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# EXPERIMENTAL STUDY OF HYDROCARBON R290 IN WATER COOLER REFRIGERATION SYSTEM

C S Choudhari[1,*], S N Sapali[2]

## ABSTRACT

Environment friendly hydrocarbon R290 is one of the options for the next generation refrigeration systems. In warm climatic countries, water cooler is the widely used refrigeration application and R22 is the predominantly used refrigerant in these refrigeration systems. In accordance with international agreements, use of refrigerant R22 is to be stopped on urgent basis because of its environmental concerns, ozone depletion and global warming. This paper presents an experimental study on the performance of laboratory water cooler charged with environment friendly refrigerant R290. A laboratory water cooler of nominal cooling capacity 1.5 kW is developed. Pull down tests and energy consumption tests at condensing temperatures of 38°C, 43°C, and 48°C is conducted as per Indian standard IS1425 (Part 1): 2001. Performance parameters such as pull-down time, pressure ratio, discharge gas temperature, average compressor energy consumption, energy consumption over a period of 24 hours, coefficient of performance and performance parameter of the water cooler refrigeration system are measured. Observed performance parameters also proved the compatibility of mineral oil with refrigerant R290. The overall performance of the developed water cooler suggests refrigerant R290 as a better long- term alternative refrigerant for water cooler applications.

***Keywords**: Hydrocarbon, R290, Flammable Refrigerant, Water Cooler*

## INTRODUCTION

Refrigeration technology has forever played an important role in improving the human standard of living. Inventions such as the refrigerator and air-conditioner have become a necessity for food preservation and comfort living. However, rapid development of the refrigeration industry over the years has contributed significantly towards the environmental problems of global warming and climate change [1]. Specifically, widely used refrigerant for last fifty years, chlorofluorocarbon (CFC) and hydro chlorofluorocarbon (HCFC) are majorly responsible for environmental degradation. The whole world is in the process of controlling the use of environmentally unfriendly CFC, HCFC, and hydro fluorocarbon (HFC) refrigerants. International agreements, Montreal and Kyoto protocols and their subsequent amendments have been effectively implemented for the sustainable development of the refrigeration industry [7]. India became a party to the Montreal protocol in 1992 and efforts have been put at the national level to phase out CFCs and HCFCs as prescribed by the Montreal protocol. The Government of India also has prepared a detailed roadmap in 1993 for phasing out of HCFC refrigerants as per its national Strategy. As per the amendment in Ozone Depleting Substance Regulations (2014), manufacturers of refrigeration and air conditioning appliances are expected to phase out HCFCs by January 2025. In view of this, there is a renewed strategy of use of natural hydrocarbon R290 (Propane) as a replacement to pollutant synthetic refrigerants.

In India, the water cooler is one of the widely used applications of the refrigeration and R22 is the predominantly used refrigerant in water cooler refrigeration systems. R22 is an ozone-depleting substance with higher global warming potential of 1700, whereas R290 is a non-ozone depleting substance with a very negligible value of global warming potential (GWP) (< 20) [2, 3]. Refrigerant R290 possesses excellent thermo-physical properties such as high latent heat ofevaporation, lower density and viscosity and higher values of thermal conductivity and specific heat. Flammability is the only concern because of which it was neglected for many years. With the need of environment-friendly refrigerant, in last couple of years, there is growing interest in the use of R290 in different refrigeration and air conditioning applications. By taking proper care with the support of technological

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*[1]Department of Mechanical Engineering,AISSMS College of Engineering, Pune, India*
*[2]Department of Mechanical Engineering, College of Engineering, Pune, India*
**E-mail address: cschoudhari@aissmscoe.com*
*Orcidid: 0000-0003-4219-5371*
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developments, use of R290 as a refrigerant is quite possible. Table 1 compares the main properties of the refrigerants R290 and R22.

