Current Trends in Technology and Science
ISSN: 2279-0535, May-2020, Volume: XI, Issue: III

Performance Analysis of Single Stage Vapour Compression Refrigeration Cycle Using Eco-Friendly Refrigerant

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Abstract: the main things is that the Refrigeration and air conditioning systems have enough capacity to maintain the desired temperature at a worst-case and also required suitable design so it can operate various load condition. For the production of hot water and space heating currently heat pump heating method is using because it is the most energy efficient method. Main advantages of heat pumps is it consume less energy, improving the performance of heating and reducing the negative effects on the environment compared to other heating methods. The further improvement of performance of vapour compression refrigeration cycles acting as heat pumps has been targeted by several researchers so that heat pumps will be able to achieve wider penetration into the building heating market. The major objective of this paper is to provide a comprehensive understanding of both simple and complex refrigeration cycles and to review the current status achieved in the performance of improved vapour compression refrigeration cycle.

Key words: Single stage refrigeration system, cascade refrigeration cycle; automatic cascade refrigeration system; refrigerant; ejector.

1. Introduction

Refrigeration is a technology which absorbs heat at low temperature and provides temperature below the surrounding by rejecting heat to the surrounding at higher temperature. Simple vapour compression refrigeration system which consists of four major components compressor, expansion valve, condenser and evaporator in which total cooling load is carried at one temperature by single evaporator but in many applications like large hotels, food storage and food processing plants, food items are stored in different compartment and at different temperatures. Therefore there is need of multi evaporator vapour compression refrigeration system [1].

Refrigeration technology plays an important role in human production and life; it is widely used in daily lives, commerce, and industrial production. The traditional single-stage compression refrigeration system (STCRS) and absorption refrigeration system (STARS) are two basic forms of the refrigeration technology. STCRS is used in air conditioning, human life, food storage, and transportation [2].

Absorption refrigeration system (STARS) is commonly used for freezing applications and can effectively convert the low-grade waste heat into high-grade cold energy. However, when the temperature deference between cold energy and heat source increases, both co-efficient of performance (COP) and economy of STARS will decrease; thus, the application of refrigeration system at a low evaporation temperature is seriously limited[3].

The theoretical cycle used to compare the performance of refrigerants is based on single stage vapour compression refrigeration cycleconsisting of compressor, condenser, expansion valve and evaporator [4]. The schematic diagram of the vapour compression refrigeration cycle is shown in the Figure 1.

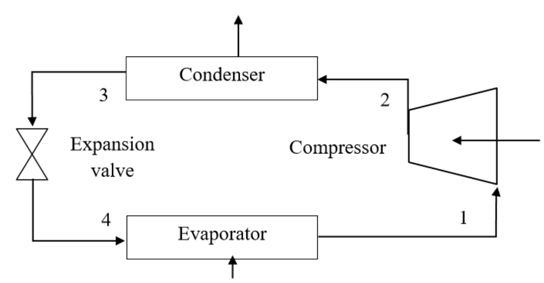

Figure 1 Schematic diagram of the vapour compression refrigeration cycle

The challenge in refrigeration and air conditioning is to remove heat from a low temperature source and dump it at a higher temperature sink. Compression refrigeration cycles in general take advantage of the idea that highly compressed fluids at one temperature will tend to get colder when they are allowed to expand. If the pressure change is high enough, then the compressed gas will be hotter than our source of cooling (outside air, for instance) and the expanded gas will be cooler than our desired cold temperature. For this situation, we can utilize it to cool at a low temperature and reject the warmth to a high temperature. Fume pressure refrigeration cycles explicitly have two extra points of interest. To start with, they misuse the huge warm vitality required to change a fluid to a fume so we can expel bunches of warmth out of our cooled space. Second, the isothermal idea of the vaporization permits extraction of warmth without raising the temperature of the working liquid to the temperature of whatever is being cooled. This is an advantage on the grounds that the closer the working liquid temperature moves toward that of the environmental factors, the lower the pace of warmth move. The isothermal procedure permits the quickest pace of warmth move.

