ISBN: 978-93-94570-41-2

1. Analysis of Performance Improvement Methods for a Vapor Compression Refrigeration System

Dr. S. S. K. Deepak, Avinash Mishra, Abhishek Tiwari, Jaykishan Kashyap, Nandkishor Banjare

Department of Mechanical Engineering,
Bhilai Institute of Technology,
Raipur, Chhattisgarh, India.

1.1 Introduction:

Refrigerator is a cooling appliance comprising a thermally insulated compartment and a refrigeration system is a system to produce cooling effect in the insulated compartment. Meanwhile, refrigeration is defined as a process of removing heat from a space or substance and transfers that heat to another space or substance. Nowadays, refrigerators are extensively used to store foods which deteriorate at ambient temperatures; spoilage from bacterial growth and other processes is much slower in refrigerator that has low temperatures. In refrigeration process, the working fluid employed as the heat absorber or cooling agent is called refrigerant. The refrigerant absorbs heat by evaporating at low temperature and pressure and remove heat by condensing at a higher temperature and pressure. As the heat is removed from the refrigerated space, the area appears to become cooler. The process of refrigeration occurs in a system which comprises of a compressor, a condenser, a capillary and an evaporator arranged as depicted schematically in Figure 1.1.

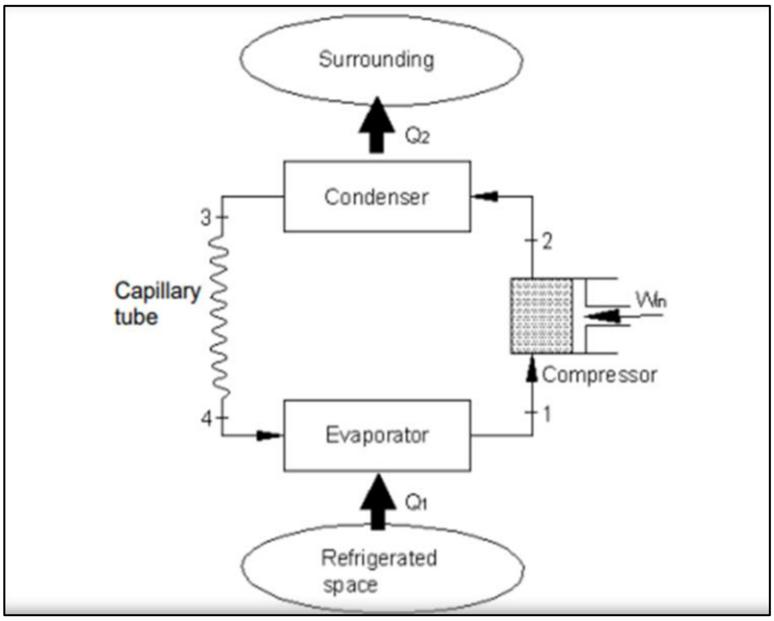

Figure 1.1: Schematic Diagram of A Refrigeration System

Compressor is a mechanical device to compress and pump the refrigerant vapor from a low-pressure region (the evaporator) to a high-pressure region (the condenser). The condenser is a device for removing heat from the refrigeration system. In the condenser, the high temperature and high-pressure refrigerant vapor transfers heat through the condenser tube wall to the surrounding. When the temperature of the refrigerant vapor reaches the saturation level, the latent heat is released causes condensation process and the refrigerant vapor changes it phases into liquid form. The capillary tube controls the refrigerant flow from the condenser to the evaporator and separates the system to high pressure and low-pressure sides. The evaporator is a device for absorbing heat from the refrigerated space into the refrigeration system by evaporating the refrigerant. To accomplish the process of the heat removing from the refrigerated space, a system called refrigeration plant is created and the plant works in a thermodynamic cycle which obeys Second Law of Thermodynamic. The refrigeration plant used in the present work is called refrigerator. Currently, the refrigerator is used widely around the world and this appliance become necessity for household. Performance of a modern refrigerator is very efficient but the research still ongoing to optimize the system. In fact, the same system would produce different performance if it is operated in different countries especially between tropical climate countries and countries with four climate seasons. Performance study of the refrigeration system in the present work is one of effort to discover performance of the Refrigerator by Analysis three important parameters which are refrigeration capacity, compressor work and coefficient of performance (COP).

