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Vapour Compression-Absorption Hybrid Refrigeration System and Optimization using Cooling tower

Vatsal Agrawal[1], Rohan Juneja[2], Kahaan Dalal[3], Tirek Prajapati[4], Dr. Bansi Raja[5]

[1-4]Student, Department of Mechanical Engineering, Indus Institute of Technology and Engineering, Rancharda, Via: Thaltej, Ahmedabad, Gujarat, India
[5]Dr. Bansi D. Raja, Dept. of Mechanical Engineering, Indus Institute of Technology and Engineering, Ahmedabad, Gujarat, India

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Abstract - *The R134-DMF vapour compression and absorption hybrid refrigeration system combines the strengths of both a normal VCRS and a VARS system in a complex hybrid system. This includes the increase in performance, decrease in energy consumption and efficiency rise, amongst other things that are optimized than the normal systems, and can be a huge optimized system which is what might potentially be required in an upcoming energy crisis the world would soon face.*

Key Words: Hybrid system, Cascade refrigeration system, Absorption refrigeration, compression refrigeration, Nano refrigerant, Waste heat recovery, Modified VCRS, Cooling tower

1. INTRODUCTION

The refrigeration means a continuous extraction of heat from a body whose temperature is already below the ambient temperature. In a refrigerator, heat is manually pumped from a lower temperature to a higher temperature. As per the Second Law of Thermodynamics, this procedure must be performed with the application of some external work. It is thus obvious that the supply of power is a constant requirement to drive a refrigerator [1]. In the general vapour compression refrigeration system, the effect of refrigeration is obtained as the refrigerant evaporates at low temperatures. The required input to these systems is in the form of mechanical energy required to run the compressor. Thus, these systems are also known as a mechanical refrigeration system [2].

In recent years, many researchers tried to find the results of tube inclination on the flow pattern, heat transfer coefficient, and pressure drop, it was found that tube inclination will change the flow pattern because of which the heat transfer coefficient also changes. The researchers also found that the main parameters that influence on pressure drop and heat transfer coefficient, are vapor quality, mass velocity, saturation temperature, etc., although Mr. R. G. Deshmukh (2018) in his article showed that tube inclination has a sufficient effect on the heat transfer coefficient, but recently many researchers found that the magnetic field will affect the heat transfer coefficient and hence on the COP of VCR cycle. Due to the application of the magnetic field the molecule gets broken, resulting in the decreased viscosity of the fluid which in turn decreases the power required by the compressor to pump the refrigerant and also improves the heat transfer rates in the condenser and evaporator due to increased mass flow rate. It was noticed that for convective condensation and evaporation in inclined tubes that the inclination angle influences the heat transfer coefficient. Under specific conditions, an inclination angle of -30° (slightly downward flow) leads to an optimum heat transfer coefficient. He concluded from the literature that the magnetic field has a positive effect on the heat transfer coefficient, but there is not been a proper correlation yet which can relate the magnetic field intensity and heat transfer coefficient. Using inclination and magnetic field are both effective techniques for improving the heat transfer coefficient but the application of magnetic field has an insignificant effect on pressure drop, whereas inclination has the significant effect on pressure drop the magnetic treatment is more effective techniques for enhancing the heat transfer rates than inclination [3].

Arijit Kundu et al. [4] presents experimental research on two-phase flow evaporative heat transfer of refrigerants R134a and R407C, in a smooth copper tube inclined at five different angles from 0° to 90°. The experimentation was carried over a mass velocity range of 100–300 kg/m2s, heat flux range of 3–10 kW/m2, the inlet temperature range of 5° to 9° C, and vapor quality varied from 0.1 to 0.9. The applied test section was 1.2 m length of smooth copper tube with an inner diameter of 7.0 mm, and an outside diameter of 9.52 mm. The comparison is made for the effects of vapor quality, mass velocity, heat flux, and tube inclinations on the evaporative heat transfer coefficient for both refrigerants. The results indicated that mass velocity and heat flux was affecting the heat transfer coefficients significantly. By increasing mass velocity and heat flux, the heat transfer coefficient was also getting raised for both refrigerants. There was a vapor quality range between 30% and 40% for R407C and 65–75% for R134a for which heat transfer coefficient is maximum The result indicated that heat transfer coefficients of pure fluid R134a are higher than that of refrigerant R407C for all stated parameters.

