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Experimental Investigation of a Vapor Compression Refrigeration (VCR) System with Integrated Mechanical Subcooling

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Abstract—*This paper deals with an experimental investigation of a Vapor Compression Refrigeration System with Integrated mechanical subcooling and comparing the results with a Simple Vapor Compression Refrigeration System. The experimental results show an increase in cooling capacity by 30.33% and decrease in dryness fraction of the refrigerant entering the evaporator by 57.35% when compared to the cooling capacity and dryness fraction for a Simple Vapor Compression Refrigeration System operating between the same parameters. The Coefficient of Performance (COP) decreases by 17.06% in case of VCR System with Integrated Mechanical Subcooling as compared to Simple VCR system because of the use of two compressors in case of VCR with Integrated Mechanical Subcooling whereas in case of simple VCR system only one compressor is used. Further designing of large systems operating between 5^0C and 40^0C is done and various COPs at different degrees of subcooling are calculated and plotted. The design proves and shows that the COP will also increase if VCR with Integrated Mechanical Subcooling is used for larger refrigeration systems which hence proves the usefulness of Integrated mechanical subcooling to improve the various performance parameters of a simple VCR system.*

1. INTRODUCTION

Refrigeration & Air-conditioning systems consume a large amount of the world's generated electrical power in maintaining thermal comfort and suitable climatic conditions for occupants. The mechanical vapor compression technology is laying down the basis of many important industrial, agricultural and household refrigeration applications. Various methods have been proposed to improve the energy efficiency of VC systems. From thermodynamic standpoint, further cooling of liquid refrigerant leaving condenser can significantly improve cooling capacity and can also improve the system performance. This methodology is identified as Subcooling. Subcooling has been mainly used in medium and low-temperature refrigeration systems wherein a simple vapor-compression refrigeration system is provided with some kind of subcooling arrangement to improve the cooling capacity of the system. One type of sub-cooling is the mechanical type, where a separate VC cycle exists solely for the purpose of providing subcooling to the main cycle. When the subcooling is obtained with the help of an integrated cycle coupled with the main Vapor compression cycle then it is called Integrated Mechanical Subcooling.

An experimental setup is fabricated for the Vapor Compression Refrigeration System with Integrated Mechanical Subcooling and then analysis is done on the readings obtained. The results obtained are compared with the results of a basic Vapor compression refrigeration system. In the same setup there is provision to switch off subcooling, thus converting the system to basic Vapor compression refrigeration system. This experimental analysis is performed by running the system both with and without subcooling. The configuration without subcooling is termed as 'base configuration' and the one with subcooling is termed as 'subcooler configuration'. The refrigeration system uses a 140 W hermetic reciprocating compressor for the main cycle. A 80 W hermetic reciprocating compressor is used for subcooler cycle. It must be noted that R134a is used as a working fluid in both main and subcooler cycle. A subcooler is used after the condenser which extracts the heat from the main cycle refrigerant and hence it acts as an evaporator for subcooler cycle. The condenser is common for both the cycles and both the compressors compress upto the condenser pressure.

Experimental readings such as pressure and temperature values are noted for a week and then the average values of all the days is used for calculation purposes. Finally the results for the two configurations are compared. To obtain the pressure readings, three pressure gauges are installed which give the evaporator pressure, intermediate pressure and the condenser pressure. Also to obtain the temperature readings, digital thermometers are used at necessary locations.

2. LITERATURE REVIEW

Khan et al.[1], Bahel et al.[2], Zubair [3] and Zubair et al.[4] have investigated an integrated mechanical subcooling system by creating thermodynamic models and then analysing them on EES(Engineering Equation Solver) and finding results. No experimental work has been done. In either of these studies, they found that the system performance improved when operating in situations where the difference between the condensing and evaporating temperatures is large.

Zubair [3] and Zubair et al.[4] have investigated the second law analysis of an integrated mechanical-subcooling system using an ideal refrigerant cycle model. They showed that the irreversible losses in the expansion device (the major source of irreversibility) can be significantly reduced by operating the system at the optimum subcooling conditions. This optimum condition was found to occur at a subcooler saturation temperature about halfway between the condensation and evaporation temperatures.

Majority of work done by Khan et al.[1], Bahel et al.[2], Zubair[3], Zubair et al.[4], Khan et al.[8], Khan et al.[9] and Khan et al.[10] deal with thermodynamic modelling and using softwares such as EES to predict the performance of the systems. The results from the softwares are not verifiable unless verified by a physical setup, hence a need arised for studying the system by fabricating a physical setup.

