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Experimental Investigation of COP in Domestic VCRS by Sub-Cooling of Refrigerant Using Waste Heat

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ABSTRACT

Engineers are continually being asked to improve processes and increase efficiency. These requests may arise as a result of the need to increase process throughput, increase profitability, or accommodate capital limitations. Processes which use heat transfer equipment must frequently be improved for these reasons. vapour compression refrigeration system is based on vapour compression cycle. vapour compression refrigeration system is used in domestic refrigeration, food processing and cold storage, industrial refrigeration system, transport refrigeration and electronic cooling etc. So improvement of performance of system is too important for higher refrigerating effect or reduced power consumption for same refrigerating effect. By sub-cooling using heat exchanger at condenser outlet refrigerating effect increases and power consumption or work input decreases. Thus performance of cycle is improved. Along with this waste heat also recovered. The essential quantity of heat recovered is not the amount but it is value. COP of Vapor Compression Cycle is increased by lowering the power consumption /work input or increasing the refrigerating effect. By using sub-cooling and using waste heat at condenser outlet refrigerating effect increases and power consumption or work input decreases. Thus performance of cycle is improved.

Keyword- *Compressor, Condenser, Cooling unit, Evaporator, expansion device, Subcooling*

1. INTRODUCTION

Vapor compression refrigeration system is based on vapour compression cycle. vapor compression refrigeration system is used in domestic refrigeration, food processing and cold storage, industrial refrigeration system, transport refrigeration and electronic cooling etc. So improvement of performance of system is too important for higher refrigerating effect or reduced power consumption for same refrigerating effect. By sub-cooling using heat exchanger at condenser inlet refrigerating effect increases and power consumption or work input decreases.

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To satisfy the upgraded needs of human beings per capita energy consumption is rising and leading to global warming resulting in an environment imbalance. Therefore it is necessary to design and develop the methods for optimal use of available energy. Enormous quantity of milk is produced and consumed daily all over the world. Milk produced is required to be chilled to 4 1C to arrest the bacterial growth and preserve its quality. Considerable amount of energy is consumed in the milk chilling processes hence it is very essential to focus on improving the efficiency of refrigeration system used for this purpose. In the refrigeration system large amount of heat is dissipated through condenser. It is possible to improve overall efficiency of the system by recovering waste heat generated in refrigeration of milk. It leads in reducing the overall energy costs and increase in COP. One way of recovering heat is to use heat exchanger wherein high temperature refrigerant loses heat to the cold water circulated through it. Development of such efficient methods to recover this dissipated (waste) heat.

2. THEORY

The simple vapor compression refrigeration cycle is shown in Fig 1. Nowadays, this system is used almost everywhere and is the most popular in the refrigeration system. It consists of four essential parts-

1 .Compressor
2. Condenser
3. Expansion Valve
4. Evaporator.

