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Research Article

Performance Estimation of Air Conditioner Using Water Cooled Condenser

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Abstract:
The objective of this research paper is to study the effect of using water for condenser cooling on the performance of an air conditioner. A condenser is immersed in a tank in which water is circulated through it. The air conditioner based on vapour compression refrigeration system is experimented with for different percentages of condenser immersion in a water tank. The result obtained is compared with that of a conventional air conditioner, which indicates that there is a rise in heat transfer of the condenser with an increase in water flow rate. The water cooled condenser exhibits better performance than the conventional air-cooled condenser. An increase in coefficient of performance of 11.6% is obtained when the three-fourth condenser is dipped in a water tank with a flow rate of 400 liter per hr.

Keywords: *COP, Condenser, VCRS, Heat transfer*

1. Introduction

Due to rapid population growth and enhanced living standards, the consumption of electrical energy in air conditioners increased. One of the global challenges is to reduce the consumption of electrical energy in air conditioning applications. Improving the performance of an air conditioner by employing a submerged-in-water condenser to enhance the heat transfer will have a positive effect on energy consumption and will be able to contribute to clean energy goals. The sales volume of air conditioners in India in 2018 was 5.5 million pieces, which increased to 8 million pieces in 2022 and is estimated to further rise to 20 million pieces by 2028. There is an anticipated volume growth of air conditioners by 17.3% in 2025 in India due to the country's rising middle class and increasing urbanization [1]. By 2050, it is estimated that the power requirement for cooling will increase many folds. This has urged the researchers to improve the efficiency of air conditioners. Amongst many, one of the reasons for the reduction in efficiency of air conditioners in summer is due to the lower condenser performance since only forced air is used to cool the condenser refrigerant. In a dusty environment, the air-cooled condensers fail to perform due to limited heat transfer. The predicted rise in global temperature by 3 °C up to the end of this century will directly affect the condenser efficiency as well. Any improvement in the efficiency of the air conditioner will reduce the electricity consumption and help in sustainable growth. This will serve the purpose of achieving the goal of lowering the carbon footprint. The objective of this research paper is to study the effect of using water for condenser cooling on the performance of an air conditioner with a view of increasing the performance coefficient.

2. Literature Review

Singh et al. [2] simulated the Vapour compression refrigeration system (VCRS) with a subcooler and deduced the optimum value of evaporator and condenser temperatures to minimize the power input to the compressors. Taliv et al. [3] experimented on a vapor compression refrigeration system and concluded that the air flow rate using cellulose

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for evaporative cooling leads to an increase in Coefficient of Performance (COP) of 2.3% as compared to conventional systems. The other method of enhancing the performance of VCRS is presented by Babarinde et al. [4] by using multi-walled carbon nano-tubes in refrigerant to increase COP by 25.5%. Research has been done to enhance the air conditioner performance by cooling condenser refrigerant using water as a coolant. Heat exchanger, designed to pre-cool the refrigerant before condenser using water as a coolant by Siricharoenpanich et al. [5], increased the COP by 31.2% as compared to conventional systems. Thiangchanta et al. [6] found a heat rejection increase of 74.3% with their pre-cooling system when compared with the traditional condenser in an air conditioner. This resulted in a reduction of energy requirement by 26.6%. A cooling pad of 100 mm thickness for cooling air before passing over a condenser by Martinez et al. [7] proved to be effective since this increased COP by 10.6% by reducing power consumption and increasing refrigerating effect. Condensate in the heat exchanger for cooling the air before the condenser coil has increased the effect of refrigeration by 3.6% and the overall COP by 11.71% when compared with conventional air conditioners by Ambarita et al. [8]. Yang et al. [9] employed an atomization cooling element with condensate to pre-cool condenser air, resulting in an enhancement of refrigerating capacity by 8.1% and a reduction in power consumption by 9.5%, thereby increasing the energy efficiency ratio by 20%. A synchronized condensate water drain used to decrease the air temperature used as coolant for the condenser by Sawan et al. [10] resulted in saving 5.3% energy. Forty-four percent rise in COP and a 20% reduction in power were obtained by Ndukaife et al. [11] using a pad of 50 cm thickness and spraying water over it to cool the condenser in a split air conditioner. Liu et al. [12] experimented with the dual independent evaporative condenser and deduced that the COP enhancement is due to water spray rate and air velocity. An evaporative cooling pad for cooling condenser air was employed by Atmaca et al. [13] and concluded that the influencing parameters are higher outdoor temperature and lower relative humidity for maximum COP. The result obtained shows the increase in COP by 35.3% and cooling capacity by 18.6%. Ketwong et al. [14] investigated the effect of feed water temperature, wet bulb temperature of air, and mass ratio of feed water to circulating air on evaporative condenser in air conditioning. The high mass ratio of feed water to circulating air is needed when wet bulb temperature is lower than feed water temperature in a hot, dry climate. From the literature available it was found that none of them immersed condenser coils in water to cool it.

