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Analysis of an Evaporator-condenser-separated Mechanical Vapor Compression System

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An evaporator-condenser-separated mechanical vapor compression (MVC) system was presented. The better effect of descaling and antiscaling was obtained by the new system. This study focused on the method of thermodynamic analysis, and the energy and exergy flow diagrams were established by using the first and second law of thermodynamics analysis. The results show that the energy utilization rate is very high and the specific power consumption is low. Exergy analysis indicates that the exergy efficiency is low, and the largest exergy loss occurs within the evaporator –condenser and the compressor.

Keywords: Mechanical vapor compression; Sewage treatment; Thermodynamic; Exergy

Introduction

Sewage treatment is an important way to protect the ecological balance and mitigate the shortage of global water resources. Distillation-based water treatment has been used in many industries, such as pulp wastewater treatment, printing and dyeing wastewater treatment [1]. Distillation mainly includes vapor compression (VC), multiple effect evaporation (MEE), and multi-stage flash (MSF). Vapor compression basically includes thermal vapor compression (TVC) and mechanical vapor compression (MVC) [2]. In the process of MVC system, the low-temperature vapor is compressed by the compressor to increase the pressure, temperature and enthalpy. Then the compressed vapor is used as heat vapor, in order to achieve the purpose of separation, evaporation and energy saving [3].

MVC research includes the establishment of mathematical models, design methods, experimental research, and performance evaluation. Ettouney [4, 5] provided a comprehensive design model of the single-effect MVC system. They also analyzed the system and provided the design and operation characteristic parameters. Bahar et al [6] evaluated the performance of a set of MVC system using the experimental approach. Kronenberg and Lokiec [7] improved MVC system in order to achieve the dual purpose of low power consumption and high water productivity, and the rate of water production had increased to 3000m^3/d and the energy consumption had decreased to 8.1kWh/m^3. Veza [8] reported the MVC system containing two units in which the capacity of both units had reached to 500m^3/d and the average equipment efficiency is from 87.3 % to 90.2 %.

Nowadays, the MVC system is mainly used in the process of seawater desalination. Compared with TVC [4, 9], MVC does not require a high pressure steam generator, and the process is also more simple. In order to retain as much heat as possible, MVC system recovers latent heat by the evaporator/condenser and the sensible heat of concentrated water by the preheater. Compared with reverse osmosis technology [10], MVC requires low pre-treatment, so it avoids the secondary pollution due to various additives. In short, the MVC system has the following advantages [4]: modular system construction, a

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Nomenclature

A	Heat transfer area	**Greek letters**	
Cp	Specific heat at constant pressure($kJ\cdot kg^{-1}\cdot ℃^{-1}$)	α	Preheater's heat transfer efficiency factor
Ex	Exergy(kW)	β	Evaporator's heat transfer efficiency factor
h	Enthalpy($kJ\cdot kg^{-1}$); h_0 standard state	γ	Condenser's heat transfer efficiency factor
I	Exergy destruction($J\cdot mol^{-1}$ or $J\cdot kg^{-1}$)	λ	Latent heat($J\cdot kg^{-1}$)
K	Overall heat transfer coefficient($W\cdot m^{-2}\cdot K^{-1}$)	π	Vapor compressor's pressure ratio
k	Isentropic index	**Subscripts**	
M	Mass flow rate($kg\cdot s^{-1}$)	CO	Condenser
Q	Quantity of heat(J)	CS	Concentrated- Sewage Preheater
R	Gas constant	c	Concentrated
S	Entropy($J\cdot kg^{-1}\cdot k^{-1}$);$s_0$ standard state	EV	Evaporator
T	Temperature(℃)	PS	Purified- Sewage Preheater
ΔT	Temperature difference (℃)	p	Purified
Δt_m	Logarithmic mean temperature difference (℃)	s	Sewage
W	Compress work($kJ\cdot s^{-1}$)	v	Vapor

simple and compact structure, simple pre-treatment and operation. Large MVC system has the low production cost with the average energy consumption of 10.4~11.2kWh/m^3 [8]. However, when dealing with the wastewater with complex composition, the existing mechanical vapor compression system has encountered insurmountable difficulties in descaling and antiscaling [7, 10 and 11] due to the structural constraints. So the service life, reliability and the usable range of the traditional MVC system are limited. Based on existing technology, this paper presents a new mechanical vapor compression system that separates the evaporator from the condenser. The deficiencies of the traditional MVC system can be overcome by using this technology. So it greatly expands the application of MVC beyond the desalination technology. The system greatly increases the adaptability of wastewater, and keeps the system running efficiently.