2. Overview of Past work

Continuous efforts have been made by numerous researchers on different types of refrigeration system. Wonder to improve their performance and make them cost effective. Article [6], studied analytically thermal performances that changing with evaporator and condenser temperatures of two stage vapour compression refrigeration plant using R22 and found considerable effect on plant irreversibility and concluded that there is need for optimizing the conditions imposed upon the condenser and evaporator.

The effect of operating parameters on COP, work input and cooling capacity of single-stage vapour compression refrigeration system. There is great influence on energetic parameters due change in suction pressure, condensing and evaporating temperatures [7].

Authors of [8] proposed the absorption part has been designed to improve the performance of absorption – vapour compression cascade cycle as serial flow double effect. The detailed thermodynamic analysis has been made of double effect absorption –vapour compression cascade refrigeration cycle.

Article [9] introduces a new concept of Two Stage Vapour Compression-Absorption Cascade Refrigeration System (TSVCACRS) for achieving low temperature Industrial Cooling. The system comprises of Two Stage Vapour Compression System having flash intercooler integrated with single stage vapour absorption refrigeration system, thermally coupled by means of cascade condenser heat exchanger. That proposed TSVCACRS system would minimize the compressor works up to 28%, compared to existing installed TSVCACRS.

A comparative performance analysis in automobile air conditioning system using refrigerants formed by hydro fluorocarbons (HFC) and their mixtures. Also, technical difficulties of refrigerants are discussed [10].

The performance of a commercial vapour compression refrigeration plant, generally adopted for preservation of foodstuff, using R22 and its candidate substitute (R417A) as working fluids. The working of the plant was regulated by on/off cycles of the compressor, operating at the nominal frequency of 50 Hz, imposed by the classical thermostatic control [11].

Authors of [12] used alternative refrigerant fluids for ground source heat pump. Alternative refrigerants instead of R22 were used. Performance coefficients were investigated by using alternative refrigerants in a single-stage vapor compression system without sub-cooling and superheating.

Article [13] performed comparative evaluation of an automobile air-conditioning system using R134a and its alternative refrigerants. R290, R600a, R407C, R410A, R404A, R152a and R1234yf were used as refrigerants. A comparative performance analysis in automobile air conditioning system using refrigerants formed by hydro fluorocarbons (HFC) and their mixtures. Also, technical difficulties of refrigerants are discussed [14].

3. REFRIGERATION SYSTEMS

Heat flows naturally from hot to colder body. But, in refrigeration system there is opposite phenomena i.e. heat flows from a cold to a hotter body. This is achieved by using a substance called a refrigerant. The refrigerant (R12) absorbs heat and hence evaporates at a low pressure to form a gas. This gas is then compressed to a higher pressure, such that it transfers the heat it has gained to ambient air or water and turns back (condenses) into a liquid. Thus, heat is absorbed, or removed, from a low temperature source and transferred to a higher temperature source.

Single stage vapor compression refrigeration system is considered as numerical exemplification of the proposed study. The system is composed by a mechanical piston compressor, a condenser, a throttling valve and an evaporator, as shown in Figure 2.

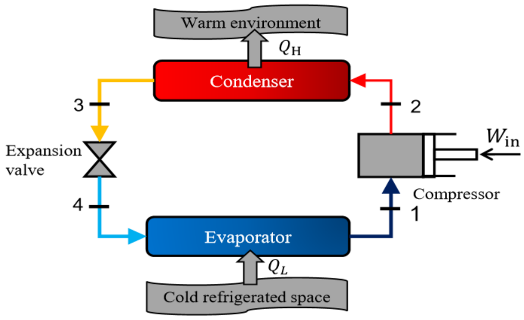

Fig. 2: Single stage Vapor Compression Refrigeration System

Refrigerating circuit A VCR system, in its simplest form, consists of two heat exchangers, an expansion valve, and a compressor, Fig. 2. The ideal VCR system consists of four processes:

- Isentropic compression,
- Isobaric heat rejection and condensation,
- Isenthalpic expansion, and
- Isobaric heat absorption and evaporation.

Fig. 3 shows the refrigeration cycle on p-h diagram. The refrigerant evaporates entirely in the evaporator and produces the refrigerating effect. Then, it is extracted by the compressor at state point 1, compressor suction, and is compressed is entropically from state point 1 to 2. Next, it is condensed to liquid in the condenser, and the latent heat of condensation is rejected to the heat sink.

