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Influence of Abrupt Pressure Drop on the Refrigerating Effect of a Typical Vapour Compression Refrigeration System (VCRS)

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ABSTRACT

Energy recovery is the prime requirement today to optimize energy consumption. The maximum utilization of thermal energy is achieved by properly designed Heat Exchangers, and selection of temperature program. This paper work elaborates the influence of abrupt pressure drop on the refrigerating effect of a typical vapour compression refrigeration system (VCRS) in relation to performance of condenser. The purpose of paper is to compare the COP of refrigerator by using Spiral micro-tube condenser with the conventional type condenser. It was observed from the research that abrupt pressure drop improves refrigerating process of a VCR system. Also, the effectiveness of the heat exchanger for other varying shaped coil is more than that for the U- shape coil. In this context, it is essential to carry out the research for COP increment; thus, spiral micro-tube air cooled condenser will be attached in the domestic refrigeration test rig to find out the COP of the system.

1. Introduction

Energy recovery is the prime requirement today to optimize energy consumption. The maximum utilization of thermal energy is achieved by properly designed heat exchangers, and selection of temperature program. In current scenario the household refrigerators work on the vapour compression refrigeration system which holds high coefficient of performance. Most of the domestic and commercial refrigerators are operates on 'Vapour-Compression' cycle and run for normal COP value which holds the scope of improvement with alteration made in components assembled in system [1-10]. Fig. 1 shows the schematic diagram of components for typical vapour-compression refrigeration system. Basic components of refrigeration system as shown in the Fig., they are compressor, condenser, expansion valve, evaporator. Compressor is motor driven, it sucks vapour refrigerant from evaporator and compresses. In Condenser high pressure vapour refrigerant is condensed into liquid form in the condenser using cooling medium such as water. High pressure refrigerant is throttled down to evaporator pressure and rate of flow is metered in the expansion valve. Refrigerant effect is obtained at the evaporator, low pressure liquid refrigerant flows in the coils of evaporator and absorbs heat from product; the refrigerant vaporizes and leaves for compressor [11-15]. From point 1 to point 2, the vapour is compressed at constant entropy and exit compressor as a vapour which holding very high temperature.