3. Experimental Set Up and Methodology

The set-up consists of a split air conditioner working on a vapor compression refrigeration system as shown in figure 1. It is composed of a compressor (0.7 ton - R22), condenser, expansion valve, and evaporator coil. The air to be conditioned is passed through the duct, which has an area of 0.071 sq. m., a length of 0.91 m, a fan (2800 rpm, 225 mm sweep, 80 W) fitted on one end, and a hygrometer is placed on both sides. Digital temperature indicators are placed at the inlet of the compressor, the outlet of the condenser, and in water tanks. Pressure gauges are placed at the inlet and outlet of the compressor to measure the refrigerant pressure. The mass flow rate of refrigerant is measured using a glass tube rotameter (0 to 100 lph). The accuracy of the temperature sensor is ±1°C and that of the pressure gauge is 2% if the full scale deflection. Conventional condenser is kept in a water tank to disperse latent heat due to phase change of refrigerant. Condenser consist of 24 turns and each coil is of 7mm diameter.

Power consumption is measured using an energy meter with a constant equal to 3200. The condenser is immersed in the tank of size 18*12*7 cubic inch (25 Litre) filled with water. Water is circulated from the tank to a bucket and again pumped back into the tank.

The experimentation was performed by submerging the condenser coils in water. For experimentation, three distinct configurations were considered having two different water flow rates. The first is when half of the condenser is dipped, the second is when three fourth of the condenser is dipped, and the third is when the condenser is fully submerged in water. The mass flow rate was taken at 200 lph and 400 lph for each of the half, three fourth and full submergence. The results were compared with those of the conventional air conditioner, wherein the cooling medium of the condenser is forced air. For each configuration, the readings were obtained for a period of 30 minute. After that, the temperature of the cooling water rises to the extent that it ceases to cool the condenser further.

The pressure of refriger ant before and after the compressor was taken. Compressor inlet and condenser outlet temperature was measured by temperature sensor. The temperature of water before and after passing through the tank was measured for all three configurations. The time taken for 10 revolutions of the energy meter was observed. Enthalpy before and after compression were determined using the standard pressure-enthalpy chart of the R-22 refrigerant. The difference in this enthalpy is the work required for compression. Similarly, the pressure and temperature readings were used for calculating the refrigerating effect. The ratio of refrigerating effect and compressor work is the coefficient of performance. In the duct, the condition of air before and after passing over the evaporator was measured using a hygrometer. An anemometer was used to measure the air velocity in the duct, which were 2.5 m/s. The effect of submerging the condenser at different levels in water was studied. The reading for different configurations of modified systems and conventional system is as shown in Table No. 1.