**Table 1.** Main properties of refrigerants R290 and R22 [2, 3]

| Refrigerant | Thermodynamic properties | | | | | Safety properties | | Environmental properties | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Number | Mw | NBP | Tc | Pc | $h_{fg}$ | LFL | ASHRAE 34 Safety group | atm. life | ODP | GWP |
| | kg/Kmol | °C | °C | MPa | kJ/kg | % | | yr | | 100 yr |
| R290 | 44.10 | -42.2 | 96.7 | 4.25 | 425.4 | 2.1 | A3 | 0.04 | 0.000 | 20 |
| R22 | 86.47 | -40.7 | 96.2 | 4.99 | 233.7 | -- | A1 | 12 | 0.055 | 1700 |

In the present study, the performance of a water cooler refrigeration system, specifically designed and developed for water cooler using R290 is investigated for different condensing temperatures. Experiments were performed as per Indian standards IS1425 (Part 1): 2001.

Many researchers have reported that refrigerant R290 and its mixtures performs well and can be a better substitute to CFC and HCFC refrigerants in various applications [8-19].Purkayasthaet. al. [5] have investigated the performance of refrigerant R290 in a R22 heat pump system with a capacity of 15 kW. Coefficient of performance (COP) of R290 system is observed to be 18 % higher than that of the R22 system. In addition to that, mass flow rate of the R290 is found to be 50 % lower than that of the R22 system. Tested heat pump system with R290 showed lower discharge temperatures in comparison with R22 system. Granrydet. al. [11] have performed of thermodynamic cycle analysis and heat transfer analysis for R290 system and R22 system and strongly agreed upon the conclusions made by Purkayasthaet. al.[5]. Devottaet. al. [7] has conducted experiments using 5.13 kW capacity window air conditioner in order to investigate and to assess the R290 refrigerant as a substitute to refrigerant R22. R290 system showed lower cooling capacity by 6.5-9.5 % and lower power consumption by 12.4-13.5% than the R22 system. Also, R290 system showed better energy performance with higher COP values by 2.8-7.9% than R22 system. All investigations till date indicate that natural refrigerant R290 is being suggested and implemented in small capacity air conditioners, heat pumps and commercial applications [12, 14].

## EXPERIMENTATION

### Experimental Setup

A laboratory water cooler is developed in the author's laboratory and its performance analysis is carried out using refrigerant R290. Figure1 shows the schematic diagram of the experimental set up consisting of water cooler refrigeration system with a hermetically sealed compressor designed for R22, using mineral oil as lubricating oil. Evaporator used is of immersed coil type fitted in a PUF insulated evaporator tank fitted with an immersed heater to provide cooling load to the evaporator. For maintaining different condensing temperatures, shell and tube type condenser with refrigerant in shell side and cooling water in tube side is used. Different condensing temperatures are achieved and maintained by varying the temperature and flow rate of cooling water through tubes of the shell and tube condenser. The water pump is provided to circulate cooling water from cooling water tank to the condenser. In order to remove the heat of condensation from cooling water in the cooling water tank for maintaining the temperature of cooling water, a small capacity cooling tower and a separate chiller is used, as shown in Figure1.A submercible pump in evaporator tank generates required water movement.

The refrigeration system is instrumented with pressure gauges to measure pressure at compressor inlet, compressor outlet, condenser pressure, evaporator inlet and evaporator outlet. For temperature measurements, resistance temperature detector (RTD) (Pt100) temperature sensors are placed at compressor inlet, compressor outlet, condenser outlet, evaporator inlet and outlet. Digital energy meter (Make: Nippen, Model number: EM-34L) and wattmeter ( Make: Sutaria, Model: AW9531) is used to measure the energy consumption of a compressor and heater input, respectively.

