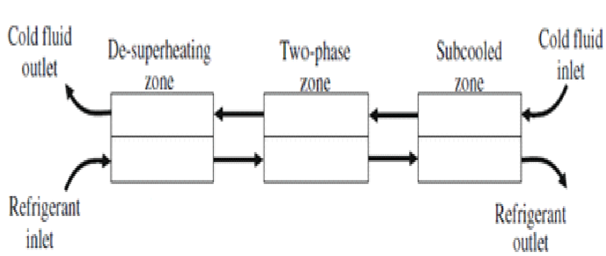


Fig. Condenser three zones

2.3 Simulation methodology

ISSN 2229-5518

During designing it is necessary to follow proper steps and apply checks in between so that accuracy of designing process can be maintained. To maintain the accuracy during designing process, a feedback system is used, in which proper checks are done in between some of the steps. First of all, from the specification of the existing water cooler heat rejected at the condenser Qrej is calculated. Then by assuming initial data such as diameters of pipes, etc. heat rejected by each zone viz. desuperheating, condensing and sub-cooling of the condenser is calculated and they are summed up as Qtotal. If Qrej and Qtotal are nearly equal then assumed initial data is within the range to proceed ahead. This is the first check in the design process.After this check, the length of the condenser Lcondenser is being calculated, considering as one lumped two-phase zone. Then, considering a three zone model of the condenser, length of the condenser for each zone is calculated separately and they are summed up to get Ltotal. Then it is checked that Lcondenser and Ltotal are nearly equal. If they found to be nearly equal, then assumed initial data and calculated lengths are accurate. If during any check the values did not found to be nearly equal then initial set of assumed values are changed and again all the steps are repeated. A detailed design procedure with different feedback steps can be understood easily through flow chart of the design which is given in next point.

2.4 Calculations

(i)For Air cooled condenser

Time required for cooling 20 litre water upto 140c is 50 min.
Evaporator pressure=2.5 bar
Condenser pressure=13 bar
Enthalpy at the start of compression (h1)=398 KJ/Kg
Enthalpy at the end of compression (h2) =430 KJ/Kg
Enthalpy at the start of expansion (h3=h4)=265 KJ/Kg

a)COPTH = Refrigerating Effect/compressor work
= (h1-h4)/(h2-h1)
= (398-265)/(430-398)
=4.156

b)Cooling capacity
Qw=mw.Cpw.(Twi-Two)
= (20/50*60)*4.187*(26-14)
=0.3349 KW

c)Compressor Power
Pcomp=No of blinks * Energy meter costant/3600*time for blink
=10*3200/3600*58
=.1532 KW

d) Actual COP = cooling ccapacity/comp. power
= .3349/.1532
= 2.18

(ii)For Water cooled condenser without waste water

Time required for cooling 20 litre water upto 140c is 50 min.
Evaporator pressure=3 bar
Condenser pressure=10 bar
Enthalpy at the start of compression (h1)=400 KJ/Kg
Enthalpy at the end of compression (h2) =428 KJ/Kg
Enthalpy at the start of expansion (h3=h4)=256 KJ/Kg

a)COPTH = Refrigerating Effect/compressor work
= (h1-h4)/(h2-h1)
= (400-256)/(428-400)
=5.14

b)Cooling capacity
Qw=mw.Cpw.(Twi-Two)
= (20/44*60)*4.187*(26-14)
=0.3806 KW

c)Compressor Power
Pcomp=No of blinks * Energy meter costant/3600*time for blink
=10*3200/3600*60
=.1481 KW

d) Actual COP = cooling ccapacity/comp. power
= .3806/.1481
= 2.57

(iii)For Water cooled condenser with waste water

Time required for cooling 20 litre water upto 140c is 42 min.
Evaporator pressure=3 bar
Condenser pressure=9 bar
Enthalpy at the start of compression (h1)=400 KJ/Kg
Enthalpy at the end of compression (h2) =424 KJ/Kg
Enthalpy at the start of expansion (h3=h4)=256 KJ/Kg

a)COPTH = Refrigerating Effect/compressor work
= (h1-h4)/(h2-h1)
= (400-256)/(424-400)
=6

b)Cooling capacity
Qw=mw.Cpw.(Twi-Two)
= (20/42*60)*4.187*(26-14)
=0.3987 KW

c)Compressor Power
Pcomp=No of blinks * Energy meter costant/3600*time for blink
=10*3200/3600*62
=.1433 KW

