PERFORMANCE EVALUATION OF CASCADE REFRIGERATION SYSYTEM USING DIFFERENT REFRIGERANTS

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Abstract

An cascade is a device in a process used to turn the liquid form of a chemical substance such as water into its gaseous-form/vapor. The liquid is evaporated, or vaporized, into a gas form of the targeted substance in that process.

In this work the cascade model designed in CERO software and analysis in ANSYS software with AZEOTROPIC mixture of R290 & R600 is made with R600 concentrations of 0%, 20%, 40%, 60%, 80% and 100% in R290 and it is used in a Refrigeration unit with different flow rates by fixing the other input parameters constant.

In this thesis the analysis it is known that higher flow rates of the refrigerant mixture increases the heat transfer rates but in the expense of higher work consumption which will affect the coefficient of performance of the refrigerant unit which is not advisable to use since the work utilization of the good refrigeration unit should be lesser for unit of refrigeration.

CFD analysis to determine the heat transfer coefficient, mass flow rate, heat transfer rate, pressure drop and velocity at different mass flow rates (1, 1.5 &2kg/s).

1. INTRODUCTION

Achieving temperature lower than the atmosphere is done by employing refrigeration system. Among traditional refrigeration systems like vapor compression system are widely used for household refrigeration systems and different storages such as food, medicine, cryogenic products etc. Ideally, Using simple single stage vapor compression refrigeration system lowest evaporation temperature that can be achieved is around -25°C. This temperature is a bit higher in actual system due to irreversibility. Which can be achieved using refrigerant having normal boiling point temperature around this range. Kilicarslan et al. states that single stage vapor compression systems are not suitable for low temperature applications due to difficulty in compression process of the refrigerant in between large pressure ratio and solidification temperature of refrigerants. Johnson et al. listed two major limitations of single stage vapor compression refrigeration system . Firstly, if pressure goes below certain limit, the compression process becomes too expensive and secondly, after compression the refrigerant must have pressure below its critical pressure to ensure two-phase condensation process. In industrial processes like natural gas liquefaction, preservation of complex medicine and vaccine [e.g. COVID-19 vaccine preservation needs around -70°C, cryogenic process and other very low temperature applications employing single stage vapor compression refrigeration system is not a feasible option thermodynamically or economically. This problem calls for a need of different approach to achieve the desired level of cooling effect at very low temperature. Widely used refrigeration technologies for low temperature application can be separated in the two major category based on working fluid types used which are the systems using pure working fluids and systems using mixed working fluids which is generally the combination of different organic compounds. Systems that employ single refrigerant as working fluid are either simple vapor compression system or another innovative system that uses multiple stages of vapor compression systems or combination of absorption system and vapor compression system on top of another named ‘Cascade Refrigeration System’. The system which has several refrigeration cycles above each other, each cycle ranging in different temperature and pressure level, exchanging heat through a common heat exchanger in between, generating a huge cooling effect at very low temperature is defined as the cascade refrigeration system. The first usage of cascade refrigeration system is found in 1877 which was built by Cailletet and Pictet who used ethylene and SO2/CO2 separately to build the system. Then later on, in 1908 helium was liquefied using precooling by cascade refrigeration cycles with air and hydrogen . Since then, a trend of using one refrigeration cycle above another was introduced. This is where the term 'Cascade Refrigeration System' first occurred.

Refrigeration System

There are mainly two types of thermodynamic systems: (1) work producing plant (e.g. Power Plants) and (2) work consuming systems (e.g. refrigeration and air conditioning systems). The refrigeration system is a work consuming device. A refrigeration system is a work consuming device as it uses external power input to generate a cooling effect using combinations of different components and a heat transfer fluid. The refrigeration system, serving the purpose of cooling a space by heat rejection, is widely used in almost all industries and households worldwide. This device either cools or maintains the temperature of storage below the temperature of the environment. This operation can be executed by implementing the Carnot cycle in reverse, which is not feasible in real life as it's an ideal concept. The isothermal processes of heat absorption and rejection cannot be achieved. In real life, the refrigeration cycle is executed by applying the well-known vapor compression refrigeration cycle.

