



Testing of Environment Friendly Refrigerant R290 for Water Cooler Application

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PAPER INFO

Paper history:

Received 26 August 2017

Received in revised form 04 November 2017

Accepted 30 November 2017

Keywords:

Coefficient of Performance

Experimentation

Refrigerant R290

Water Cooler

ABSTRACT

This paper presents environment friendly refrigerant R290 as a solution to the environmental concerns like depletion of ozone layer and rise in global warming because of wide use of synthetic refrigerants R22 and R134a. The water cooler is the widely used refrigeration application in warm climatic countries. Refrigerant R22 and R134a are predominantly used refrigerants in water cooler refrigeration systems. These refrigerants are to be phased out as per the international agreements, Kyoto and Montreal protocol. This experimental study investigates the applicability of the environment friendly refrigerant R290 for applications, especially in warm climate sub-tropical and tropical countries like India. A water cooler test facility of a nominal cooling capacity 1.5 kW is especially designed, developed for R290 and its performance is investigated at different operating conditions. Performance parameters like cooling capacity, discharge gas temperature and coefficient of performance are analyzed. Results showed that compressor energy consumption and discharge gas temperatures are lower for the water cooler refrigeration system. The overall performance of the especially developed system for water cooler application proved that R290 can be a better alternative refrigerant with respect to energy efficiency and greenhouse impact as a replacement to R22 and R134a.

doi: 10.5829/ije.2018.31.01a.21

1. INTRODUCTION

In most of the warm climatic developing countries, synthetic and environmentally unfriendly refrigerant R22 and R134a are widely used in refrigeration and air conditioning applications. Both the refrigerants possess good thermo-physical properties and are dominating refrigerants since last fifty years. However, because of the environmental concerns like depletion of ozone layer and rise in global warming, these refrigerants are to be phased out. International agreements like Kyoto and Montreal protocol have set the time limits for phasing out the environmentally and unfriendly refrigerants. R22 (hydro chlorofluorocarbon) is an ozone depleting refrigerant with higher global warming potential ($GWP_{R22} = 1700$) whereas R134a is a substance with higher GWP value ($GWP_{R134a} = 1300$) because of which both refrigerants are to be phased out on the urgent basis and this seems to be a challenging task for developing countries [1-3]. In this scenario, for

the sustainable development of the refrigeration industry, there is renewed interest at all the levels of stake holders of the refrigeration industry for the use of 'natural refrigerant' like R290. Refrigerant R290 (Propane) is a hydrocarbon with zero ozone depletion potential (ODP) and very low GWP value of less than 20. R290 owns many advantages such as excellent thermodynamic properties, lower cost, ease of availability, compatibility with most of the materials generally used in refrigeration systems, and compatibility with the mineral oil as well as synthetic lubricating oils [4-6]. Flammability is the only concern and R290 was neglected for years with the contention that flammable refrigerants are not safe for the use in refrigeration and air conditioning applications. However, because of the environmental mandate, technological developments and psychological acceptance, use of R290 refrigerant is increasing in last couple of years.

In warm climate countries, water cooler is the widely used refrigeration application using R22 and R134a refrigerants. Present experimental study

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investigates the suitability of refrigerant R290 for water cooler application. Systematic experimentation is carried out using water cooler test facility which is designed and developed in the laboratory, especially suitable for refrigerant R290.

