Performance Evaluation of Locally Fabricated Public Water Cooler

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Abstract. This study aims to supply sufficient drinking water for hot land regions in Ethiopia, specifically higher institutions such as ASTU, Dilla, Semera, Derie dawa, Gambiela and Assosa Universities. The investigation focuses on evaluating the performance of locally manufactured public water coolers developed using the VCRS system.

The predestined parameters are inlet temperature of water (44 °C), the estimated time, the volume of water, surrounding temperature of the air (28 °C), and heating load of evaporates (12847.87 kJ). Two models are designed in the present investigation, the first one for experimental and the second for numerical analysis and for compare with experimental analysis and previse investigation. After design and select the component the model developed and simulated using EXCEL. R134a is selected as a refrigerant because it has less global warming potential, zero ozone depletion potential value, inexpensive and easily available. Aluminum sheet, R134a, spray foam, thermostat, and VCRs components are materials used to fabricate the coolers. The walls of the storage tank is wounded by the evaporator coil. Due to high performance of cooler, the storage type of water cooler is selected. The theoretical results have been validated with experimental results and the present study compares with the literature. As per this investigation, the cop of the cooler is recorded 3.17 and 3.89 for experimental and theoretical results respectively. This result variation is detected due to ideal assumption of VCRs process.

Keywords: VCRs · Storage tank · Locally manufactured · COP · Public water cooler

Nomenclature

VCRs	= Vapour compression refrigeration system
ASTU	= Adama Science and technology University
Cop	= Coefficient of performance

1 Introduction

This study is focus on storage type water cooler using VCRs. Human being consume two-litter water per day [1]. However, in hot region of Ethiopia challenges to supply cooled water to their society for higher institutions, social service organizations and industries. Specifically in higher institutions such that ASTU, Asosa, Semera, and Dilla

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university directly use hot water for drinking purpose. The society buy mineral waters daily. Locally fabricated public water cooler seems the solution for this challenge and unexpected expenses. A storage type water cooler is developed to produce cold water and to preserve water temperature between 7 °C and 13 °C by reduce the temperature of hot water from 44 °C [2].

In nature heat is always transfer from high-temperature to low-temperature object without requiring any devices. However, the reverse process cannot occur by itself. Therefore, refrigerators device require transferring heat from a low-temperature to a high-temperature region. Water cooler is one of refrigerator device to cools water by removing heat from it, using VCRs or absorption refrigeration cycle [3]. This paper use VCRs using four basic components. In VCRs, the refrigerant compressed in compressor then condense in constant pressure in condenser them routed in capillary tube to decrease the temperature of refrigerant for evaporation in evaporator coil [4] (Fig. 1).

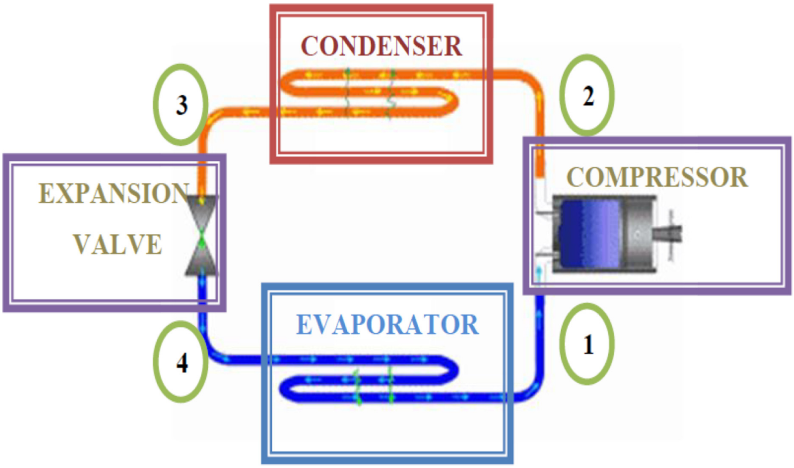

Fig. 1. Simple VCRC schematic diagram

2 Methods and Materials

The fabricated cooler design is based on knowledge from previse investigation and Numerical analysis. Theoretical and experimental approaches used as a methodology in this study. The numerical (theoretical) approach use governing equation in each analysis of components. The experimental approach used in this study is to test and validation with numerically developed model results at the same working condition. Therefore, in order to achieve the required objective, this study will use both numerical and experimental method.