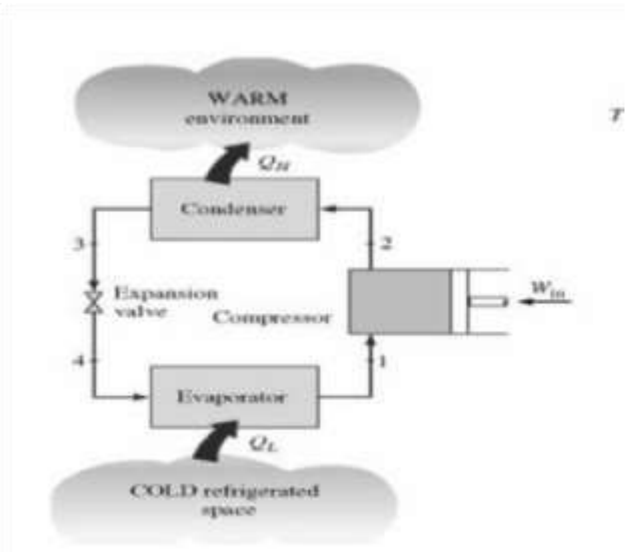


Figure 2.1: Vapor Compression Refrigeration cycle is used

Cascade Refrigeration System

In the basic vapor compression refrigeration system, there's only one stage and one refrigerant used. During very low-temperature applications (e.g. below -40oC) . Production of low temperature is limited by the following reasons-

1. The temperature at which refrigerant solidifies.
2. If the refrigerant has a very high boiling point, a high suction volume will be encountered at the inlet of the compressor due to very low pressure of evaporation.
3. High boiling point refrigerant will have very high condensation pressure.
4. High-pressure ratio results in a lower COP.
5. Hard to achieve lower evaporation temperature. To counter these limitations the cascade refrigeration system is introduced. Cascade refrigeration system is the series connection of multiple refrigeration cycles with refrigerants having a progressively lower boiling point. As there are different cycles combined separately, there's an option to vary refrigerants in different stages according to cooling requirements. The first usage of the cascade refrigeration system is found in 1877 which was built by Cailletet and Pictet [27] who used ethylene and SO2/CO2 separately to build the system. Then later on, in 1908 helium was liquefied using pre-cooling by cascade refrigeration cycles with air and hydrogen. There are different types of cascade refrigeration systems. Most commonly used systems are, two stage cascade, three stage cascade, cascade absorption system, etc. Two Stage Cascade Refrigeration System The simple vapor compression refrigeration system discussed in section

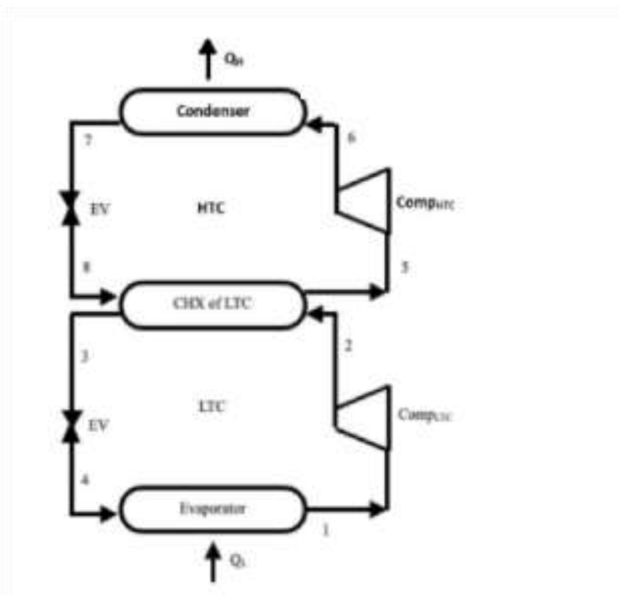
2.2.1 is the most used refrigeration cycle as it's adequate for most of the common applications. Sometimes the required cooling effect can't be achieved using one cycle