Process description

A schematic diagram for the Evaporator- Condenser-Separated MVC (ECS-MVC) system is shown in Fig. 1. This MVC system separates the evaporator from the condenser and it is the single effect process. The ECS-MVC system includes the evaporator, condenser, vapor compressor, purified-sewage preheater, and concentrated-sewage preheater. The non-condensable gases ejector, sewage filtering apparatus, controllers and demister are not shown in this diagram. The ECS-MVC system is operated as: (1) Preheat the sewage(M_s) by purified- sewage preheater and concentrated-sewage preheater. (2) Send the preheated sewage with the temperature of T_2 into the evaporator to evaporate. (3) The former vapor flows through the demister into the vapor compressor. The compression process increases the saturation temperature of the vapor to a higher value and adds an additional amount of superheat. In this process, the compressed energy consumption becomes the internal energy of saturated vapor. (4) Superheated vapor that has passed through the condenser heat exchanger tube releases the latent heat which can be the heat source of the evaporator. At the same time the vapor is condensed into purified water (M_p). (5) The purified water (M_p) from the condenser passes into the purified-sewage preheater to heat the sewage. (6) Meanwhile, the concentrated water (M_c) also passes into the concentrated-sewage preheater to heat sewage.

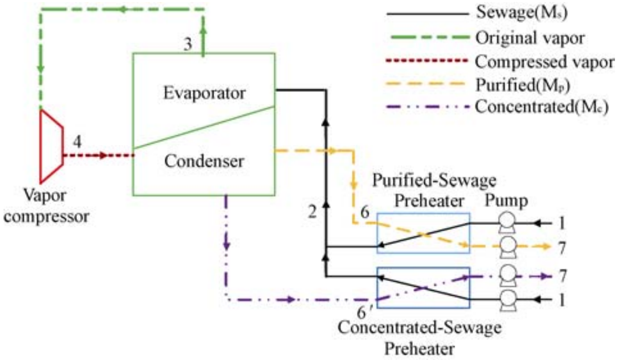

Fig. 1 Schematic diagram for the ECS-MVC system

The ECS-MVC system was carried out in a rotating disk evaporator, so there is a relative movement between the evaporator and the condenser. The schematic diagram for the evaporator and condenser structure is shown in Fig. 2. Condenser tubes and evaporator disks are staggered with small interval. The center of evaporator disk is slightly higher than the liquid level. The condenser tubes are all under the liquid level [12].

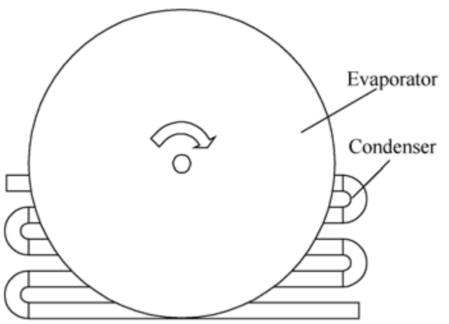

Fig. 2 Schematic diagram for the evaporator and condenser

The evaporator/condenser heat exchange tubes of the traditional MVC system play a dual role of evaporation and condensation [5]. In the heat exchange tubes, the vapor changes from gas into liquid. Outside the tubes, the sewage evaporates into gas through the heat absorption. Although this structure is compact, scale is easily formed after long-term use. Especially when the spray structure is adopted, the scaling problem is more serious. Furthermore, scale reduces the efficiency of the heat transfer as well as system efficiency, to make it unable to run for a long time. The evaporator and the condenser are separated in our new MVC system. In the condenser, the vapor condensation latent heat is delivered to the sewage by forced convection, and then the heat is transferred to the evaporator by convection. This heat makes the water film which adhered on the evaporator evaporated. In addition, the wiper blades were placed on the outer surfaces of the rotating evaporator disk. To improve the heat transfer during evaporating, wiper blades have been employed to reduce the thickness of evaporating film [13]. Meanwhile, the wiper brush or wipe the condenser tubes so that this separated structure inhibits the formation of the scale to a certain extent. When the system is in operation, the heat transfer is enhanced and the scaling rate is greatly reduced.