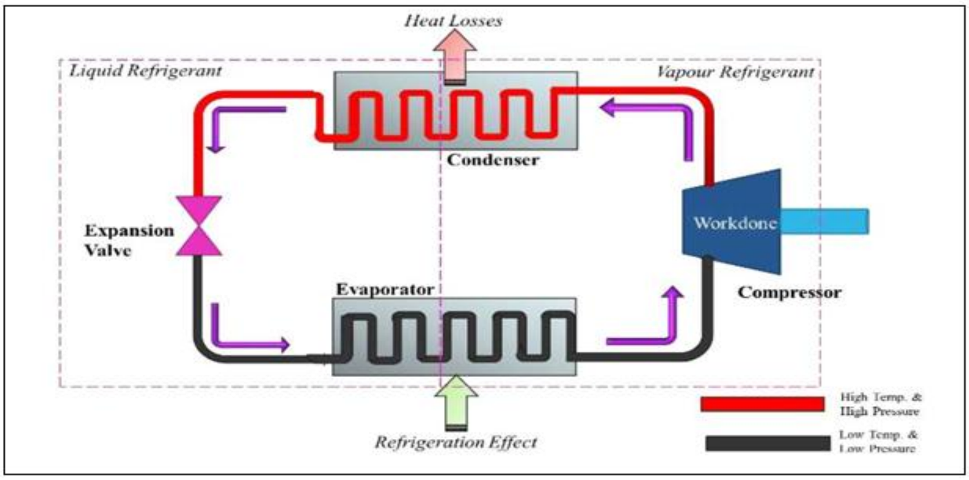

Fig1. Simple Vapor Compression Cycle

Compressor is said to the heart of the vapor compression system compresses the vapor refrigerant from the evaporator pressure(Pe) to the condenser pressure (Pc), so that vapor can be condensed at the corresponding saturation temperature (tc), the condenser rejects the heat of refrigerant to the surrounding either by water or air which is act as cooling medium. Hence the phase transfer takes place from vapor refrigerant to liquid refrigerant enters in to the expansion valve. The expansion valve, also known as the throttle valve, expands the liquid refrigerants from high pressure liquid refrigerant to low pressure liquid refrigerant. Finally, liquid refrigerant enters in the evaporator. The evaporation is achieved in coils of low pressure and temperature, where cooling effect is produced by absorbing heat from the cooling space, the refrigerant phase transfer occurs from liquid refrigerant to vapor refrigerant, only pure vapor the goes back to the compressor completing the cycle.

The term sub-cooling refers to a liquid existing at a temperature below its normal boiling point. For example, water boils at 373 K; at room temperature (300 K) the water is termed "sub-cooled". A sub-cooled liquid is the convenient state in which, say, refrigerants may undergo the remaining stages of a refrigeration cycle. Normally, a refrigeration system has a sub-cooling stage, allowing technicians to be certain that the quality, in which the refrigerant reaches the next step on the cycle, is the desired one. Sub-cooling may take place in heat exchangers and outside them

