Thermodynamic Analysis of Steam Ejector Refrigeration Cycle

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Outline

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- INTRODUCTION
- EJECTOR REFRIGERATION CYCLE
- ANALYSIS OF THEORETICAL MODEL
- RESULTS AND DISCUSSION
- CONCLUSIONS
- ACKNOWNLEDGEMENT

1 INTRODUCTION

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Why we should to study the Steam jet refrigeration system ?

As we know,during the past decade, the use of fossil fuels promoted the development of human civilization, but also caused the deterioration of the global environment. And, the utilization of low-grade thermal energy can effectively improve energy efficiency and reduce the use of fossil fuels.

Steam jet refrigeration systemcan operate with low-grade thermal energy such as the industrial waste heat, solar energy, steam exhaust or other low-grade energy heat, which makes it environment-friendly.

1 INTRODUCTION

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What reserches have been down?

Author	Time	Results
Maurice Leblanc	1910s	Poor design and processing level limited its COP.
Butterworth and Sheer	2007	The high-pressure water from vertical pipelines in deep mine shafts improved the system's performance.
Oliveira et al.	2009	Studied the effect of the area ratio γ_A between primary nozzle and constant area section on the system performance.
Ma et al.	2010	The increase in boiler temperature, the coefficient of performance (COP) did not always increased,
Aphornratana *et al.*	2013	The expansion angle in the primary nozzle outlet of the primary fluid and the position in the mixing chamber of the mixed fluid played an important role in the ejector performance.

1 INTRODUCTION

This paper's work:

In this paper, an iterative program on a constant-area ejector refrigeration system, in which water was used as the refrigerant, was employed to optimize the design of the ejector