Thermodynamic model analysis

The temperature-entropy chart for the ideal cycle of the ECS-MVC system is shown in Fig. 3. Here is what ideal means: (a) The compression process is isentropic and reversible; (b) No heat loss; (c) No flow loss; (d)The working fluid is pure salt-free water or water vapor, without considering the increase of the working fluid boiling point as the concentration increases.

In Fig.3, the process 1-2 and the process 6-6'-7 recover the heat from the purified water and concentrated water which carried out in the preheater. Certainly, this process increases the temperature of the sewage. The process 2-2'-3 is carried out in the evaporator, and the saturated water absorbs heat to evaporate. The process 3-4 increases the saturation temperature of the vapor to a higher value and adds an additional amount of superheat in the compressor. The process 4-5-6 is a process that the sensible heat releases superheat and the steam changes into saturated steam, and then releases the latent heat of condensation. Process 7-1 can be considered as a process occurred in the outer environment. The following thermodynamic model analysis is based on the temperature-entropy chart.

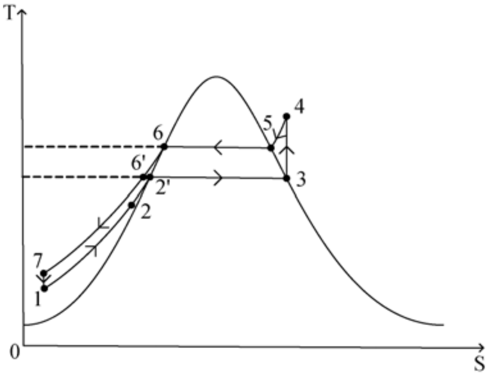

Fig. 3 Temperature-entropy chart for the ideal cycle

Same as the traditional MVC system, the mass of the ECS-MVC system is balanced.

$$M_s = M_p + M_c \tag{1}$$

In purified-sewage preheater and concentrated- sewage preheater, the heat absorbed by the sewage is equal to the heat released by the purified water and the concentrated water.

$$M_s Cp_s (T_2 - T_1) = M_p Cp_p (T_6 - T_7) + M_c Cp_c (T_{6'} - T_7) \tag{2}$$

The heat transfer area can be determined by the amount of the heat from the preheater, including the purified-sewage preheater and the concentrated-sewage preheater.

$$A_{PR} = \frac{M_p Cp_p (T_6 - T_7)}{\alpha_{PS} K_{PS} \Delta t_{mPS}} + \frac{M_c Cp_c (T_{6'} - T_7)}{\alpha_{CS} K_{CS} \Delta t_{mCS}} \tag{3}$$

α_{PS} is the heat transfer efficiency factor of the purified-sewage preheater. α_{CS} is the heat transfer efficiency factor of the concentrated-sewage preheater. α_{PS} and α_{CS} were 0.9 [14]. K_{PS} is the overall heat transfer coefficient of the purified-sewage preheater. K_{CS} is the overall heat transfer coefficient of the concentrated-sewage preheater. When the fouling coefficient was 0.0005, K_{PS} and K_{CS} were 2838W/(m^2·k)[15]. Δt_m is the Logarithmic mean temperature difference (LMTD).

$$\Delta t_{mPS} = \frac{(T_6 - T_2) - (T_7 - T_1)}{ln \frac{T_6 - T_2}{T_7 - T_1}} \tag{4}$$

$$\Delta t_{mCS} = \frac{(T_{6'} - T_2) - (T_7 - T_1)}{ln \frac{T_{6'} - T_2}{T_7 - T_1}} \tag{5}$$

In the evaporator, the preheated sewage absorbs the heat and the temperature continues to rise. When it reaches a certain temperature, the sewage begins to evaporate as saturated vapor.