In this paper aluminum sheet, evaporator coil, compressor, condenser coil, dryer, expansion valve, the refrigerant and thermostat are used as raw materials. Due to its higher thermal conductivity to absorbed heat easily through the wall of the tanker from the hot water aluminum is chosen material for the tanker. Insulation material used to prevent heat transfer from surrounding to tanker. In addition, aluminum less expensive than stainless steel and it is the second most common food grade materials. The materials and individual components of refrigeration system that are used to fabricate public water cooler are easily available in the market so, it is necessary to fabricate water cooler locally (Figs. 2 and 3).

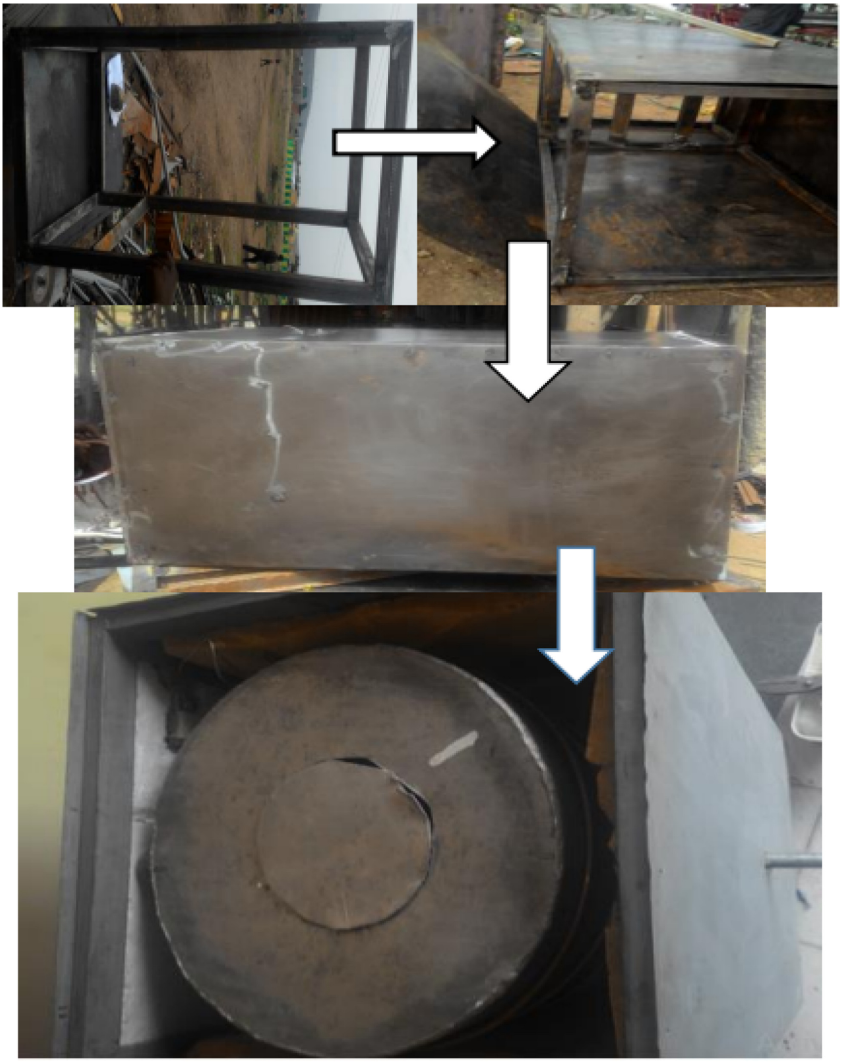

Fig. 2. Fabrication process of box of cooler

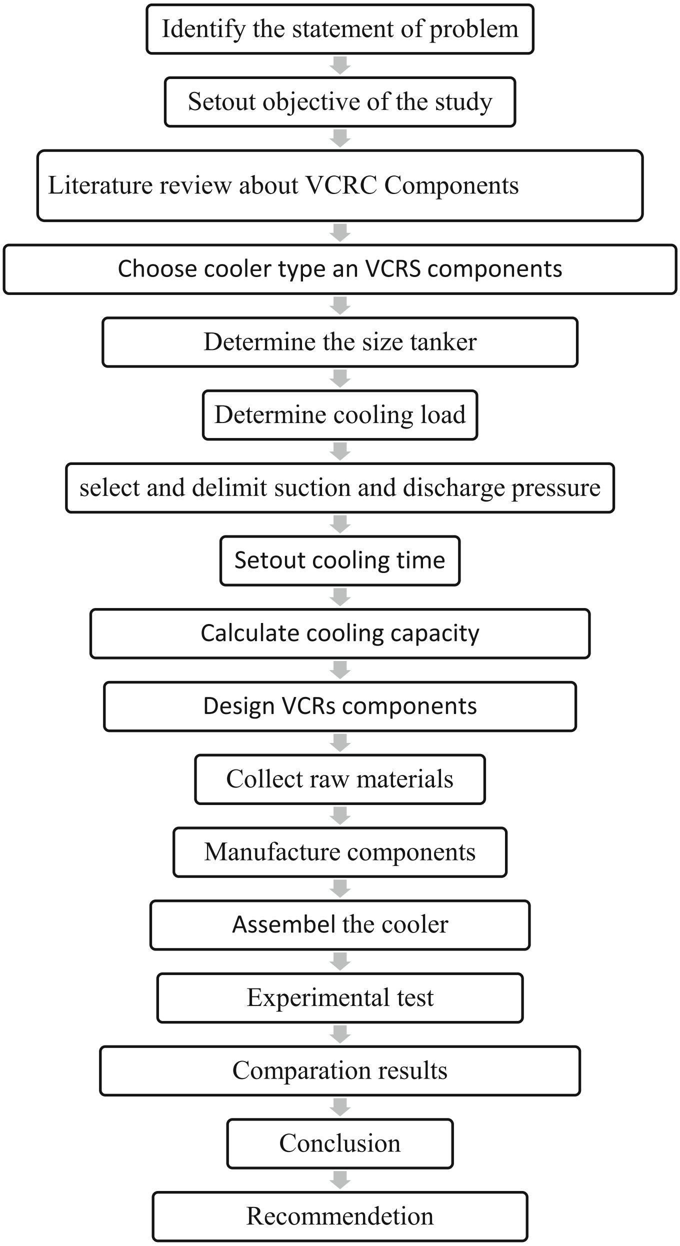

Fig. 3. Design methodology of cooler

Measured and Assumption Variables

T_{in} inlet temperature (°C)
T_{out} exit temperature (°C)
V Size of tanks (L)
C_p Specific heat (J/kg°C).

