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Experimental Test of Locally Fabricated Public Water Cooler

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Abstract**: *The main challenge in the rift valley and low land regions of Ethiopia, the society directly utilize ground hot water for both drinking and shower due to this cause the society is forced to buy cooled bottled mineral water daily. The use of locally fabricated public water coolers seems to be a solution to this problem. The objective of this study is the performance evaluation of locally fabricated public water cooler using a vapor compression refrigeration system. The four basic components of the water cooler, namely, the condenser, evaporator, compressor and the capillary tube are designed and selected separately. The amount of water to be cooled(0.083m^3), ambient air temperature(28°C), water temperature (44°C), the time required to cool water and the evaporator heat load(cooling load of water is 12847.87 KJ) are the predetermined parameters. The raw materials used to fabricate public water cooler are aluminum sheet, compressor, evaporator coil, condenser coil, capillary tube, filter-dryer, refrigerant fluid, water tap, insulator and thermostat. A comparison of experimental and theoretical results has been done and the COP of the cooling system from the theoretical analysis is 3.89 and correspondingly that of an experimental result is 3.17. This shows some variation is observed because of the ideal assumption of the vapor compression refrigeration processes. Also, a Comparison of the present study with literature has been done.***

Keywords: COP, performance evaluation, Refrigerant, vapor compression refrigeration cycle, Water cooler.

I. INTRODUCTION

Water his is an essential part of life for practically almost all organisms living on the planet today. A human being can go many days without food, but cannot go long without water. So, the recommended dose for human consumption of water is just under two litters per day [1]. But in Ethiopia, social service organizations and industries suffer to supply proper cooled water to their society and labors in large volumes. This problem is broadly seen in the rift valley and low land regions of the country. For instance, in different higher institutions like ASTU, Semera, Dire Dewa, Asosa, Dilla and other societies directly utilize ground hot water directly for both drinking and showering. Due to this, the society is forced to buy mineral waters daily.

In order to tackle this problem and unexpected expenses using public water cooler is mandatory. However, obtaining the refused cooler with proper capacity in the market is not possible. Hence locally manufacturing of public cooler is found to be necessary. A water cooler is designed to decrease the temperature of underground hot water (33.6 - 44°C) and to produce cold water and to maintain the temperature of water in the range 7°C to 13°C for quenching the thirst of the people working in a hot environment [2]. During this, the outside temperature varied from 25°C to 31°C. A water cooler is a device that cools water by removing heat from it, either through a vapor – compression or absorption refrigeration cycle; with the key components being the compressor, condenser, evaporator, and expansion device. This study focuses on the performance evaluation of locally fabricated public water coolers based on vapor compression refrigeration cycle. The vapor-compression refrigeration cycle uses a circulating liquid refrigerant as the medium which absorbs and removes heat from hot water to be cooled and subsequently rejects that heat somewhere else. Vapor is routed through a condenser where it is cooled and condensed into a liquid by flowing air. This is where the circulating refrigerant rejects heat from the system and the rejected heat is carried away by air [3]. The condensed liquid refrigerant routed through an expansion valve where it undergoes an abrupt decrease in pressure. That pressure reduction results in the adiabatic flash evaporation of a part of the liquid refrigerant. [4]. The cold mixture is then routed through the coil or tubes in the evaporator. The water evaporates the liquid part of the cold refrigerant mixture. At the same time, the water is cooled and thus lowers the temperature of the hot water to the desired temperature.

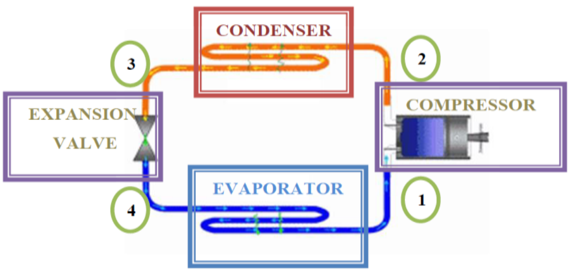

Fig. 1. Schematic diagram of a Simple VCRC [5].