1.2 Domestic Refrigerators:

A refrigeration system provides cooling in a closed space by lowering the temperature. The refrigeration systems we use in our homes are domestic refrigerators. Domestic refrigerators are home appliances that store food and drinks. Unlike a large commercial system, a domestic refrigerator provides cooling to a smaller area. A refrigerator is a rectangular storage container that can easily fit in a kitchen space. We also use them in ice cream parlors, small stores, and garages to keep food and drinks cold. A refrigerator transfers heat from the space inside to its external environment. It will cool the space inside to a temperature below the room temperature. If we keep food at room temperature, it can spoil easily. The growth of bacteria present in food slows down when we cool it. The cold temperatures inside a refrigerator help food stay fresh longer. It’s essential to keep perishable foods like meat and dairy products refrigerated. If we leave milk on the kitchen counter, bacteria will spoil it within two to three hours. However, keeping milk at a lower temperature will stay fresh for a week or two.

1.3 Main components of domestic refrigerator:

The essential function of refrigerators is to use the evaporation of a liquid (refrigerant) to absorb heat. The main working parts of a refrigerator include a compressor, a condenser, an evaporator, an expansion valve, and a refrigerant.

A. Compressor: Refrigerant is truly the lifeblood of a refrigerator. It starts in the form of a gas, then a liquid, and back to a gas as it cycles through the refrigerator’s parts. This is the process that cools the refrigerator. In the early stages of refrigerator technology, toxic gases such as ammonia were used as refrigerants. That changed in the 1930's, when manufacturers began using freon instead. Freon was used for many decades until recent discoveries by scientists found it was harmful to the Earth's environment. Most modern refrigerators now use a compound called HFC 134a.

B. Condenser: The condenser is where the refrigerant liquefies. The condenser receives the hot vapor, which are cooled down into a liquid. It's distinguishable by its large copper coils, and you can find them along the bottom or at the back of your unit.

C. Expansion valve: This cooling process then shifts to the expansion valve, which is a thin set of copper tubes. The expansion valve lowers the liquid refrigerant's temperature and pressure dramatically, causing about half of it to evaporate. This refrigerant repeatedly evaporating at extremely low temperatures is what creates the cool temperatures inside your refrigerator and/or freezer.

D. Evaporator: The evaporator is where the cooling process ends and begins the process of the next cycle. It takes the remaining refrigerant liquid and turns it back into a vapor, which the compressor takes to start it all over again.

1.4 Review of Literature:

Vapor compression refrigeration cycle has four elements: evaporator, compressor, condenser and expansion valve, respectively [1]. Vapor compression refrigeration system is most commonly and domestic as well as large scale method of producing refrigeration effect. One hand these systems provided quick refrigeration effect and heat rejection on other hand by the chemical properties of refrigerant. The quantity of rejected heat from such systems is quite high and this heat is removed in atmosphere as a waste [2]. This refrigeration cycle is approximately a Rankine cycle run in reverse. A working fluid (often called the refrigerant) is pushed through the system and undergoes state changes (from liquid to gas and back) [3].

The latent heat of vaporization of the refrigerant is used to transfer large amounts of heat energy, and changes in pressure are used to control when the refrigerant expels or absorbs heat energy [4]. However, for a refrigeration cycle that has a hot reservoir at around room temperature (or a bit higher) and a cold reservoir that is desired to be at around 34°F, the boiling point of the refrigerant needs to be fairly low. Thus, various fluids have been identified as practical refrigerants. The most common include ammonia, Freon (and other chlorofluorocarbon refrigerants, CFCs), and HFC-134a (non-toxic hydrofluorocarbon) [5]. Condenser is an important component of any refrigeration system. In a typical refrigerant condenser, the refrigerant enters the condenser in a superheated state. It is first de-superheated and then condensed by rejecting heat to an external medium [6]. Compression is the first step in the refrigeration cycle, and a compressor is the piece of equipment that increases the pressure of the working gas. Refrigerant enters the compressor as low-pressure, low-temperature gas, and leaves the compressor as a high-pressure, high-temperature gas [7]. The condenser, or condenser coil, is one of two types of heat exchangers used in a basic refrigeration loop. This component is supplied with high-temperature high-pressure, vaporized refrigerant coming off the compressor. The condenser removes heat from the hot refrigerant vapor gas vapor until it condenses into a saturated liquid state, a.k.a. condensation [8]. When the refrigerant enters the throttling valve, it expands and releases pressure. Consequently, the temperature drops at this stage. Because of these changes, the refrigerant leaves the throttle valve as a liquid vapor mixture, typically in proportions of around 75 % and 25 % respectively [9]. Throttling valves play two crucial roles in the vapor compression cycle. First, they maintain a pressure differential between low- and high-pressure sides. Second, they control the amount of liquid refrigerant entering the evaporator [10] The coefficient of performance (COP) and energy consumption need more attention to provide high performance with low energy consumption of a vapor compression refrigeration system. [11].