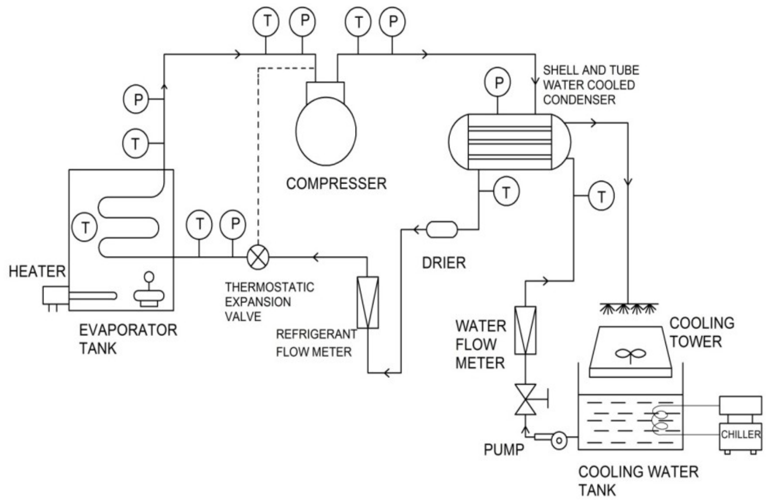


**Figure 1.** Schematic diagram of the experimental setup

## Experimental Procedure

Initially, the assembled refrigeration system is flushed with nitrogen gas and is tested for leakagewith dry nitrogen at a pressure of 12.41 bar (G). The system is kept under a nitrogen pressure of 12.41 bar (G) for 24 hours to ensure that the system is leak proof. Before the charging of R290 with required quantity, the system is evacuated for an hour.

Developed R290 water cooler refrigeration system is tested as per Indian Standard IS1475: Energy consumption and performance: 2001[9]. Pull down tests are carried out for the condensing temperature of 38 °C, 43 °C and 48 °C. Pull-down time of the system is measured by noting the time required to reduce the water temperature inside the evaporator tank from 32°C to 15°C [9].

Cooling capacity rating tests are carried out to assess the energy performance of the water cooler refrigeration system. As per Indian standard IS1475, water coolers are tested for water inlet temperature of 30°C and for maximum water outlet temperature of 13.5 °C [9]. Thermostat is set for a range of 5 °C with cut-off and cut-in temperatures of 10 °C and 15 °C respectively, referring Indian standards IS11338:1985 for thermostats in water coolers. The water cooler refrigeration system is developed for a water flow rate of 60 liters per hour (LPH) and accordingly, cooling load is applied gradually and maintained constant at steady state condition. Under steady state condition, the system is run for 24 hours continuously to investigate the system performance. At 38°C condensing temperature, continuous on-off cycle tests are conducted whereas at 43°C and 48°C condensing temperature continuous running tests are conducted. Performance parameters like pressure ratio, compressor discharge temperature, energy consumption per 24 hours, average compressor energy consumption, coefficient of performance, and performance parameter of the water cooler are observed.

Pressure ratio of refrigeration system for different condensing temperatures is calculated by taking the ratio of compressor discharge pressure and inlet pressure. For the measurement of discharge temperature, a temperature sensor is attached to the compressor discharge line with proper insulation around the sensor to minimize the temperature deviation due to the changes in the surroundings. During 24-hour test run, after every hour instantaneous compressor power consumption is measured for constant cooling load.24 hour energy consumption of the compressor is measured by noting down initial and final readings of energy meter for the duration 24 hours. Performance parameter of the water cooler system is calculated as a ratio of the total cooling effect obtained and total compressor energy consumption for 24-hour test period.

## RESULTS AND DISCUSSION

Pull down tests are carried out to assess the cooling rate of the developed system at different condensing temperatures. Figure 2 shows the experimental results of the pull-down speed test for R290 water cooler for condensing temperatures of 38°C, 43°C and 48°C.The pull-down time of water cooler to lower down temperature of

30 liters of water from 32 °C to 15 °C is 27 min., 33 min. and 44 min. at condensing temperatures of 38°C, 43°C and 48°C respectively which is satisfactory for the considered cooling capacity of the developed water cooler. Reduction in cooling rate of the system at higher condensing temperature is because of reduction in volumetric efficiency of the compressor at higher pressure ratio.