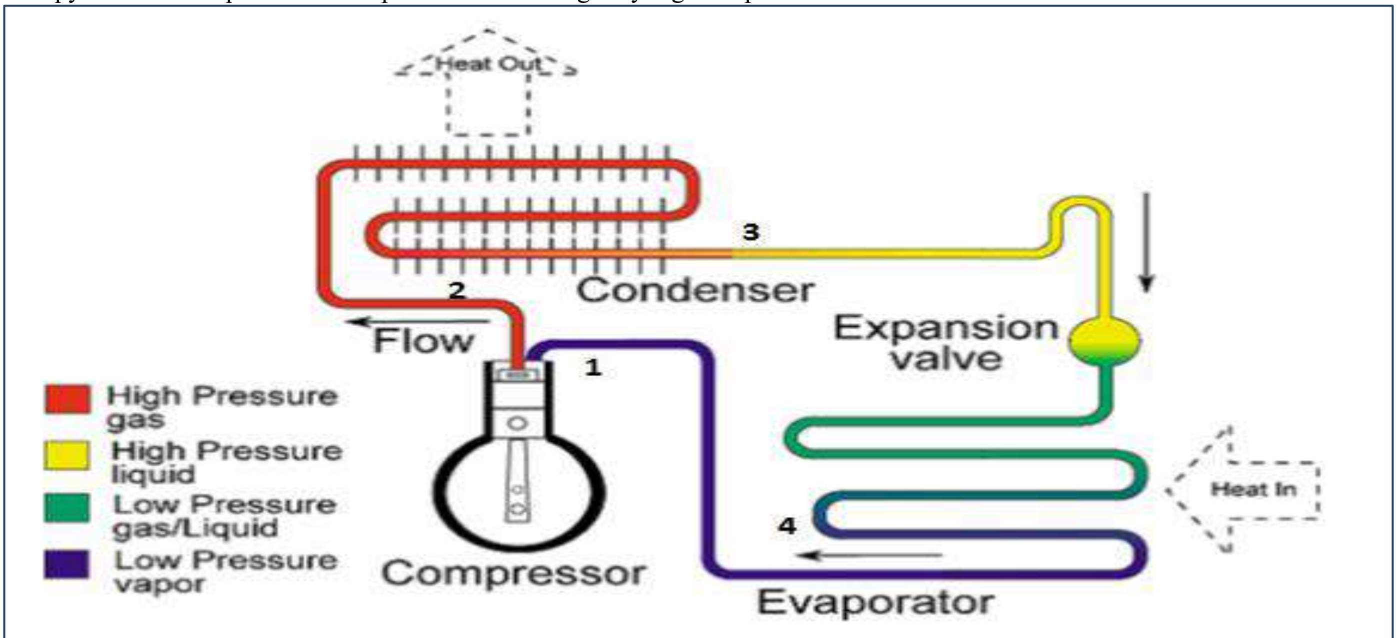

Fig. 1: Vapour Compression Refrigeration System

From point 2 to point 3 and further to point 4, the vapour travels through condenser which cools the vapour until it starts condensing, and then condenses the vapour into a liquid by removing additional heat at constant pressure and temperature.

The liquid refrigerant goes through expansion valve/throttle valve, where its pressure decreases abruptly, causing flash evaporation and auto-refrigeration of less than half of the liquid it further results in forming mixture of liquid and vapour at the lower temperature and pressure as shown in Fig. 1. The cold liquid/vapour mixture then travels through the Evaporator coil and get vaporized by cooling the warm air, being blown by fan across the Evaporator coils or tubes. The resulting refrigerant vapour returns back to the compressor inlet at point 1 to complete the thermodynamic cycle and so on [16-17]. This article elaborates the heat exchanger i.e. condenser. Condenser is mainly classified based on the shape of the coils and type of flow of refrigerant. Condenser is a device or unit used to condense a substance from its gaseous to its liquid state, by cooling it. In so doing, the latent heat is given up by the substance, and will transfer to the condenser coolant. Condensers are typically heat exchangers which have various designs and come in many sizes ranging from rather small (hand-held) to very large industrial-scale units used in plant processes. For example, a refrigerator uses a condenser to get rid of heat extracted from the interior of the unit to the outside air. Condensers are used in air conditioning, industrial chemical processes such as distillation, steam power plants and other heat-exchange systems. Use of cooling water or surrounding air as the coolant is common in many condensers. A surface condenser is an ex-ample of such a heat-exchange system. It is a shell and tube heat exchanger installed at the outlet of every steam turbine in thermal power stations. Commonly, the cooling water flows through the tube side and the steam enters the shell side where the condensation occurs on the outside of the heat transfer tubes. The condensate drips down and collects at the bottom, often in a built-in pan called a hot well. The shell side often operates at a vacuum or partial vacuum, produced by the difference in specific volume between the steam and condensate [18-22]. Conversely, the vapour can be fed through the tubes with the coolant water or air flowing around the outside. Larger condensers are also used in industrial-scale distillation processes to cool distilled vapor into liquid distillate. Commonly, the coolant flows through the tube side and distilled vapor through the shell side with distillate collecting at or flowing out the bottom. The fan is used to blow the outside cooling air, in, through the heat exchange section at the sides; and out the top, through the grating. These condenser units are located on the outside of the building they are trying to cool, with tubing between the unit and building; one for vapor refrigerant entering, and another for liquid refrigerant leaving the unit. Of course, an electric power supply is needed for the compressor and fan inside the unit.