Thermo Dynamic Analysis of Cascade Refrigeration

They must be easy to use, affordable, and readily available with no significant new or unfamiliar technology required. Because the required evaporating temperature of the refrigeration system in lowtemperature applications, such as rapid freezing and frozen food storage, is between –40°C and –55°C, a single-stage vapour-compression refrigeration system is insufficient, and two-stage or cascade refrigeration systems are used instead. The high- and low-pressure sides of a two-stage refrigeration system are charged with the same refrigerant, but the high and lowtemperature circuits of a cascade system are filled separately with acceptable refrigerants.

A condenser, sometimes known as a cascade, is a heat exchanger that releases or absorbs heat to allow condensation.
The principle of construction: The refrigerant will be physically separated from the air. at the cascade refrigeration evaporator and condenser. As a result, heat is transferred through conduction.

We'd like to have a heat exchanger that can handle these procedures.
Higher conductivity - its certain characteristic guarantees the temperature variation between the exterior and interior walls is kept to a minimum.
• High contact factor– this feature ensures that the tubes are in contact with as much of the passing air mass as feasible.



2.LITERATURE REVIEW

Cimsit and Ozturk [1] analysed theoretically the performance of VCACRS with H2O-LiBr and NH3H2O as fluid pair in absorption section and R134a, R410A and NH3 refrigerants in the compression section of cascaded refrigeration system. It was presented that electrical energy consumption in the cascaded refrigeration cycle was 48-51% lower than conventional VCRS.
Chinnappa et al. [2] described a VCACRS consisting of a conventional R22 VCRS cascaded with a solar operated, NH3-H2O, VARS for air conditioning application. It was found to yield 49.5% saving in electrical energy consumption by the compression system.
Fernandez-Seara et al. [3] carried out the theoretical study to analyze a VCACRS from the view point of first law of thermodynamics. The system was integrated with a cogeneration system having exhaust gas temperature upto 873 K and it was found that electrical energy consumption was reduced by 133% in one of the configuration. The CO2 and NH3 were used as refrigerants in the compression section and NH3-H2O as the working pair in absorption section. Kairouani and Nehdi [4] theoretically studied the comparative performance of three refrigerants (R717, R22, R134a) in the compression section with NH3H2O fluid pair in the absorption section of the VCACRS. Geothermal heat was supplied in the generator at the temperature of 335 K for a fixed evaporation temperature of 263 K. The highest performance was obtained by R717. They achieved a refrigeration effect of about 10 MW with the compressor power of 1.65 MW and reported that the same refrigeration effect could be produced by a conventional VCRS by consuming 3.6 MW of electricity which was 54% more than the combined installation consumption.

Garimella et al. [5] modelled VCACRS fo naval ship application where the absorption section was powered by the exhaust heat from the onboard gas turbine power plant.

MATERIALS AND METHODS

Refrigerants are the working fluids used as a heat transfer medium in refrigeration system. Performance of refrigeration system depends significantly on the thermophysical and chemical properties of refrigerants. First refrigerant ether was employed in the hand operated vapor compression system by Perkins. In earlier days, ethyl chloride and ammonia were mostly used as refrigerant. Also, sulphur dioxide, methyl chloride and carbon dioxide were used around 1880s . Around 1910-1930 N2O3, CH4, C2H6, C3H8 etc. were used for medium and low temperature systems. Freon was developed in the 1930s by E.I. du Pont de Nemours and Co. Freon consists of hydrocarbon with fluorine or chlorine replacing hydrogen atoms. Using different combinations of carbon, hydrogen, chlorine, fluorine different refrigerants were developed later who are known as chloro-fluoro-carbon. They can be used for wide range of applications. Calm et. al. divided the refrigerant's development progression into four categories. (i) Firstgeneration – Whatever available Common refrigerants of first generation were generally different solvents and volatile fluids. As the early refrigeration system's refrigerants were only selected on the basis of cooling effect, most of them were toxic and flammable. Also, they were highly reactive with the system materials.

