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Waste Heat Recovery : An Analytical Study Of Combined Ejector And Vapour Compression Refrigeration System

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Abstract

Vapour compression refrigeration system is most commonly and domestic as well as large scale method of producing refrigeration effect. Due to higher co-efficient of performance these systems capture most of the refrigeration field either domestic or industrial. As on 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. This paper is a hypothetical approach towards the utilization of waste heat of a vapour compression refrigeration system. The rejected heat could be used to operate any other low grade heat required refrigeration system such as simple ejector refrigeration system. On the basis of some analytical examples we propose a combined cycle in this article. It is a suitable way of utilization of such waste heat hence improve the co-efficient of performance of a vapour compression refrigeration plant.

Keywords : combined cycle, combined refrigeration cycle, waste heat recovery system, combined cooling method, Ejector refrigeration system.

Introduction

Waste heat recovery is continuously gaining popularity among industries but still a lot of industrial processes work without heat recovery. Heat powered refrigeration systems are becoming more and more attractive for the efficient use of energy and could have significant impact on the savings of the electrical energy consumption and hence on the reduction of pollutant gases. Ejector refrigeration systems using halocarbon compounds have the advantage of utilizing low-grade thermal energy at temperatures as low as 60 °C, which is available from a number of sources, such as solar thermal energy at lower temperatures, waste steam, flue gas, exhaust from automobiles, etc. Nguyen *et al.* (2001) developed a pump-less ejector refrigeration system driven by solar thermal energy. Water was used as refrigerant in the system, which goes back to the generator from the condenser by means of the gravity force. A prototype was constructed and the experiments were done with the system. The results showed that the COP can be up to 0.32 with the operation condition: generation temperature of 76.6 °C, evaporation temperature of 1.5 °C, condensation temperature of 26.82 °C, and the cooling capacity of 5.09 kW. The minimum vertical separation of the condenser to the generator was 7 m mentioned in the paper; the large height of the system restricted the use of such system in some circumstances. [1] On other way, combined vapour compression and ejector refrigeration system is other method to maximize the co-efficient of performance of vapour compression system by using heat recovery phenomenon. This article focus on utilization of heat rejected by vapour compression refrigeration plant. For example, a vapour compression refrigeration plant working between pressure limits 3 bar and 12 bar and temperature limits 0 °C and 50 °C, having refrigeration capacity 7 tones. The amount of heat rejected from this plant during condensation process is approx 29.9 kJ/s. [2] This heat is rejected to the atmosphere by air circulation or water circulation in the condenser. This heat could be recovered by waste heat recovery phenomenon, according to which the waste heat is used to drive any equipment or plant before releasing it to atmosphere.

Ejector or jet pump refrigeration is a thermally driven technology that has been used for cooling applications for many years. In their present state of development they have a much lower COP than vapour compression systems but offer advantages of simplicity and no moving parts. Their

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greatest advantage is their capability to produce refrigeration using waste heat as a heat source at temperatures above 80°C. [3,4] There are several benefits associated with the successful completion of a waste heat powered ejector refrigeration system. A potential application for this system is to power the air conditioning system with no additional heat supplied. There is potential for an ejector refrigeration system to run off the waste heat from the generator to cool food and medicine. This ejector refrigeration system provides a benefit that traditional refrigerators do not, a non hazardous working fluid. In an ejector refrigeration system, the ejector converging - diverging nozzle is the most expensive component and its design is unique to changing operating conditions. Another consideration associated with the ejector is that it could take multiple iterations to achieve the desired operating conditions. This would require buying a new ejector, as you cannot easily adjust the geometry of this converging-diverging nozzle after it has been manufactured.

Need

As we discuss above that a large amount of heat is rejected to the atmosphere which is generally useless. For example a cold storage of food products and space conditioning for the comfort of human beings and their major applications. the conventional Refrigeration and air conditioning systems are based on vapour compression machine and required work input for their system operation, on the other hand, vapour absorption refrigeration system are currently attracting increasing interest; first ,because an ARS can be driven by low –temperature heat sources (solar energy, geothermal energy, industrial waste, etc.) and may, therefore, provide a means for converting waste heat into useful refrigeration; second ,because the use of CFC refrigerants and the consequent environmental damage are easily avoided. Following are the aspects regarding the recovery of waste heat; [5]

- *Energy efficiency improvement is considered widely in various industries.*
- *The main purpose is to reduce the overall cost of production by reducing the energy cost. Other benefits are also obtained such as increasing the life of fossil fuel reserves as most of the energy needs of industry are derived by fossil fuels and alleviating the burden of pollution on environment.*
- *Present paper reviews the different researches in the recovery of waste heat which is one of the method of increasing energy efficiency.*

Proposed Combined Cycle

There a possible way to utilise this waste heat i.e waste heat powered ejector refrigeration system. The waste heat obtained from the vapour compression refrigeration system could be used to phase change of the refrigerant in generator of the ejector system. In this way it might be possible to improve the co-efficient of performance of a vapour compression system by combining it with simple ejector system, which would be operated by this waste heat, obtaining from compression cycle. The two refrigeration systems i.e one is high grade energy operated and other one is low grade energy operated system could be joined together to form a combined refrigeration system so that improve the COP of the plant. Here we propose a theoretical approach to operate an Ejector refrigeration plant by the waste heat from the condenser of a vapour compression refrigeration plant. In this way an additional cooling effect is obtained without giving any additional energy or heat.