Many researchers have reported that refrigerant R290 and its mixtures with other different refrigerants can be a better substitute to chlorofluorocarbon (CFC) and hydro chlorofluorocarbon (HCFC) refrigerants in various applications [5-18]. R290 mixtures have been tried mainly, either to lower down the flammability of the refrigerant R290 or to match with saturation pressure of the original refrigerant for drop in experimentation. Purkayastha et. al. [7] have tested the refrigerant R290 in a R22 heat pump system with a heating 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, 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 gas temperatures in comparison with R22 system. Granryd et. al. [5] have carried out thermodynamic cycle analysis and heat transfer analysis for R290 system and R22 system and their conclusions strongly matched with the conclusions made by purkayastha et. al. [7]. Jung et. al. [8] have strongly recommended environment friendly hydrocarbon mixture (R290/R600a) for domestic refrigerators. Hwang et. al [9] have conducted energy consumption tests for hydrofluorocarbon (HFC) mixtures of refrigerants R404A, 410A and R290 using a walk in refrigeration system. It is found that the COP of R290 based system is upto 10% higher than those of used HFC mixtures based systems. Zhou et. al. [10] have analyzed the performance of a split type air conditioner using refrigerants R22 and R290. Their results indicated that the refrigerant charge required for R290 system is 44 % lower when compared with R22 system and R290 system consumes 12.1-12.3% lower power than the R22 system. Devotta et. al. [11] have 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 about 6.5-9.5 % and lower power consumption about 12.4-13.5% than the R22 system. Also, R290 system showed better energy performance with higher COP values about 2.8-7.9% than R22 system. Urchueguia et al. [14] have evaluated the experimental performance of a commercial type refrigeration system with a nominal cooling capacity of 20 kW. Refrigeration system was evaluated with scroll and reciprocating compressors using same mineral oil as lubricating oil. The comparative experimental performance with R22 and R290 refrigerants indicated that coefficient of performance of the system with refrigerant R290 increases by 1 – 3% for both types of

compressors. Sanchez et al. [15] have conducted drop in experimentation for R290 in R134a system. The system showed higher cooling capacity and higher COP using R290 about 40.5% to 67 % and 22.4% to 2.8% respectively than that of R134a. It is observed that the displacement of the compressor for R134a is too high for R290 and resizing of a compressor is must. Study concluded that R290 is not a drop-in substitute for R134a system. All investigations till date indicate that natural refrigerant R290 is being suggested and is being implemented in small capacity air conditioners, heat pumps and commercial applications [3, 12, 13]

Present work investigates the possibility of using refrigerant R290 for water cooler application in sub-tropical and tropical countries with warm climatic conditions. Expecting reliable results of the experimentation, mostly adopted drop-in experimentation is avoided and a new water cooler test facility is designed and developed considering properties of refrigerant R290. Results of this investigation should significantly contribute to the application of R290 as a refrigerant in water cooler applications.

2. THE REFRIGERANT R290

2. 1. Main Physical and Environmental Characteristics

Refrigerant R290 is a natural refrigerant with excellent environmental and thermo physical properties. However, flammability is the only concern because of which it is neglected. Table 1 shows the thermodynamic, safety and environmental properties of R290 in comparison with R22 and R134a refrigerants.

Refrigerant R290 has very good thermodynamic properties in comparison with R22 and R134a. The molecular weight of R290 is lower about 49% and 56.7% than R22 and R134a, respectively. Lower molecular weight indicates higher latent heat of evaporation of the refrigerant. Latent heat of evaporation of R290 is 82 % higher than R22 at the normal boiling point. Because of the higher latent heat of evaporation, lower mass of refrigerant R290 is sufficient for the same cooling capacity in comparison with R22 and R134a. Being a flammable refrigerant, lower charge requirement is the very advantageous for R290. With R290, compressor discharge temperatures are also expected to be lower because of higher heat capacity. Lower discharge gas temperature is very important property, especially for hermetically sealed compressors.

Normal boiling point (NBP) decides most of the properties of the refrigerant. NBP of R290 and R22 closely matches. Similar NBP of the refrigerants indicate similar application area and also similar saturation pressures. NBP of R290 is slightly lower with slightly lower saturation pressure than R22.

TABLE 1. Some of the main properties of refrigerant R290, R22 and R134a [19, 20]

Refrigerant Number	Thermodynamic properties					Safety properties		Environmental properties		
	Mw (kg/Kmol)	NBP (°C)	Tc (°C)	Pc (MPa)	h _{fg} (kJ/kg)	LFL (%)	ASHRAE 34 Safety group	atm. life (yr)	ODP	GWP (100 yr)
R290	44.10	-42.2	96.7	4.25	425.4	2.1	A3	0.041	0.000	20
R22	86.47	-40.7	96.2	4.99	233.7	--	A1	12	0.055	1700
R134a	102.03	-26.1	101.1	4.06	216.87	--	A1	14.6	0.000	1300

NBP of R134a is higher and thus it is a low pressure refrigerant in comparison with R22 and R290.

