Performance Analysis of Vapour Compression Refrigeration System with Mechanical Subcooling

S. Panneerselvam, P. Thangavel, S. Kannaki

Abstract: ***This experimental work focuses the performance comparison of Vapour Compression Refrigeration System (VCRS) with mechanical subcooling. The experimental study of VCRS has been carried out with two categories such as air cooling and mechanical subcooling. The various performance measures like Coefficient of Performance, compressor input and condenser heat rejection rate and refrigeration effect are compared in these two categories at different evaporator loads (50,100,150,200,250 Watts) with respect to the results obtained. Mechanical subcooling provides a better performance as compared to conventional air cooled refrigeration system upto 22% improvement in COP, 8% improvement in refrigeration effect, 7% improvement in condenser heat rejected. The result provides that mechanical subcooling could be used to improve the performance of VCRS. This noval concept can be implemented in very large capacity of VCRS used in industrial refrigeration system.***

Key words: COP, Condenser heat rejection rate, Mechanical subcooling, Refrigeration effect.

I. INTRODUCTION

A considerable percentage of the electricity is consumed by refrigeration systems that are often air-cooled is more when compared to water cooled. There is a large temperature difference between the condenser and evaporator. Because of this reasons there is high power consumption by compressor and lesser refrigeration effect per unit mass flow rate of the refrigerant. Under such condition, the compressor should operate for a long period of time to produce required cooling effect, which can harm the system [1]. Refrigeration and air conditioning systems are mainly used in supermarkets and malls. Energy utilized can be reduced by including a sub-cooling loop. Dedicated mechanical subcooling is one of the possible ways. In this method there are two condensers exists separately for main and subcooling cycles. The most important thing is the increase in cooling capacity of evaporator and decrease in head pressure and temperature at main condenser. This helps to increases the life of the compressor by decrease the superheat temperature at the exit of compressor. Yang and Zhang [2] studied an integrated low temperature and mid temperature supermarket refrigeration system using two different refrigerants R404A or R134a and found that 27% improvement in energy savings in the case of optimum subcooler design.

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S.Panneerselvam, Department of Mechatronics Engineering, Sri Krishna College of Engineering and Technology, Coimbatore, India.

P.Thangavel, Department of Mechanical Engineering, Kongu Engineering College, Perundurai, India.

S.Kannaki, Department of Mechatronics Engineering, Sri Krishna College of Engineering and Technology, Coimbatore, India.

In the same system there was another one study has been done with using the refrigerants R12 and R22 as the working fluids, and attained 8% improvement in performance [3]. The work done by the researchers Qureshi et.al showed that, working fluid R134a was used in main cycle as well as dedicated mechanical subcooling cycle and they found that at optimum conditions there has been 40% improvement in COP was observed [4]. Dedicated mechanical subcooling can be employed in two types such as complete design of system or by retrofitting the available existing system. R134a is a main substitute for R12 and R22 at high-temperature levels [5]. Since the subcooling cycle operates at higher temperature, so refrigerants R134a, R410A and R407C are commonly used for high and medium temperature applications. Bilal et al [6] conducted an experiment which gives amount of subcooling is consistently larger when outside ambient temperature is lower. Subcooling was found to approximately range between 5 to 80C, which helps to improve the cooling capacity of the evaporator during the day time and hence COP of refrigerator is improved and more power consumption by compressor. The increase in the cooling capacity results in an increase in the COP of the system demonstrated through the use of the second-law efficiency. The percentage of increase in efficiency depends on ambient temperature, which is inversely proportional to temperature.