1.5 Working of Vapor Compressor Refrigerator System:

1.5.1 Components:

A. Evaporator: One kind of evaporator is a kind of radiator coil used in a closed compressor driven circulation of a liquid coolant. That is called a refrigeration system to allow a compressed cooling chemical, such as R-22 (Freon) or R-410A, to evaporate/vaporize from liquid to gas within the system while absorbing heat from the enclosed cooled area, for example a refrigerator or rooms indoors, in the process. This works in the closed refrigeration system with a condenser radiator coil that exchanges the heat from the coolant, such as into the ambient environment.

Figure 1.2: Evaporator

B. Expansion Device: Expansion device is also known as throttling device is an important device that divides the high-pressure side and the low-pressure side of a refrigerating system. It is connected between the receiver and the evaporator containing liquid refrigerant at high pressure and liquid refrigerant at low pressure). The expansion device performs the following function. It reduces the high-pressure liquid refrigerant to low pressure liquid refrigerant before being fed to the evaporator. It maintains the desired pressure difference between the high- and low-pressure side of the system, so that the liquid refrigerant vaporizes at the designed pressure in the evaporator. It controls the flow of refrigerant according to the load evaporator.

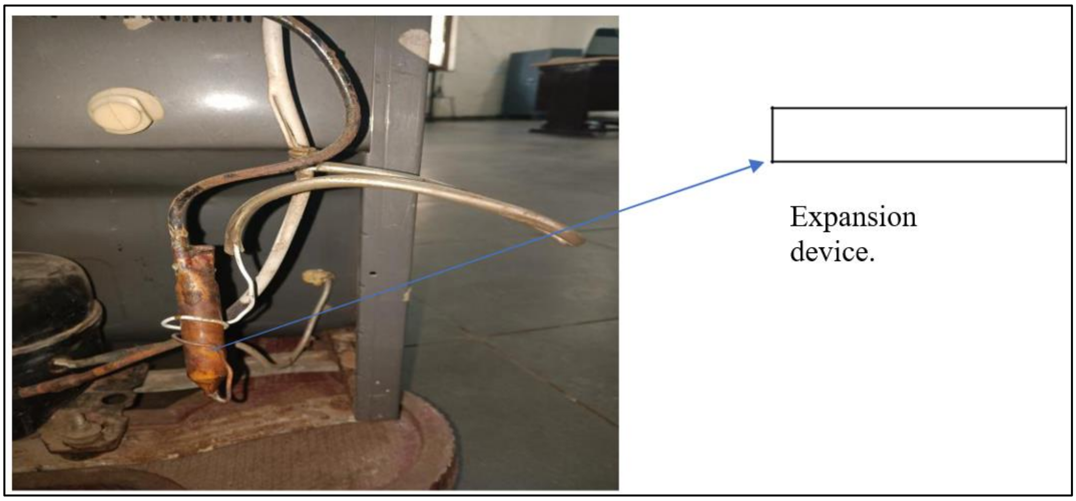

Figure 1.3: Expansion device

C. Compressors: A compressor is the most important and often the costliest component (typically 30 to 40 percent of total cost) of any vapor compression refrigeration system (VCRS). The function of a compressor in a VCRS is to continuously draw the refrigerant vapor from the evaporator, so that a low pressure and low temperature can be maintained in the evaporator at which the refrigerant can boil extracting heat from the refrigerated space. The compressor then has to raise the pressure of the refrigerant to a level at which it can condense by rejecting heat to the cooling medium in the condenser.