Some of the first-generation refrigerants are ether, CO2, HCOOCH3, SO2, NH3, CCl4 etc. After some setbacks with these refrigerants (environmental and performance reasons) researches were initiated in search of alternative refrigerants. (ii) Secondgeneration – Safety and Durability After property table for different chemicals was developed in early 1900s, refrigerants were searched on the basis of toxicity and flammability with stable chemical properties. In 1930, Midgley and Henne showed the effect of varying amount of chlorination and fluorination in hydrocarbon-based refrigerants. Midgley et. al. described the variation of boiling points, flammability and toxicity with the varying number of fluorine and chlorine in hydrocarbon-based refrigerants. Some secondgeneration refrigerants are, CFCs, HCFCs, HFCs, H2O etc. (iii) Third-generation - Ozone Protection In the 2nd half of 20th century, new problem was detected. Leakage of CFC refrigerants from refrigeration systems was directly or indirectly influencing the depletion of ozone layer of the earth's atmosphere. Damage to this ozone layer around the earth is a huge environmental concern as it protects life on earth from different harmful rays coming from the sun. Later on, in Vienna convention and Montreal protocol strictly recommended the elimination of these types of refrigerants from being used in refrigeration systems. This protocol initiated the search for "Nutral Refrigerants". Phasing out ozone depleting refrigerants eventually provided a significant positive outcome, after the worst year in 1998. (iv) Fourth-generation – Global Warming When the ice of poles started melting, resulting in sea level rise, global warming became a major concern of environmentalists worldwide. There are different reasons behind this phenomenon. However, one of the most significant reasons is related to refrigerants. Restrictions were imposed due to governments and engineering manufacturers' environmental concerns in selecting refrigerants that have high global warming potential values. Synthetic refrigerants are being removed from usage in systems worldwide and are being replaced. Some low global warming potential refrigerants shown by Calm et. al.[9] are, R-32, R152a, R-161, R-31I1, R-600, R-290 etc.

MATERIAL PROPERTIES

R-290

- Thermal conductivity-0.101 w/m-k
- Specific heat-239j/kg k
- Density – 5.80kg/m3

R-600

- Thermal conductivity-0.0256 w/m-k
- Specific heat-96.65 j/kg k
- Density – 2.51kg/m3

4. MODELING AND ANALYSIS

The use of computer technology in the design and documentation processes is known as CAD. CAD (computer-aided design) is the term used to describe the computer-assisted drafting process. Users can use CADD software, or environments, to simplify design processes such as drawing, documentation, and production.The most common form of CADD output is electronic files for printing or machining. Industryspecific software (construction, manufacturing, etc.) raster-based (pixelated) settings, whereas vectorbased (linear) environments are used by graphicbasedsoftware.