Further superheating has a prominent effect on refrigeration systems, the superheating of refrigerant prevents the damage of compressor vanes, this superheating of refrigerant may give the additional cooling effect on account of improving co-efficient of performance if the superheating takes place inside the evaporator during cycle operation under given working conditions [5, 6].

1.1 Combined Refrigeration Systems

In the article by Ganesh Chembedu (2017), a model of combined vapour compression refrigeration system is proposed by adding a high EER compressor, diffuser at condenser inlet, passing waste heat from condenser to generator, ejector, and fan at the evaporator. In the general refrigerant compressor, it has mechanical power, distribution losses, Electric motor losses, volumetric efficiency losses, and heat losses. He concluded that with diffuser and fan, power consumption was less for the same refrigerating effect which had resulted in improved performance. He added that the condenser size and cost got reduced due to more heat transfer [7].

Wang et al. [8] have proposed a combined cooling, heating and power (CCHP) system to produce cooling output, heating output and power output simultaneously. This trigeneration system has a large number of benefits include increased efficiency, high part-power efficiency, low emissions, and lower air and exhaust flows.

Pilavachi [9] in his paper is predicting about the uncertainty of market potential for micro-gas turbines, he introduced mini-and micro-gas turbines for combined heat and power, specifically for power generation in the industrial sector. He emphasized number of advantages and potentials of mini- and micro-turbines compared to other technologies.

This Article by Shyam Agarwal (2018), comprises the configuration of combined refrigeration system which is integration of a vapour compression and vapour absorption system. The integrated system is energized by a micro gas turbine to generate cooling at the low temperatures. The waste heat from the exhaust of micro gas turbine is used to drive the vapour absorption system while the vapour compression system is directly powered by the small gas turbine. The compression system is at the low temperature stage while the absorption system is at high temperature stage boost the performance of compression system. The power generation using gas turbine as combined heat and power (CHP) as well as the heat-power-refrigeration (Tri-generation) systems are gaining momentum due to their beneficial overall efficiency about 70-85%. The Tri-generation system consists Gas-turbine, Heat-recovery steam generator (HRSG) and Vapour-absorption refrigeration system [10].

Further other researchers have developed many improved refrigeration systems based on cascading of compression and absorption systems and also developed certain combined compression-absorption system or other such hybrid systems.

The paper by José Fernández-Seara (2006), he carried out a study to analyze a refrigeration system in cascade with a compression system at the low-temperature stage and an absorption system at the high-temperature stage to generate cooling at even lower temperatures, as well as the possibilities of powering it by means of a cogenerative subsystem. CO_2 and NH_3 are the selected refrigerants in the compression stage and the binary mixture of NH_3–H_2O in the absorption stage. The paper presents the results obtained regarding the performance of the refrigeration system and the adaptability between the power requirements of the refrigeration system and the power supplied by the cogeneration system taking into account the present Spanish Regulations about the use of cogeneration systems [11].

1.2 Refrigerants and Nano Refrigerant

A variety of vapour compression refrigeration systems are available to easily employ at almost all applications with the refrigeration capacities ranging from watts to megawatts. A huge variety of refrigerants can be used in these systems to suit different applications, capacities, etc. In an article by L.J. He (2009), he found that R134a-DMF and R134a–DMA systems exhibit better performance, compared to other R134a–absorbent systems. The circulation ratio is less and COP is more for the R134a–DMF system compared to the R134a–DMA system [12].