$$Q_{2-2'} = M_s Cp_s \left(T_{2'} - T_2\right) \tag{6}$$

$$Q_{2'-3} = M_p \lambda_{EV} \tag{7}$$

The total heat absorbed in the evaporator is equivalent to the heat exchanged in the evaporator.

$$Q_{2-3} = Q_{2-2'} + Q_{2'\text{-}3} = \beta K_{EV} A_{EV} \Delta T \tag{8}$$

β is the heat transfer efficiency factor of the evaporator and the value of β was 0.8. K_{EV} is the overall heat transfer coefficient of the evaporator, the value of K_{EV} was 2600W/(m^2·k)[13]. ΔT means the temperature difference between the condensing and evaporating temperatures, thus the temperature difference of the evaporator heat transfer, numerically $\Delta T = T_6 - T_{2'}$.

The evaporator heat transfer area can be calculated based on the formulas from (6) to (8).

$$A_{EV} = \frac{M_s Cp_s \left(T_{2'} - T_2\right) + M_p \lambda_{EV}}{\beta K_{EV} \Delta T} \tag{9}$$

The heat released from the condenser is equal to the sum of the sensible heat of superheat compressed vapor and the latent heat of condensation.

$$Q_{4-5} = M_p Cp_v \left(T_4 - T_5\right) \tag{10}$$

$$Q_{5-6} = M_p \lambda_{CO} \tag{11}$$

Temperature T_4 is determined by the compression ability of the compressor, so T_4 can be expressed by T_3 and the vapor compressor's pressure ratio (π).

$$T_4 = \pi^{(k-1)/k} T_3 = \pi^{(k-1)/k} T_{2'} \tag{12}$$

where π=1.2, the isentropic index k=1.33[16].The expression $Q_{4\text{-}5}$ can be calculated based on Eq. (12).

$$Q_{4-5} = M_p Cp_v \left[\left(\pi^{(k-1)/k} - 1\right) T_{2'} - \Delta T \right] \tag{13}$$

$$Q_{4\text{-}6} = Q_{4\text{-}5} + Q_{5\text{-}6} = \gamma K_{CO} A_{CO} \Delta T \tag{14}$$

γ is the heat transfer efficiency factor of the condenser, the value of γ is 0.9. K_{CO} is the overall heat transfer coefficient of the condenser, the value of K_{CO} was 3000W/(m^2·k)[15].

Using the formula (10) ~ (14), the evaporator heat transfer area may be calculated with the relation

$$A_{CO} = \frac{M_p Cp_v \left[\left(\pi^{(k-1)/k} - 1\right) T_{2'} - \Delta T \right] + M_p \lambda_{CO}}{\gamma K_{CO} \Delta T} \tag{15}$$

The system operating parameters and the energy flow diagram can be established by the first law of thermodynamics. The design conditions and the operating parameters are calculated as shown in Table 1.

The ECS-MVC system requires the energy supplied by the electric heater at startup. When the system is running, the energy into the system includes the enthalpy of the sewage, the electrical compressor power, the electrical pumping power, and the enthalpy added by the auxiliary heating device. However, the energy out of the system includes the enthalpy of the purified water, the enthalpy of the concentrated water and the enthalpy of the non-condensable gases. It's worth mentioning that the analysis is based on the ideal cycle, so the heat loss could be ignored.

Table 1 Operating parameters of ECS-MVC ideal process

Item	Basis for calculating	Value
M_s(kg·s^{-1})	Capacity(design value),1000 t/d	11.6
M_p(kg·s^{-1})	Purification rate,0.8 (design value)	9.3
M_c(kg·s^{-1})	Eq.(1)	2.3
T_1(℃)	Environment temperature (design value)	20
P_1(MPa)	Environmental pressure (design value)	0.1013
T_2(℃)	T_2=T_2'*Preheater efficiency(design value)	98
$T_{2'}$(℃)	Distillation temperature (design value)	100
$P_{2'}$(MPa)	Saturated pressure corresponding to the saturated temperature	0.1013
T_3(℃)	$T_3 = T_{2'}$	100
P_3(MPa)	Saturated pressure corresponding to the saturated temperature	0.1013
T_6(℃)	$\Delta T = T_6 - T_{2'}$ ΔT =3.7℃ (design value)	103.7
P_6(MPa)	Saturated pressure corresponding to the saturated temperature	0.1156
T_5(℃)	$T_5 = T_6$	103.7
P_5(MPa)	Process 4-5-6 along the isobaric line	0.1156
P_4(MPa)	Process 4-5-6 along the isobaric line	0.1156
T_4(℃)	Eq.(12); $\pi = P_4/P_3$; k=1.33	112.4
$T_{6'}$(℃)	$T_{6'} = T_{2'}$	100
T_7(℃)	Eq.(2)	24.9
P_7(MPa)	Environmental pressure (design value)	0.1013