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II. MATERIALS AND METHODS

The constructed public water cooler specification is based on knowledge obtained from the field study, literature review and theoretical calculations which are meeting with the needs or requirements of the user nearby ASTU. Based on these data inputs, preliminary calculations could be done to get the first estimate of the cooling load, and the size of the water cooler was selected based on maximum cooling capacity and amount of cooled water required. The water cooler is installed based on a maximum number of students in one block of ASTU student dormitory. The cooled water requires per day is 400 to 480 liters of water (use maximum size) so, the size of the tanker (volume of water) to be cooled is 80 liters. By considering the stray water volume of a tanker is 83 litters (0.083m^3). The raw materials used in this study include aluminum sheet, compressor, evaporator coil, condenser coil, capillary tube, filter-dryer, refrigerant fluid, water tap and thermostat. The aluminum sheet is selected as the material for the tanker due to its higher thermal conductivity to absorbed heat easily through the wall of the water tanker from the hot water. However, heat gain from the surrounding affecting the water through the aluminum. So, a highly insulating material is required to reduce heat gain from the surrounding. Also, aluminum is the second-most-common food-grade metal next to stainless steel and it is less expensive than stainless steel. It is used for its lightweight, low cost, and rust resistance, and is prized in cookware for the speed with which it heats. Before welding aluminum in oxyacetylene, the aluminum sheet must bend cylindrically.