d) Actual COP = cooling ccapacity/comp. power
= .3987/.1433
= 2.78

3 TEST FACILITY AND EXPERIMENTATION

An existing water cooler of the voltas is modified by replacing the air cooled condenser by water cooled tube in tube condenser with the facility to use waste cold water. Schematic of experimental setup of water cooler with water cooled condenser is shown in Fig. 4.1 the tap water line from reservoir is divided into two sub lines, one goes to the storage tank of water cooler and other goes to the water cooled condenser. A strainer and a flow control valve are fitted in the water line to the water cooled condenser. A strainer is used to the tap water for condenser cooling, to avoid any possibility of entry of debris. A flow control valve controls the supply of water to the condenser to shut off the water supply during the off period of the water cooler. Controlled flow waste water from water cooler is mixes with the fresh water. The mixed water is supplied to the water cooled condenser. A dedicated power meter is used to measure the energy consumed shown in Fig.

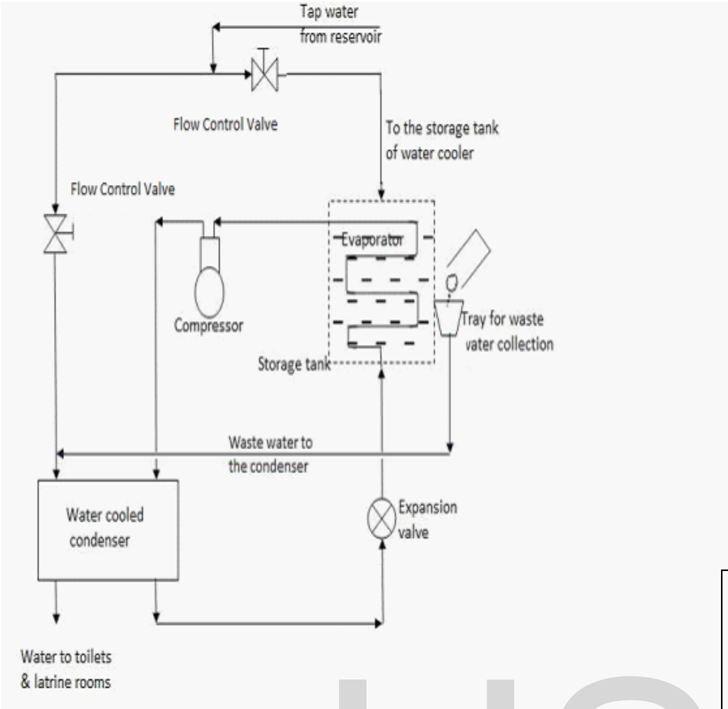


Fig. Schematic diagram of modified water cooler with water cooled condenser

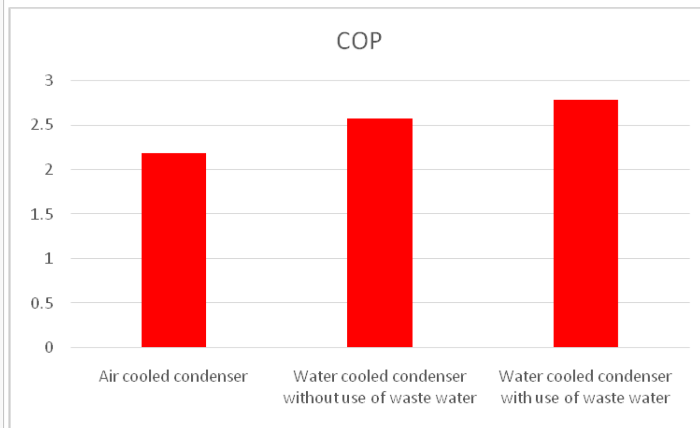
Experimental set up containing water coolers with both air cooled condenser and water cooled condenser arrangement is shown in Fig. The tap water line from reservoir is divided into two sub lines, one goes to the storage tank of water cooler and other goes to the water cooled condenser. Whenever the water cooler is turned on the normally closed solenoid valve gets opened and water starts flowing through the condenser. Fig. shows the arrangement tap water line to both cooler and condenser. Fig. gives the overview of condenser whereas Fig. shows the connections of refrigerant and cooling water to the condenser.. Water from flow control valve flows through the outer pipe of the condenser and refrigerant flows through the inner pipe of the condenser. Refrigerant looses heat to the water and condensed. Waste water at water cooler is sent to the condenser. Before entering to the condenser both tap water and the waste water are mixed in mixing chamber as shown in Fig.