The article by S. Mariappan(2013) performed an experimental investigation to measure performances of a 1 ton of a vapor absorption refrigeration system employing tetrafluoro ethane /dimethylformamide. Plate heat exchangers are used as system components for the evaporator, condenser, absorber, generator, and solution heat exchanger. He concluded that this refrigerant and the absorbent mixture is chemically stable, non-corrosion, completely miscible in a comparatively wide temperature range. COP increases with increasing the evaporating temperature 'Te' and decreasing condensing temperature 'Tc'. In reverse, the circulation ratio decreases with an increase in the evaporating and condensing temperature. It is observed that the range of operating temperature of the system R134a + DMF is widest [13].

In hobby only refrigerants were utilized in the refrigeration process and that they were having a worldwide warming coefficient at high level. Now, as time changes the advanced techniques are coming into existence with the assistance of them the refrigeration process becomes more efficient and safe as compared to previous in atmospheric prospective.

K. Pawale (2017) in his research, mentioned about the recent advancements in nanotechnology that have originated the new emerging heat transfer fluids called Nano-fluids.

Nano-fluids are prepared by dispersing and stable suspending nanometre sized solid particles in conventional heat transfer fluids. Past researches have shown that a really bit of suspending nanoparticles have the potential to reinforce the thermo physical, transport and radiative properties of the bottom fluid. Due to improved properties, better heat transfer performance is obtained in many energy and warmth transfer devices as compared to traditional fluids which open the door for a replacement field of scientific research and innovative applications [14].

2. PROPOSED REFRIGERATION SYSTEM

The concept of Cascading also holds good for the Compression and absorption system. These systems can be cascading of two Vapour Absorption Systems and can be designed as an integration of Vapour absorption and compression systems also.

In their Article on 'Compression–absorption cascade refrigeration system' the Author José Fernández-Seara [11] has used two refrigerant alternative for the VCRS, CO_2 and NH_3 which concludes to have no major effect on the VARS as the amount of heat transfer is same for both the refrigerants, whereas the cascade system COP presents a maximum value when the intermediate temperature is varied. Further the intermediate temperature depends on the evaporator temperature and should be determined in the earlier stages of design. The effect of the evaporation temperature on the optimal intermediate temperature is more significant with NH_3 than with CO_2 as refrigerant in the compression system.

The Article states that the (CACRS) cascade refrigeration system could be integrated with a cogeneration system, since this would supply simultaneously the electricity to the compression system and the heat to the absorption system [11]. Further such systems are called Hybrid Refrigeration systems which will be introduced in the next section.

2.1 Hybrid compression-absorption refrigeration systems

Hybrid refrigeration systems are further more complex systems compared to all the above mentioned systems. These refrigeration systems have a large range of possibilities for modifications into the conventional VCRS & VARS, generally these include a large number of components such as multiple heat exchangers, multiple condensers and evaporators (cascade systems), components using renewable energy source for better COP, turbines and other such expansion devices, etc. Basically a hybrid refrigeration system can have any possible combination of components in both series and parallel circuits for increasing COP. Hybrid refrigeration systems proposed in this report and supporting articles particularly focus on reducing the amount of work and energy input into the system and reducing exergy destruction in various processes of the system for better performance. Therefore systems have comparatively less power and energy input desired for industrial usage in places that have fewer resources, basically aimed to have better economical solutions for the standard cycles.

This system was proposed by Wei Han (2013) keeping the energy efficiency and energy destruction as the centre of focus. In the article the authors have proposed a system which uses the waste heat from the ARS to convert into useful work and increased cooling energy which would also reduce electricity consumption of conventional VCRS. This ACHRS (absorption-compression hybrid refrigeration system) was developed in such a way that it also utilizes the sensible heat of flue gases more efficiently [15].