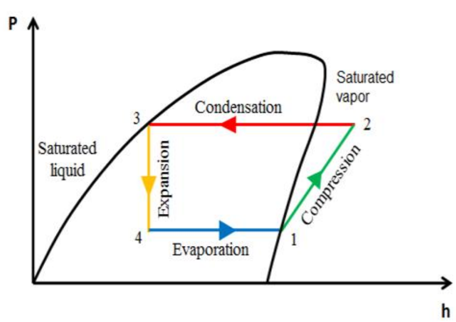

Figure 3. Diagram pressure (p) vs enthalpy (h) [14]

The liquid refrigerant, at state point 3, flows through the expansion valve, which reduces it to the evaporating pressure. In the ideal vapor compressor cycle, the throttling process at the expansion valve is the only irreversible process, usually indicated by a dotted line. Some of the liquid flashes into vapor and enters the evaporator at state point 4. The remaining liquid portion evaporates at the evaporating temperature, thus completing the cycle [14].

4. Practical difficulties with Carnot refrigeration system

It is difficult to build and operate a Carnot refrigeration system due to the following practical difficulties:

a. During process 1-2, a mixture consisting of liquid and vapour have to be compressed is entropically in the compressor. Such a pressure is known as wet pressure because of the nearness of fluid. By and by, wet pressure is extremely troublesome particularly with responding blowers. This issue is especially extreme in the event of rapid responding blowers, which get harmed because of the nearness of fluid beads in the fume. Despite the fact that a few kinds of blowers can endure the nearness of fluid invapour, since responding blowers are most generally is refrigeration, customarily dry (pressure of fume just) is wanted to wet pressure.

b. The second practical difficulty with Carnot cycle is that using a turbine and extracting work from the system during the isentropic expansion of liquid refrigerant is not economically feasible, particularly in case of small capacity systems. In addition, if one considers the inefficiencies of the turbine, then the net output will be further reduced. As a result using a turbine for extracting the work from the high pressure liquid is not economically justified in most of the cases1.

One way of achieving dry compression in Carnot refrigeration cycle is to have two compressors – one isentropic and one isothermal as shown in Fig. 4.

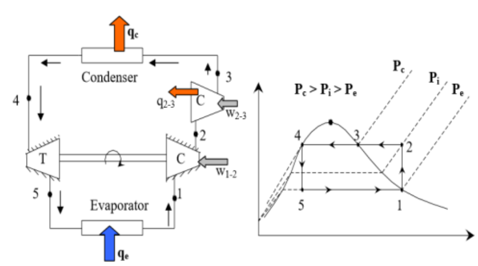

Fig.4. Carnot refrigeration system with dry compression

As shown in Fig.4, the Carnot refrigeration system with dry compression consists of one isentropic compression process (1-2) from evaporator pressure Pe to an intermediate pressure Pi and temperature Tc, followed by an isothermal compression process (2-3) from the intermediate pressure Pi to the condenser pressure Pc. Though with this modification the problem of wet compression can be avoided, still this modified system is not practical due to the difficulty in achieving true isothermal compression using high- speed compressors. In addition, use of two compressors in place of one is not economically justified.

From the above conversation, unmistakably from down to earth contemplations, the Carnot refrigeration framework should be changed. Dry pressure with a solitary blower is conceivable if the isothermal warmth dismissal process is supplanted by isobaric heat dismissal process. Also, the isentropic extension procedure can be supplanted by an isenthalpic choking process. A refrigeration framework, which consolidates these two changes, is known as Evans-Perkins or converse Rankine cycle. This is the hypothetical cycle on which the real fume pressure refrigeration frameworks are based.