4 Performance Results

A test facility is developed to measure the performance of the modified water cooler by replacing air cooled condenser to water cooled condenser. A novel concept is implemented to utilize the waste cold water from water cooler as supplement water for water cooled condenser. Tests are conducted. Further, performance is measured throughout the day with equal interval of time to study the effect of ambient conditions.

For each test, same quantity of water i.e 20 liters was cooled from 26 0C to 14 0C. A typical results showing comparison of COP, cooling capacity, power consumed and time required for cooling for air cooled condenser system with water cooled condenser system is shown as follows:

Fig-Variation of COP of Air and Water cooled condenser.



	Air cooled condenser	Water cooled condenser without waste water	Water cooled condenser with waste water
COP	2.18	2.57	2.78
Cooling Capacity kw	0.3349	0.3806	0.3987
Power consumed kw	0.1532	0.1481	0.1433
Cooling time(min)	50	44	42

Table:-Performance Parameter comparison.

Energy and Expenses calculation

1) For Air cooled condenser:-

Pcomp= .1532 KW/hr

=.1532*12 hrs*30 days

= 55.152 units

Expenses= 55.152*5 Rs/unit

= 275.76 Rs for 1 month.

2) For Water cooled condenser without waste water:-

Pcomp= .1481 KW/hr
=.1481*12 hrs*30 days
= 53.316 units
Expenses= 53.316*5 Rs/unit
= 266.58Rs for 1 month.
3For Water cooled condenser with waste water:-
Pcomp= .1433 KW/hr
=.1433*12 hrs*30 days
= 51.588 units
Expenses= 51.588*5 Rs/unit
= 257.94Rs for 1 month.

Water cooled system	Saving in Rs for 1month	Saving in Rs for 6month	Saving in Rs for 1year
Without waste water	9.21	65.11	110.17
With waste water	17.86	106.86	213.87

Table:- Money saving in Rs.

5 Conclusion

It is always desirable to keep the condenser pressure low in a vapor compression system. Water cooled condenser can be employed in a water cooler to enhance the condenser cooling. Further, employing water cooled condenser also provides opportunity to use the waste water of the water cooler. An in-house facility is developed by modifying the existing water cooler system by replacing a water cooled condenser which facilitates the use of waste water in place of air cooled condenser. Accordingly, a water cooled condenser system is designed and developed for existing water cooler. Performance of the proposed water cooled condenser system is also compared with air cooled condenser system. The modified system saves energy by reducing condenser heat rejection temperature and in turn decreasing compressor power

The water cooled condenser system enhances COP and reduces energy consumed thereby increasing scope improvement in performance of water cooler. The COP water cooled condenser system more than that of air cooled condenser system. The cooling capacity and time required for cooling are the important parameters and should complement to each other. It is observed that the time required for cooling in air cooled condenser is lower than that of water cooled condenser and in turn cooling capacity is more in case of air cooled condenser system. However, power consumed in water cooled condenser system is significantly lower due to reduced mass flow rate of refrigerant as compared to air cooled condenser system. High flow rate of cooling water offer better performance at the cost of water. Waste water utilization of the water cooler with low flow rate brings the system COP almost similar to medium flow which saves the water.

Acknowledgment

Department of Mechanical Engineering, here knowledge is considered as the liable asset and it is proved that the power of mind is like a ray of sun; and when strenuous they illume.
First and foremost, we express our gratitude towards our guide Dr. S. S. Kore, who kindly consented to acts as our guide. I cannot thank him enough; his patience, energy, an utmost contagious positive attitude, and critical comments are largely responsible for a timely and enjoyable completion of this assignment. I appreciate his enlightening guidance; especially his pursuit for the perfect work will help us in the long run.
I am very much thankful to our Prof. M. M. Dange (H.O.D. Mechanical Engineering) for their whole hearted support in study. I would like to thank to all our teachers at various levels of our education, from whom I have gained more than just academic knowledge. They have positively influenced and shaped our ideas and made me a better person.
I am also grateful to all our friends and parents without their support this task was difficult. Finally I would like to thank all our lab assistants, Teachers and non teaching staff members.

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