Figure 1.4: Compressor

D. Condenser: It is ultimately in the condenser that heat is rejected in a VCRS refrigeration machine. The vapor at discharge from the compressor is super-heated. Desirer heating of the vapor takes place in the discharge line and in the first few coils of condenser.

It is followed by the condensation of the vapor at the saturated discharge temperature. In some condensers, subcooling may also takes place near the bottom where there is only liquid.

However, the sensible heat of the latent heat of the condensation process.

Figure 1.5: Condenser

1.6 Working of Vapor Compressor Refrigerator System Cycle:

Vapor Compression Refrigeration uses mechanical energy by repeating compression and expansion of coolant fluid to achieve cooling by Joule–Thomson effect.

A majority of big refrigeration systems in use nowadays use the Vapor Compression Refrigeration.

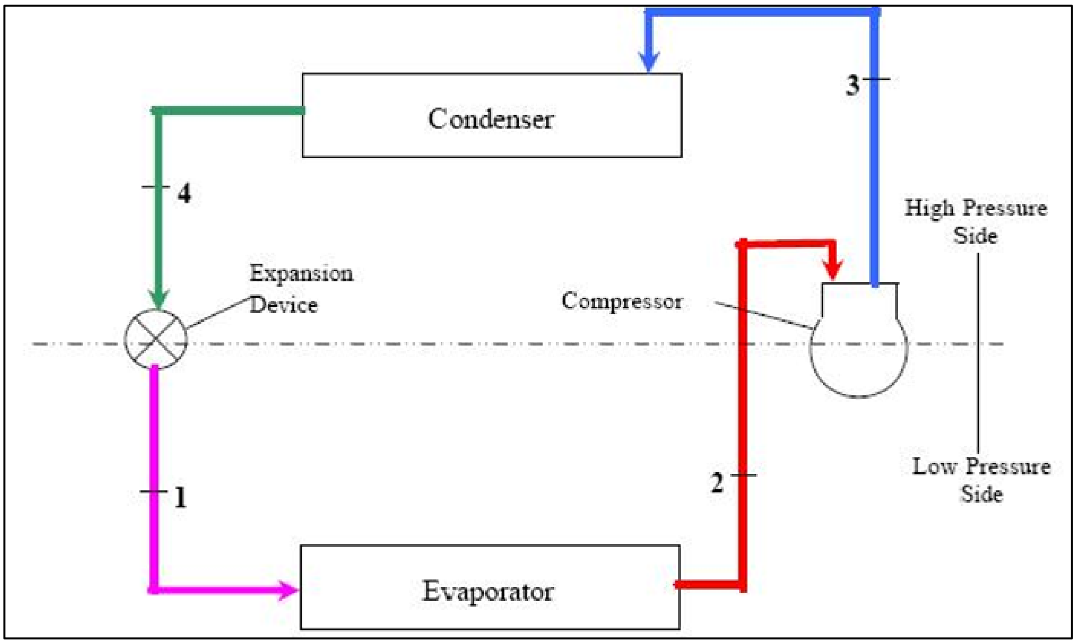

Figure 1.6: Schematic diagram of Vapor Compression Refrigeration System

From the above figure by following processes analysis:

Process (1-2) From points 1 to 2, low-pressure liquid refrigerant in the evaporator absorbs heat from its surrounding environment, usually air, water or some other liquid and gets evaporated into gas. As such, the refrigerant is slightly superheated at the outlet of the evaporator.

The evaporating liquid absorbs heat from the surroundings, thus performing the cooling or refrigeration duty for the surrounding air, water or other medium. This is where the refrigeration actually occurs

Process (2-3) From point 2 to 3 on figure-1.6, the superheated vapor from evaporator enters the compressor where its pressure is increased due to compression. The temperature also typically increases, since a part of the energy put into the compression process is transferred to the refrigerant.

Process (3-4) From point 3 to point 4 on figure-1.6, the pressurized and superheated gas from compressor outlet is sent to a condenser. The initial part of the cooling process de-superheats the gas before it is then turned back into liquid. the cooling for this process is usually accomplished by use of air or water.