2. Literature Review

Lots of modifications and exploration has been done on refrigeration system in order to improve the efficiency and ease of getting cooling effect. Lohote et al. (2017) contributed by using spiral and micro channel condenser to raise COP of refrigerator to the value that was never before [23]. The geometry, enhanced surface area of such micro channels is found adding positive results in the enhancement of COP value and work is elaborate through research work drafted in the paper. The experimental work centres on the performance study of spiral and micro channel shaped condenser used in refrigerator, holding 165 litters' capacity. For spiral and micro channel shape condensers, COP value found increased by 5.06 % and 13.82 % respectively over the conventional refrigeration system. When spiral condenser is replaced by micro channel there is increase in refrigeration effect and compressor work by 12.02 % and 6.25 % respectively with increase in rate of heat rejection consider-ably. The summarized observations from the performance of micro channel shape base condenser reveals that the refrigeration system has better performance over conventional refrigeration system, supported with regular shape condenser. Santosh et al. (2015) performed the experimental investigation of vapour compression refrigeration system with spiral shaped condenser [17, 24-25]. The work is centres on the COP of refrigeration system using conventional condenser made of MS with Cu coating; and the verifying effect of performance using conventional condenser made of copper material. Experiment was done on kelvinator refrigerator of 165 liters and hermitic compressor is used. Result obtained from the conventional condenser is compared with spiral shaped condenser with varying pitch from 1.5 inch to 2.25 inch. The optimum COP is 4.25and it is obtained at 2-inch pitch of the coil. After experimental investigation of various condensers, final result comes as spiral shaped condenser coil (Cu) of diameter 6.35 mm, 8500 mm length and 2-inch pitch is recommended for VCR system of domestic refrigerator of 165 liters capacity with R134a as refrigerant. Vivek et al.(2003) presented experimental analysis of domestic refrigeration system by using wire-on-tube condenser with different spacing of wire [26]. Operating parameters like heat transfer rate, condenser pressure and condenser temperature are considered. Refrigerating effect is increased by using wire-on-tube condenser comparatively power consumption remains same as with air cooled condenser in a domestic refrigeration system. Therefore wire-on-tube condenser can replace the ordinary air-cooled condenser in a domestic refrigeration system [27-30]. The conclusion of this paper is that discharge pressure of 9 mm fins spacing is about the same with that of 6 mm fins spacing with average percentage reduction of 5.7%. The discharge pressure of 3 mm fins spacing was the highest with average value of 4.7% and 10.2% higher than those of 6 mm fins spacing and 9mm fins spacing respectively. At steady-state conditions, the discharge pressures for 3 mm, 6 mm, 9 mm were 34.41, 32.00 and 30.56 bar, respectively. Wang, et al. (2013) described comparative Performance Assessment of water-cooling condenser, air cooling condenser and evaporation condenser [18]. Various performance parameters are considered to evaluate the performance of different condenser system on the same condition; for instance: refrigerating capacity and COP of water-cooled condenser. The refrigerating capacity of water-cooling condenser system increases 2.9 - 14.4%; than evaporative condenser system and also COP of water-cooling condenser system increases 1.5 - 10.2% than evaporative condenser system. The refrigerating capacity and COP of evaporating condenser system is more by 31% and 14.3% than air cooled condenser. At the same evaporating temperature and condensing temperature, the refrigerating capacity, heat rejection and COP of the water-cooling condensing system are better than that of evaporative cooling system and air-cooling system. When temperature is 40°C, the evaporating temperature ranges from -24°C to 13°C. An evaporative condenser system's performance is same as the water-cooling condenser system. But an evaporative condenser system is much better than the air cooling condenser system. Here the advantages of water saving and energy saving of evaporative condenser is most obvious. Mohan et al. (2016) designed Mini-Scale Refrigerator. The performance analysis is concerned about design of mini-scale refrigerator by using spiral micro-tube evaporator and miniature compressor [31-32]. A mini-scale vapour compression refrigeration system of 300-Watt cooling capacity using R134a as a refrigerant was designed, built and tested. This test indicates that the actual COP of the developed system is 1.6 and second law efficiency is 19%. The experiments also show that the system was able to dissipate heat fluxes of 48 W/cm^2 and keep the junction (chip) temperature below 82˚C. The refrigeration cycle is designed for this mini refrigerator using Cool-pack software. Bhatkar et al., (2015) experimental performance of R134a and R152a using Spiral micro-tube Condenser was done. The performance analysis is concerned with the comparison of performance between conventional refrigerator and Spiral micro-tube refrigerator with R134a and R152a refrigerant. The author concludes that refrigerant charge was reduced by 40% with the use of micro-channel condenser over the conventional condenser [33]. Discharge temperature of R152a was more than R134a by around 6 to 10°C. The condensation temperature drops by 2 to 2.5°C by using micro-channel condenser over the conventional condenser for same ambient temperature. The compressor energy consumed by R152a is slightly less than R134a from -10 to 15°C. COP with R152a refrigerant was more than R134a for all evaporator temperatures. Condenser capacity for R152a was higher than R134a because of large latent heat. Bilal et al.(2014) studied experimental observation on the impact of fouling on the condenser of a vapor compression refrigeration system. An experimental study of condenser fouling factor on some performance characteristics and properties of a simple vapor compression system is presented. It can be concluded that due to fouling heat transfer rate of condenser was decreases [34]. Rober et al.(2011) performed design, fabrication, and evaluation of a ceramic counter-flow spiral micro-tube heat exchanger. In a refrigeration system, compressor absorbs more power due to pressure drop in condenser. In spiral micro-tube condenser to optimize the pressure drop various design parameter is considered. Pressure drop is dependent upon shear stress, wetted perimeter and cross-sectional area. To analyze pressure drop, shear stress is represented as frictional factor, Reynolds number [35-37]. Pressure drop is inversely proportional to cube of channel height.

