Effect of adding flash tank on the evaporator's thermal load of the Combined Ejector-Absorption Cooling System

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Abstract: - A modified combined absorption-ejector cooling system using aqua-ammonia (NH3-H2O) refrigerant has been investigated. Removable flash tank was added between the condenser and the evaporator. The modified cycle brings the advantage of improving in the ejector entrainment ratio. In addition, an improving of cooling effect inside the evaporator, due to a reduction in the amount of flash gas delivered to the evaporator. A computer program has been developed to simulate the refined cycle. The results of the proposed cycle design have compared with the combined cycle (ejector-absorption) without flash tank. The results showed that the cooling effect, and the capacity of the evaporator was improved by adding flash tank.

Key-Words: - absorption system, combined absorption cooling system, ejectors, evaporators.

1 Introduction

Absorption cooling system has broadly paid attention, due to increase in ozone depletion effect and the environment hazards through using CFC and HCFC refrigerant. The increase in the power consumption of air-conditioning applications pushes researchers toward the absorption cooling system that used low energy input such as renewable energy (Solar energy and geothermal energy). In addition, absorption cooling systems are important due to its usage of natural refrigerant such as water, ammonia, lithium bromide and, etc.. However, the performance of the absorption cooling system is still a challenging task since the coefficient of performance (*COP*) is generally poor when it compared with the conventional vapor compression. Researchers have been performed different studies on absorption cooling systems. They studied the effects of operation parameters, variant refrigerant pairs and its effects on the *COP* of the absorption cooling cycles [1, 2, and 3]. Others studied combined ejector-absorption cooling system of different working fluid and cycle's arrangement [4, 5, 6, 7, 8, and 9]. From previous studies, the combined-cycle absorption cooling system with ejector provided higher *COP* [10]. In this study, a combined absorption-ejector cooling system has developed and studied theoretically by adding flash tank between the condenser and the evaporator. A simulation program was developed to analyze the effect of adding flash tank on the cooling effect of the system. As a result, significant improvement happens to the cooling effects specially when used low evaporating temperature with high condenser temperature.

2 System Description

The ordinary combined cycle (absorption-ejector system) added an ejector between the rectifier and the condenser. Enhancement of the refrigerant flow rate at the evaporator has been achieved [16]. And figure 1 shows the schematic diagram.

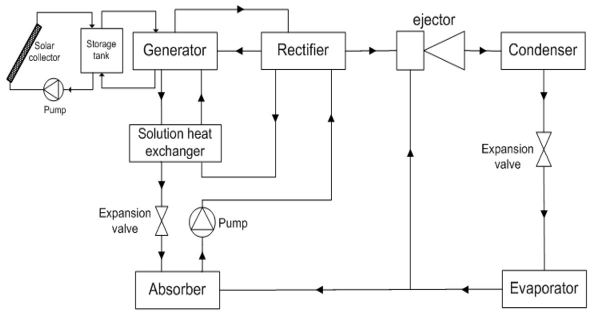

Figure 1. Combined absorption ejector refrigeration cycle (J. M. Abdulateef 2010)

ISBN: 978-1-61804-041-1

While, figure 2 shows the arrangement of the proposed combine cycle by adding an ejector, and flash tank to the absorption cooling cycle.

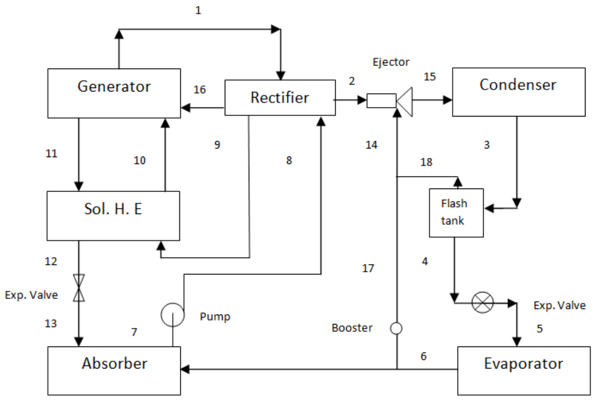

Fig.2 Schematic diagram of proposed combined absorption-ejector cooling system

The NH3-H2O solution is heated at the generator by heat source (solar collector) Q_g to produce the high-pressure ammonia vapor solutions at (1). Heat from a high-temperature source used in the generator to separate the binary solution of water and ammonia, and finally vaporized ammonia. Due to the vapor pressure for the absorbent (water) which is sufficiently high, some of the water vapor contains exit from the generator. The refrigerant processed to the rectifier to remove water vapor as much as possible through the fact that water is volatile. The water vapor returns from the rectifier through (16) to the generator. So highly concentrates ammonia vapor is preceded to the ejector at (2). In this study, we will assume 99% of ammonia vapor pass to the ejector. On the ejector, the vapor coming from the flash tank (secondary flow), with the primary ammonia vapor from the rectifier are mixed and flow to the condenser. Inside the condenser, the vapor condensates to liquid at (3) and the heat of condensation Q_{cond} is rejected to the environment. The condensate ammonia from (3) expanded to the intermediate pressure at the flash tank, to get saturation liquid properties a point (4), then point (18) which represents the saturation vapor properties.