2 EJECTOR REFRIGERATION CYCLE

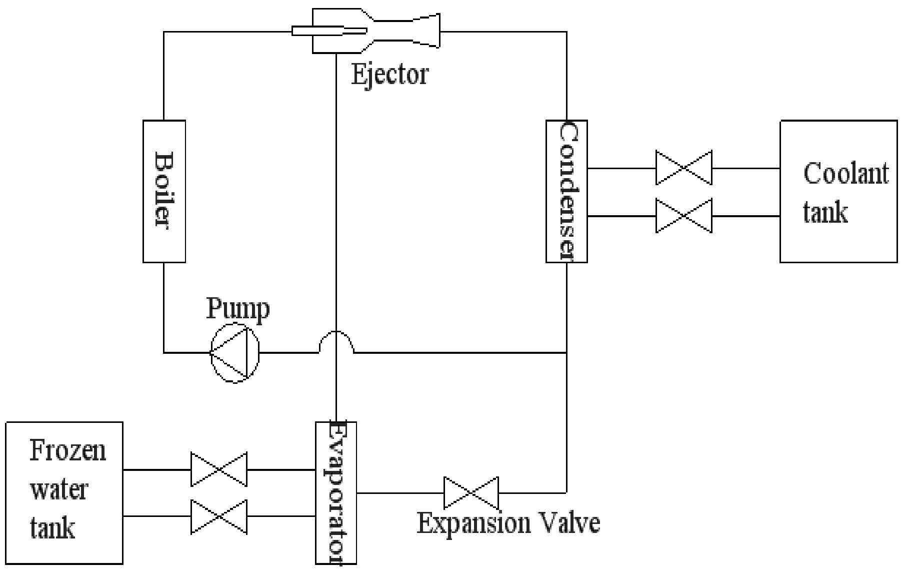

Figure 1: A schematic view of the steam ejector refrigeration system

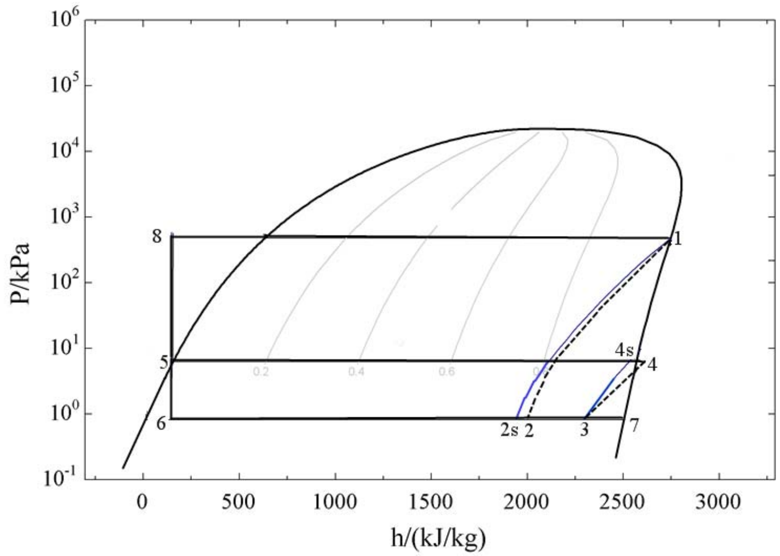

Figure 2: The P-h diagram of the steam ejector refrigeration system

μ is defined as the entrainment ratio of the ejector:

$$\mu = m_7 / m_1$$

3 ANALYSIS OF THEORETICAL MODEL

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To simplify the steam jet refrigeration cycle model, assumptions are also made as follows:

- The pressure losses are neglected;
- There is no heat exchange between other parts of the system and the environment;
- The nozzle efficiency and diffuser efficiency of the ejector are given values (Alexis and Rogdalis, 2003);
- The throttling process is seen as isenthalpic process;
- The subcooling degree and evaporation and condensation temperature are known;
- The pressure of two fluids into the suction chamber is the same and the given value, and the fluid in the ejector is one-dimensional homogeneous flow.

energy conservation

$$h_1 + u_1^2/2 = h_{2s} + u_{2s}^2/2 \qquad (2)$$

$$m_1 = u_1 A_1 / v_1 \qquad (3)$$

$$\eta_n = \frac{h_1 - h_2}{h_1 - h_{2s}} \qquad (4)$$

The velocity of the secondary fluid from the evaporator can be calculated by the formula

$$m_7 = u_7 A_7 / v_7 \qquad (5)$$

3.1 Energy Analysis

The mixing process of two fluids in the mixing chamber satisfies momentum conservation and energy conservation,

$$(m_1 + m_7)u_3 = P_0(A_2 + A_7) + m_1 u_2 + m_7 u_7 - P_3 A_3 \tag{6}$$

$$(m_1 + m_7)(h_3 + u_3^2/2) = m_1(h_2 + u_2^2/2) + m_7(h_7 + u_7^2/2) \tag{7}$$

The iterative program takes mass conservation of mixing process as the iterative criterion

$$m_3 = u_3 A_3 / v_3 \tag{8}$$

The fluid state in ejector outlet is obtained through the overall energy balance

$$(m_1 + m_7)\cdot(h_4 + u_4^2/2) = m_1\cdot(h_1 + u_1^2/2) + m_7\cdot(h_7 + u_7^2/2) \tag{9}$$

3.1 Energy Analysis

The diffuser efficiency in diffusion process is

$$\eta_d = \frac{h_{4s} - h_3}{h_4 - h_3} \tag{10}$$

Cooling capacity of steam jet refrigeration cycle is given as

$$Q_0 = m_7(h_7 - h_6) \tag{11}$$

Energy consumption of steam jet refrigeration cycle is presented by

$$W = m_1(h_1 - h_5) \tag{12}$$

The coefficient of performance for system is

$$COP = Q_0 / W \tag{13}$$

3.2 Exergy Loss Analysis of Individual Components

The exergy loss of the condenser (Jiang *et al.*, 2007):

$$I_k = (m_1 + m_7)\cdot[h_4 + u_4^2/2 - h_5 - (T_m + 273)(s_4 - s_5)] - (m_1 + m_7)\cdot(1 - \frac{T_m + 273}{T_k})\cdot(h_4 - h_5) \quad (14)$$

The exergy loss of throttle valve:

$$I_f = m_7(T_m + 273)(s_6 - s_5) \quad (15)$$

The exergy loss in the evaporator:

$$I_0 = m_7\cdot[h_6 - h_7 - u_7^2/2 - (T_m + 273)(s_6 - s_7)] - m_7\cdot(1 - \frac{T_0 + 273}{T_m + 273})\cdot(h_7 - h_6) \quad (16)$$