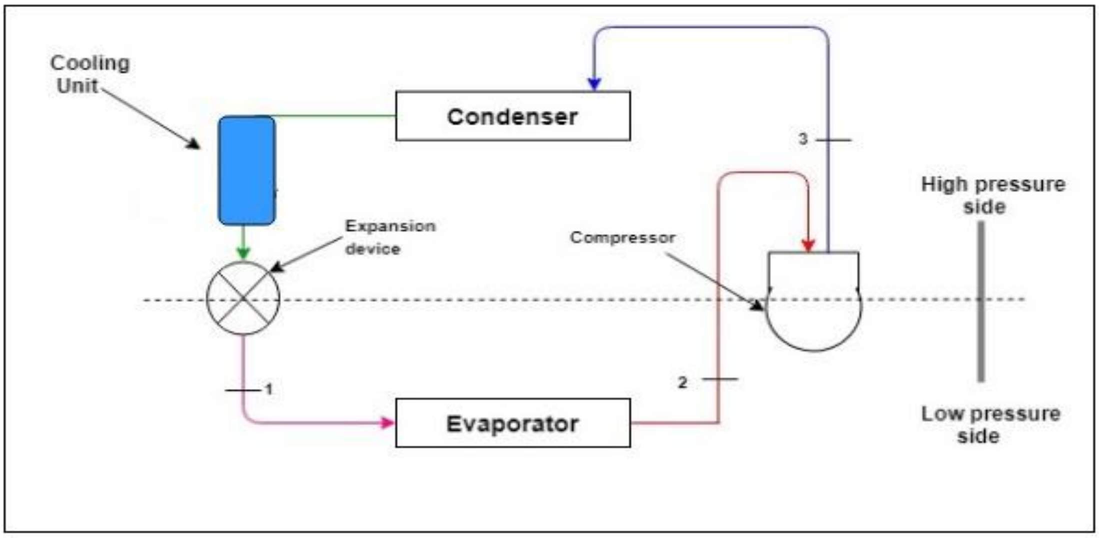

Fig 2.Modified VCR System

The state of the refrigerant entering the expansion device of conventional vapor compression cycles is usually assumed to be saturated liquid. However, liquid cooling below saturation reduces the throttling losses and potentially increases COP. Sub-cooled liquid prior to expansion process can be obtained by adding extra components such as internal heat exchangers in single-stage cycles and in two-stage cycles. Subcooling can also be achieved by an auxiliary cooling system such as a thermoelectric device, a secondary vapor compression system – also known as mechanical sub-cooling or using available coolant supplies, such as condensate water from evaporator. An additional heat-sink cooled heat exchanger, usually denominated sub-cooler, can also be used to obtain sub-cooling. Typically, a high-side pressure receiver is installed between the condenser and the sub-cooler in order to separate liquid from vapor before liquid runs through the sub-cooler. One can think of the sub-cooler not only as separate heat exchanger but as part of a then larger condenser which has some of its surface allocated to sub-cool liquid. In fact, the most conventional way to obtain sub-cooling in systems without a liquid receiver is by utilizing part of condenser heat transfer area to cool down the liquid below the saturation temperature. Rather than in a high side pressure receiver, the liquid-vapor interface is eliminated inside the tubes of the condensers, as liquid refrigerant accumulates towards the exit of the heat exchanger. The so-called condenser sub-cooling is typically obtained during a refrigerant charging procedure. The question raised by Gosney (1982) is whether one would be better off using the sub-cooling heat transfer surface, either within the condenser or in a separate sub-cooler, to reduce the condensing pressure and consequently the compression work. Linton et al. (1992) experimentally investigated the effect of condenser liquid sub-cooling on a refrigeration system performance. Results showed that the cooling COP and refrigeration capacity of all three refrigerants benefited from sub-cooling increase (from 6°C to 18°C): R134a (12.5%), R12 (10.5%) and R152a (10%), while condensing temperature was kept artificially constant. Subcooling has also been subject of publications related to automotive air conditioners. These systems are usually equipped with either a high-side liquid receiver or a low-side accumulator in order to absorb fluctuations in refrigerant charge. Yamanaka et al. (1997) presented a concept of a sub-cool system in which the liquid receiver is installed before the last pass of a parallel flow micro channel condenser rather than at the exit of the condenser. COP would benefit from sub-cooling due to an increase in enthalpy difference across International Refrigeration and Air Conditioning Conference at Purdue, July 16-19, 2012evaporator. Condensers with integrated receiver and sub-cooler pass have become standard in state-of-the-art automotive air conditioning systems. Pomme (1999) also presented a similar study in which sub-cooling was generated by a pre-expansion valve between the condenser exit and the liquid receiver. A few publications that examined the influence of the refrigerant charge on the COP indirectly explored the relationship between sub-cooling and COP. Corberan et al. (2008) maximized COP by varying the refrigerant charge in an R290 heat pump equipped with a thermostatic expansion valve.

They explained that the system responded to increasing charge by rising the condenser sub-cooling since no receiver was installed. The COP maximizing charge was related to a COP maximizing sub-cooling. Primal and Lundqvist (2005) had also optimized the charge of a R290domestic water heat pump and found the corresponding sub-cooling to be 4-5°C.Although condenser sub-cooling is a practical issue in the everyday of refrigeration and air conditioning systems, to the best of authors' knowledge, this topic has not been the subject of a systematic study in the open literature so far. This study is an attempt to start filling up this gap. First, this paper will theoretically explore the performance trade off associated with condenser subcooling using cycle analysis. Then, important thermodynamic properties related to this trade-off will be identified and a sensitivity analysis will be presented for different refrigerants. Second, a comprehensive simulation model of an air conditioner will be used estimate potential for COP improvement with condenser sub-cooling for different refrigerants. Finally, the effect of sub-cooling on the performance of an actual vehicular air conditioning system will experimentally investigated for two refrigerants (R134a) under the same operating conditions.

2.1 Working Principle of VCR System

A simple vapor compression refrigeration system consists of the following equipments:

1. Compressor
2. Condenser
3. Expansion valve
4. Evaporator

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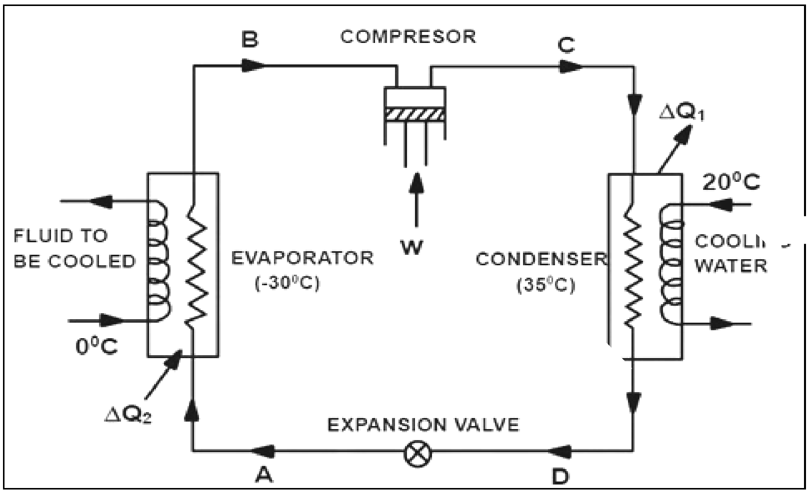