A further reduction in temperature happens in the pipe work and liquid receiver (3b-4 on figure-1.6), so that the refrigerant liquid is sub-cooled as it enters the expansion device. This step is where the heat absorbed from process fluid at the evaporation stage is vented out to atmosphere.

Process (4-1) From point 4 to point 1 the high-pressure sub-cooled liquid passes through the expansion device, which reduces its pressure as well as controls the flow into the evaporator. The process is repeated from now in cycle.

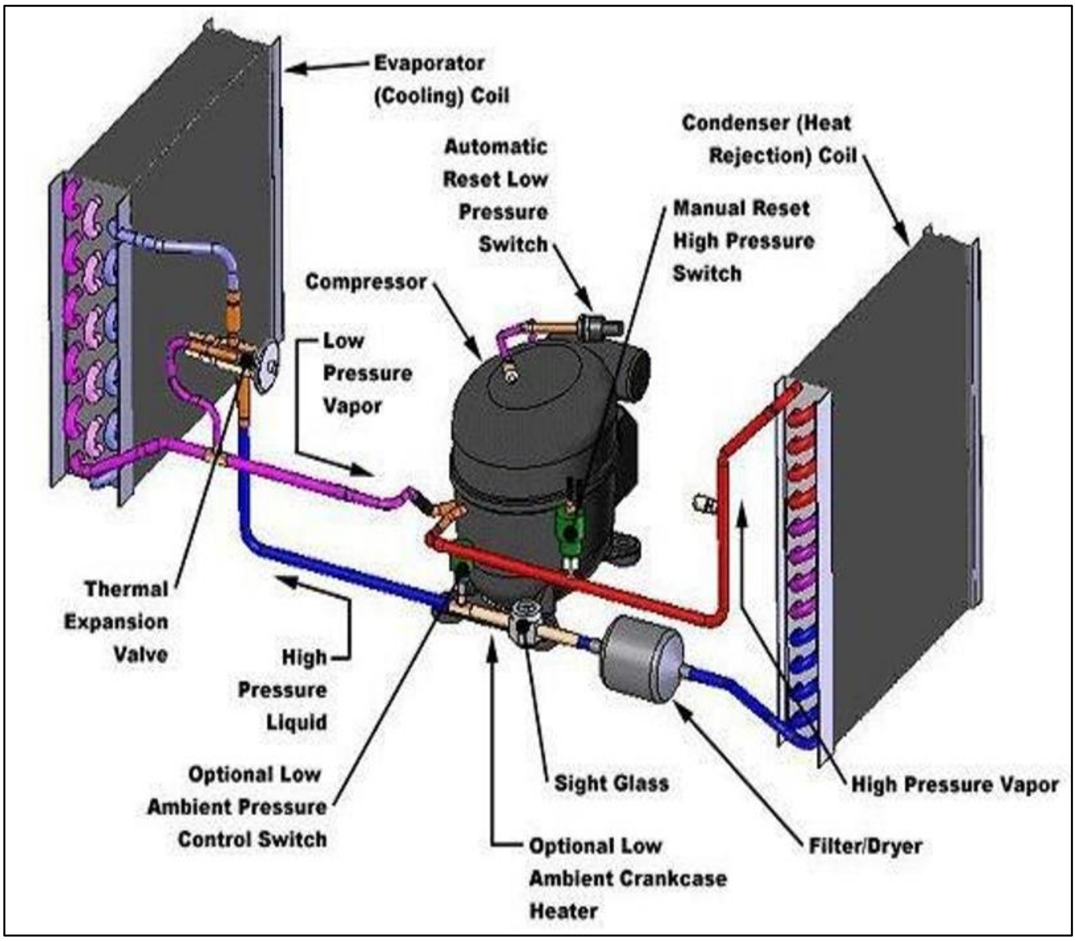

Figure 1.7: Components set-up

a. International Journal of Advanced Mechanical Engineering. ISSN 2250-3234 Volume 6, Number 1 (2016), pp. 17-26 © Research India Publications http://www.ripublication.com.
b. International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-8 Issue-8 June, 2019.
c. International Journal of Scientific & Technology Research Volume 8, Issue 09, September 2019 ISSN 2277-8616.