The exergy loss in the boiler:

$$I_e = m_1\cdot[h_8 - h_1 - u_1^2/2 - (T_m + 273)(s_8 - s_1)] + m_1\cdot(1 - \frac{T_m + 273}{T_s + 273})\cdot(h_1 - h_8) \quad (17)$$

Exergy loss of primary fluid passing through the primary nozzle:

$$I_1 = m_1[h_1 + u_1^2/2 - h_2 - u_2^2/2 - (T_m + 273)(s_1 - s_2)] \quad (18)$$

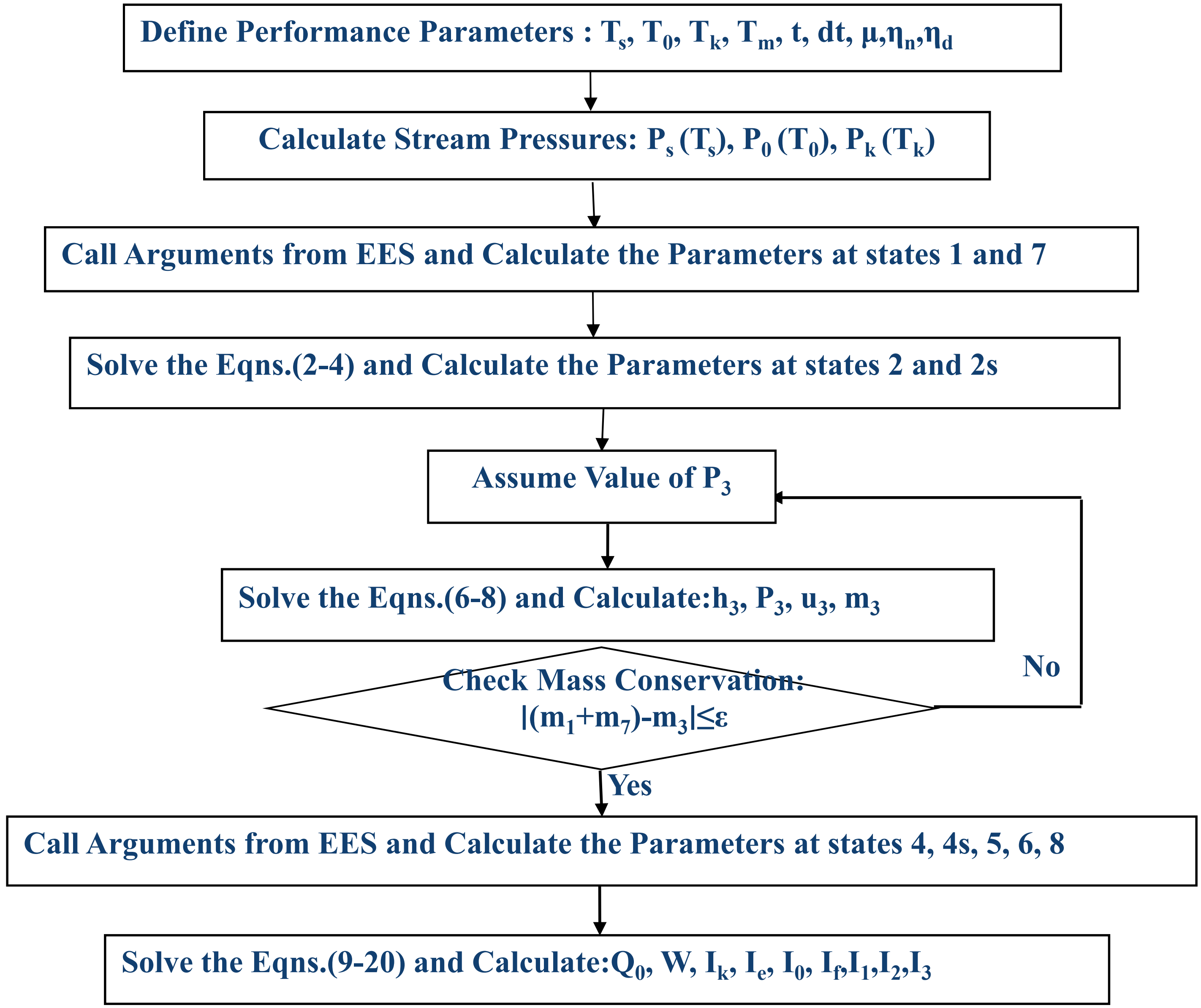
The exergy loss of mixing process in mixing chamber

$$I_2 = m_1[h_2 + u_2^2/2 - h_3 - u_3^2/2 - (T_m + 273)(s_2 - s_3)] + m_7[h_7 + u_7^2/2 - h_3 - u_3^2/2 - (T_m + 273)(s_7 - s_3)] \quad (19)$$