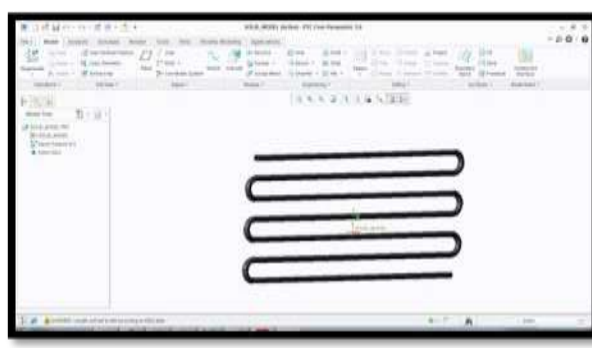


Fig: 3d Model Of condenser

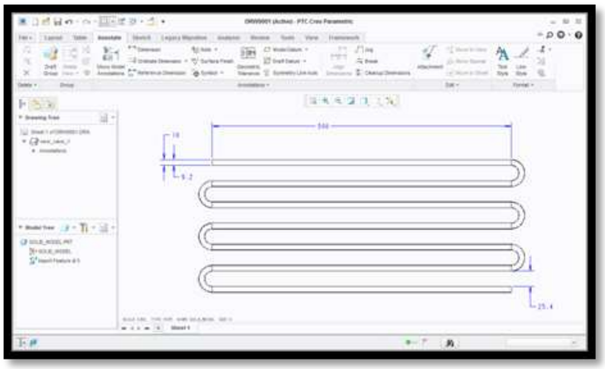


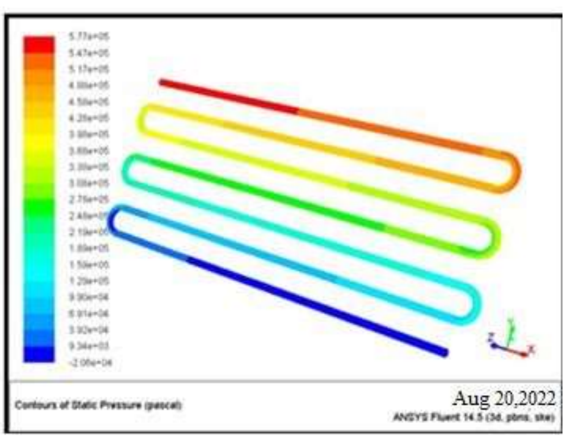
Fig: 2D Drawing

Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyse problems involving fluid flows. The computations required to model the interaction of liquids and gases with boundary conditions-defined surfaces are performed on computers. With high-speed supercomputers, better solutions are feasible.

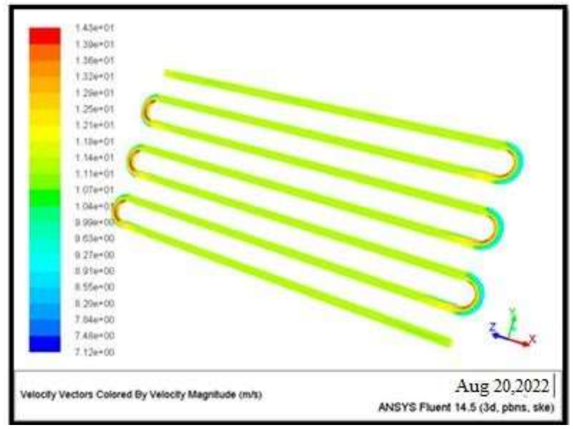
Volume fraction (Φ)	Density (kg/m³)	Specific heat (J/kg-k)	Thermal conductivity (w/m-k)
0.2	1245.48	1040.042	0.0076
0.4	1164.36	1036.67206	0.0111808
0.6	1083.24	1 32.7972	0.019106
0.8	1002.12	1028.2951	0.038677

CFD ANALYSIS OF CONDENSER

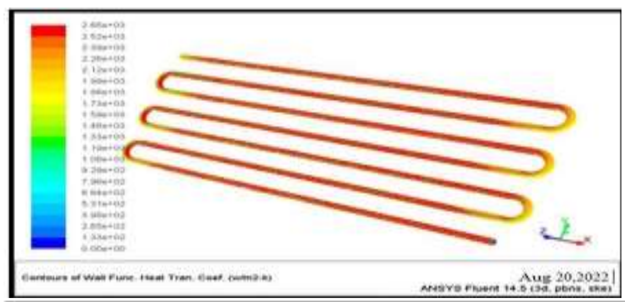
Pressure



Velocity



Heat Transfer Coefficient plot

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                 Mass Flow Rate                  (kg/s)
-------------------------------- --------------------
                          inlet              1.0000001
            interior-____nsbr              2452.7971
                         outlet            -0.99904591
                wall-____nsbr                      0
-------------------------------- --------------------
                            Net          0.00095421076