Figure 5 shows the schematic of a standard, saturated, single stage (SSS) vapour compression refrigeration system and the operating cycle on a T s diagram. As shown in the figure the standard single stage, saturated vapour compression refrigeration system consists of the following four processes:

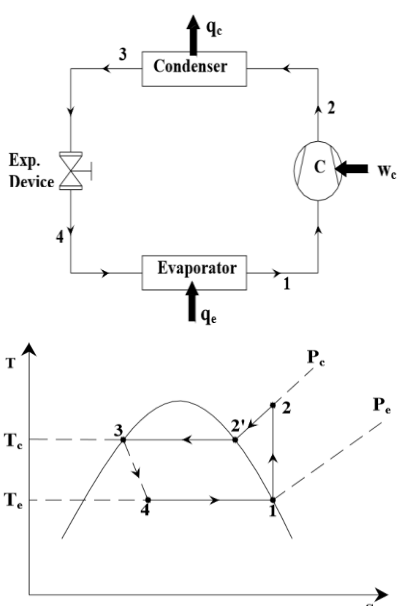

Fig. 5. Standard Vapour compression refrigeration system

Process 1-2: Isentropic compression of saturated vapour in compressor Process 2-3: Isobaric heat rejection in condenser Process 3-4: Isenthalpic expansion of saturated liquid in expansion device Process 4-1: Isobaric heat extraction in the evaporator

By comparing with Carnot cycle, it can be seen that the standard vapour compression refrigeration cycle introduces two irreversibility: 1) Irreversibility due to non-isothermal heat rejection (process 2-3) and 2) Irreversibility due to isenthalpic throttling (process 3-4). As a result, one would expect the theoretical COP of standard cycle to be smaller than that of a Carnot system for the same heat source and sink temperatures. Due to this irreversibility's, the cooling effect reduces and work input increases, thus reducing the system COP.

5. IMPROVED SINGLE-STAGE CYCLES

It is known from theory that an ideal reversible cycle having the highest COP is the Carnot cycle which includes two isothermal and two adiabatic processes (Figure 6b). The development in most useful genuine fume pressure cycles happening in an extension valve is an irreversible choking process. This causes a decreased cooling limit and an expanded work prerequisite in examination with the Carnot cycle. In light of the standard of the temperature parting wonder of a Ranque Hilsch vortex tube in which a flood of gas isolates itself into a hot and cold stream, article [16] have suggested an improved extension process with a substitution of the development valve by a Ranque Hilsch vortex tube as appeared in Figure 6a. By this, the fluid refrigerant is choked to the evaporator pressure while the fume refrigerant is isolated with hot and cold streams. The cool fume alongside the fluid is lead to the evaporator while the hot fume keeps dismissing its warmth before coming to the evaporator. This prompts a lower nature of refrigerant, for the most part at a point exceptionally near state 1 in the Carnot cycle, entering the evaporator. The creators tried the cycle with thirteen refrigerants and indicated diverse improved exhibitions. Authors of [17] produced a theoretical analysis explaining the establishment of a secondary circulation in the vortex tube. They demonstrated that a vortex tube satisfies three required processes employed in heat pumps:

(i) the working fluid moves heat continuously between a high pressure and a low pressure region,

(ii) (ii) the compressed working fluid is hotter than the surrounding medium to give off heat and

(iii) (iii) the expanded working fluid is colder than the surroundings to absorb heat. Although the potential benefits of vortex tubes have been realized, its application to heat pumps has attracted little interest from the engineering community.

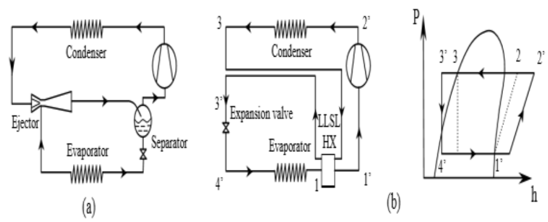

Figure 6: Cycles with (a) ejector and (b) liquid-line/suction-line heat exchanger

6. CONCLUSIONS

In this study identified various vapour compression system which is applied for the heat pumps. Vapour compression cycle are available in simple cycle to complex cycles and it is also modified from single-stage to multi-stage cycles for achieving the improved performance. The alternative cycles are design in such way so it can increase the performance, reduces the consumption of energy and less losses. Along with improved performance, the complexity of the cycles and the cost of systems increase due to the increased number of stages and the addition of new components. As of now, the streamlined cycle utilizing a fume infused blower is by all accounts the most proficient for heat siphons for structures both in its exhibition and conservativeness because of the activity of a two-phase cycle with just a solitary blower and the flexibility of adjusting its ability from a solitary stage cycle to a two-phase cycle.

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