The exergy loss in pressure expanding process in the subsonic diffuser:

$$I_3 = (m_1 + m_7)[h_3 + u_3^2/2 - h_4 - u_4^2/2 - (T_m + 273)(s_3 - s_4)] \quad (20)$$

3.2 Exergy Loss Analysis of Individual Components



4 RESULTS AND DISCUSSION

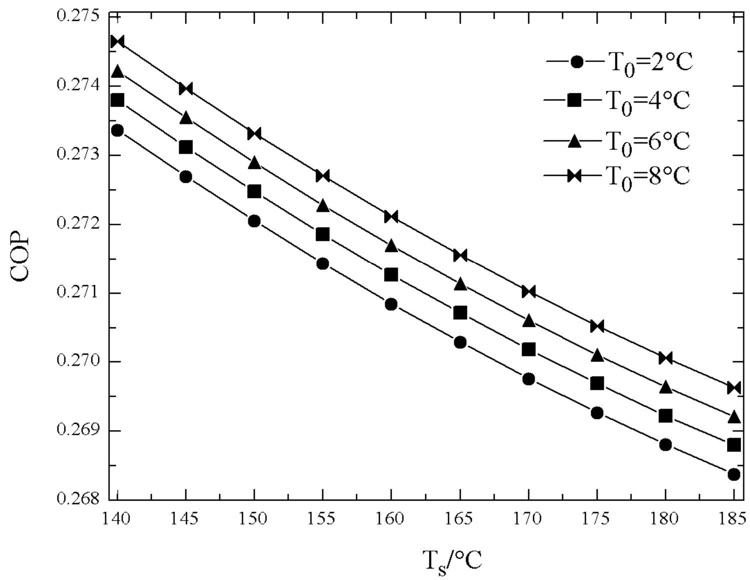


Figure 4: COP of ejector refrigeration cycle versus boiler temperatures(T_s) and evaporating temperatures(T_0)

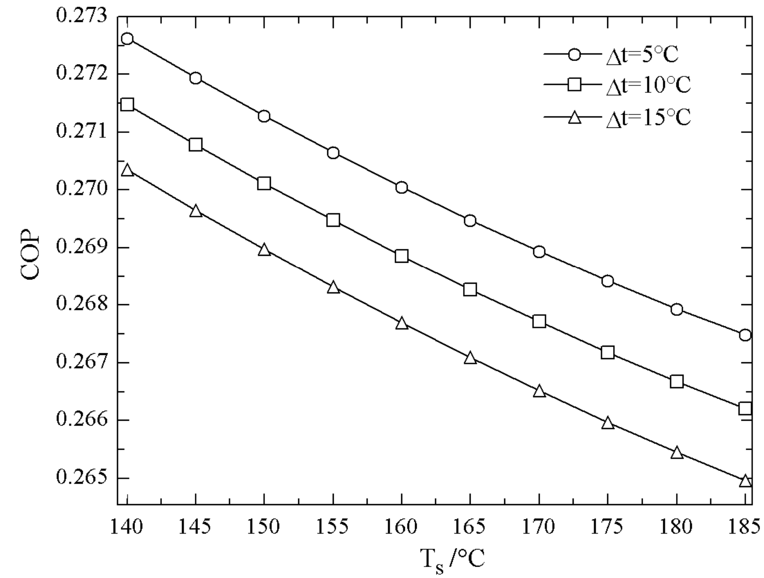


Figure 5: COP of ejector refrigeration cycle versus boiler temperatures(T_s) and superheat degrees(Δt)

Fig.4 shows that increasing the boiler temperature and decreasing the evaporating temperature decreases the COP .

In Fig.5, COP is decreased with the superheat degree increase. The superheat degree increases the steam's quality in the primary nozzle outlet and decreases the entrainment ratio and COP.