II. EXPERIMENTAL SETUP

The conventional vapour compression refrigeration system operates on basic refrigeration cycle which consists of four processes namely compression, condensation, expansion and evaporation. Refrigerant undergoes all these process which is a substance or mixture, usually a fluid, used in refrigeration cycle. In most cycles it undergoes phase transitions from liquid to gas and back again. Many working fluids have been used for such purposes. Fluorocarbons, especially chlorofluorocarbons and other common refrigerants used in various applications are ammonia, sulphur dioxide, and non-halogenated hydrocarbons such as propane and isobutane etc. In this refrigeration system hydrocarbon (HC) is used as refrigerant for absorb and remove heat. Experiments were conducted at various thermal load conditions such as 50, 100,150,200,250 Watts respectively. There are two cycles in this experimental setup as shown in fig.1 one is main cycle and another one is for improving main cycle performance called subcooling cycle. The cycle starts with compression process low pressure low temperature vapour refrigerant enters into the compressor suction line.

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After the compression process the refrigerant pressure and temperature gets increased and phase change takes place then it goes to delivery line. Now high temperature high pressure gaseous refrigerant enters in the condenser. Then there are two pressure gauges provided at suction and delivery heads which shows inlet and outlet pressure of compressor. Heat transfer takes place in condenser by means of convection mode in air cooled condenser and conduction mode in water cooled condenser now temperature of refrigerant gets reduced but the pressure remains constant. Then the high pressure low temperature refrigerant pass through the expansion valve which may be thermal expansion valve or solenoid valve or capillary tube, expansion process is likely to be throttling process. In throttling process enthalpy of process remains constant but pressure gets reduced. Now the low pressure liquid or gaseous refrigerant enters the evaporator, evaporator is also a heat exchanger, which absorbs the heat from the place to be cooled which is our final output. Because of temperature rise refrigerant changes its phase then again goes through suction line. For measuring temperature, thermocouples were placed at various places such as inlet and outlet of compressor, condenser outlet, and evaporator inlet etc.

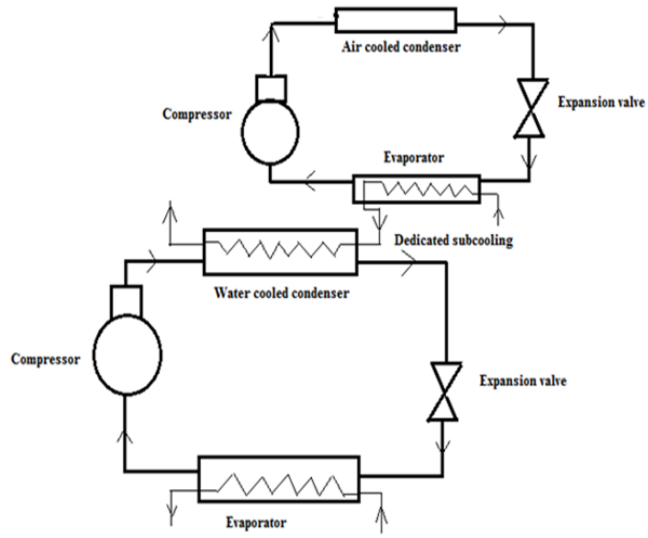

Fig - 1 Schematic representation of refrigeration system with subcooling

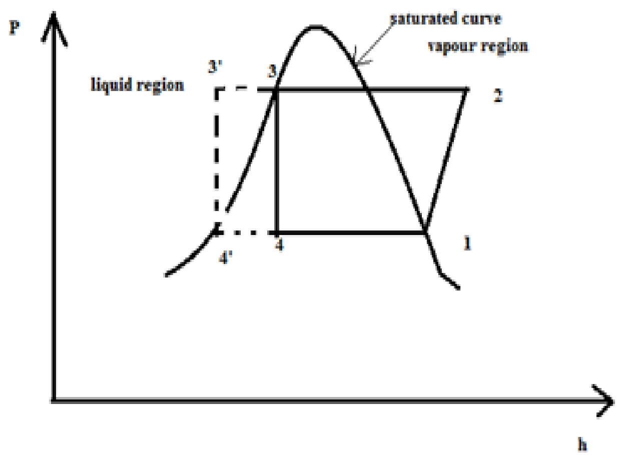

Fig - 2 P-h Diagram of VCRS with Subcooling

Process 1-2 compression process
Process 2-3 condensation process
Process 3-4 expansion process
Process 4-1 evaporation
Process 2-3'condensation with subcooling
Process 3'-4'expansion with subcooling
Process 4'-1evaporation with subcooling