Since enthalpy is a single-valued function of the temperature, the enthalpy of the sewage, purified water, concentrated water and non-condensable gases can be obtained according to the temperature. The adiabatic compression work done by the compressor can be calculated using the following formula.

$$W = \frac{R}{k-1} T_3 \left(\pi^{(k-1)/k} - 1\right) \tag{16}$$

R is the gas constant, k is isentropic index and the value is 1.33. So W=4.82kWh/m^3, by the unit conversion, the compression work is 161.29kJ/s.

The atmospheric distillation system involves 3 pumps. In accordance with the design requirements, select the feed pump 5.5kW, the purified water pump 2kw and the concentrated water pump 1kW. So the total pump power is 8.50kJ/s.

The mass of the non-condensable gases and the leaks can be estimated by the MVC experiment [17], which is 0.0021m^3/s. Non-condensable gases and leaks are approximated as air, so the enthalpy of non-condensable gas and leaks is 0.74 kJ / s.

Therefore, the energy flow of the atmospheric distillation ECS-MVC system is illustrated in Fig. 4.

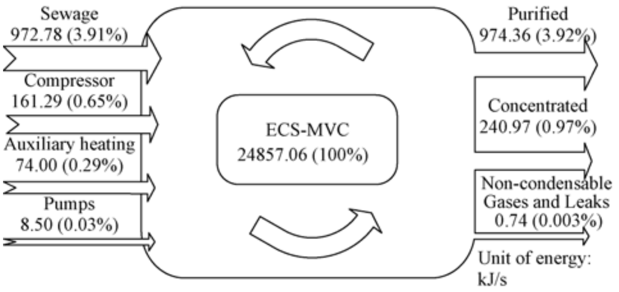

Fig. 4 Energy flow diagram

It is obvious that a large amount of energy is in the inner loop when the system is running. Only a small part of the energy flows into or out of the system. To maintain the system cycle, the electric energy which is 0.97% of the total energy should be provided. Thus the energy consumption of the system is low, and the energy utilization rate is very high. Besides, a lot of energy is in the inner loop, and the evaporator and the condenser heat load is relative large. So the heat transfer area should be larger than the calculated value.

The specific power consumption of ECS-MVC system can also be accessed by the first law analysis. Fig.4 shows that the total energy consumption equals to the energy consumption at startup and the energy consumption during the calculation period while the system running. Here 30 consecutive days is worked for the calculation period. By calculating, the total energy consumption is 200385.86kWh. According to the design value, the product water is 24000m^3 during the calculation period. Therefore, the specific power consumption of ECS-MVC system is 8.35kWh/m^3.

The energy consumption of the ECS-MVC system is less than 10.4~11.2 kWh·m^{-3} which is the energy consumption of the MVC system reported by J.M. Veza [4]. It is because of the calculation is based on ideal cycle.

Second law of thermodynamics analysis

Second law analysis can show the irreversibility in different parts of the system. The Second Law of Thermodynamics is used to describe and quantify the exergy losses involved in the different processes taking place in ECS-MVC system, which has considerable significance for both the design and the operation of the system.

Exergy is an extensive thermodynamic function defined as the maximum amount of work obtainable when a stream of substance is brought from its initial state to the environmental state [18]. The exergy for ECS-MVC under the ideal condition is expressed by Eq. (17).

$$E_X = (h - h_0) - T_0(S - S_0) \tag{17}$$

Ex is the exergy flow rate; h is the enthalpy; s is the entropy. Exergy is a state parameter. In order to simplify the calculation, select the initial state of the sewage as the standard state. So the standard state is T=T$_1$=20℃, h$_0$=83.86 kJ·kg^{-1} and s$_0$=0.2963 k J·kg^{-1}·k^{-1}.