Cycle Description

There are two refrigeration plants (as shown in figure) one is simple vapour compression plant (a-b-c-d-a) and other one is Simple ejector system (1-2-3-4-5-6-1) [6] join together to form a combined refrigeration system. As we can see from block diagram as well as T-s diagram that heat required to operate the ejector cycle is coming from condenser of the vapour compression cycle. In vapour compression cycle process a-b is condensation, vapour refrigerant reject its latent heat and convert in liquid form, process b-c is expansion, obtain low pressure liquid refrigerant, process c-d is evaporation of refrigerant, producing cooling effect by absorbing heat from surrounding, process d-a is compression, obtain high pressure vapour refrigerant; and cycle repeats its path. On other hand, Referring to the basic ejector refrigeration cycle in Figure ,the system consists of two loops, the power loop and the refrigeration loop. In the power loop, low-grade heat, Q_G, (obtaining from condenser of vapour compression system) is used in a generator to evaporate high pressure liquid refrigerant (process 6-1). The high pressure vapour generated, known as the primary fluid, flows through the ejector where it accelerates through the nozzle. The reduction in pressure that occurs induces vapour from the evaporator, known as the secondary fluid, at point 2. The two fluids mix in the mixing chamber before entering the diffuser section where the flow decelerates and pressure recovery occurs. The mixed fluid then flows to the condenser where it is condensed rejecting heat to the environment, Qc.

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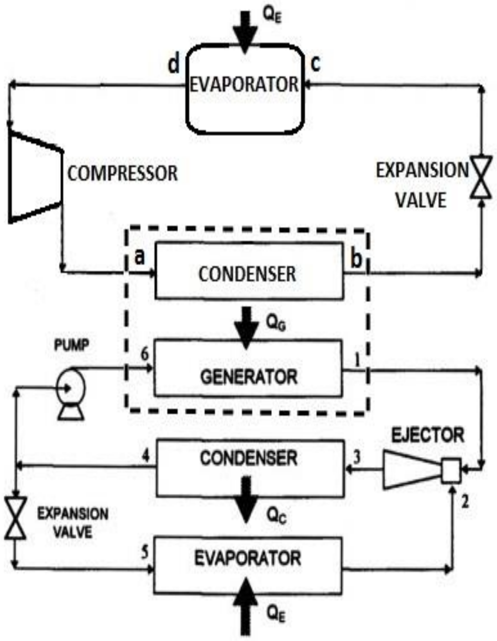

Fig. Combined VCC-Ejector system.

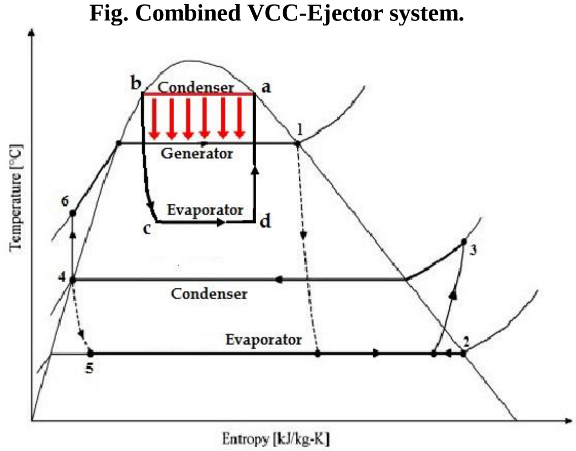

Fig. Combined VCC-Ejector system on T-s diagram.

A portion of the liquid exiting the condenser at point 4 is then pumped to the boiler for the completion of the power cycle. The remainder of the liquid is expanded through an expansion device and enters the evaporator of the refrigeration loop at point 5 as a mixture of liquid and vapour. The refrigerant evaporates in the evaporator producing a refrigeration effect, Q_E, and the resulting vapour is then drawn into the ejector at point 2. The refrigerant (secondary fluid) mixes with the primary fluid in the ejector and is compressed in the diffuser section before entering the condenser at point 3.The mixed fluid condenses in the condenser and exits at point 4 for the repetition of the refrigeration cycle.