III. Materials and Methods

Experimental setup consists of hermetically sealed reciprocating compressor, air cooled and water cooled condenser, expansion device such as capillary tube or solenoid valve, and an evaporator coil for cooling the water. And refrigerant used is hydro carbon. While doing experiments it is essential to note down the pressure and temperature at various places for this purpose two pressure gauges are fitted at inlet and outlet of compressor and temperature sensors are placed at inlet and outlet of compressor, outlet of condensers (both air cooled and water cooled), and inlet and outlet of evaporator. Then air cooled system is turned on with 100% evaporator water load, after water reaching 28^0C, various heat loads such as (50, 100,150,200,250Watts) applied in the evaporator water, and reading were taken at a constant interval of time (every 10 minutes). After that air cooled is turned off and water cooled system is turned on. Now for water cooling, chilled water is supplied from another small refrigeration system i.e subcooling system. For same conditions and loads readings were taken and performance of the refrigeration system is calculated.

IV. PERFORMANCE ASSESSMENT OF VCRS

For assessing the performance of refrigeration systems following data are required,
There are two conditions of refrigerant namely subcooling and super heating
If the refrigerant in subcooling condition, $h_{sub}=h_{sat}-Cp_{sat}(T_{sat}-T_{sub})$
In case of superheated condition, $h_{sup}=h_{sat}+Cp_{sat}(T_{sup}-T_{sat})$
h_{sat}- enthalpy at saturated condition (kJ/kg)
h_{sub}- enthalpy at subcooled condition (kJ/kg)
h_{sup}- enthalpy at superheated condition (kJ/kg)
Cp_{sat}- specific heat of refrigerant at saturated condition (kJ/kgK)
T_{sat}- saturated temperature (K)
T_{sub}- subcooled temperature (K)
T_{sup}- superheated temperature (K)
Compressor input = h_2-h_1
Condenser heat rejection = h_2-h_3
Refrigeration effect = h_1-h_4
Coefficient of performance = $(h_1-h_4)/(h_2-h_3)$
Where,
h_1- enthalpy at compressor inlet kJ/kg
h_2- enthalpy at compressor outlet kJ/kg
h_3- enthalpy at condenser outlet kJ/kg
h_4- enthalpy at evaporator inlet kJ/kg

V. Results and Discussion

The experiment was conducted on vapour compression system with and without using subcooling methods at various load conditions. Based on readings taken from system, compressor input, heat

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rejected in condenser, refrigeration effect and COP of the system are calculated, and performance results are compared. Then the percentage of improvements in refrigeration effect, condenser heat rejected and COP are calculated. Then the results were plotted in graph. From fig- 3 it is clear that maximum heat rejection in condenser at starting condition after some period of time gradually heat rejection in condenser reduced reason for reduction in heat rejection is increase in water temperature. And there is a criterion for heat rejection, when heat load increases in evaporator heat rejection decreases. From fig- 4 when compared to air cooled system, at 50Watts load there is an improvement in performance in the range of 3-7%. For 100Watts load it reduces to 1.8- 4.7%. At maximum load i.e 250Watts there is only 0.4-3.9% improvement in heat rejection. While considering refrigeration effect versus time. The maximum refrigeration effect could be obtained by giving minimum evaporator load. Fig- 5 clearly indicates that maximum refrigeration effect was attained at 50 Watts load. For 250Watts there is only minimum refrigeration effect. Fig- 6 shows when compared to air cooled system maximum improvement in refrigeration effect at minimum load and minimum improvement in maximum load. When the load increases in evaporator, refrigerant should remove more heat from the system so we attain only minimum effect. Next thing is Coefficient of Performance (COP), from fig- 7 it is depends on refrigeration effect and compressor input. When refrigeration effect increase COP increase and vice versa. As same as refrigeration effect at more COP at 50Watts and fewer COPS at 250Watts load. Again comparing the performances of air cooled and subcooled system, subcooled system attains maximum performance. It is shown in fig- 8 at maximum load condition there is only few percentage improvement in COP. System attains more COP at initial conditions and when time goes on compressor input increases so the performance of the system decreases. Whenever subcooling is used there is a more power consumption by compressor as same as [7]. From fig - 9 at minimum load compressor work is less and for higher loads compressor have to work more.