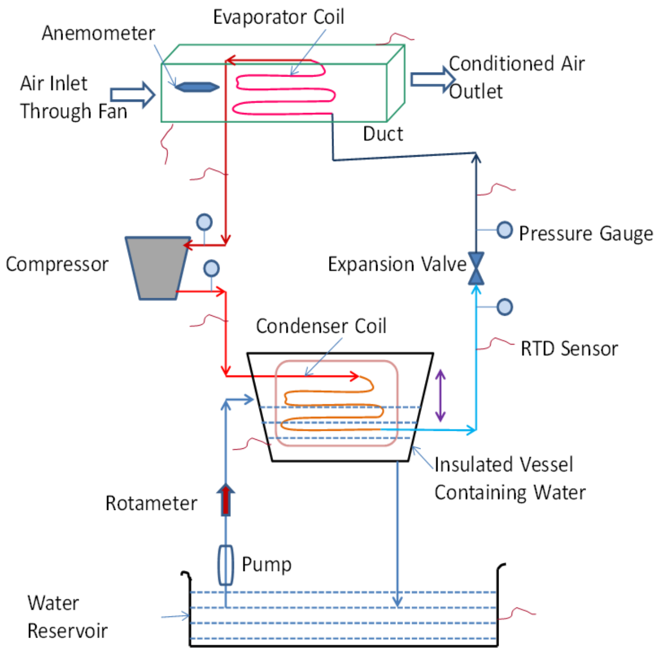

Fig. 1. Experimental Set up

Table 1: Reading for Different Configurations

Configuration	VCRS Parameters					Cooling Water Parameters		Parameters of Air in the duct			
	P_1 (bar)	P_2 (bar)	T_1 (˚C)	T_3 (˚C)	t (sec)	Tw_s (˚C)	Tw_f (˚C)	DBT_i (˚C)	WBT_i (˚C)	DBT_o (˚C)	WBT_o (˚C)
Conventional	2.9	16.6	33	41	7.16	-	-	31	30	23	22
50%-200lph	3.2	17.2	30	44	8.15	27.1	41.2	31	30	19.5	15.4
50%-400lph	3.2	17	31	42	8.28	29.8	39.9	31	29	16.2	13.6
75%-200lph	3.4	17.2	31	43	8.65	28.6	38.8	36	35	24	23
75%-400lph	3.6	17.4	33	43	9.5	29.8	41.3	35	33	24	21
100%-200lph	3	17	33	42	8.65	28.3	41.3	32	30	24.4	22
100%-400lph	3	16.4	29	42	8.7	29.8	40.6	33	32	24.2	21

P-Pressure; T-Temperature; DBT-Dry bulb temperature; WBT-Wet bulb temperature. Suffix: 1-Inlet to compressor;2-Exit of compressor;3-Exit of condenser; i-Duct inlet; o-Duct outlet, w-water; s-start of experiment; f-After 30 min.; t- Time for 10 flash in sec on energy meter; lph-Litre per hour.

4. Data Reduction

The Compressor Work (W_c) for VCRS is calculated using the formulae

$$W_c = h_2 - h_1$$

The refrigerating effect (R.E.) for VCRS is calculated using the formulae

$$R.E. = h_1 - h_4$$

h_1 is the enthalpy before compression obtained from ph chart of R22 using inlet compressor pressure and temperature, h_2 is the enthalpy of refrigerant after compression, h_4 is the enthalpy before evaporator.

Coefficient of performance of VCRS (COP_{VCRS}),

$$COP_{VCRS} = \frac{R.E.}{W_c}$$

Similarly the air conditioner effectiveness ($\mathcal{E}_{ac}$) is calculated from the condition of air before and after passing over the evaporator in duct and energy meter reading.

$$\epsilon_{ac} = \frac{\text{Change in Enthalpy of air in duct in kW}}{\text{Work required measured from Energy meter in kW}}$$

$$\text{Change in Enthalpy of air in duct in kW} = \rho A v (h_i - h_o)$$

Where ρ is density of air after passing over evaporator, A is the area of duct, v is air velocity, h_i and h_o is the enthalpy of air at inlet and outlet respectively in kJ/kg from psychometric chart, c_p is specific heat at constant pressure, $\dot{m}$ is the mass flow rate of water and ΔT is difference in temperature.

The heat transfer rate of water in the tank is calculated using

$$Q = \dot{m} * c_p * (\Delta T)$$

5. Results and Discussion

The optimum result is the maximum value of COP, as it indicates the performance of the VCRS. The results obtained are as shown in table no. 2.

Table 2: Results for Different Configurations

Configuration	Pressure Ratio	On the Basis of Enthalpy Difference of Refrigerant in VCRS				On the Basis of Difference Air Enthalpy in duct and energy meter reading			
		Refrigerating Effect (kJ/kg)	Compressor Work Done (kJ/kg)	Theoretical COP	Variation of COP	Refrigerating Effect (kW)	Compressor Work Done (kW)	Actual COP	Variation of COP
Conventional	4.51	182	53	3.43	-	4.56	1.57	2.9	
50%-200lph	4.33	176	51	3.45	0.6%	4.34	1.4	3.1	6.90%
50%-400lph	4.29	185	54	3.43	-0.1%	4.5	1.38	3.26	12.41%
75%-200lph	4.14	180	49	3.67	7.1%	4.36	1.36	3.22	11.03%
75%-400lph	4	176	46	3.83	11.6%	4.98	1.32	3.76	29.66%
100%-200lph	4.5	181	53	3.42	-0.4%	4.63	1.37	3.37	16.21%
100%-400lph	4.35	178	53	3.36	-2.1%	4.23	1.36	3.12	7.59%

The performance of VCRS for different configurations is depicted in figure no.02.