The critical temperature and critical pressure of refrigerant are very significant, especially when refrigeration system is to be operated under higher ambient conditions. Performance of a refrigerant having lower critical temperature decreases drastically at higher ambient temperature conditions. Critical temperature of R290 is slightly higher than that of R22 making it suitable for higher ambient temperature conditions.

Thermo-physical properties of refrigerant decide the performance of the refrigeration system to a larger extent and hence selection of the refrigerant for particular application. Table 2 shows main thermophysical properties of the refrigerants R290, R22 and R134a, at evaporating and condensing temperature of 10°C and 43°C, respectively.

Higher thermal conductivity of R290 in both liquid and vapour phases improves the heat transfer rate in both condenser and evaporator. Major source of irreversibility in the system is viscosity of the refrigerant, affecting condensation and boiling heat transfer. Lower viscosity of R290 helps in improving performance of the system. The higher specific heat of R290 gives lower compressor discharge temperature for R290 systems. The vapor pressure of R290 is lower than that of R22 which helps in reducing compressor power consumption. Due to lower liquid density of R290, the refrigerant charge required would be lower resulting in lower friction and better heat transfer coefficients in evaporators and condensers.

ASHRAE standard 34, classifies refrigerant R290 as a class A3 refrigerant which means that it is nontoxic and highly flammable refrigerant. Flammability and toxicity of the refrigerant is not an issue when refrigerant is in a closed system. When it comes in contact with air due leakage or any other reason, problem starts. According to ASHRAE standard 15, leakage concentration of R290 should not exceed the 20% of lower flammability limit. Lower flammability limit (LFL) is the minimum allowable amount of refrigerant in air to avoid fire accident. However, fire will occur with the release and the mixing of the refrigerant with air, only when refrigerant proportion in air is 1% to 10%, there is presence of an ignition source

TABLE 2. Physical properties of refrigerants R290, R22 and R134a [20]

Property	Temp (°C)	State	Refrigerant		
			R290	R22	R134a
Saturation pressure (MPa)	10	Liq.	0.636	0.680	0.414
		Vap.			
	43	Liq.	1.466	1.648	1.100
		Vap.			
Density (kg/m ³)	10	Liq.	514.73	12467	12610
		Vap.	13.783	28.82	20.226
	43	Liq.	462.08	11151	1133
		Vap.	32.497	71.614	54.512
Viscosity (μPa-s)	10	Liq.	113.35	193.71	234.87
		Vap.	7.7544	11.798	11.099
	43	Liq.	80.160	133.86	155.36
		Vap.	9.0346	13.554	12.526
Thermal conductivity (W/m °C)	10	Liq.	0.1009	0.0902	0.0876
		Vap.	0.0169	0.0101	0.0124
	43	Liq.	0.0856	0.0752	0.0734
		Vap.	0.0220	0.0132	0.0158
Specific heat (kJ/kg °C)	10	Liq.	2.5733	1.1993	1.3704
		Vap.	1.8353	0.7852	0.9454
	43	Liq.	2.9605	1.3601	1.5167
		Vap.	2.3261	0.6807	1.1721

with energy more than 2.5×10^{-4} kJ or a hot surface with a temperature higher than 440°C [19, 20]. Out dated international standards for the use of flammable refrigerant are also equally responsible for the limited use of refrigerant R290. Most of the existing regulations are not in favour of R290 refrigerant as there was an option of safe refrigerants like CFCs and HCFCs for about 50 years. In recent years, various groups and organizations have started working on a development of new safety standards and codes for the application of flammable refrigerants for promoting use of hydrocarbons to some extent.

3. EXPERIMENTATION

3.1. Experimental Set Up A refrigeration system for water cooler application is especially designed and developed for the refrigerant R290 and an experimental facility for the performance testing of the developed refrigeration system is constructed in the author's laboratory. The experimental facility, as shown in Figure 1, consist of a refrigerant loop for main vapour compression refrigeration system (VCRS) to be evaluated for water cooler application, cooling water loop required to remove the heat of condensation of refrigerant from shell and tube type condenser and additional VCRS to remove heat from the cooling water in cooling tank.