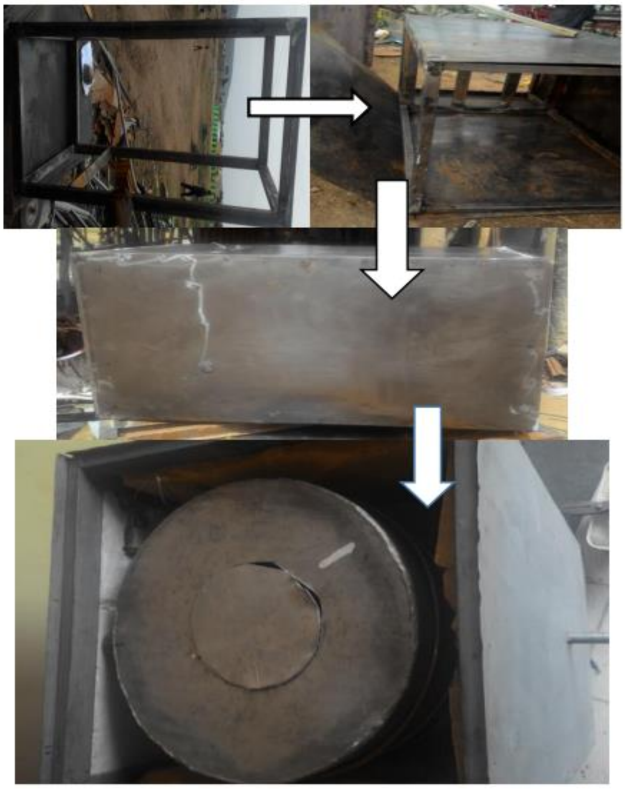

Fig. 1. Manufacturing process of cooler box

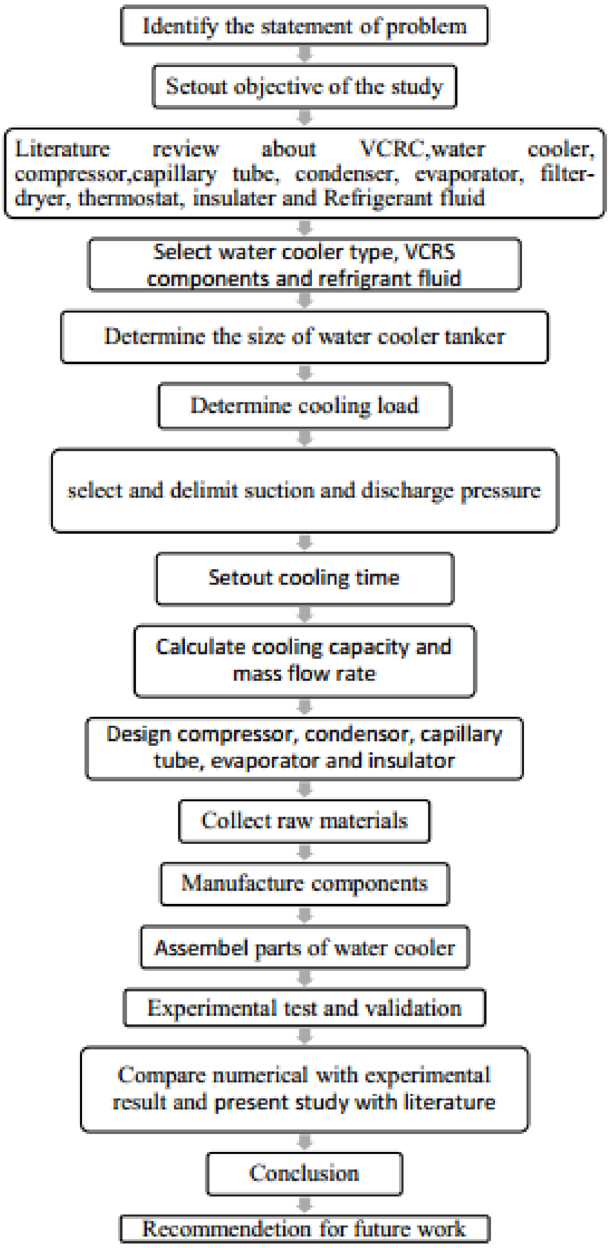

Fig. 2. Work flow diagram of public water cooler

Variables that are directly measured and Assumption

T_{in} Inlet temperature of water (℃)

T_{out} Out let temperature of water (℃)

V Volume of water to be cooled (L)

C_p Specific heat of water$(J/kg℃)$

ρ_i Density of water $(\frac{kg}{m^3})$

T Time taken to cool water (s)

k *Thermal conductivity of Spray foam* $({}^{W}/{}_{m\ *\ ℃})$

D_{co} *Diameter of condenser(mm)*

D_e *Diameter of evaporatorr(mm)*

D_{ca} *Diameter of capilary tube(mm)*

:

Variables that are calculated [4, 8 & 9]

Cooling load

$$Q_L = \rho_i\,(\mathrm{kg/m^3}) * V(m^3) * C_p(J/kg^{\circ}C) * (T_{in} - T_{out})\,(^{\circ}C) \quad (1)$$

Cooling capacity

$$Q_c = Q_L/time(\mathrm{min}) \quad (2)$$

pressure ratio

$$r_p = \frac{P_c}{P_e} \quad (3)$$

Mass flow rate of refrigerant ($^{\mathrm{kg}}/_{\mathrm{s}}$)

$$\dot{m} = \frac{\text{Cooling capacity } (Q_c)}{(h_1 - h_4)} \quad (4)$$

Power of compressor

$$(W_c) = \Delta h_c * \dot{m} \quad (5)$$

Coefficient of performance

$$COP = \frac{h_1 - h_4}{h_2 - h_1} \quad (6)$$

Critical radius of insulation $R_c = \frac{K}{h_o}$ (7)

Table 1. General summary about components of water cooler

Components	Selected type for this study
Refrigeration cycle	Vapour compression refrigeration system
Water cooler	Storage type
Compressor	Hermetic sealed
Condenser	Air cooled wire-and-tube type
Evaporator	Bare tube type
Expansion device	Coiled type capillary tube
Filter-dryer	Throw away type
Thermostat	Cold thermostat
Insulation	Spray foam
Refrigerant fluid	R134a