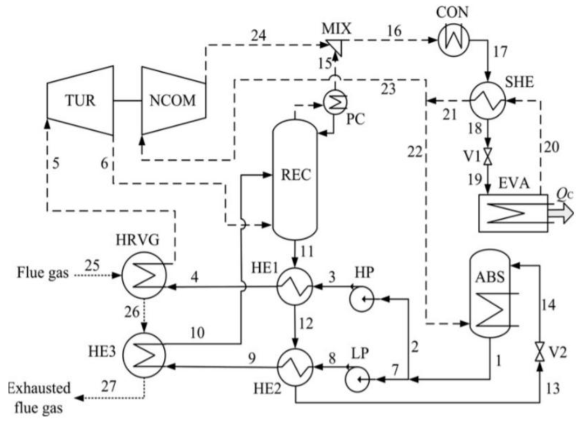

Fig -1 Flow Chart of Absorption-Compression Hybrid Refrigeration System [15].

The **Figure 1** shows the flowchart of the ACHRS, as seen here unlike other cascade systems a binary mixture of ammonia-water is used as working fluid where ammonia is refrigerant for both the VCRS and VARS subsystems and water is used as absorbent for the VARS sub system. It consists of a heat driven compression subsystem and an absorption subsystem, integrated by an absorber and a rectifier. Further the generation process of the system is divided stage wise into a number of heat exchangers and an HRVG where cascading of heat from flue gases and heat of weak solution leaving the rectifier is used in the above mentioned HEs for stage wise pre-heating of the mixture. As seen in the **Figure 1** the mixture from the absorber is divided into two separate parts where first half is heated at extremely high temperature in HRVG and both refrigerant and water gets vaporized, due to the HP and HRVG, a superheated steam with extremely high temperature and pressure is generated which is expanded in the turbine (this generated work is employed for compression as mentioned above) an the high temperature steam is sent to the rectifier. Similarly the other half of this mixture from absorber is used to heat the mixture using the waste heat of these flue gases used in HRVG and is also sent to the rectifier where ammonia vapour is used further for refrigeration purpose. The stream from the compressor and the Rectifier is merged at a junction before the condensation from where the further cycles run as usual.

According to this Article [15] the cascade use of sensible heat in this hybrid system dramatically enhances the overall performance of the system. The COP of the proposed system is 0.71, which is 41.9% higher than that of the conventional NH_3–H_2O ARS. The effects of flue gas and cooling water temperatures on thermodynamic performance are also investigated. The COP of the hybrid system increases from 0.67 to 0.71 when gas temperature rises from 300 C to 350 C. The COP of the hybrid system increases from 0.71 to 1.04 as cooling water temperature decreases from 30° C to 10 C.

2.2 Reference refrigeration system

The conventional vapour compression refrigeration system is taken as a reference system, this system has a liquid cooled condenser that has a cooling tower attached to it. As mentioned by Rahul Wandra (2015) in his article, the COP of VCRS (water cooled condenser) is increased by using cooling towers. The cooling tower consists of a single or double thickness cellulose pad within the system, this study focused on improving the COP of a conventional compression refrigeration system. To improve the overall performance of the system the cooling tower performance was improved using good water wet ability of cellulose pad that caused a uniform water circulation over the entire surface of the pad and proper contact between water and cooling air [16].

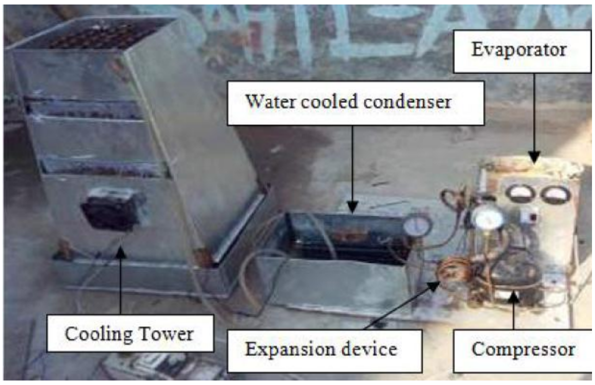

Fig -2 Reference VCRS system with cooling tower [16]

The VCRS (water-cooled condenser) was attached with a cooling tower consisting of two different cellulose pads of the same thickness. In the first case, a single pad of 2inch thickness was employed in a cooling tower at two different surrounding temperatures of 27°C and 30°C. There was a notable change in COP from 4.93 to 4.68 as the surrounding temperature increased. Similarly in another case when double pads of the same thickness were used in the cooling tower, the COP changed from 5.15 to 4.98 as we moved from 27°C to 30°C.