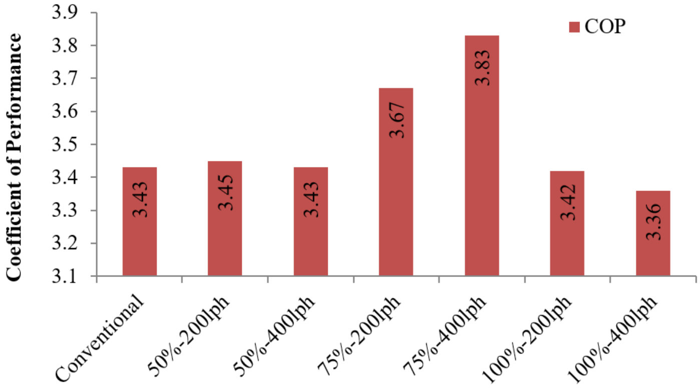

Fig. 1. COP for Different Configurations

The percentage variation of COP obtained by conventional VCRS and the three configurations of condenser immersion in a water tank having two distinct flow rates is as shown in figure no. 3. The COP rise of 11.6% is obtained using water as a coolant for a condenser dipped three-fourth in a water tank with a flow rate of 400 lph. This indicates that some portion of the condenser should remain open to the atmosphere to enhance the performance of VCRS.

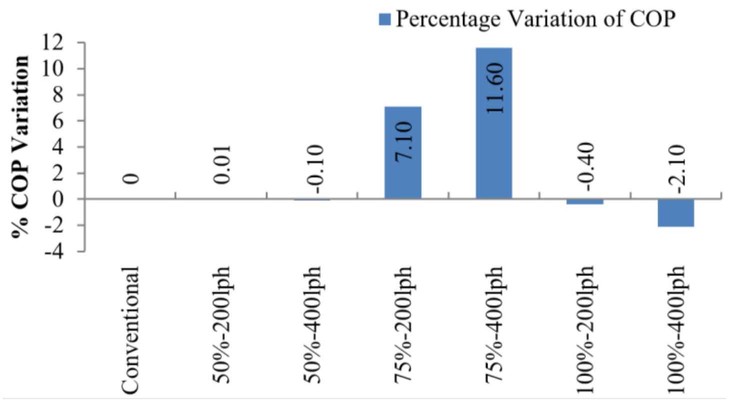

Fig. 3. Percentage COP Variation for Different Configurations

The rise of COP is attributed mainly to the decrease in compressor work by 13.6%, as shown in figure no. 4.

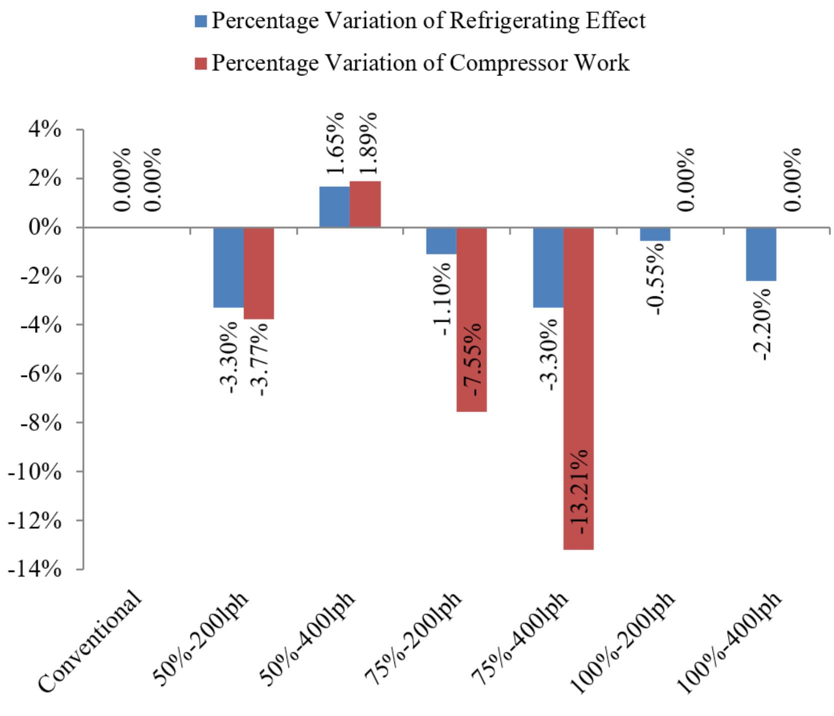

Fig. 2. Percentage Variation of Refrigerating Effect and Compressor Work

The reason behind this is the low pressure ratio, which is the result of a rise in suction pressure.