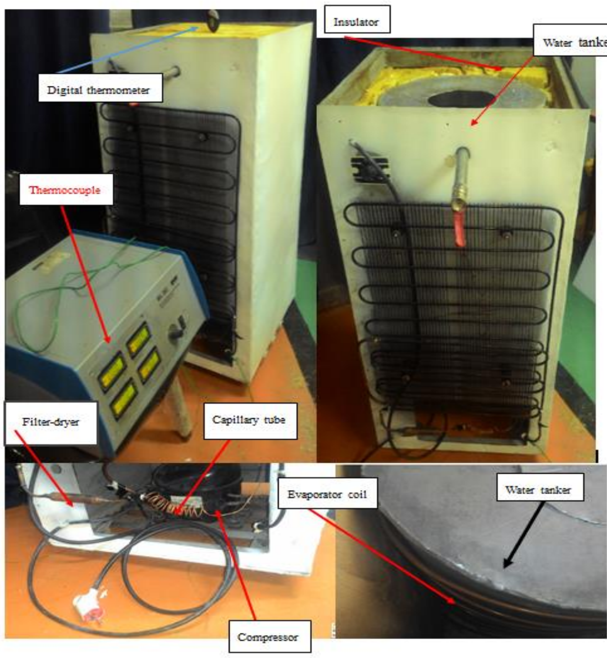

Fig. 3. Equipment's for experimental set-up

III. RESULT AND DISCUSSION

The overall performance of system is subjective by operational parameters such as the evaporating and condensing temperatures, flow rates of refrigerant and ambient temperature, tests with the experimental cooler was planned in such a way as to allow for the evaluations of their effects on COP and various operational conditions. The experimental was designed using the fabricated public water cooler with the following inputs: evaporating temperature -4℃, condensing temperature 46.3℃ and an average ambient temperature of 28℃. Data obtained from the experiment was used to assess the quality of the model relative to the experimental tests.Firstly, the design of the public water cooler for the student dormitory is started by fixing the volume of water-cooled (V), V= 0.083 m3 with an inlet temperature of 44 ℃ and wants to decrease an outlet temperature of 10℃ in thirty minutes.

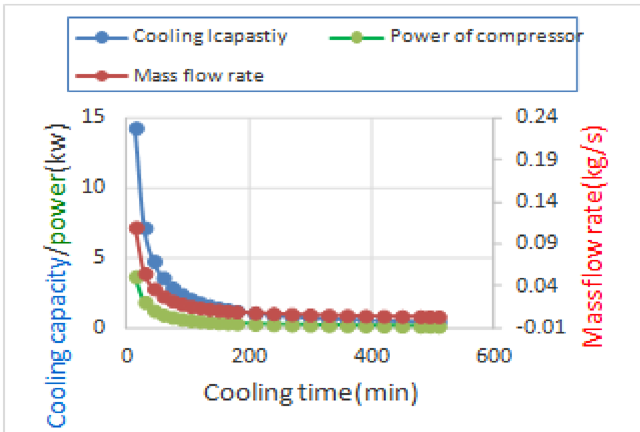

Fig. 4. Power of compressor requires, cooling capacity and mass flow rate of refrigerant at different cooling time

A. Comparisons of theoretical and experimental results

Table (2) shows the comparison between the experimental and theoretical data. There is a slight variation between the theoretical and the experimental data is due to heat loss, which at present it is almost impossible to prevent since there is no perfect insulation of heat and frictional pressure drops in connecting lines.