Water cooler refrigeration system consists of a hermetically sealed reciprocating type compressor designed to operate with R22 and mineral oil, an immersed coil type evaporator, a thermostatic expansion valve (TEV) and a shell and tube type water cooled condenser (heat transfer area 0.43 m^2).

PUF (poly urethane foam) insulated evaporator tank fitted with immersed electric heater is used to provide the cooling load to the refrigeration system. A sub mercible pump is kept inside evaporator tank to maintain a desirable water movement. The refrigeration system is instrumented with pressure gauges to measure pressures at compressor inlet, compressor outlet, condenser and evaporator outlet. For temperature measurements, resistance temperature detectors (RTD), (Pt100) temperature sensors are placed at compressor inlet, compressor outlet, condenser outlet, evaporator inlet and outlet. The energy consumption of a compressor is recorded with a digital energy meter and heater input with a wattmeter.

3.2 Experimental Procedure Initially, the refrigeration system is flushed with nitrogen gas and is

tested for leakage with dry nitrogen at a pressure of 12.41 bar (g). Leakages are identified if any with soap solution and later system is kept under a nitrogen pressure of 12 bar (g) for 24 hours to ensure that there is no leakage in the system. Before the charging of refrigerant R290 with required quantity, the system is evacuated for an hour.

Developed water cooler refrigeration system is tested at different evaporator temperatures in the range of 10°C to 18°C with a gap of 2°C . Considering the higher ambient temperatures in tropical countries, condensing temperatures are maintained at 38°C , 43°C , 48°C and 55°C . At constant condensing temperature, performance parameters such as cooling capacity, compressor energy consumption, coefficient of performance of the system and discharge gas temperatures are measured for different evaporator water temperatures of 10°C , 12°C , 14°C , 16°C and 18°C . Condensing temperature is maintained by varying cooling water flow rate through shell and tube condenser and evaporator water temperature is maintained by varying heater input through dimmer. For every operating condition, the system is allowed to reach to the steady state and readings are noted down. For the measurement of discharge gas temperature, a temperature sensor is attached to the discharge line of the compressor by providing proper insulation to avoid the effect of the surroundings.

4. RESULTS AND DISCUSSION

Especially designed and developed water cooler refrigeration system for refrigerant R290 is tested to analyse it's performance at different operating conditions. The system is tested at different condensing temperatures of 38°C , 43°C , 48°C and 55°C for the evaporator temperature in the range of 10°C to 18°C .

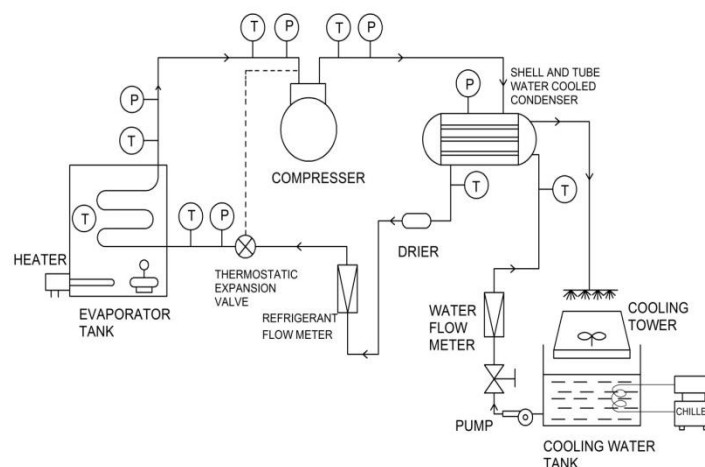


Figure. 1. Schematic diagram of the experimental set up

Performance parameters evaluated are cooling capacity (Q_e), compressor energy consumption (W_c), coefficient of performance (COP) and discharge gas temperature (T_d).

Variation in the cooling capacity and compressor energy consumption with evaporator temperature at different condensing temperatures is presented in Figure 2. Cooling capacity of the system at constant condensing temperature increases with increase in evaporator temperature. With an increase in evaporator temperature, reduction in the specific volume of the refrigerant at the inlet of the compressor increases the mass of refrigerant circulated per unit time, which subsequently improves cooling capacity of the system. The rise in specific refrigeration effect with an increase in evaporator temperature also improves the cooling capacity of the system. Lower cooling capacity at higher condensing temperature is mainly because of reduction in volumetric efficiency of compressor at higher pressure ratios.