The second law analysis is based on the exergy balance equation which explained that the exergy into the system and the exergy leaving the system equal to the exergy loss of the system. The exergy loss is the sum of the working medium in the irreversible process within the system, and the external exergy loss caused by leakage, heat transfer and other factors [18].

$$I = \sum_{in} E_X - \sum_{out} E_X \tag{18}$$

The exergy that enter into the system, include exergy of the sewage, the compressor, the pump, and the auxiliary heating device. Note the exergy of the incoming sewage is zero, since its state is taken as the standard state. Compressor, auxiliary heating, and pump are driven by electricity, so the exergy is their own power. Thus,

$$\sum_{in} E_X = 161.29+74+8.5=273.79kW$$

The exergy that flows out of the ECS-MVC, includes the exergy of the purified (E$_{x,\,p}$), the concentrated (E$_{x,\,c}$), the non-condensable gases and leaks. As the exergy of non-condensable gas and leaks are extremely small relative to the system, so here it is negligible.

$$E_{X,\mathrm{p}} = m_p\left[(h_7 - h_0) - T_0(S - S_0)\right]=1.714kW$$

$$E_{X,c} = m_c\left[(h_7 - h_0) - T_0(S - S_0)\right]=0.424kW$$

$$\sum_{out} E_X=1.714+0.424=2.138kW$$

The exergy efficiency of this ECS-MVC system is:

$$\eta_{\mathrm{II}}=\sum_{out} E_X / \sum_{in} E_X=0.88\%$$

This exergy efficiency is quite low, but it is very close to the second law efficiency presented in Ref.[19] for the similar systems. In the ECS-MVC exergy destruction takes place in preheater, ECS-MVC unit (evaporator and condenser), compressor and pump. The method of estimating each of this destruction is described in the following section.

A. Exergy loss in preheater

Due to fluid friction and heat transfer, the entropy is created in purified-sewage preheater and concentrated-sewage preheater. The increase in entropy leads to the exergy loss.

The exergy that enters the preheater, includes the exergy of the hot purified water ($E_{x,6}$) and the hot concentrated water($E_{x,6'}$). The exergy that flows out of the preheater, includes the exergy of the cool purified water ($E_{x,p}$), the cool concentrated water ($E_{x,c}$) and the hot sewage ($E_{x,2}$). Each of the exergy is calculated by Eq. (17). Therefore the destruction in preheater I_p is

$$I_P = E_{X,6} + E_{X,6'} - E_{X,p} - E_{X,c} - E_{X,2}$$
$$= 396.5604 + 89.568 - 1.714 - 0.424 - 430.798$$
$$= 53.192 kW$$

The fraction of exergy destruction within preheater is

$$I_p / \sum_{in} E_X = 53.192 kW / 243.790 kW = 21.81\%$$

B. Exergy loss in ECS-MVC unit

The exergy that enters the ECS-MVC unit, includes the exergy of the hot sewage ($E_{x,2}$), the hot vapor ($E_{x,4}$) and the auxiliary heating ($E_{x,a}$). The exergy that flows out of the ECS-MVC unit includes the exergy of the cool vapor ($E_{x,3}$), the hot purified water ($E_{x,6}$) and the hot concentrated water ($E_{x,6'}$).

As the compressed vapor is the heat source for the ECS-MVC unit, the exergy $E_{x,4}$ is the thermal exergy. That heat is released by the vapor and expressed as $Q_{4\text{-}6}$. Similarly, $E_{x,a}$ is also a thermal exergy. According to the definition of the thermal heat, its expression is as follows,

$$E_{X,Q} = (1 - \frac{T_0}{T})Q \tag{19}$$

Therefore the destruction in ECS-MVC unit I_U is

$$I_U = E_{X,2} + E_{X,4} + E_{X,a} - E_{X,3} - E_{X,6} - E_{X,6'}$$
$$= 430.798 + 5039.710 + 15.540 - 4861.470$$
$$- 396.560 - 89.568$$
$$= 138.450 kW$$