1.7 Analysis of Performance:

The refrigeration is defined as the process of removal of heat from a region or state or a substance to reduce and maintain its low temperature and transferring that heat to another region, state or substance at higher temperature.

The refrigeration process that employed in the domestic refrigerator is based on a vapor compression cycle as shown in Figure 1.8 and collaborated with Figure 1.8. there are three main parameter that were considered in this study; compressor power, refrigeration capacity and coefficient of performance (COP).

Process line from 1 to 2 represents compressor power. Compressor power is defined as the power needed to do the compression process in watt. The compressor power is determined by multiplying enthalpy change across the compressor to the mass flowrate, thus

$$P = \dot{m}(h_2 - h_1) \qquad (1)$$

Meanwhile, process from point 2 to 3 represents heat rejection through condenser. The amount of heat rejected is not significant in the present study. Process from point 3 to point 4 shows throttling effect through capillary tube whereby the working pressure of refrigerant will be reduced from discharge pressure to suction pressure.

Refrigeration capacity, which is represented by process line 4 to 1, is defined as the amount of heat absorbed by a unit mass of refrigerant in evaporator.

The refrigeration capacity can be obtained using equation below:

$$\dot{Q}_{in} = \dot{m}(h_1 - h_2) \qquad (2)$$

The coefficient of performance (COP) is a measure of efficiency of the refrigerator. The COP of a domestic refrigerator is the ratio of the refrigeration capacity to the energy supplied to the compressor. It can be expressed by equation 3. \

$$\text{COP} = \frac{\dot{Q_{in}}}{p} = \frac{\dot{m}}{m} \times \frac{(h_1 - h_4)}{(h_2 - h_1)} \qquad (3)$$

1.8 Installation of Domestic Refrigerator:

Before installing the unit, make sure that the floor in the kitchen is strong, the existing flooring will easily withstand the weight of the appliance with all its contents.

Otherwise, it will be necessary to make repairs and strengthen the floor. A simple instruction will explain how to properly install any refrigerator on the level are as follows-

a. Make sure that there are gaps between the refrigerator, walls and furniture;
b. by adjusting the height of the legs, set the fridge to the right level position;
c. Lift the front legs so that the fridge body tilts back a little so that the door can close easily;
d. check once more the level of the fridge;
e. make sure that the appliances are fixed firmly on the floor, do not wobble and do not tilt.

After the fridge is installed, you need to complete it: set the racks, shelves, baskets for vegetables, trays for eggs.

It is necessary to check that all the parts exactly fit into the appropriate grooves and do not shift during operation.

In this way you will exclude the probability of food falling down after loading the refrigerator.

Figure 1.8: Installing the Unit

1.9 Specification of Domestic Refrigerator:

Brand	Whirlpool
Model name/year	DC -5256/2012
Freezer Capacity (liter)	80
Fresh Food Compartment Capacity (liter)	230
Power Rating	160W
Current Rating	0.9A
Voltage	220-240V
Frequency	50Hz
No of door	Single
Compressor	Hermetic - sealed
Refrigerant type	R134a

Figure 1.9: Specification of Domestic Refrigerator

1.10 Comparative Analysis of Recent Researches on VCR System Using Domestic Refrigerator:

Study of 23 recent researches conducted on vapor compression refrigeration system done nationally and internationally, have been summarized in tabular form. It basically includes the methodology carried during those research works and major outcome obtained. Key recommendations as a result of the researches have been also mentioned that can be applied in domestic refrigerator for performance enhancement.

1.11 References:

1. Soliman A.M., Rahman A. and Ookawara S. (2019): Enhancement of vapor compression cycle performance using nanofluids. – Journal of Thermal Analysis and Calorimetry, vol.135, No.2, pp.1507-1520.
2. Firoj H Pathan, Sanchit Gandhi, Mahesh Kachhiya. IJSRD- www.ijsrd.com Utilization of Waste Thermal Energy from VCR Cycle Firoj Pathan, Sanchit Gandhi, Mahesh Kachhiya, Aman Sharma.
3. A K Bajpai and Vivek Dwivedi, ISSN 2278 – 0149 www.ijmerr.com, National Conference on "Recent Advances in Mechanical Engineering" RAME – 2014.
4. Miss. Rohini Zade, Prof. Prashant Walke Prof. Avinash Khanderao. Vol 6 www.irjet.com Experimental investigation on the performance of V. C. R. system using refrigerant.
5. Ansari N., Arora A. and Manjunath K. (2020): The effect of eco-friendly refrigerants on performance of vapor compression refrigeration system with dedicated mechanical subcooling. - Advances in Energy and Built Environment, Springer, pp.43-54.