Fig 3.Working of Simple Vapour Compression System

The schematic diagram of the arrangement is as shown in Fig. The low temperature, low pressure vapor at state B is compressed by a compressor to high temperature and pressure vapor at state C. This vapor is condensed into high pressure vapor at state D in the condenser and then passes through the expansion valve. Here, the vapor is throttled down to a low pressure liquid and passed on to an evaporator, where it absorbs heat from the surroundings from the circulating fluid (being refrigerated) and vaporizes into low pressure vapor at state B. The cycle then repeats. The exchange of energy is as follows:

- Compressor requires work, δw. The work is supplied to the system from the surroundings.
- During condensation, heat δQ1 the equivalent of latent heat of condensation etc, is lost from the refrigerator.
- During evaporation, heat δQ2 equivalent to latent heat of vaporization is absorbed by the refrigerant.
- There is no exchange of heat during throttling process through the expansion valve as this process occurs at constant enthalpy.

2.2 Simple Vapour Compression Cycle

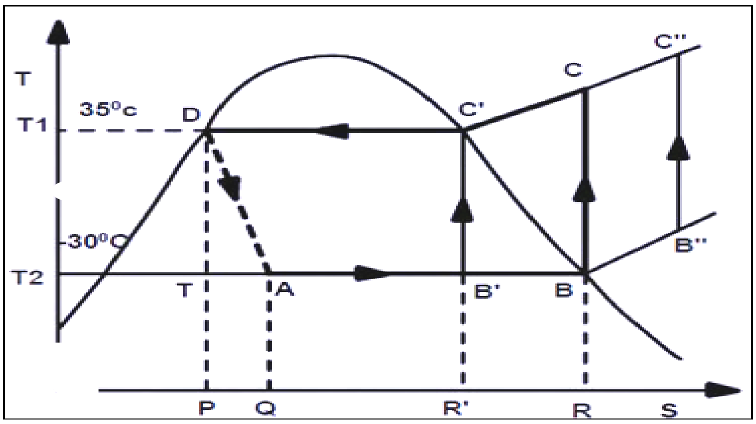

Fig 4.T-S Diagram of Refrigeration Cycle

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Figure shows a simple vapor compression refrigeration cycle on T-s diagram for different compression processes. The cycle works between temperatures T1 and T2 representing the condenser and evaporator temperatures respectively. The various process of the cycle A-B-C-D (A-B'-C'-D and A-B"-C"-D) are as given below-

1. Process B-C (B'-C' or B"-C"): Isentropic compression of the vapor from state B to C. If vapor state is saturated (B), or superheated (B"), the compression is called dry compression. If initial state is wet (B'), the compression is called wet compression as represented by B'-C'.
2. Process C-D (C'-D or C"-D): Heat rejection in condenser at constant pressure.
3. Process D-A: An irreversible adiabatic expansion of vapor through the expansion value. The pressure and temperature of the liquid are reduced. The process is accompanied by partial evaporation of some liquid. The process is shown by dotted line.
4. Process A-B (A-B' or A-B") : Heat absorption in evaporator at constant pressure. The final state depends on the quantity of heat absorbed and same may be wet (B') dry (B) or superheated (B").