         Total Heat Transfer Rate                    (w)
-------------------------------- --------------------
                          inlet             -40833.457
                         outlet              40794.746
                wall-____nsbr                      0
-------------------------------- --------------------
                            Net             -38.710938
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Table: CFD Results

At mass flow rate 1 kg/sec

Fluid	Pressure (Pa)	Velocity (m/s)	Heat transfer coefficient (w/m²-k)	Mass flow rate (kg/s)	Heat transfer rate(W)
R-290	5.77e+05	1.43e+01	2.65e+03	0.00095421	38.710938
(Φ=0.2)	6.61e+05	1.52e+01	3.12e+03	0.0018023252	73.214844
(Φ=0.4)	7.16e+05	1.63e+01	3.43e+03	0.004491	182.23047
(Φ=0.6)	8.89e+05	1.75e+01	4.31e+03	0.001823	73.769531
(Φ=0.8)	9.66e+05	1.88e+01	6.24e+03	0.002842	114.39844
R-600	1.12e+06	2.06e+01	8.19e+03	0.004652	185.85547

At mass flow rate 1.5 kg/s

Fluid	Pressure (Pa)	Velocity (m/s)	Heat transfer coefficient (w/m²-k)	Mass flow rate (kg/s)	Heat transfer rate(W)
R-290	1.34e+06	2.15e+01	3.83e+03	0.0047117	192.57813
(Φ=0.2)	1.52e+06	2.28e+01	4.49e+03	0.00090575218	36.8984
(Φ=0.4)	1.81e+06	2.344e+01	4.92e+03	0.0032984	133.6132
(Φ=0.6)	2.00e+06	2.63e+01	6.19e+03	0.003185482	134.1289
(Φ=0.8)	2.74e+06	2.84e+01	8.93e+03	0.006955	279.98043
R-600	1.86e+06	3.09e+01	1.17e+04	0.00254344	101.82031

2kg/s mass flow rate

Fluid	Pressure (Pa)	Velocity (m/s)	Heat transfer coefficient (w/m²-k)	Mass flow rate (kg/s)	Heat transfer rate(W)
R-290	2.25e+06	2.86e+01	4.97e+03	0.0035150051	144.34375
(Φ=0.2)	3.39e+06	3.05e+01	5.83e+03	0.012027264	489.45313
(Φ=0.4)	2.63e+06	3.26e+01	6.38e+03	0.00502657	204.19531
(Φ=0.6)	4.10e+06	3.50e+01	7.99e+03	0.0093023	376.00781
(Φ=0.8)	3.10e+06	3.78e+01	1.15e+04	0.007047	283.2812
R-600	3.33e+06	4.12e+01	1.51e+04	0.0077912	311.95313

CONCLUSION

The Azeotropic mixture of R290 and R600 is made by mixing R600 concentrations of zero percent, twenty percent, forty percent, sixty percent, eighty percent, and 100 percent in R290. It is used in a refrigerator with high drift quotes by keeping the other enter parameters constant.

The results of the analytical warmth transfer rates at distinct drift rates are virtually identical. In order to get a clear picture of the costs of heat transfer at various drift fees, the values are compared.

Therefore, a slight flow charges i.e When using our refrigerant combination, a speed of 1.5 kg/sec is recommended for the refrigeration unit.

It has been discovered that higher R290 concentration combinations consume more work for pumping and follow the flow because R290 is denser than R600, which is once more not recommended because it lowers the refrigeration unit's COP. However, the awareness of R600 within the R290 does not follow a specific fashion in the warmth transfer rates at specific glide rates. Additionally, higher concentrations of R290 indicate corrosion in the cascade and condenser device tubing.

As a result, higher concentrations of R600 appear to be producing more beneficial effects than higher concentrations of R290.Then, 20% R290 and 88% R600 are used because they provide higher heat transfer fees while consuming less energy.

According to the results, a 20 percent R290 &80 percent R600 combination at 1.5 kg/sec flow rate is acceptable for the refrigeration unit without affecting its COP.

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