At constant condensing temperature, with an increase in evaporator temperature, compressor energy consumption goes on increasing, reaches to peak and then starts decreasing. With the increase in evaporator temperature, specific work of compression decreases and at the same time, specific volume of the refrigerant at the entry of the compressor also decreases. Because of this, at particular evaporator temperature, compressor work reaches to peak. As this system is designed and developed for water cooler application, maximum power consumption occurs at 15°C evaporator temperature and then starts decreasing.

In order to minimize emission of green gases, the energy performance of a refrigeration system is very important. The coefficient of performance (COP) is the measure of energy performance of the refrigeration system and defined as the ratio measured cooling capacity of the system and energy input to the compressor.

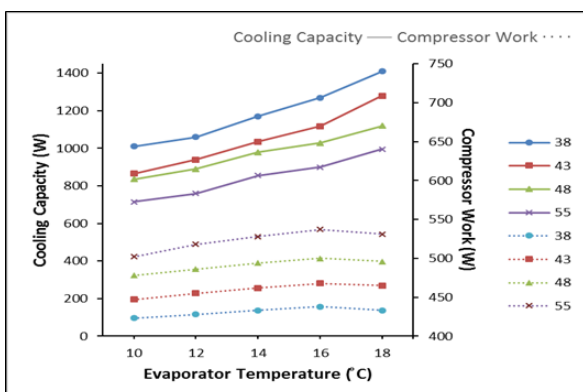


Figure 2. Variation in cooling capacity and compressor energy consumption with evaporator temperature

Figure 3 shows the COP variation for the system for different evaporator temperatures at different condensing temperatures. COP improves with increase in evaporator temperature and falls with increase in condensing temperature. COP values of the developed refrigeration system for evaporator temperature range of 10°C to 18°C, are in the range of 2.38 to 3.25, 1.93 to 2.75, 1.74 to 2.18 and 1.38 to 1.95 for the condensing temperatures of 38 °C, 43 °C, 48 °C and 55 °C respectively. These values are very well comparable with the refrigerant R22 when validated with previous results from the literature [11, 13]. Increase in COP with evaporator temperature is because of the higher rise in cooling capacity than the rise in compressor work required with increase in evaporator temperature. Reduction in COP at higher condensing temperature is because of lower cooling capacity and higher compressor work at higher condensing temperature.

Another important performance parameter is compressor discharge gas temperature. When compared with R22 and R134a, R290 refrigerant gives lower discharge temperatures because of its higher specific heat values [14]. This is another advantageous property of R290. Figure 4 shows the variation in compressor discharge temperature with evaporator temperature for different condensing temperatures. It is observed that the discharge temperature of the compressor for a constant condensing temperature is almost constant for the considered evaporator temperature range. Compressor discharge temperature values observed are 54 °C, 58 °C, 63 °C and 69 °C for the condensing temperatures of 38 °C, 43 °C, 48 °C and 55 °C respectively. These lower discharge temperature values improve the stability and life of the refrigeration system. At lower discharge temperatures, reduced temperature of the cylinder walls and lower suction superheat of refrigerant vapour reduces the rate of carbon and acid formation in the system improving the lifetime and reliability of the system. At higher condensing temperature, compressor discharge temperature found higher.