3. CYCLE DESCRIPTION

In this cycle [Figure 1], two refrigerant loops are employed. The outer bigger loop is main cycle while the smaller inner loop is the subcooler cycle. Main system components are condenser, two expansion valves, two compressors, one sub-cooler and an evaporator. Both the cycles contain the same refrigerant. Both the refrigerant loops are connected through a common heat exchanger ie. subcooler. Heat transfer takes place inside the subcooler ie. the main cycle refrigerant subcools whereas the subcooler cycle refrigerant takes the heat and the subcooler hence acts as an evaporator for the subcooler cycle. It should be noted that the refrigerant exits the condenser at state 3 as a saturated liquid at high-pressure and then enters the subcooler. Inside the subcooler, the refrigerant is cooled below the saturated liquid state by exchanging heat with the subcooler cycle refrigerant and its state changes from state 3 to state 4 and then enters the expansion device of the main cycle. On the other hand, the subcooler-cycle refrigerant enters the subcooler at state 6 and after cooling the main cycle refrigerant, it exits at state 7, as a low temperature & low pressure saturated vapor. The main cycle refrigerant enters the evaporator at state 5 and leaves at state 1. The refrigerant vapor gets compressed from state 1 to state 2 in main cycle compressor and from state 7 to state 8 in subcooler cycle compressor respectively. The state after state 2 and state 8 is state 9. From state 3 to state 6 the refrigerant which is bled off for the subcooler cycle is expanded in the capillary. The main cycle refrigerant is expanded from 4 to 5 in the capillary. The Pressure enthalpy diagram (P-h) diagram is drawn in Figure 2. The experimental setup is shown in Figure 3.

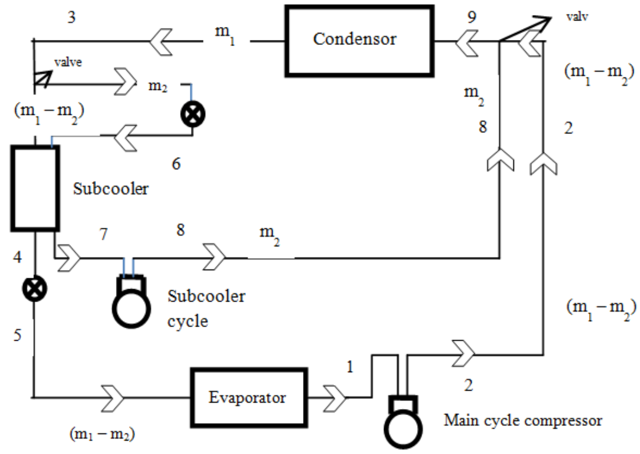

Figure 1: Schematic Cycle of Vapor Compression Refrigeration System with Integrated Mechanical Subcooling

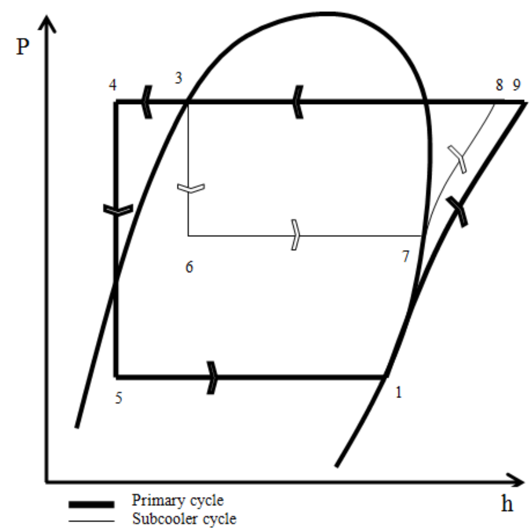

Figure 2: P-h Diagram of the Cycle

Figure 3: Experimental Setup for the Cycle

4. EXPERIMENTAL RESULTS

To perform this study we have to take some assumptions into account, which are:

a) There are no heat losses in the lines.
b) There are no pressure losses in the lines.

Readings were taken for a week in the month of February at NIT Kurukshetra and average was taken.

A current clamp meter is used to find the draw able current by the compressors which came out to be 0.5 A and 0.285 A for 140 W and 80 W compressors respectively. Thus the effective drawing power for the compressors are (0.5*220 = 110 W) & (0.285*220=62.857 W) respectively. The calculations are hence done according to these calculated powers that the compressors are drawing.