The optimum result is obtained at a lower pressure ratio, as shown in figure 5. The rise in suction pressure, though, reduces the refrigerating effect, but that is just by 3.3%. Higher pressure ratios require compressors to operate at higher speeds, which can lead to increased energy consumption, wear and tear, and potentially reduce compressor lifespan.

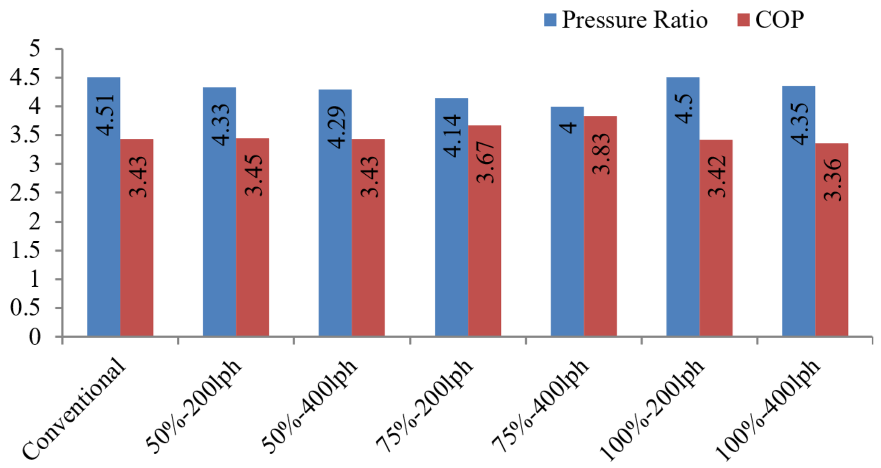

Fig. 3. COP and Pressure Ratio for Different Configurations

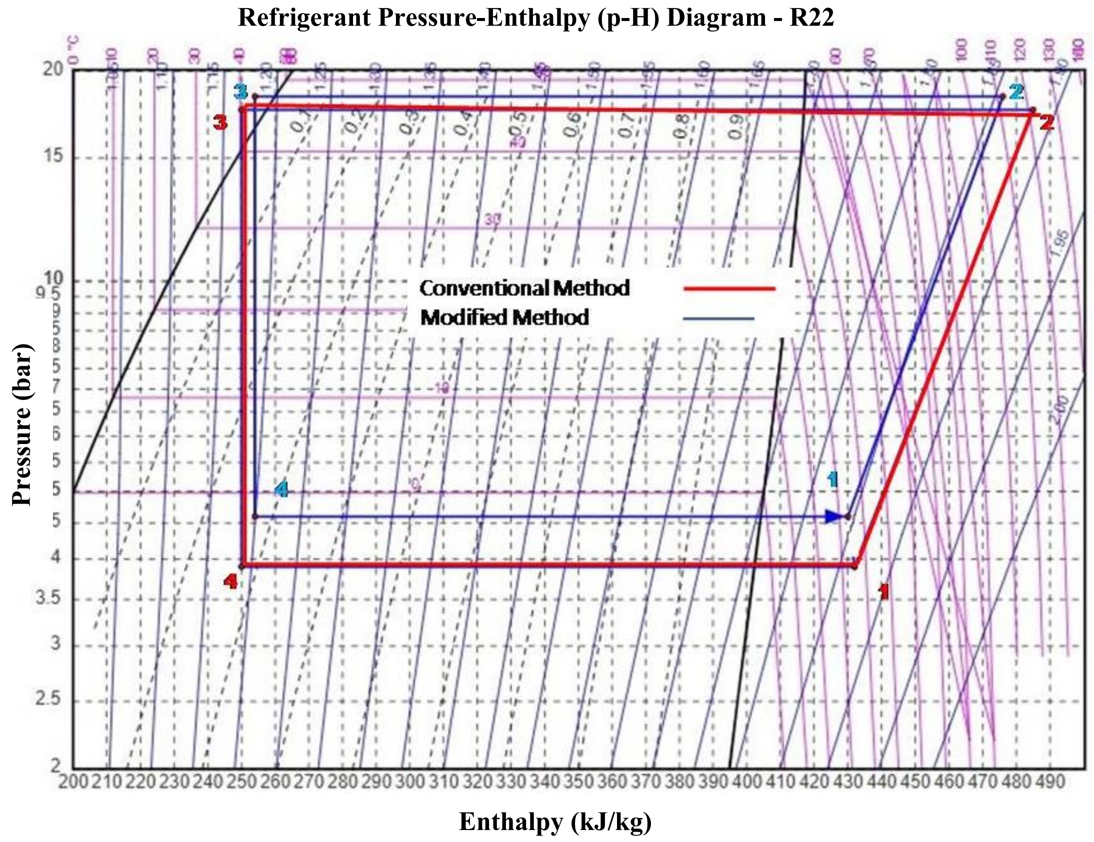

Fig. 4. VCRS cycle comparison of conventional with optimum modified system

Figure 6 shows the VCRS cycle comparison on the ph chart of conventional with optimum modified system. The reduced pressure ratio has comparatively less compressor work required, which improved the COP of the modified system. Figure 7 shows the variation of water temperature for different configurations. As seen in the figure, the maximum heat transfer occurs in the 75%-400 lph configuration, which is the reason for the improved COP of VCRS.

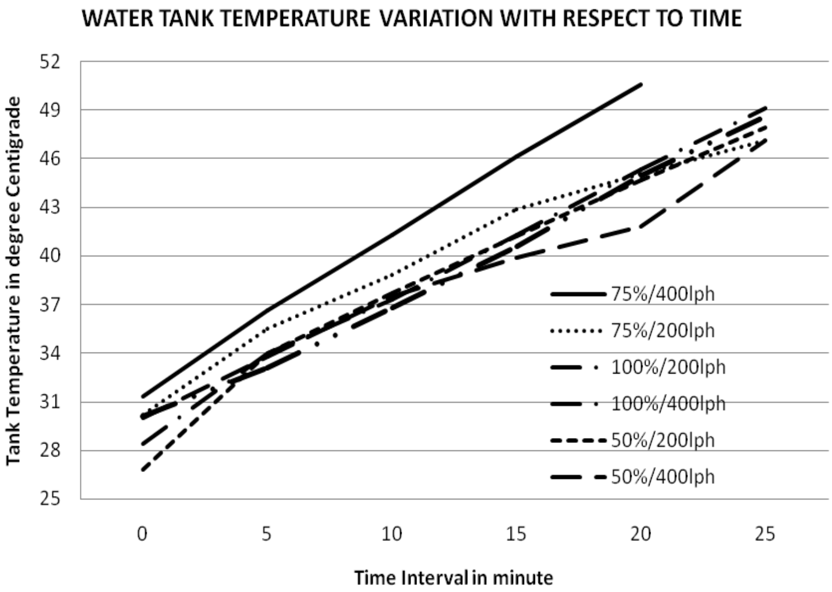

Fig. 5. Water Temperature Variation with time for different Configurations

6. Implications/Limitations/Future Research

In a hot, dry region and during peak summer the condenser tends to show reduced performance. This modified system is extremely beneficial in dusty environments where the performance of the condenser is adversely affected if air is used as a cooling medium. The only limitations are the corrosion to condenser material and the availability of clean water.

The water from the condenser can be cooled further by losing some of its heat to refrigerant just before the compressor. This cooling of water by giving its heat to refrigerant at the compressor inlet will increase the COP further. The cooling of the water inlet of the compressor can be achieved by passing it over the last small portion of