3. Methodology

The influence of abrupt pressure drop on refrigerating effect of a typical VCR system will be studied according to the research work of Sushant et al., (2017) who tried to improve the performance analysis of a VCR system using a spiral micro-tube condenser rather than conventional. According to Sushant et al., (2017), the effectiveness of the condenser can be increased by many methods some of them are [19]:

Geometry of the condenser coil
Increase the surface area
Thermal conductivity of the tube material
Fin spacing

The foregoing literature shows that there is chance to increase the effectiveness of the condenser considering the geometry of the condenser tube.

3.1 Experimental Setup

Block diagram of the experimental setup is shown below:

Fig. 2 Experimental Setup, Source: Sushant et al., (2017)

3.2 Experimental Work

The analysis of refrigeration system using spiral micro-tube condenser set up is built considering various parameters. The measured parameters are actual coefficient of performance, theoretical coefficient of performance, mass flow rate of refrigerant, heat rejection ratio, heat rejected by condenser and heat transfer coefficient. From various operating conditions, data obtained from refrigeration system using spiral micro-tube condenser was compared with conventional condenser system. In experimental procedure, performance of spiral micro-tube condenser, and conventional condenser was compared using refrigerant which is R134a (Tetrafluoroethane). The two condensers are connected in parallel and operated by closing, opening of throttle valve.

4. Observation and Results

By running the system with conventional and spiral condenser individually we observed that system with spiral micro-tube condenser works efficiently in terms of the coefficient of performance more than system with conventional condenser. Graphs are drawn on the basis of some parameters which affect the performance of the system. Some of the important graphs are shown below:

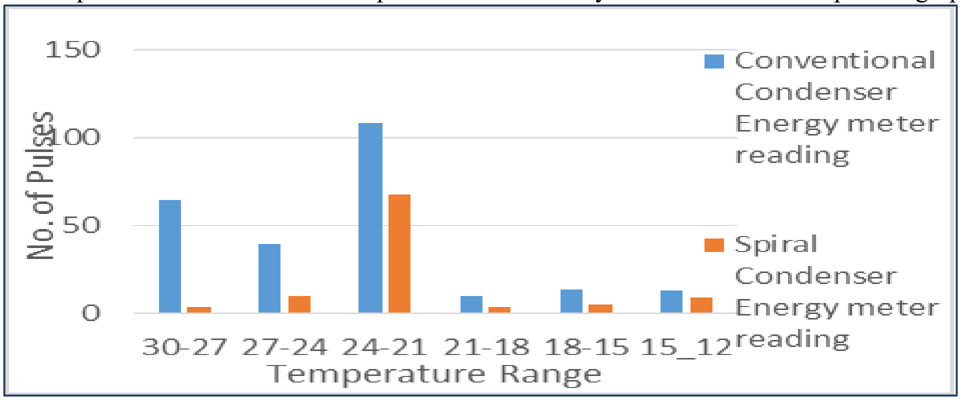

Fig.3 Plot between no. of pulses vs temperature range, Source: Sushant et al., (2017)

From the above graph it clearly observed that the energy consumption from the system with spiral micro tube Condenser is lower than the conventional condenser system.

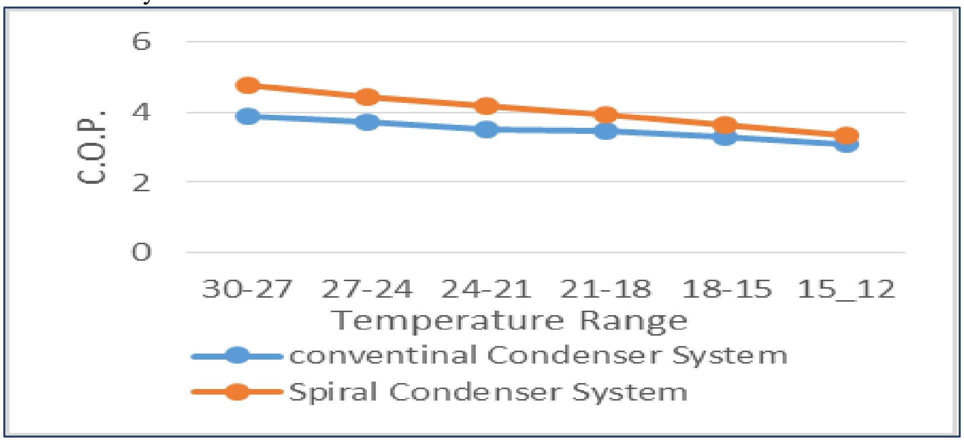

Fig. 4 C.O.P. for both systems with conventional and spiral micro-tube Condenser, Source: Sushantet al., (2017)

Coefficient of performance of the system continues decreasing because load on evaporator is increasing gradually. From the above graph it clearly shows that COP of the system with spiral micro-tube condenser is greater than the system with conventional system.

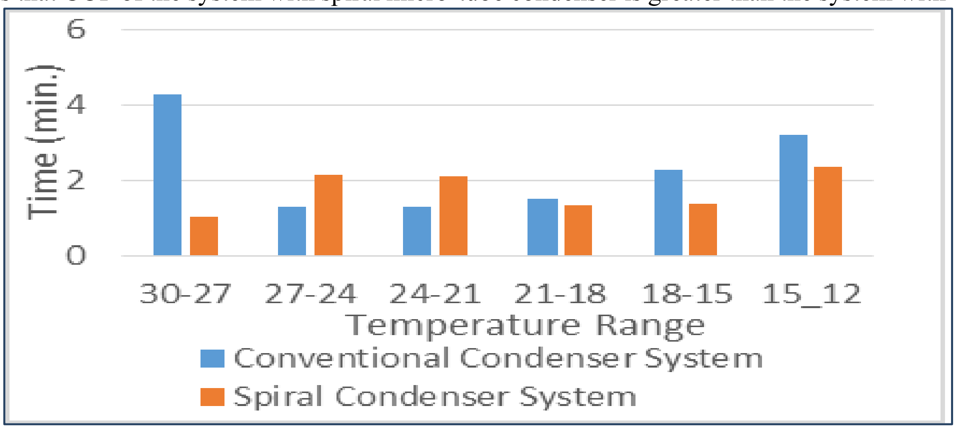

Fig. 5 Plot between Time vs. temperature, Source: Sushant et al., (2017)