For base configuration, variation of suction and discharge pressure along with ambient temperature, over a period of several hours, is shown in Figure 4. Experimental results show that pressure reaches its maximum value when the ambient temperature is at its highest point because of the rise in condensing temperature and thus in condenser pressure.

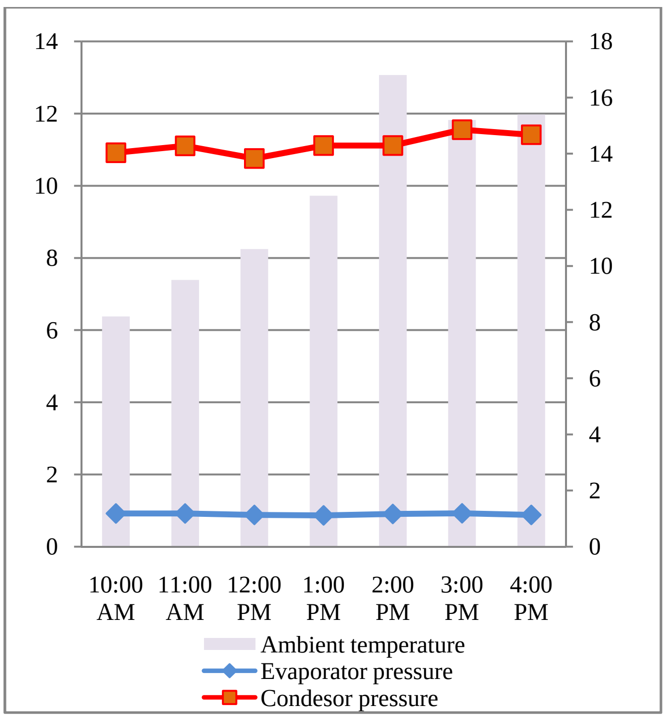

Figure 4: Variation of Suction & Discharge Pressure with Ambient Temperature for Base Configuration

For subcooler configuration, variation of suction pressure, intermediate pressure and discharge pressure along with ambient temperature, over a period of several hours, is shown in Figure 5. Experimental results show that pressure reaches its maximum value when the ambient temperature is at its highest point because of the rise in condensing temperature and thus in condenser pressure.

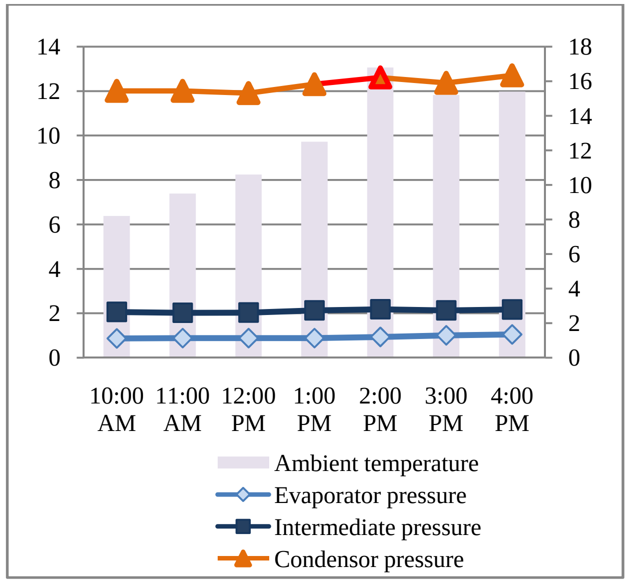

Figure 5. Variation of Suction, Intermediate & Discharge Pressure with Ambient Temperature for Subcooler Configuration

Figure 6 and Figure 7 show the Variation of Cooling Capacity with time for base and subcooler configurations respectively.

The Cooling Capacity for subcooling configuration increases by 30.33% as compared to base configuration.