ρ_i Water Density $\left(\frac{\text{kg}}{\text{m}^3}\right)$
T Time to cool (s)
k Thermal conductivity $\left({}^{w}\!/_{\text{m} * {}^\circ\text{C}}\right)$
D_{co}, D_e D_{ca} *Diameter of condenser, evaporater and expansion valve (mm)*

Calculated Variables

Cooling load

$$Q_L = \rho_i\left(\text{kg}/\text{m}^3\right) * C_p(J/kg^\circ\text{C}) * (T_{in} - T_{out})(^\circ\text{C}) \tag{1}$$

Cooling capacity

$$Q_C = \frac{Q_L}{time(\text{min})} \tag{2}$$

Pressure ratio

$$r_p = \frac{P_c}{P_e} \tag{3}$$

Mass flow rate $\left({}^{\text{kg}}\!/_{\text{s}}\right)$

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

Input power (Fig. 4) (Table 1)

$$(\dot{W}_c) = \Delta h_c * \dot{m} \tag{5}$$

Table 1. Refrigeration cycle and components of cooler

Components	Choose for the investigation
Refrigeration cycle	VCRs
Water cooler	Storage
Compressor	Centrifugal
Condenser	Air cooled
Thermostat	Cold thermostat
Expansion valve	Coiled
Filter	Dispose type
Evaporator	Tube type
Insulation	Spray foam
Refrigerant	R-134a