2.3 Simple VCRS with Subcooling

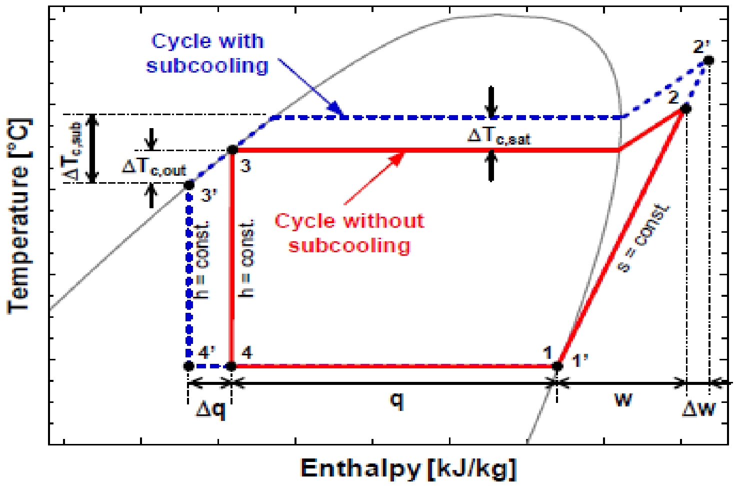

Fig 5. Schematic of Cycles With And Without Subcooling In a T-h Diagram

From fig, the refrigeration effects of heat absorb or extracted,

RE = h1 - h4 = h1 - hf3

And work done,

W = h2 - h1

C.O.P. = REFRIGERATING EFFECT⁄ COMPRESSOR WORK

2.4. EXPERIMENTAL WORK

The Refrigeration Test Rig works on vapour compression cycle. The refrigeration (i.e. process of maintaining a closed space temperature below ambient temperature) is accomplished by continuously circulating, evaporating and condensing a fixed supply of refrigerant in a closed system. Evaporation occurs at a low temperature and low pressure while condensation occurs at a high temperature and pressure. Thus it is possible to transfer heat from an area of low temperature (in this case calorimeter) to an area of high temperature (the surroundings).

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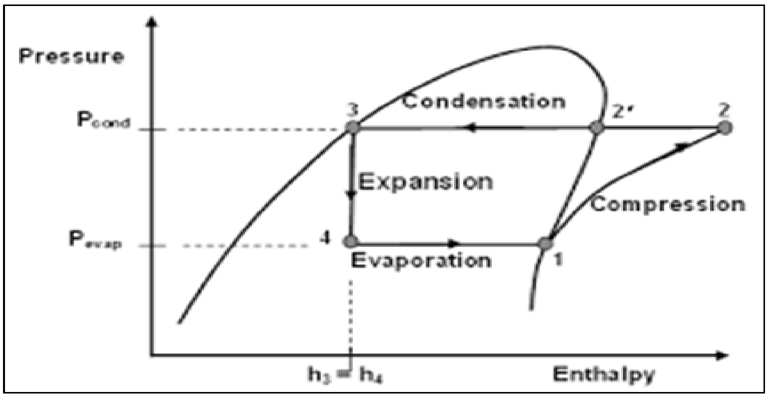

Fig 6.P- h Diagram of Simple VCR System

The compressor pumps the low-pressure refrigerant from the evaporator through the accumulator, increases its pressure, and discharges the high-pressure gas to the condenser. The accumulator prevents liquid refrigerant entering the compressor. In the condenser, the refrigerant rejects its heat to the surroundings by passing air over it. At that pressure, the refrigerant loses its latent heat and liquefies. Then the refrigerant passes through the drier/filter where any residual moisture or foreign particles present, these are plugged. The flow of refrigerant into the evaporator is controlled by expansion device where its pressure and consequently temperature is lowered to the saturation temperature at the corresponding pressure. The low temperature refrigerant enters the evaporator where it absorbs heat from the surrounding medium and evaporates. The compressor sucks the cold vapours and the cycle repeats.

The required instrumentation is provided to measure the various parameters at different points. This includes pressure gauges, temperature indicators and controller, energy-meters, heater for applying load and flow meter to measure the refrigerant flow.

Operating Procedure-

- Put the machine in the proper position where its level is horizontal and it is well ventilated.
- The machine must have at least 1.5 meters clearances from all sides.
- Give 230 volts, 50Hz, and 1 phase supply to the unit.
- Incoming cable should be adequate size (at least 4 sq. mm) to prevent overheating of it.
- The electrical point should have a MCB of 16 Amps rating.
- Ensure proper earthlings.
- Fill the water tank with clean water.
- Start the compressor by putting the switch ON.
- Also switch on the heater; it will start automatically at set point.
- Control the water flow to heat exchanger around 6 LPM.
- Record all the readings as per the observation table.
- Calculate the results as per the procedure mentioned. At various points.

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Precautions-

- The plant should not be left with water in the tank when not in use.
- Do-not start the heater in the dry tank.
- Do-not tamper with the temperature as well as the pressure settings.