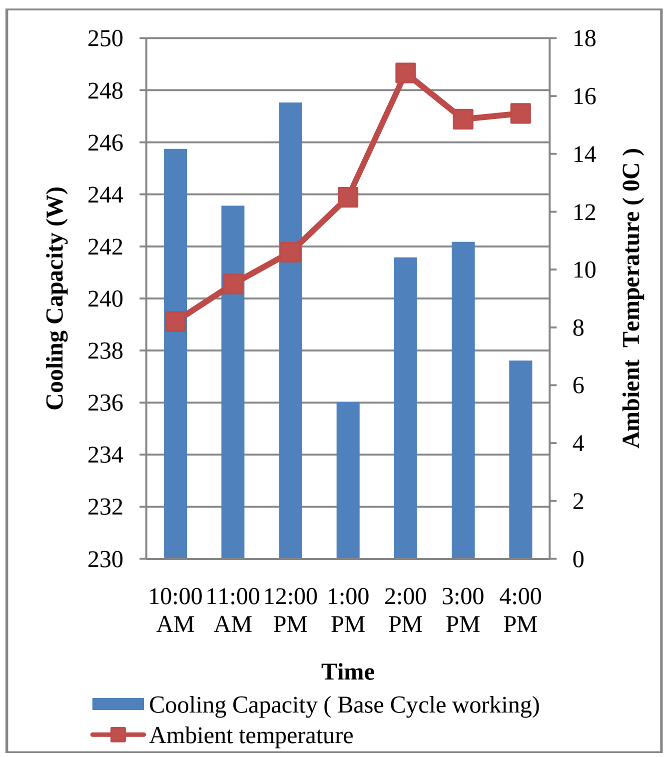

Figure 6. Variation of Cooling Capacity with Time and Ambient Temperature for Base Configuration

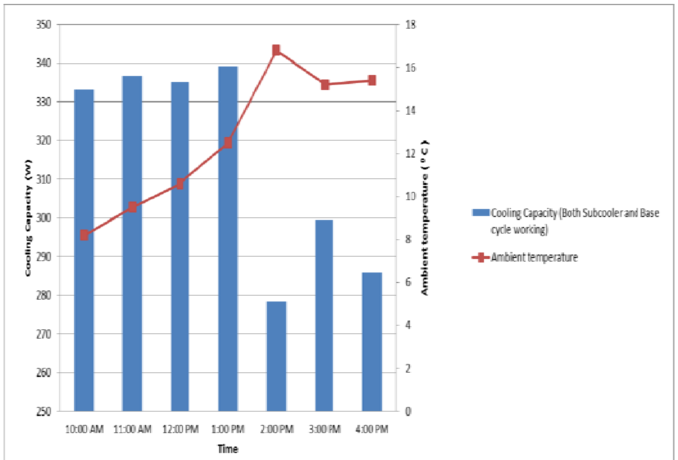

Figure 7. Variation of Cooling Capacity with Time and Ambient Temperature for Subcooler Configuration