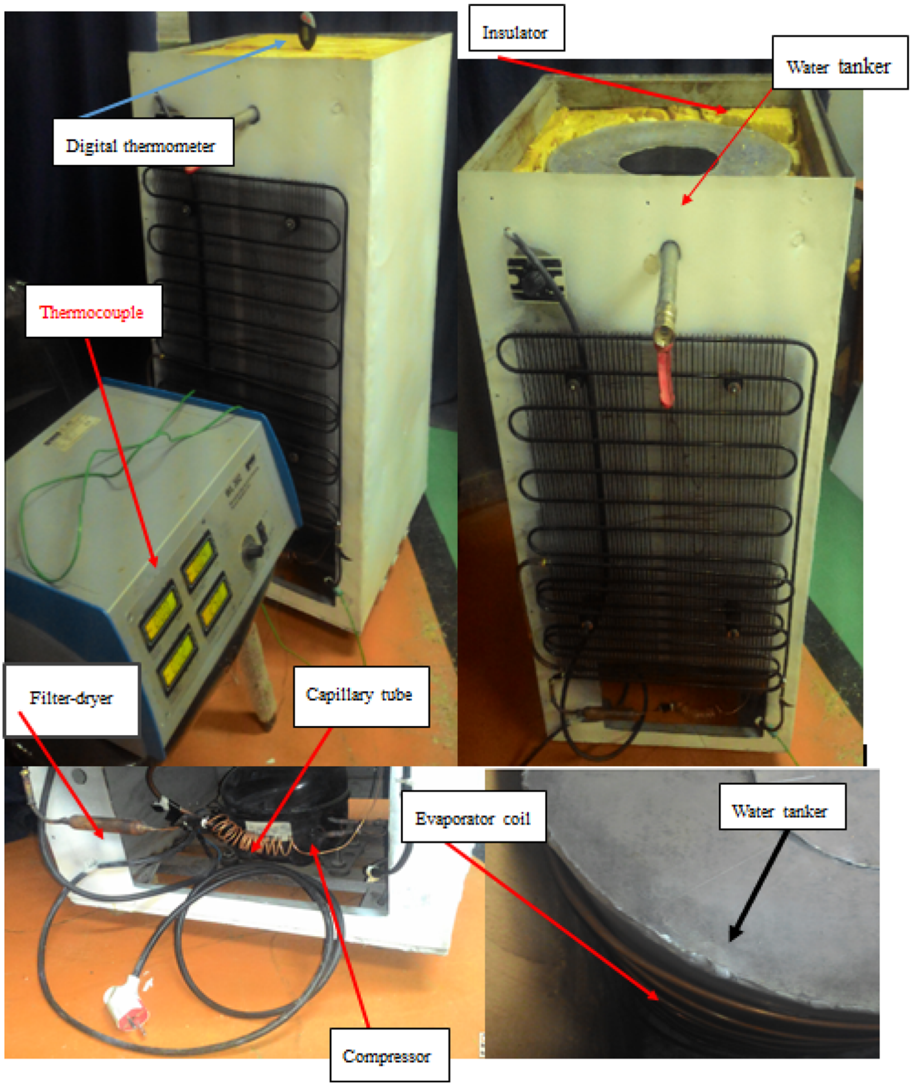

Fig. 4. Experimental set-up of water cooler

COP

$$COP = \frac{h_1 - h_4}{h_2 - h_1} \tag{6}$$

$$insulation\, R_c = \frac{K}{h_o} \tag{7}$$

3 Result and Discussion

Fabricated cooler use for develop experiment using evaporating condensing temperatures (−4 °C), condensing temperatures (46.3 °C) , flow rates of refrigerant and ambient temperature of air (28 °C), volume of water-cooled (0.083 m^3) reduce to 10 °C from of 44 °C in 30 min. Condensing temperatures, the evaporating temperature, flow rates of refrigerant and ambient temperature, are operational parameters that affect overall performance of system. Tests with the experimental cooler was planned for the evaluations of their effects on COP and various operational conditions (Fig. 5).