Table 2. Comparison of theoretical and experimental results

No.	***Name of parameters***	***Results***				***Unit***
		Theoretical		**Experimental**	**Percentage error(%)**	
Time require to cool water		**30 min**	**300 min**	**300 min**		
1	Evaporator pressure	252.7	252.7	257	1.7	kPa
2	Condenser pressure	1200	1200	1252.9	4.2	kPa
3	Mass flow rate	0.055	0.0055	-------	------	Kg/s
4	Pressure ratio	4.75	4.75	4.88	2.7	__
5	Power of compressor	2.45	0.25	0.25	1.2	Hp
6	Coefficient of performance	3.89	3.89	3.17	18.5	__
7	Length of evaporator	50.88	14.9	15.24	2.2	M
8	Length of condenser	15.3	6.3	6.75	6.7	M
9	Length of capillary tube	3.8	3.1	3.6	13.9	M

Coefficient of performance of experimental result is less than that of theoretical result, because of condenser temperature of experimental is much larger than that of theoretical, due to heat transfer only in natural convection. Atmospheric air is the cooling medium for this refrigeration systems. Since the ambient temperature at a location can vary over a wide range, the heat rejection temperature may also vary widely. In hermetic sealed compressors additional heat transfer from the motor winding to refrigerant takes place. The effect of this transfer is to increase the temperature of refrigerant, thereby increasing the specific volume. So, rejection in the condenser. Figure (6) shows the comparison between the experimental and theoretical performance of the system.
The thermostat stops the compressor when the temperature of water reach 10°C. As the temperature of water rises up due to additional hot water add to tanker or external heat transfer to water from surrounding the thermostat on the compressor and start removal heat until temperature of water reaches 10°C.

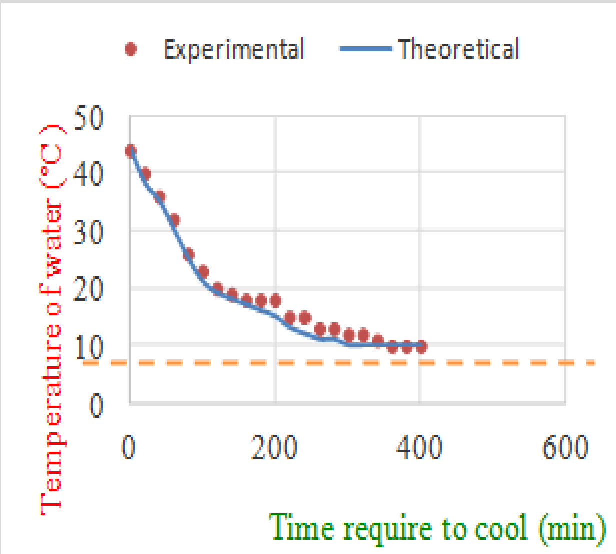

Fig. 5. Theoretical and experimental water temperature versus time

It can be observed that in Figure (6), that the theoretical and the experimental data followed the same trend. The difference may be associated with heat leakage. It is interesting to note that the theoretical predicted almost a linear relationship for the COP with the experimental results. The theoretical model reaches a steady-state much faster than the experiment. This difference between the theoretical and experimental results might be attributed to uncertainties within the theoretical parameters. The thermal resistances between the aluminum and the water were measured based on other experiments. However, these measurements have uncertainties, which meant that the resistances may not be exact. Additionally, the properties of the system may change as time-lapses and temperatures change. Properties of the materials were assumed to be constant but may change with temperature. Water movement also was not taken into account, but water may have been moving due to vibrations of the compressor on the system and induced water movement as the temperature of the water decreased. Water movement, for example, would increase the heat transfer coefficient between the water and the cold side of the aluminum, reducing the thermal resistance. This would increase the amount of heat absorbed and decrease the temperature of the water.

B. Comparison of present study with literature

To decide where to put the present study in the literature and to compare the results, Table (3) may help.