μ

4 RESULTS AND DISCUSSION

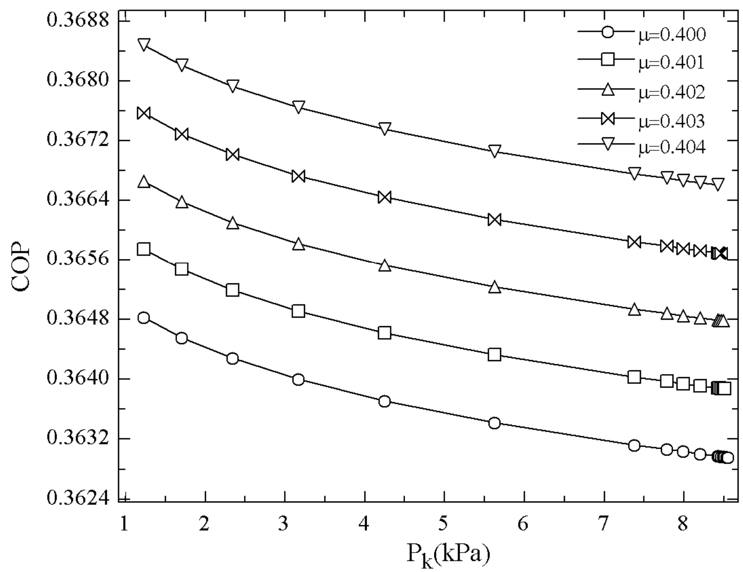


Figure 6: COP of ejector refrigeration cycle versus boiler pressure(P_k) and entrainment ratios(μ)

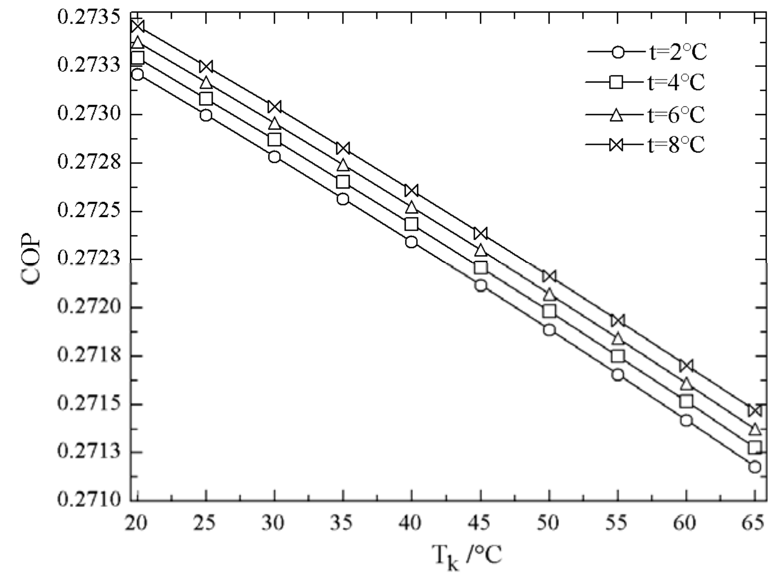


Figure 7: COP of ejector refrigeration cycle versus condensing temperatures(T_k) and supercooling degrees(t)

In Fig.6. With the same entrainment ratio, the increase of condensing pressure causes a choke in ejector and therefore decreases its performance.

In Fig.7,It can be seen from the figure that the lower the condensing temperature, the higher the COP, and the rise of the supercooling degree increases the COP.