$$P_{ft} = \sqrt{P_{cond} P_{evp}} \qquad (1)$$

The saturated liquid ammonia from the point (4) is expanded adiabatically through the expansion valve and get the point (5) which enters the evaporator and produces the necessary cooling effect $Q_{evp.}$ After the evaporation of liquid ammonia inside evaporator point (6) is calculated. A quantity of the vapor sucked by the ejector using the booster, and the remaining entered the absorber. At the absorber, the solution absorbs the refrigerant vapor comes from (6). The strong solution comes from the generator (11) through the solution heat exchanger (12) then expansion device (13). The heat produced by this reaction Q_{abs} is rejected to the environment. Finally, the weak solution point (7) pump by the solution pump (8) to the rectifier (9) then get sensible heat via solution heat exchanger (10) and enter the generator. And by this the cycle is completed.

3 Theoretical Background

The development of mathematical models for different components of the system is essential before the simulation program of the system is considered for evaluation the performance. Once the enthalpy, the concentration of weak and strong solution, the mass and the pressure values at all points are known. The mass and energy balance can be applied to yield the thermal load required in the individual component of the system. To evaluate the *COP* for the cycle, energy balance required through the generator and evaporators [11, 12, 13, and 14].

$$Q_{gen} = m_1 h_1 + m_{11} h_{11} - m_{10} h_{10} - m_{16} h_{16} \qquad (2)$$

$$Q_{evp} = m_5 (h_6 - h_5) \qquad (3)$$

$$W_p = (P_8 - P_7) v_7 m_7 \qquad (4)$$

The thermal *COP* for the proposed cycle can be defined as the ratio of cooling capacity to the necessary heat input to the cycle.

$$COP = \frac{Q_{evp}}{(Q_{gen} + W_p)} \qquad (5)$$

4 Results and discussions

A computer simulation program has been investigated to analyze the proposed combined absorption-ejector cycle. The operations condition of the cycle were selected as T_{gen}= 60-120 °C, T_{cond}= T_{rect}= 20-50 °C, T_{evp}= -14-14 °C, and mass flow rate of the refrigerant = 0.0166 kg/s. The effectiveness of the heat exchanger assumed to be 0.5. The ejector mainly consists of a nozzle, mixing chamber and a diffuser. The specific parameter design of the ejector is a nozzle-throat diameter d_t =2.5 mm and diffuser inlet diameter d_k =8.1 mm. The results explain the benefit of adding flash tank on the entrainment ratio of the ejector inside the combined cycle. Moreover, its effect on the thermal loads of the evaporator, and compare with the cycle without flash tank.

From figure 3, the generator temperature does not affect the entrainment ratio of ejector and thermal load for the evaporator, since it's affected the concentration of liquid ammonia leaves the generator toward the absorber. However, this will affect the absorber and circulation ratio between the generator and absorber.

The effect of variation in condenser temperature is shown in figure 4. As the condenser temperature increases, the high pressure of the system increase and the amount of saturation liquid enthalpies leaving the condenser increase. This lead to decrease in thermal load of the evaporator because the enthalpy enters to the evaporator will come directly from the condenser in case of the combined cycle (ejector only). Moreover, the entrainment ratio of the ejector will decrease since the P_{cond} increase with constant pressure at the evaporator (secondary flow pressure), so the efficiency of ejector will decrease. This explains why the thermal load in the evaporator decreases sharply in case of the combined cycle with ejector only. While for modified combined cycle (ejector+ flash tank), the effect of the increase in the entrainment ratio moderates the decrease in thermal load due to increase in the high pressure. Since, the flash tank pressure increases proportionally with the increase of condenser pressure. Therefore, the secondary flow pressure increases. As the pressure increases in the secondary flow the entrainment ratio will increase [15]. Another reason is that the effect of flashing gas reduces because the expansion process is from the intermediate pressure of the flash tank.

The variation in absorber temperature does not affect the evaporator thermal load, since the absorber temperature affects the concentration of weak solution exit from the absorber toward the generator, figure 5 shows that the thermal load inside evaporator keep constant 30.08 and 26.35 kW for both combined cycles.