6. Hoe J., Jeon M. and Kim Y. (2010): Effects of flash tank vapor injection on the heating performance of an inverter-driven heat pump for cold regions. – International Journal of Refrigeration, vol.33, No.4, pp.848-855.
7. Choudhary C. and Sapele S. (2017): Performance investigation of natural refrigerant R290 as a substitute to R22 in refrigeration systems. – Energy Procedia, vol.109, pp.346-352.
8. Mahmood R.A. (2020): Case study of liquid suction heat exchanger in a mechanical refrigeration system using alternative refrigerants. – International Journal of Engineering and Technology. Vol.9, No.3, pp.644-648.
9. Arora A. and Kaushik S. (2008): Theoretical analysis of a vapor compression refrigeration system with R502, R404A and R507A.– International Journal of Refrigeration, vol.31, No.6, pp.998-1005.
10. Mohan raj M., Muralitharan C. and Jeyaraj S. (2010): A review on recent developments in new refrigerant mixtures for vapor compression-based refrigeration, air-conditioning and heat pump units. – International Journal of Energy Research, vol.35, No.8, pp.647-669.
11. Mahmood R., Omar M. and Noor N. (2020): Mechanical vapor compression refrigeration system: review part 1: environment challenge. – International Journal of Applied Mechanics and Engineering, vol.25, No.4, pp.130-147.
12. International Journal of Advance Research, Ideas and Innovations in Technology.
13. International Journal on Emerging Technologies 11(2) : 849-853(2020).
14. International Journal of Research and Analytical Reviews. (IJRAR) [VOLUME 5 I ISSUE 3 I JULY – SEPT 2018.
15. International Research Journal of Engineering and Technology (IRJET) Volume: 05 Issue: 05 | May-2018.
16. International Review of Education (IRE) Journals | Volume 5 Issue 1 | ISSN: 2456-8880.
17. International Journal of Technical Research and Applications e-ISSN: 2320-8163, www.ijtra.com, Volume 5, Issue 3 (May-June, 2017), PP. 12-21[6].
18. International Journal for Research in Emerging Science and Technology, VOLUME-1, ISSUE-5, OCTOBER-2014.
19. International Journal of Science and Research (IJSR) ISSN (Online): 2319-7064 Index Copernicus Value (2013): 6.14 | Impact Factor (2015): 6.391.
20. International Journal of Research in Engineering and Science (IJRES)ISSN (Online):2320-9364, ISSN (Print): 2320-9356www.ijres.org Volume 10 Issue 6 ǁ 2022 ǁ PP. 1420-1423.
21. January 2020| IJIRT | Volume 6 Issue 8 | ISSN: 2349-6002.
22. International Journal of Engineering Research & Technology (IJERT) IJERT ISSN: 2278-0181 IJERTV3IS111404.
23. International Journal of Scientific Research and Management Studies (IJSRMS) ISSN: 2349-3771 Volume 3 Issue 12, pg.: 385-393.
24. International Journal of Engineering Research and Reviews ISSN 2348-697X (Online)Vol. 3, Issue 1, pp: (98-104), Month: January - March 2015.
25. King Abdulaziz City for Science and Technology 2021DOI:10.1007/s13204-021-01936-y.
26. International Journal of Mechanical Engineering and Technology (IJMET) ISSN 0976 – 6340 (Print) ISSN 0976 – 6359 (Online).

27. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 14, Issue 3 Ver. I (May. - June. 2017), PP 92-103 www.iosrjournals.or.
28. International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056 Volume: 04 Issue: 04 | Apr -2017 www.irjet.net p-ISSN: 2395-0072.
29. Mahatma Gandhi Institute of Technical Education & Research Centre, Navsari, India © 2018 IJRTI | Volume 3, Issue 4 | ISSN: 2456-3315.