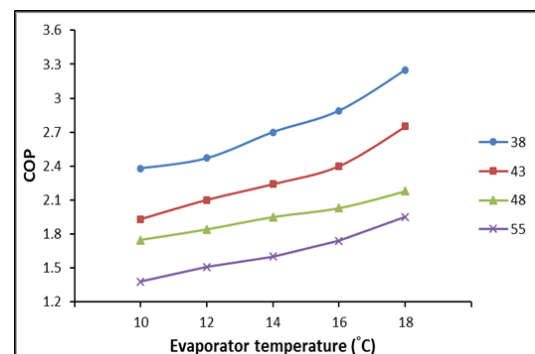


Figure 3. Variation in coefficient of performance with evaporator temperature

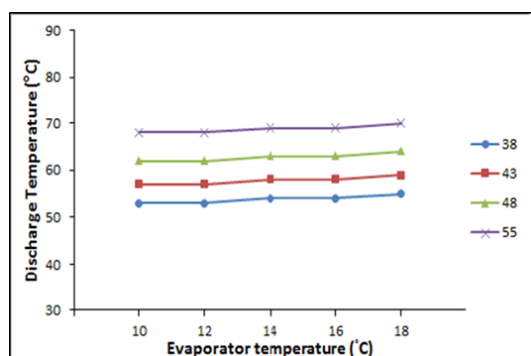


Figure 4. Variation in discharge temperature with evaporator temperature

Lower discharge gas temperatures also proved the compatibility of refrigerant R290 with mineral oil as a lubricating oil.

5. CONCLUSIONS

In the present work, water cooler test facility for the refrigerant R290 is designed; developed and experimental analysis is carried out in order to assess the suitability of refrigerant R290 for water cooler application, especially in warm climate of tropical countries. Evaporator temperature range used in this investigation correspond to water cooler application. Considering the ambient temperatures in tropical countries, condensing temperatures ranging from 38 °C to 55 °C are maintained for testing. Different performance parameters are investigated experimentally and conclusions are drawn as follows.

Following conclusions can be drawn from the study.

1. COP values of the developed refrigeration system for evaporator temperature range of 10°C to 18°C varies from 1.38 to 3.25 for the condensing temperatures of 38 °C to 55 °C. COP value is higher at higher evaporator and lower condensing temperature and vice versa.
2. Energy consumption and cooling capacity curves of a compressor observed a typical trend for different evaporator and condensing temperatures.
3. Compressor discharge temperature values are in the range of 54 °C to 69 °C for the condensing temperatures of 38 °C to 55 °C. These lower values proved the compatibility of mineral oil with refrigerant R290. Finally, this study recommends R290 as energy efficient and environment friendly refrigerant in water cooler applications, especially in the warm climate of tropical countries.

6. ACKNOWLEDGEMENTS

The present study is financially supported by the Alumina Association of College of Engineering Pune (COEP). Their assistance is gratefully acknowledged.

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PAPER INFO

چکیده

Paper history:

Received 26 August 2017

Received in revised form 04 November 2017

Accepted 30 November 2017

Keywords:

Coefficient of Performance

Experimentation

Refrigerant R290

Water Cooler

این مقاله مبرد دوستدار محیط زیست R290 را به عنوان یک راه حل برای نگرانی های زیست محیطی مانند حذف لایه ازن و افزایش گرم شدن کره زمین به دلیل استفاده گسترده از مبرد های مصنوعی R22 و R134a ارائه می دهد. کولر آبی، مبردی با کاربرد گسترده در کشورهایی با آب و هوای گرم است. مبرد R22 و R134a مبردهایی هستند که عمدتاً در سیستم های کولر آبی استفاده می شوند. این مبرد ها طبق توافقنامه های بین المللی، پروتکل کیوتو و مونترال منسوخ شده اند. این مطالعه تجربی، کاربرد مبرد R290 دوستدار محیط زیست را برای برنامه های کاربردی، به ویژه در کشورهای گرمسیری و گرمسیری گرم مانند هند، مورد بررسی قرار می دهد. تست خنک کننده آب با ظرفیت خنک سازی اسمی 1/5 کیلو وات به طور ویژه طراحی شده و برای R290 توسعه یافته و عملکرد آن در شرایط عملیاتی مختلف مورد بررسی قرار گرفته است. پارامترهای عملکرد مانند ظرفیت خنک کنندگی، دمای گاز تخلیه و ضریب عملکرد تجزیه و تحلیل می شود. نتایج نشان داد که مصرف انرژی کمپرسور و دمای تخلیه گاز برای سیستم مبرد کولر آبی پایین تر است. عملکرد کلی سیستم ویژه توسعه یافته برای استفاده از کولر آبی ثابت کرد که R290 می تواند با توجه به بهره وری انرژی و تاثیر گلخانه ای مبرد بهتری به عنوان جایگزین R22 و R134a باشد.

doi: 10.5829/ije.2018.31.01a.21