4 RESULTS AND DISCUSSION

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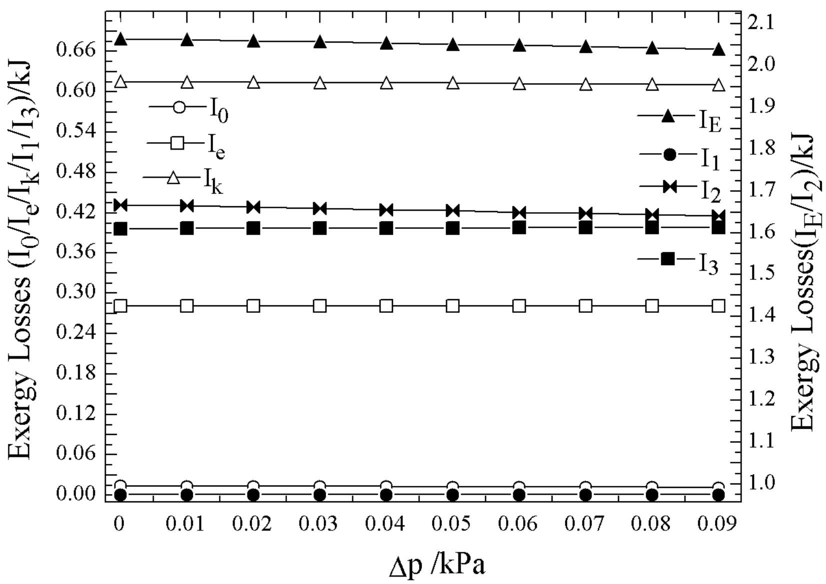

Figure 8: The exergy losses of different components versus pressure difference Δp

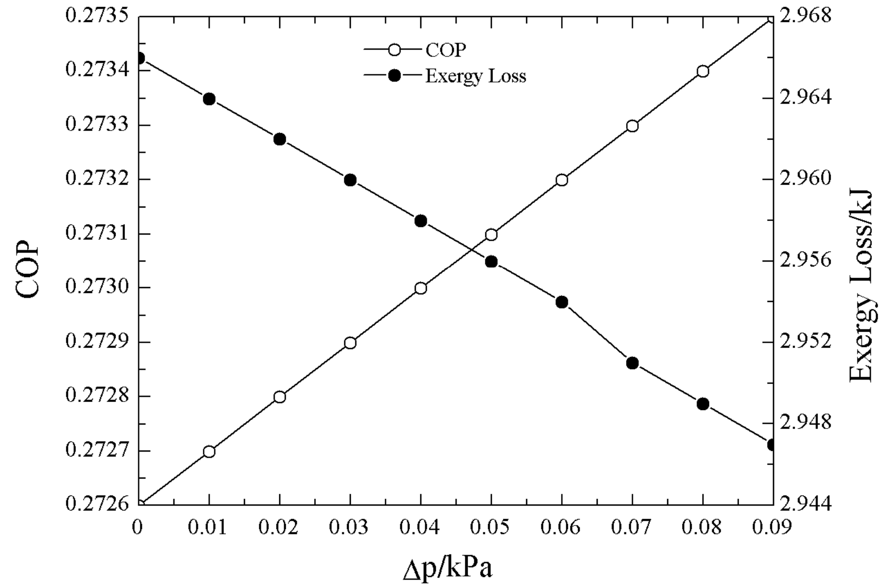

Figure 9: COP of ejector refrigeration cycle and exergy loss versus pressure difference Δp

The pressure difference between the evaporator and the primary nozzle outlet has a great impact on the COP and the exergy loss, as for the higher pressure difference, the higher COP and the lower exergy loss for the ejector refrigeration system.

5 CONCLUSIONS

This paper presents the theoretical calculation and analysis on steam jet refrigeration cycle and draws the following conclusions:

- Both *increasing* the temperature of boiler and the superheat of the primary fluid can cause choking within the ejector, entrainment ratio *decreasing*, the system's COP *decreasing*;

- The *increase* of the condensing pressure will *reduce* the system's COP while the *increas*e of subcooling will *increase* the COP;

- Most of the energy consumption of this experiment cycle is the bolier added heat. When the system is employed in the thermal power plant or other fields in which the low-grade water steam is generated, the system' COP will be improved rapidly.

5 CONCLUSIONS

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This paper presents the theoretical calculation and analysis on steam jet refrigeration cycle and draws the following conclusions:

- The maximum exergy loss of system mainly exists in the mixing chamber. The pressure difference between evaporator and the primary nozzle outlet has a great effect on exergy loss in the mixing process.

- The key point of optimizing the system is optimizing ejector, improving the secondary fluid's velocity into the suction chamber, which can reduce the relative velocity of two fluids and the exergy loss of ejector.

6 ACKNOWNLEDGEMENT

❖The EES software presented in this paper is supported by the professor Yitai Ma worked in Tianjin University.

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Thank You for your attention!