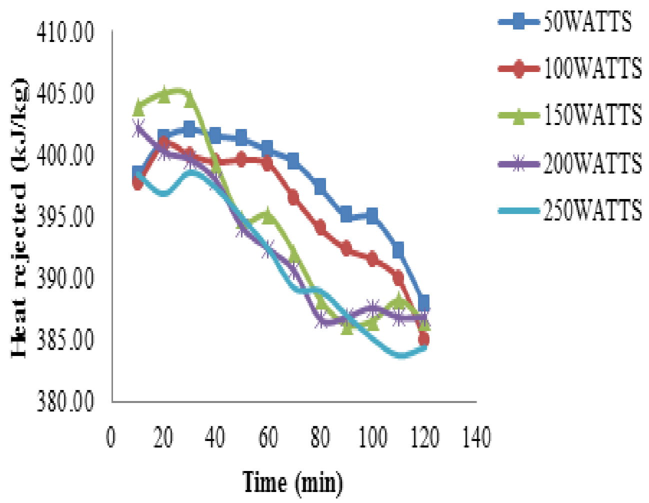

Fig- 3 Heat Rejected Vs Time

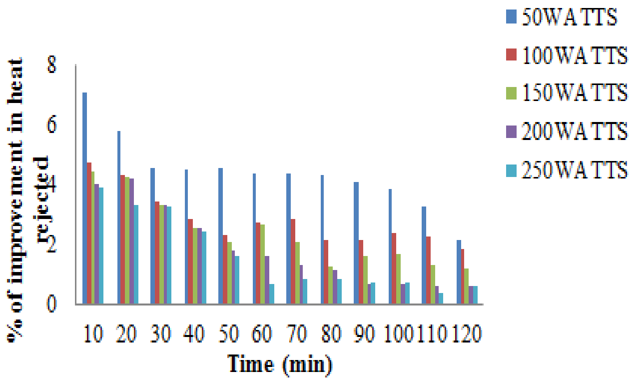

Fig- 4 Percentage of improvement in heat rejected Vs Time

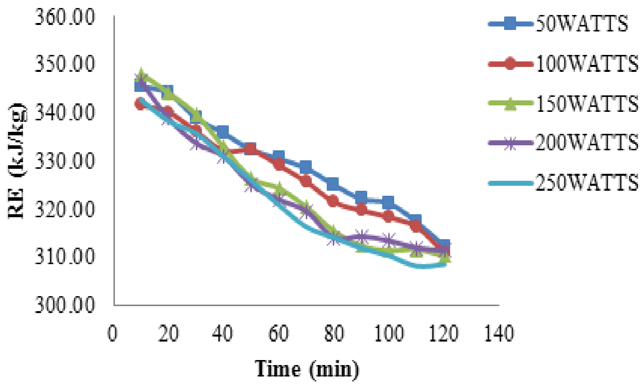

Fig- 5 Refrigeration effect Vs Time

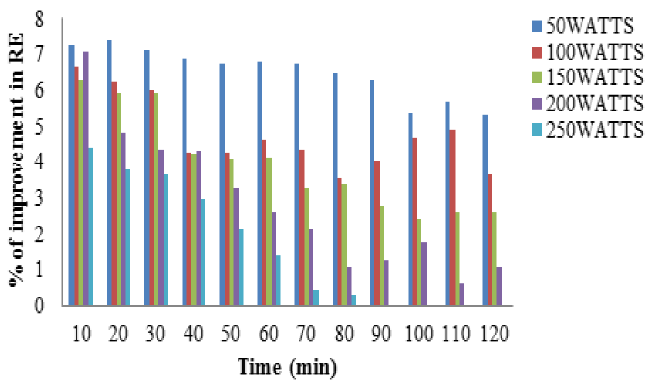

Fig- 6 Percentage of improvement in Refrigeration effect Vs Time

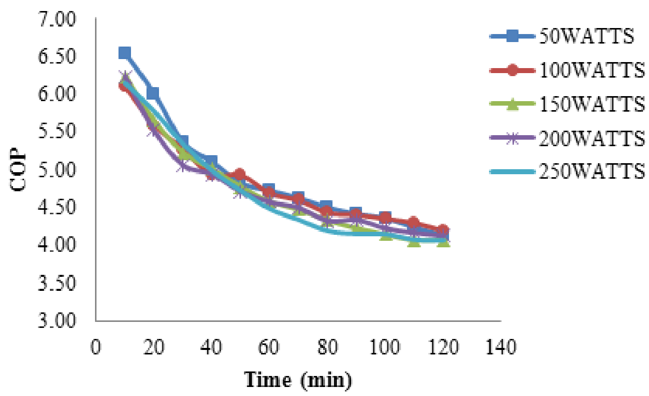

Fig- 7 COP Vs Time

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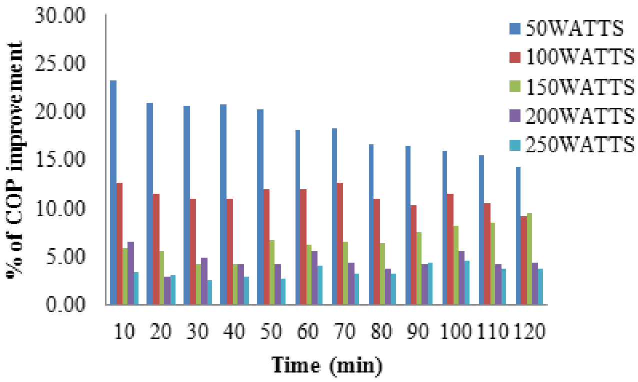

Fig- 8 Percentage of improvement in COP Vs Time

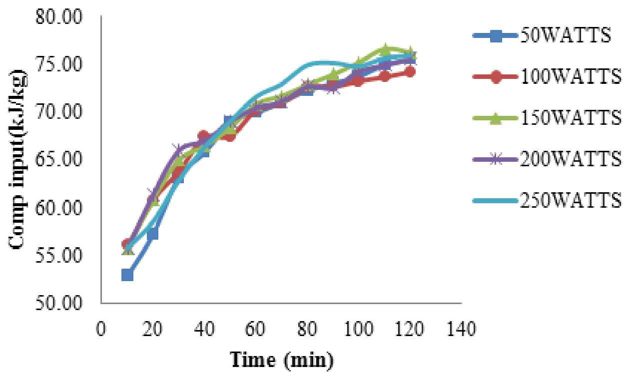

Fig- 9 Compressor input Vs Time

VI. CONCLUSION

Experiments were conducted with various load conditions in air cooled and dedicated subcooled system. This result concludes that dedicated subcooled system gives there is a considerable increases in heat rejection in condenser, refrigeration effect and COP of system when compared to air cooled system. Whenever evaporator load increases performance of the system reduces and continuous running of system for a period of time will reduce the performance with increase in compressor input. Finally it is clear that dedicated subcooling can be used for large industrial refrigeration system to improve its performance.

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AUTHORS PROFILE

S.Panneerselvam, Assistant Professor, Sri Krishna College of Engineering and Technology, Coimbatore, Bachelor of Engineering in Mechanical Engineering, Masters in Engineering Design, IEEE member and Research area is refrigeration and air conditioning.

P.Thangavel, Associate Professor, Kongu Engineering College, Perundurai. Research area is refrigeration and air-conditioning.

S.Kannaki Assistant Professor, Sri Krishna College of Engineering and Technology, Coimbatore, Bachelor of Engineering in Electrical Engineering and Masters in Power Electronics and Drives. She is doing research in Power System. She guided UG Scholars.