Table 3. Comparison of present study with literature

Parameters	Chow et al. [6]	Heydari [7]	Phelan et al. [9]	Seyfettin [8]	Present Study		
					Theoretical		Experimental
					Time to cool		
					30min	300min	300min
Heat load(w)	32	-	100-300	45	7137.70	713.77	713.77
T_e(°C)	12	20	5	0	-4	-4	-3.5
T_c (°C)	-	60	55	50	46.31	46.31	48.2
$P_e(kpa)$	443	571	349.85	292.8	252.7	252.7	257
$P_c(kpa)$	-	1681.8	1495.6	1317.7	1200	1200	1252.9
$T_{amb}(°C)$	45	36	33	30	28	28	28
Flow rate (g/s)	16.3	-	0.8- 2.5	0.35	54.78	5.48	------
Refrigerant	R134a	R134a	R134a	R134a	R134a	R134a	R134a
COP	3.34	3.0	3.0	3.89	3.90	3.90	3.17
Compressor type	Centrifugal	Piston	Scroll	Piston	Hermetic sealed	Hermetic sealed	Hermetic sealed

As shown in the table (3), in the present study, the COP for both theoretical models were 3.90 and for experimental is 3.17 and in literature COP for Chow et al. [6] is 3.34, Heydari [7] is 3.0, Phelan et al. [9] 3.0 and Seyfettin [8] is 3.89. Since the study of Phelan et al. [9] is an experimental study. So, the present study has better performance than literature for both theoretical and experimental aspect. However, it should be noted that Therefore, the present study may be thought as a milestone in the literature where a storage type public water cooler with all of the components is designed theoretically.

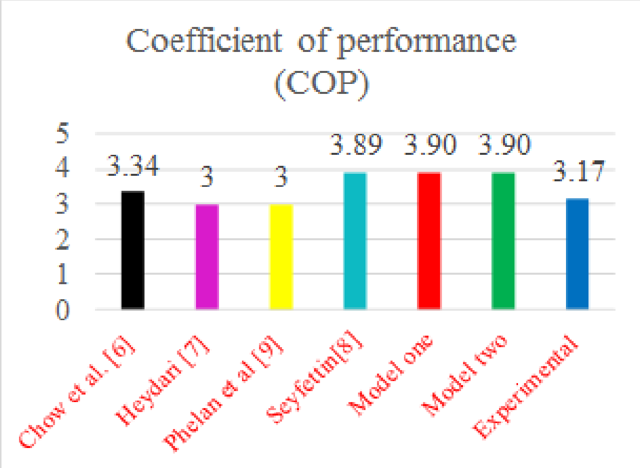

Fig. 6. Comparisons of present study with literature in COP values

IV. CONCLUSION

The overall performance of the water cooler is strongly influenced by the agreement between the major components, those are condenser, compressor, evaporator and capillary tube, and the operational parameters, such as ambient temperatures, condensing temperatures, evaporating temperatures and mass flow rate. These parameters were used in this study to validate a design model developed. The maximum cooling load used for the design is 12847.87 KJ with a 10% allowance. In the present study, two models are developed. For the first model water cooler takes 30 minutes to cool water from 44 °C to 10 °C, at a cooling capacity of 7.14 KW and 300 minutes take at a cooling capacity of 0.71 KW for the second model. The second model is developed from the first model by scale down cooling capacity by ten for comparison of theoretical with experimental results. The power of compressor requires for a first and second models is 2.46 hp and 0.245 hp respectively. In this experimental performance evaluation of a vapor compression system, the performance tests are conducted for refrigerants R134a. Test results were used to assess the quality of the model by comparing the experimental results with the model predicted (theoretical) results.).

The COP values of the theoretical results were 3.89 and the experimental results are 3.17. This shows some variation is observed because of the ideal assumption of the vapor compression. As shown in the result and discussion (figure 6) the time requires to cool water follows the same trend and almost the same as the theoretical time to cool at a cooling capacity of 0.71 KW. By comparing the present study with other vapor compression refrigeration system in table 3 they observed that this water cooler is having an excellent performance with good cooling of water and also have better efficiency. The temperature of outlet water obtain is in the range of 7 °C to 13 °C. In conclusion, a water cooler has been successfully designed and analyzed within the scope of this study. The theoretical and experimental results of locally fabricated public water cooler actually indicate that the objective of the study is achieved.

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