Time required to cool water from 30°c to 12°c is minimum for spiral micro tube condenser system as compared to convention-al condenser system. Total time required for cooling water from 30°c to 12°c by conventional system is 15.08 minutes and for spiral micro tube condenser system 11.05 minutes

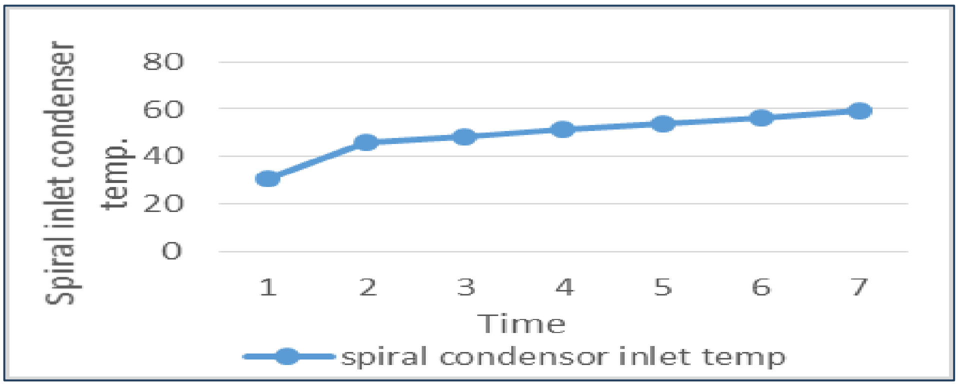

Fig.6 Spiral micro tube condenser inlet temp. vs. time, Source: Sushant et al., (2017)

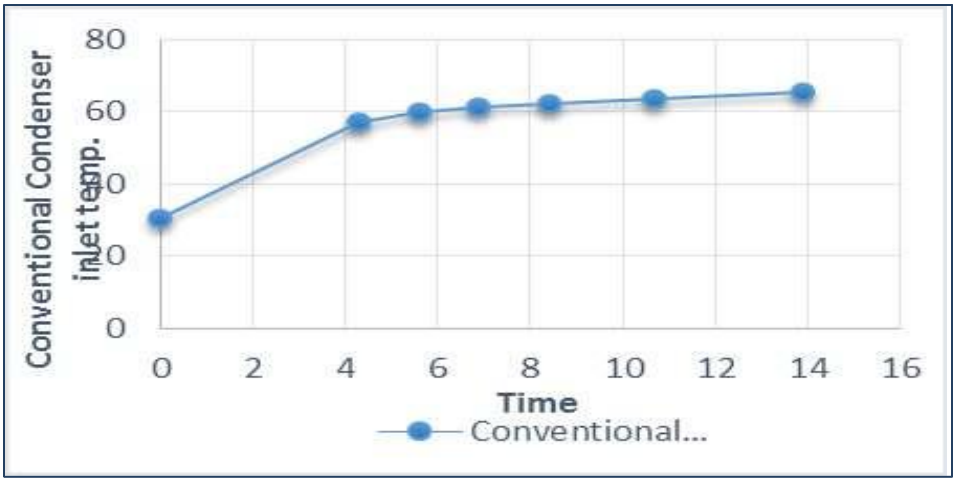

Fig. 7 Conventional condenser inlet temperature vs. time, Source: Sushant et al., (2017)

Variation of condenser inlet temperature of both spiral micro tube and conventional condenser with respect to time is shown in the above graph.

5. Conclusion

The current work is primarily concerned about the performance study of spiral micro-tube condenser used in refrigerator. The data obtained from fabricated experimental set-up are used in analyzing performance of spiral micro-tube condenser and conventional condenser (a constituent part of vapor compression system). With introduction made of spiral micro-tube condensers, the COP value was found to increase by 13.45%, over the conventional refrigeration system. When conventional condenser is replaced by micro-tube condenser there is increase in refrigeration effect and compressor power requirement decreases by 35.90%

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