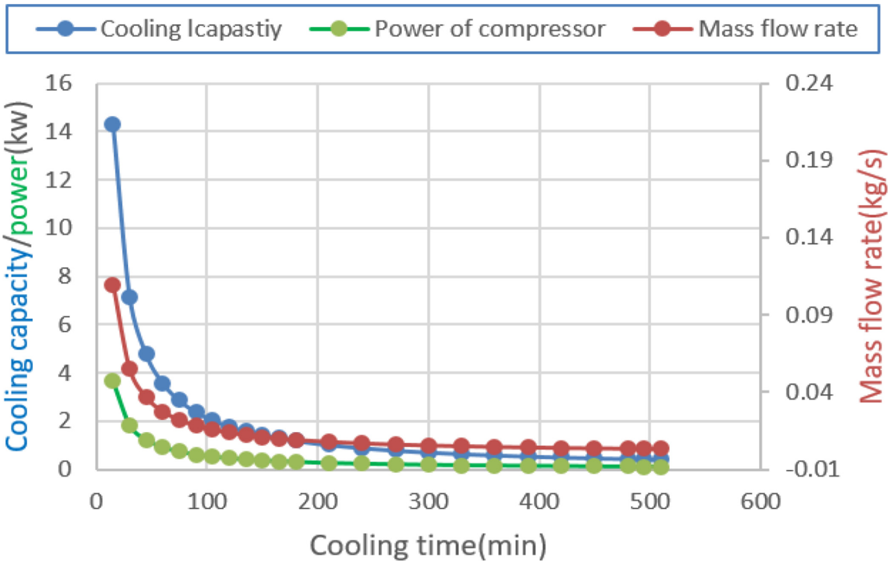

Fig. 5. Cooling capacity, compressor power and flow rate at different time to cool

3.1 Comparisons of Theoretical and Experimental Results

Due to frictional pressure drops in connecting lines, heat loss and lack of perfect insulation the results is slight variation between two results occurs as shown in Table 2.

As show in the above COP of experimental result is less than that of theoretical result because of heat transfer in non-forced convection only. Figure 6 shows the comparison between the numerical and experimental performance of the cooler.

To control the temperature of water cold thermostat require to open or close the compressor when temperature of water around 10 °C. When water temperature increase due to heat transfer from environment the cold thermostat open the motor until Tw = 10 °C.

Table 2. Experimental results and theoretical results comparison

No	Name of parameters	Results				Unit
		Theoretical		Experimental	Percentage error (%)	
t		30 min	300 min	300 min		
1	Pe	252.71	252.71	2571	1.701	*kPa*
2	Pc	1200	1200	1252.92	4.21	*kPa*
3	mr	0.0553	0.00553	–	–	Kg/s
4	Pr	4.752	4.752	4.881	2.721	–
5	Win	2.45	0.25	0.25	1.23	*hp*
6	COP	3.892	3.892	3.173	18.53	–
7	Le	50.88	14.9	15.24	2.24	m
8	Lc	15.32	6.34	6.75	6.72	m
9	Lct	3.81	3.14	3.62	13.93	m