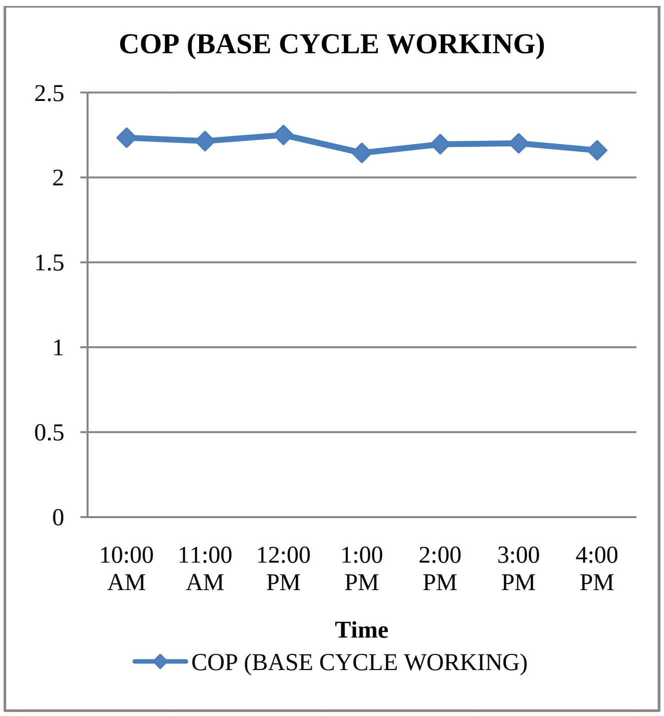

Figure 8. Variation of COP with Time for Base Configuration

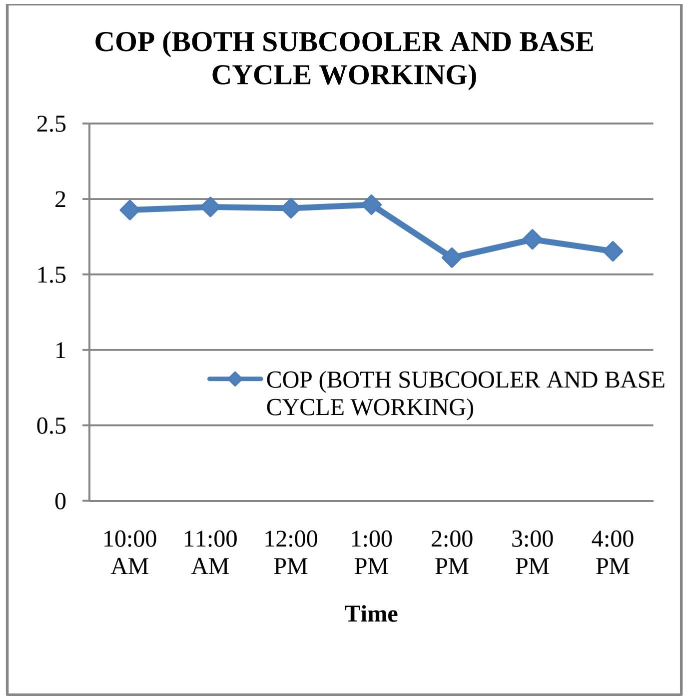

Figure 9: Variation of COP with Time for Subcooler Configuration

The COP of subcooler configuration reduces by 17.06% [Figure 10] as compared to base configuration because in base configuration single compressor of 140 W is used while in subcooler configuration two compressors of 140 W and 80 W are used. But when the system is designed for larger cooling capacity, increase in COP is also seen.

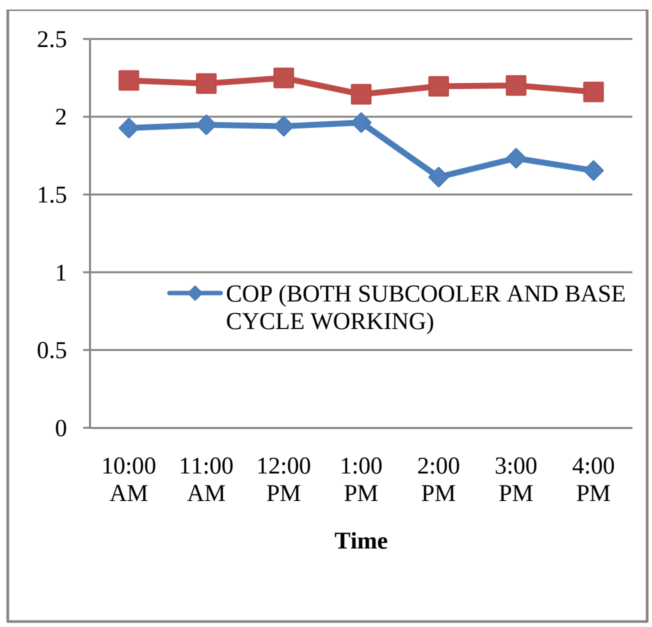

Figure 10: Comparison of COP with Time for Both (Base and Subcooler Configuration)

The Coefficient of Performance for a simple Vapor compression refrigeration system operating between 5^0C evaporator and 40^0C condenser temperatures is 6.27. When Integrated mechanical subcooling is employed for larger systems (5TR, 15TR, 25TR and 50TR) operating between the same 5^0C evaporator and 40^0C condenser temperatures then for different degree of subcooling we can see that the Coefficient of Performance for Vapor compression refrigeration with Integrated mechanical subcooling increases by 7.07% to 22.68% according to the degree of subcooling employed (10^0C, 20^0C, 30^0C and 35^0C).

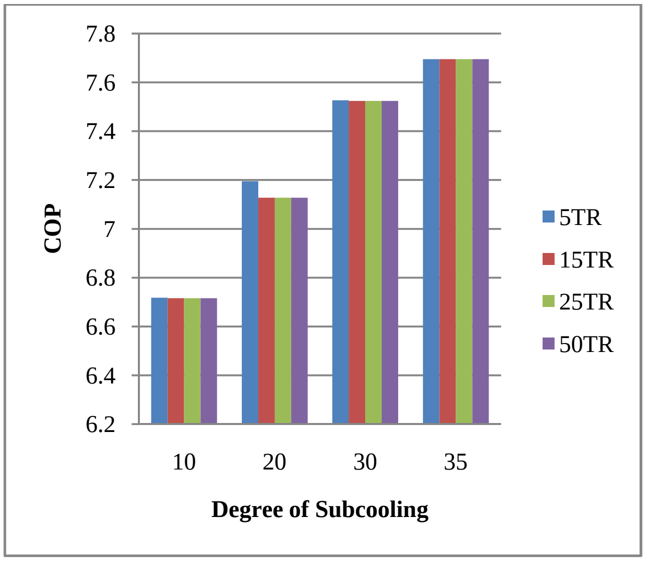

Figure 11: Comparison of COP with Degree of Subcooling for 5TR, 15TR, 25TR and 50 TR Systems

Figure 12 shows the variation in degree of subcooling with time. The degree of subcooling varies between 21 to 25 degree Celsius.