Sr. no.	Refrigerant temp (^{0}C)				Water temp. (^{0}C)		Pressure (Psig)		Energy meter reading
HRS or SN	Aft. Comp. 1	Aft. Cond. 2	Aft. Exp. 3	Aft. Evp. 4	IN	OUT	Suc.	Disch.	Sec.
1 (without cooling unit)	70	29	4	26	26	16	17	165	0.15
2 (with cooling unit)	75	34	10	25	27	17	30	260	0.14

3. EQUATION

3.1 Without sub-cooling

Standard Values and Formulae

- Standard Barometric Pressure = @ 1.013 bar = 1.013 x 100000 N /m2
- 1 Ton of Refrigeration effect = 3500 Watts = 3.5 kJ / s
- 1 bar = @ 14.5 psig

CALCULATIONS

- **Actual refrigeration effect** = M * Cp * dT
  = 15 x 4.18 x 10
- **Capacity of the test rig i.e. Output.** = 627 KW
- **Compressor work W i.e. Input.** = Rev. x 3600/ t x Meter Scale
  = 0.15 × 3600 KW
  = 540 KW

- **Actual coefficient of Performance** = $\dfrac{\text{ACTUAL REFRIGERATION EFFECT}}{\text{ACTUAL COMPRESSOR WORK}}$

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= 627/540 = **1.16**

Accordingly, enthalpies of refrigerant at salient Points are:

- H1=enthalpy of refrigerant at inlet of compressor

  = 450 KJ/ KG
- H2=enthalpy of refrigerant at outlet of compressor

  = 260 KJ/ KG
- H3=enthalpy of refrigerant after condensation

  = 260 KJ/ KG
- H4=enthalpy of refrigerant after expansion = H3

  = 420 KJ/ KG
- Theoretical compressor work = W= H1-H4

  = 450 - 420 = 30 KJ/KG
- Theoretical Refrigeration Effect = N = H4-H3

  = 420 – 260 = 160 KJ/KG

Coefficient of performance = C.O.P = N /W = 160/30 = **5.33**

3.3 With Sub-cooling By Using waste heat

Sr. no.	**Refrigerant temp (^{0}C)**				**Water temp. (^{0}C)**		**pressure (Psig)**		**Energy meter reading**
HRS or SN	**Aft. Comp. 1**	**Aft. Cond. 2**	**Aft. Exp. 3**	**Aft. Evp. 4**	**IN**	**OUT**	**Suc.**	**Disch.**	**Sec.**
1 (ice)	73	33	7	29	26	16	35	300	0.10
2 (cold water)	68	35	16	31	27	17	35	310	0.12

CALCULATIONS

- **Actual refrigeration effect** = M * Cp * dT

  = 15 x 4.18 x 10
- **Capacity of the test rig i.e. Output.** = 627 KW
- **Compressor work W i.e. Input.** = Rev. x 3600/ t x Meter Scale

  = 0.10 × 3600 KW = 360 KW

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Actual coefficient of Performance = $\frac{\text{ACTUAL REFRIGERATION EFFECT}}{\text{ACTUAL COMPRESSOR WORK}}$

= 627/360 = **1.74**

Accordingly, enthalpies of refrigerant at salient Points are:

- H1=enthalpy of refrigerant at inlet of compressor = 445 KJ/ KG
- H2=enthalpy of refrigerant at outlet of compressor = 235 KJ/ KG
- H3=enthalpy of refrigerant after condensation = 235 KJ/ KG
- H4=enthalpy of refrigerant after expansion = H3 = 425 KJ/ KG
- Theoretical compressor work = W= H1-H4 = 445 - 425 = 20 KJ/KG
- Theoretical Refrigeration Effect = N = H4-H3

  = 425 – 235 = 190 KJ/KG

Coefficient of performance = C.O.P = N /W = 190/20 = **8**

4. RESULT

Sr.no.	Parameter	COP		% Increased COP	
		Actual	theoretical	Actual	Theoretical
1	Without Cooling Unit	1.16	5.33	-	-
2	With Cooling Unit	1.24	7	6.89	31.33
3	Cold Water (as a waste heat)	1.45	7.75	25	45.40
4	Ice (as a waste heat)	1.74	8	50	50.09

5. CONCLUSION

1. When installing the cooling unit possible heat exchange between high temperature fluid and low temperature fluid which will gives a result of Subcooling of refrigerant.
2. Because of cooling unit and using cold water and ice as a waste heat for sub-cooling, the refrigeration effect of the system is increased and compressor work of the system decreased.
3. As per the result conclude that, the COP of the refrigeration system is increased by sub-cooling with using waste heat.

5. ACKNOWLEDGEMENTS

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