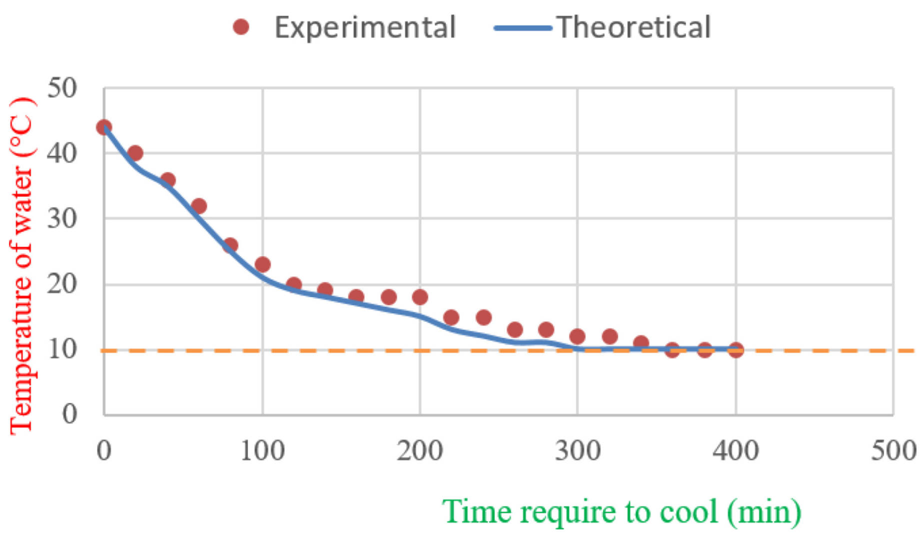

Fig. 6. Numerical and experimental water temperature versus time

In the above figure temperature of water with time require cooling, experimental and theoretical result are almost the same but some variation shows due to heat leakage occurs and materials properties assumed to be constant but change with temperature.

3.2 Comparison of Previse Investigation with the New Study

Table 3. New study with Previse investigation comparison

Parameters	Chow et al. [6]	Heydari [7]	Phelan et al [9]	Seyfettin [8]	Present Study		
					Theoretical		Experimental
					Time to cool		
					30 min	300 min	300 min
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
$T_{amb}(^{\circ}C)$	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 above, in this paper, the COP for theoretical 3.90 and for experimental is 3.17 and in previously investigated findings shows 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. Therefore, this paper has higher COP than previse investigation for both numerical and experimental aspect (Fig. 7) (Table 3).

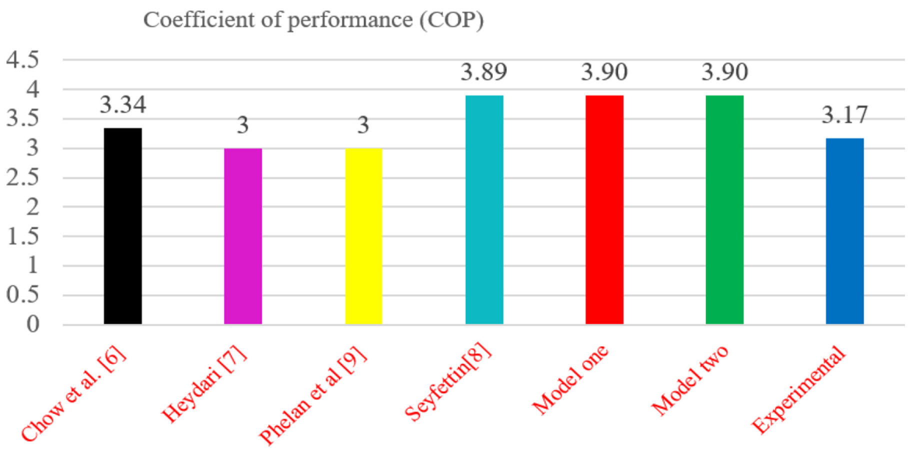

Fig. 7. Charts of comparisons between present study and literature in COP values

4 Conclusion

The experimental model is designed considering basic components of VCRs and parameters like T_{cond}, T_{eva} and $\dot{m}$. And, cooling load is 12847.87 kJ plus 10%. Currently, two cases are investigated. The first model realized a model designed by taking a 30 min to cool down from 44 °C to 10 °C, with 7.14 KW cooling capacity and the second one takes 300 min with 0.71 KW cooling capacity. Besides, compressor power requires for a first is 2.46 hp and second models is 0.245 hp. And for both model R134a is used to conduct the experimental set up. In addition, the perceived COP variation as some assumptions shows experimental results (3.17) and the theoretical results (3.89).

In the end, this study shows the public water cooler improved performance in comparisons of the previous investigation.

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