In figure 6 the variation of evaporator temperatures explained. The results show the effect of the increasing in evaporator temperature on the entrainment ratio of the ejector at specific design parameter. And it's effect on the evaporator thermal load, due to its effect on the flow rate of the refrigerant in the condenser, flash tank and the evaporator. A small increased in evaporator outlet enthalpy happen, while the main effect of the increases due to the ejector entrainment ratio. In this study, two cases are explained and showed different behavior. Firstly, in case of ejector only, as the evaporating temperature increases, the entrainment ratio will increase and this lead to increase in thermal load of the evaporator. While in second case, which is (the ejector with the flash tank), the behavior completely changed as the evaporator temperature increases the low side pressure and this produce an increase in the flash tank pressure. At fixed geometry ejector design, there is an optimum performance design of operating parameter. So any increased over the optimum design will cause the ejector to lose the performance.

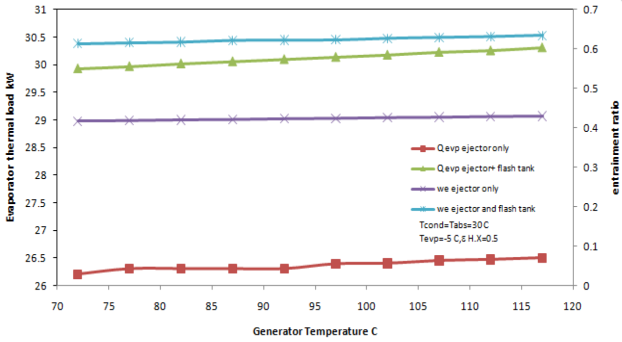

Figure 3. Variation of evaporator thermal load and entrainment ratio vs. generator temperature

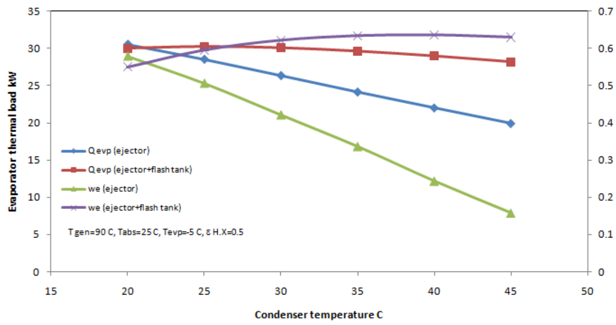

Figure 4. Variation of evaporator thermal load and entrainment ratio vs. condenser temperature

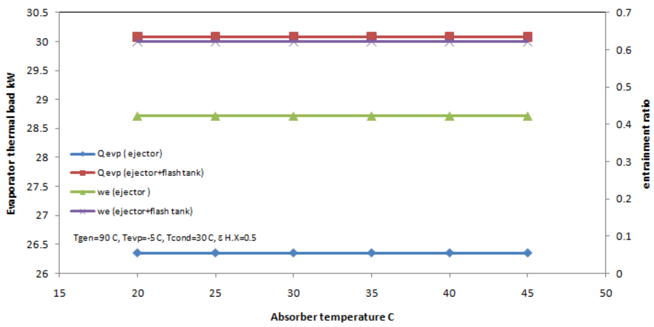

Figure 5. Variation of evaporator thermal load and entrainment ratio vs. absorber temperature

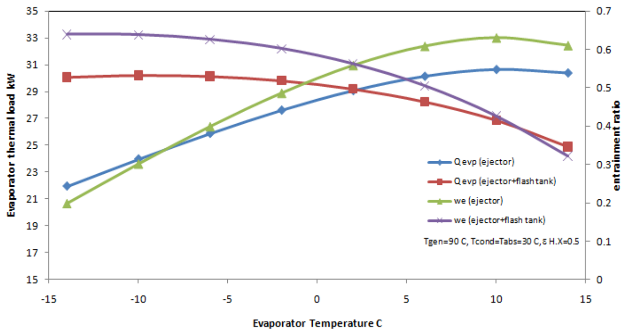

Figure 6. Variation of evaporator thermal load and entrainment ratio vs. evaporator temperature

5 Conclusion

A theoretical study of adding flash tank to the combined absorption ejector cooling system was investigated. The results show the advantage of adding flash tank on the cooling effect of the evaporator. Furthermore, investigation of the ability of the modified cycle to work within higher condenser temperature and lower evaporator temperatures have been done. Although, in some operating design, the cycle performance cannot achieve the optimum performance, due to usage a fix geometry ejector deigns. To overcome this problem, a variable ejector design parameter can be suggested and investigated for the future study.

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ISBN: 978-1-61804-041-1