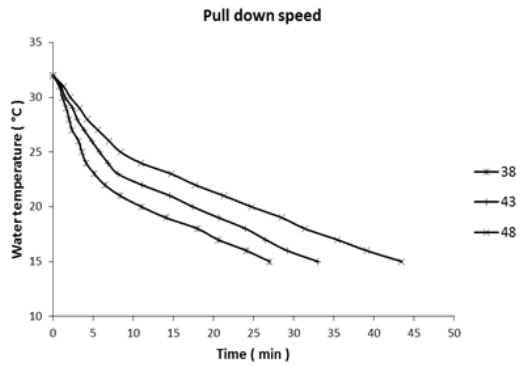


**Figure 2.** Pull down time variation at different condensing temperatures

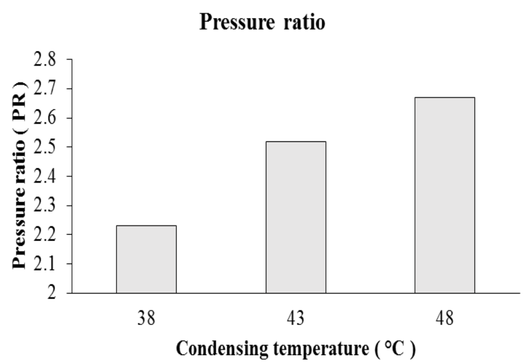


**Figure 3.** Variation in pressure ratio

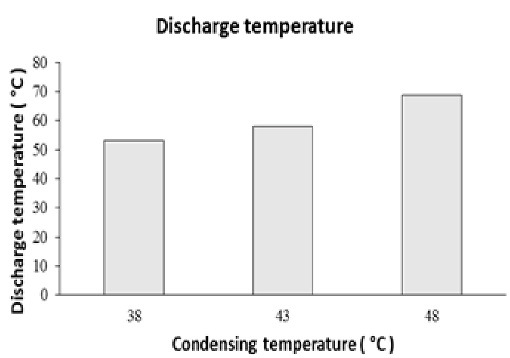


**Figure 4.** Discharge gas temperatures

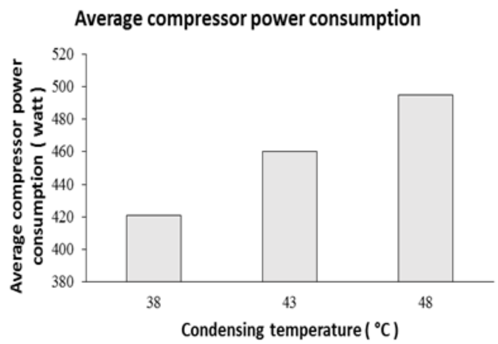


**Figure 5.** Compressor energy consumption

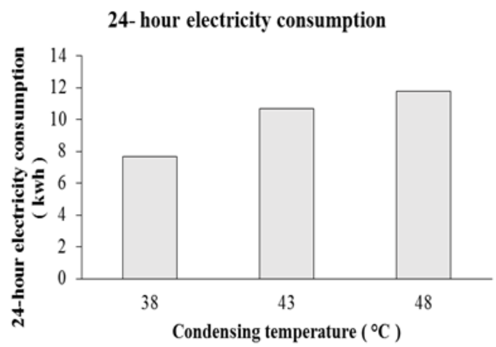


**Figure 6.** 24-hour electricity consumption

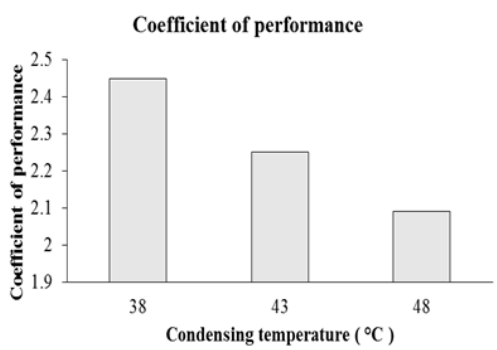


**Figure 7.** Coefficient of Performance

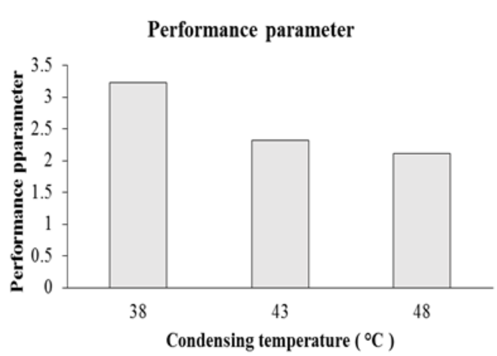


**Figure 8.** Performance parameter

Figure 3 shows that pressure ratio is higher at higher condensing temperature. Pressure ratio values observed are 2.23, 2.52 and 2.67 for condensing temperatures of 38°C, 43°C and 48 °C, respectively. Higher compression work at higher condensing temperature is because of the lower volumetric efficiency of a compressor at higher pressure ratio. Lower compressor discharge temperature improves the life of the compressor as well as the stability of the refrigerant and lubricants. Figure 4 shows the discharge gas temperature values of 53 °C, 58 °C and 69 °C for condensing temperatures of 38 °C, 43 °C and 48 °C respectively. In R290 system, discharge gas temperature values are lower because of the higher specific heat value of the refrigerant R290. These lower values also confirm compatibility of mineral oil with R290. Figure 5 shows the average energy consumption of a compressor of the developed system. Average compressor energy consumption observed is 421W, 460W and 495W at condensing temperatures of 38°C, 43°C and 48°C respectively. Figure 6 depicts the 24-hour electricity consumption of the compressor for different condensing temperatures. Observed 24-hour compressor energy consumption is 7.68 KWh, 10.68 KWh and 11.75 KWh for condensing temperatures of 38°C, 43°C and 48°C respectively. Coefficient of performance and performance parameter of system at different considered condensing temperatures is presented in Figure 7 and Figure 8, respectively. COP and performance parameter values are in the range of 2.45 to 2.09 and 3.23 to 2.11 respectively, for the condensing temperatures of 38°C, 43°C and 48°C. These COP values are comparable when compared with COP values of the R290 system tested by different researchers [7, 14].