Analysis of VCC

Let us consider a F_{-12} vapour compression refrigeration plant of refrigeration capacity 7 TR working under following conditions:

Temp (°C)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kg-K)	s_g (kJ/kg-K)
50	84.86	206.29	0.3034	0.6792
0	36.02	187.39	0.1418	0.6960

T-s diagram is shown above.

h_a = 206.29 kJ/kg

$h_b = h_c$ = 84.86 kJ/kg

Now, $s_a = s_d = s_{fd} + x\,(s_{gd} - s_{fd})$

0.6792 = 0.1418 + x (0.6960 – 0.1418)

x= 0.96

∴ $h_d = h_{fd} + x\,(h_{gd} - h_{fd})$

h_d = 181.34 kJ/kg

✓ **Refrigerant flow rate : (m)** = $\frac{3.5 \times 7}{h_d - h_c}$ = 0.253 kg/s

✓ **Rejected heat ($Q_{a\text{-}b}$)** = m (h_a- h_b)

= 0.253 (206.29 – 84.86)

= 30.72 kW

Analysis of Ejector System

An refrigerant ejector refrigeration system could be operated under given conditions:[7]

Generator temp. (T_G) = 64°C (337 K)

Condenser temp. (T_C) = 44 °C (317 K)

Evaporator temp. (T_E) = 10 °C (283 K)

Theoretical COP:

$$= \left[\frac{T_E}{T_C - T_E}\right] \times \left[\frac{T_G - T_C}{T_G}\right]$$

$$= \left[\frac{283}{317 - 283}\right] \times \left[\frac{337 - 317}{337}\right]$$

= 0.491

If actual heat supplied = 0.80 times of theoretical heat supplied. (Theoretical heat supplied is same as that of rejected from vapour compression refrigeration plant) [8]

Hence, actual heat supplied to the generator = 0.80 × 30.72 kW

= 24.57 kW

✓ Refrigerating Effect = COP × Actual heat supplied to the system.

= 0.491 × 24.57 kW

= 12.06 kW

- ✓ Cooling capacity of plant = Refrigerating effect/ 3.5
  = 12.06/3.5 **= 3.45 TR**

Result

As per calculation mentioned above, approx 30 kW heat is rejected from the condenser. This heat is utilized as source heat for ejector system. Total heat obtained could not be transferred to the generator perfectly. On consideration, 80% of the heat is utilized, the amount of actual heat supplied is 24.57 kW which is enough to operate an ejector refrigeration plant of cooling capacity 3.45 TR (produced refrigeration effect at the rate of 12.06 kJ/s) without supplying any additional heat. The overall co-efficient of performance of the combined plant could be calculated as 5.77 instead of 3.86.

Conclusion

From the above discussion and result it be concluded that the COP could be increased by 50 % by combining the VCC and Ejector refrigeration plant having the working conditions as (T_G) = 64℃ ; (T_C) = 44 ℃; (T_E) = 10 ℃. the additional refrigeration effect could be obtained by using low grade heat rejected by a 7TR vapour compression refrigeration plant using Freon F_{-12} as a working substance in VCC plant . This is a possible way of recovery of waste heat rejected by large scale vapour compression refrigeration plants as well as the heat rejected by cold storages.

The key advantage of the combined plant is the Financial and economical aspects also justify the heat recovery as in most of the cases as in most of the cases returns in term of savings are much greater than the investment costs. Since there will not be required any additional heat to operate the ejector refrigeration system, hence a possible way to maximize the performance.

References

[1] *International Refrigeration and Air Conditioning Conference at Purdue, July 16-19, 2012.*

[2] *Refrigeration and air-conditioning by Arora and Domkundwar, chapter 4 i.e Simple vapour compression refrigeration system.*

[3] *K. Chunnanond, S. Aphornratana, (2004) Ejectors: applications in refrigeration technology, Renewable and Sustainable Energy Reviews 8 129–155.*

[4] *I. W. Eames, S. Aphornratana, Da-Wen Sun, (1995) The jet-pump cycle-a low cost refrigerator option powered by waste heat, Heal Recovery systems & CHP, vol. 15, no. 8, pp. 71 i-721.*

[5] *Khaliq, A. and Rajesh,K.,2008. Energy analysis of double effect vapor absorption refrigerationsystem.Int.J.Energy Res :32,161-174.*

[6] *"A new ejector refrigeration system with an additional jet pump" J. Yu et al. / Applied Thermal Engineering 26 (2006) 312–319 (Elsevier)*

[7] *"Performance analysis of ejector refrigeration system with environment friendly refrigerant driven by exhaust emission of automobile" Pelagia Research Library, Advances in Applied Science Research, 2013, 4(5):232-237.*

[8] *http://books.google.co.in/books?id=7M84lvsnlKAC&printsec=frontcover&dq=refrigeration+and+air+conditioning+by+rs+khurmi&hl=en&sa=X&ei=iWUIU8b7FcbDrAeFtYG4DA&ved=0CDYQuwUwAQ#v=onepage&q=refrigeration%20and%20air%20conditioning%20by%20rs%20khurmi&f=false*