The experimental setup (**Figure 2**) consists of a vapour compression system with the basic components i.e. evaporator, compressor, expansion device, and condenser. A tank of ten litres is built and the condenser is put in that tank, filled with water as shown in the figures. For water circulation, a small pump (15Watt) is put in the tank and the outlet of the pump is connected to the cooling tower. The function of the pump is to transfer the hot water from the condenser tank into the cooling tower where it is cooled by passing hot ambient water over the evaporative media pad of the cooling tower and cooled water is collected in the tank which is located in the below of the cooling tower in the cooling tower tank from where it is again transferred to the condenser tank. This closed cycle in which hot water and cold water circulating is having a constant water circulation rate for all tests.

3. RESULT AND DISCUSSION

As seen from the data, using the R134A-DMF solution for the hybrid cycle is more beneficial in more ways than one. This can further be improved by using a few other techniques. Furthermore, nanoparticles can be added into the refrigerant to have a better refrigeration effect and other such benefits. One such example is adding Al2O3 to the traditional R134A. R134a+0.5% Al2O3 shows the development in actual COP by 30.85% and R134a+1% Al2O3 shows the decline in actual COP by around 8.55%. Also, due to the addition of Nano refrigerants, there is an increase in discharge temperatures. Higher discharge temperature leads to high condensing temperature and low evaporating temperatures. Also, with regards to discharge and suction pressure, there is significant increment for both the mixtures. An increase in condenser pressure, results in a decrease in the refrigerating capacity and an increase in power consumption. Superheating of the suction vapour is advisable in practice because it ensures complete vaporization of the liquid within the evaporator before it enters the compressor. The advantage of subcooling is offset by the increased work of compression. Also, any time there are high condensing pressures or low evaporator pressures, or both, there will be high compression ratios. This will cause the warmth of compression to extend and therefore the compressor will have a better discharge temperature. A high volumetric efficiency, which is caused by these additives also means that more of the piston's cylinder volume is being filled with new refrigerant from the suction line and not re-expanded clearance volume gases. The higher the volumetric efficiency, the greater the amount of new refrigerant that will be introduced into the cylinder with each down stroke of the piston, and thus more refrigerant will be circulated with each revolution of the crankshaft [14].

Similarly, one more approach that can be used in collaboration to the hybrid cycle is using a cooling tower. Further studies on the matter reveal that there is considerable change in compressor work when we vary the thickness of cellulose pad at same ambient temperature. But when we compare compressor pressure work at two different ambient temperatures for the same thickness of two cellulose pad i.e. single and double pad, compressor work is more in case of single pad. Also there is an increase in COP, when we increase the single cellulose pad to double at the same ambient temperature. But when we compare COP at two different temperatures, COP is more at a lower temperature for both cellulose pads, single and double. There is an increase in the COP from Single pad to double pad at the lower ambient temperature and a higher temperature, there is an increase in COP from single to double .It is also seen that COP decreases from higher to lower temperature when we use a single thickness pad. Similarly, COP decreases from higher to lower temperature by using a double thickness cellulose pad. Thus an increase in double of the cellulose pad increases the COP of the system at same temperature [16].

4. CONCLUSION

From the above results and discussion as well as the rest of the data submitted in this paper, we present the conclusion that not only is a R134A-DMF vapour compression and absorption hybrid refrigeration system an improvement over a regular VCRS or VARS system, but it also has a much better effect and practical uses in the future. There is also the chance of having many different additions done to this hybrid system to improve the overall performance by tweaking small things and improving the overall systems. Many small and big experimentations can be further done on this hybrid system and it can be more optimized in the future.

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