## CONCLUSIONS

In the present work, a laboratory water cooler refrigeration system for environment- friendly refrigerant R290 is designed and developed and its performance is investigated experimentally. This study is carried out to assess various aspects of refrigerant R290 such as technical viability, energy consumption, compatibility with mineral oil, feasibility under higher condensing temperatures etc.

Following conclusions are drawn from the experimental results.

Energy consumption of the system for 24-hour duration is 7.68 KWh, 10.68 KWh and 11.75 KWh at condensing temperatures of 38°C, 43°C and 48°C respectively. These values are within the limit as per IS guidelines. 24-hour energy consumption at 38°C condensing temperature is comparatively lower because of continuous cycle on-off test whereas at 43°C and 48°C condensing temperature continuous running tests are conducted.

Performance parameters and coefficient of performance values in the range of 2.45 to 2.09 and 3.23 to 2.11 respectively, which confirmed energy efficient performance of the system.

Discharge gas temperature values observed are 53°C, 58 °C and 69 °C for condensing temperatures of 38 °C, 43°C and 48 °C respectively. Lower discharge temperatures improve the life of the compressor.

Lower discharge gas temperatures and similar experimental results for the number of 24-hour duration trials confirmed the suitability of mineral oil as a lubricant with R290.

Overall, experimental investigations carried out demonstrated that R290 has strong potential as energy efficient, environment friendly and feasible refrigerant for water cooler application. These results should contribute significantly to the product development of R290 water coolers, especially in developing countries with warm climate conditions.

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## NOMENCLATURE

| | |
|---|---|
| Mw | Molecular weight |
| NBP | Normal boiling point |
| Tc | Critical temperature |
| Pc | Critical pressure |
| $h_{fg}$ | Latent heat of evaporation |

LFL Lower flammability limit
PUF Poly urethene foam
CFC Chlorofluorocarbon
HCFC Hydro chlorofluorocarbon
HFC Hydro fluorocarbon
ODP Ozone depletion potential
GWP Global warming potential

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