the evaporator coil just before the compressor. The temperature difference at the inlet of the evaporator is around room temperature, which increases the heat transfer rate. Nanofluids are used in heat exchangers to enhance the heat transfer rate [15]. Nanofluid may be employed as a coolant to enhance the thermal conductivity of the coolant and consequently COP.

7. Conclusion

The increased demand for air conditioning, particularly in split air conditioners, is causing a sharp increase in energy consumption due to the rising world temperature. The results show that the water as a coolant for the condenser is beneficial in increasing its performance and reducing the electricity requirement. The power requirement will come down by 13%, which will help in reducing global warming, greenhouse gases and carbon footprints by saving fossil fuels. The water flow rate shows significance in the enhancement of COP of VCRS. It is concluded that one-fourth of the condenser should be exposed to the atmosphere and the remaining three-fourth should be dipped in water to get maximum COP and a longer cooling effect. The maximum improvement of 11.6% in COP of modified VCRS having a condenser dipped 75% in water at a flow rate of 400 lph as compared to that of conventional VCRS. In addition to the increase in efficiency, the hot water obtained from the improved system can be used in various applications like cleaning utensils, in toilets, and for floor cleaning, to name some.

- A significant fall in compressor work is observed in water cooled condenser.
- Result in crucial rise in coefficient of performance.
- Pressure ratio reduction is results due to water cooled condenser.
- There is small reduction in refrigerating effect with the use of water for condenser cooling.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

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