The fraction of exergy destruction within ECS-MVC unit is

$$I_U / \sum_{in} E_X = 138.450 kW / 243.790 kW = 56.79\%$$

C. Exergy loss in compressor

Ideally, the compress process is adiabatic and isentropic, and exergy loss in the compressor is only relevant with its efficiency. The efficiency of the compressor (η_c) can be considered to be 0.7. The destruction in compressor I_c is

$$I_C = (1 - \eta_C) W_C = 48.387 kW$$

The fraction of exergy destruction within compressor is

$$I_C / \sum_{in} E_X = 48.387 kW / 243.790 kW = 19.85\%$$

D. Exergy loss in pump

In the ideal cycle, we do not consider the irreversibility of the pump. Exergy loss in the pump is only relevant with its efficiency η_p which is considered to be 0.8. The destruction in pump I_{pu} is calculated from

$$I_{PU} = (1 - \eta_P) W_P = 1.7 kW$$

The fraction of exergy destruction within pump is

$$I_{PU} / \sum_{in} E_X = 1.7 kW / 243.790 kW = 0.69\%$$

Verification of system exergy balance:

The total exergy loss of the system is

$$I = I_p + I_U + I_C + I_{PU} = 241.729 kW$$

$$\sum_{in} E_x - \sum_{out} E_x = 243.79 - 2.138 = 241.652 kW$$

The above calculation shows that the total exergy loss is equal to the number that the exergy into the system minus the exergy leaving the system. Therefore the system exergy is balance, and the calculation is correct.

The exergy flow diagram is shown in Fig. 5.

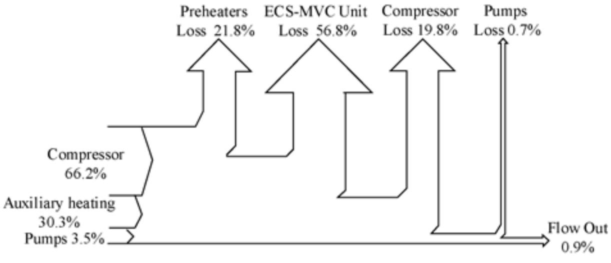

Fig. 5 Exergy flow diagram

Fig.5 illustrates the largest exergy loss (56.8%) occurs within the ECS-MVC unit, as expected. It is due to the evaporator and the condenser，which are the main heat exchanger components. The superheated vapor releases latent heat in the condenser which is transferred transfer to the liquid film on the evaporator. Higher exergy loss exits in the heat transfer process. Therefore the ECS-MVC system needs to enhance the heat transfer between the evaporator and the condenser.

The second largest exergy losses occur in the preheater (21.8%). In order to reduce this loss, the temperature difference between the hot fluid and cold fluid can be reduced. D.S. Jiao [19] reported that the compression ratio is the vital parameter for the temperature difference between evaporator and condenser. The smaller the compression ratio is, the lower the temperature difference and the higher the exergy efficiency 19.8% of exergy loss occurs in compressing. This is because the system uses the centrifugal compressor, which makes a high compression ratio. However, the centrifugal compressor has not only low efficiency but also small flow rate. Therefore it is necessary to develop an axial flow vapor compressor which has higher efficiency and greater flow rate.

Conclusion

This paper presents a new mechanical vapor compression system (ECS-MVC) which separates the evaporator from the condenser. By improving the traditional MVC system, the new system can be applied to the sewage treatment process. It can effectively solve the difficulties in descaling and antiscaling. The thermal cycle model of the system was established. The system operating parameters and the energy flow diagram was established by the first law of thermodynamics. It indicates that the energy consumption of the ECS-MVC system is low, and energy utilization rate is very high. To maintain the system cycle, the electric energy, 0.97% of total energy should be provided. The specific power consumption of system is 8.35 kWh/m^3 .

The exergy losses involved in the different processes taking place in ECS-MVC system is described by the second law of thermodynamics. The exergy efficiency is low and exergy flow diagram illustrates the largest exergy loss (56.8%) occurs within the ECS-MVC unit. Therefore the ECS-MVC system needs to enhance the heat transfer between the evaporator and the condenser.

Finally, the ECS-MVC system has the characteristics of energy saving and high efficiency.

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