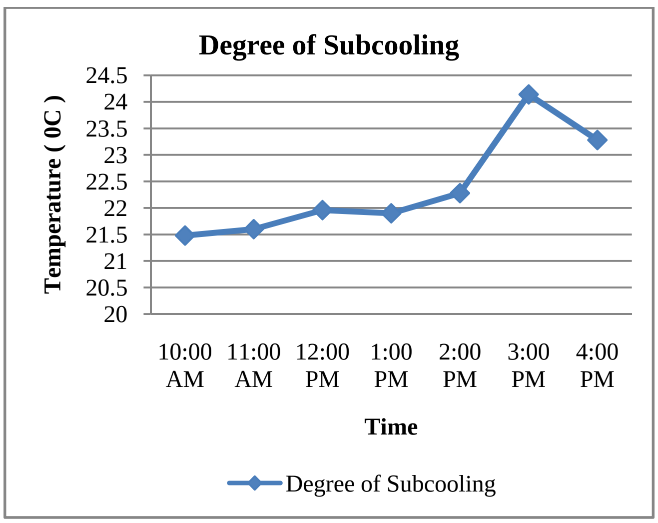

Figure 12. Variation of Degree of Subcooling over a Period of Time

The dryness fraction in case of Subcooler configuration is less as compared to the dryness fraction of base configuration by 57.35% and thus the heat absorbing capacity of the refrigerant increases and hence cooling capacity increases in case of subcooler configuration.

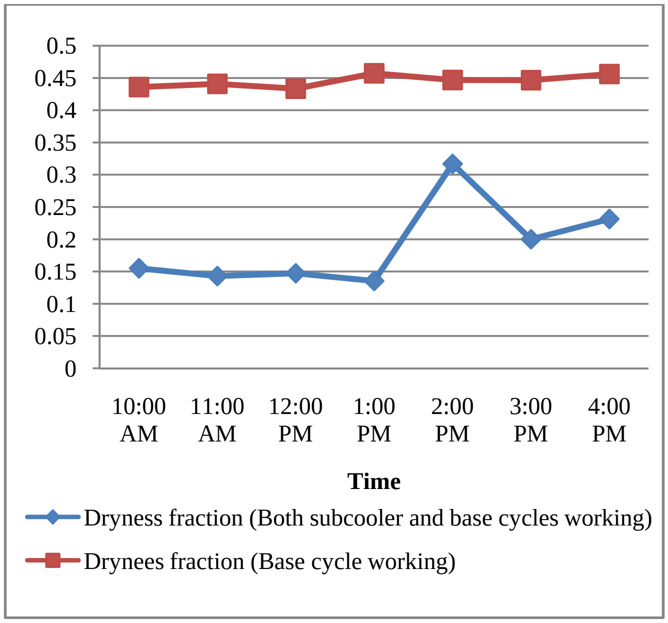

Figure 13: Comparison of Dryness Fraction of Refrigerant before Entering the Evaporator in Base and Subcooler Configurations

5. CONCLUSIONS

The experimental results show an increase in cooling capacity by 30.33% and decrease in dryness fraction of the refrigerant entering the evaporator by 57.35% for a Vapor Compression Refrigeration system with Integrated Mechanical Subcooling when compared to the cooling capacity and dryness fraction for a Simple Vapor Compression Refrigeration System operating between the same parameters.

The Coefficient of Performance decreases by 17.06% in case of VCR System with Integrated Mechanical Subcooling as compared to Simple VCR system because of the use of two compressors in case of VCR with Integrated Mechanical Subcooling whereas in case of simple VCR system only one compressor is used.

The coefficient of performance increases for larger cooling capacity systems such as proved for 5TR, 15TR, 25TR and 50TR systems, when we use Integrated Mechanical Subcooling.

Thus overall Integrated Mechanical Subcooling is beneficial for improving the performance of a basic Vapor Compression Refrigeration System.

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