Application of Mechanical Vapor Recompression in Concentration of Dilute Brine

Huizhong Cao, Luwei Yang, Zhentao Zhang, Xiaohua Wu
Ke Sheng Environmental Protection Polytron Technologies Inc, Nanjing, 210000, China

Abstract: At present, solid industrial salt or brine are usually adopted in production of ion-exchange membrane caustic soda, and such technologies as saturation of dilute brine, preprocessing and membrane filtration are adopted in production of primary brine. But the electrolytic production system is unreasonable in technology. Therefor, through analysis of working principle, selection of technology, technology flow and key point of operation, and improvement of problems existing in operation, the research on application of mechanical vapor recompression in concentration of dilute brine can improve the concentration efficiency of dilute brine.

Keywords: mechanical vapor; recompression technology; dilute brine; concentration; optimization; technology

1. Introduction

In 2013, the production capacity of caustic soda in our country reached 38000000 t/a, and the production technology of ion-exchange membrane caustic soda increasingly mature [1]. At present, solid industrial salt or brine are usually adopted in production of ion-exchange membrane caustic soda, and such technologies as saturation of dilute brine, preprocessing and membrane filtration are adopted in production of primary brine. However, the reaction rate of salt in ionic membrane electrolyzer is only 50%. After mixed with the effluent generated by other caustic soda production equipment, the high quality dilute brine generated by electrolytic production system is saturated with solid industrial salt or by returning to the salt well, such technical route is unreasonable in technology [2]. It's technically unreasonable to saturate the high quality dilute brine with low quality solid salt and to refine. This technology circulates the dilute brine in primary brine equipment, thus reduces the efficient production capacity of primary brine equipment or salt well, and wasteful problems also exist in operation. If the concentration technology of dilute brine with mechanical vapor recompression (hereinafter as MVR) is adopted, the dilute brine doesn't enter into the well or primary brine equipment and is concentrated solely, entering into the electrolyzer after refined in second refining procedure [3]. This is not only reasonable in technology, but also theoretically improves the capacity of primary brine or slat well with 50%.

2. Application Method of MVR Technology

Multi-effect vapor evaporation technique which is adopted in traditional evaporating concentration, can improve the utilization of vapor by increasing the efficiency numbers of evaporator, but the increases of the efficiency numbers may increase the investment and make the equipment larger [4]. The most important is that, no matter how large the efficiency numbers are, latent heat of flash steam generated by the last efficiency would be wasted and plenty of circulating water is necessary to refrigerate it. Therefor, the MVR technology is developed. The compressor can make recompression to the flash steam to increase the pressure and temperature of vapor, and the flash steam can be recycled while returning to the evaporator without losing the latent heat of vapor [5]. According to the calculation of dynamics, the utilization efficiency of energy evaporated by mechanical compression heat pump is 27 times of the single-effect evaporation, 7 times of the four-effect evaporation. The theoretical basis of MVR is from Boyle's Law: PV/T=K, which means that, the pressure and volume of a fixed mass of gas is in direct proportion to its temperature, namely, when the volume of gas reduces and the pressure rises, the gas temperature rises [6]. In practical production and application, the flash steam with low temperature and pressure evaporated by productive medium is recompressed mechanically to increase the temperature, pressure and bake of vapor. The compressed vapor enters into the evaporator to transfer heat with the productive medium and condensate. The productive medium is thus evaporated and concentrated, and the flash steam is generated. The requirements to make full use of latent heat of vapor inside the system are met, the Heat flux evaporated and concentrated by MVR is shown as Fig. 1.

Except cold boot or great increases of load, MVR productive equipment needs few live steam equipment (the evaporating capacity is 60t/h), live steam in cold boot (consumption is about 2t per time), no live steam is needed when the equipment operate normally. The heat of system is supplied by electric energy consumed by compressor, which greatly increases the heat efficiency of system. Based on calculation, the energy utilization efficiency of MVR is 20-30 times of multi-effect evaporation [7].

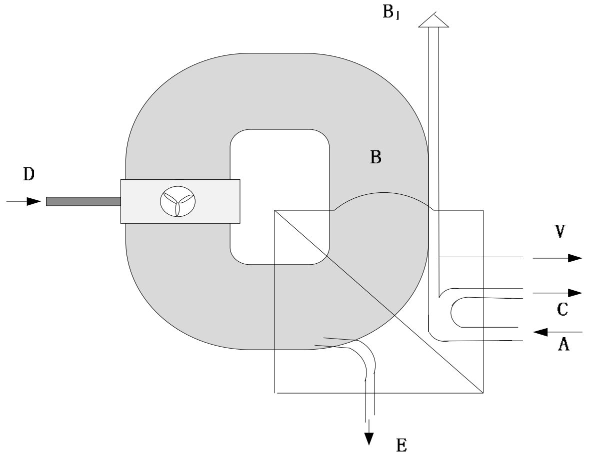

Figure 1. Heat flux evaporated and concentrated by MVR

According to the working principles of heat pump, the heat pump evaporating and concentrating system is composed of five basic parts: evaporating system, flash steam washing system, vapor compression system, degree of superheat of compressed vapor removing system and live steam system. Evaporating system: evaporating system is composed of evaporating pot, heating chamber and circulating pump; the evaporator is the core equipment of system where the concentration of dilute brine is finished; flash steam washing system: the flash steam is accompanied with feed liquid, though the entrainment is eliminated, even little feed liquid can result in huge impact, corrosion and scaling to the impeller of compressor. The direct introduction of feed liquid would influence the service life and stability of compressor, therefor, the complete washing and second defogging are very important [8]. The salt mist and water mist in vapor can be completely removed as long as the vapor washing tower and defogger are set before the flash steam enters into compressor; vapor compression system: in heat pump evaporating technology, the open centrifugal compressor is usually adopted. Compressor is a key equipment, and the steady efficient operation of compressor is of great importance to normal production; degree of superheat of compressed vapor removing system: the flash steam is absorbed by compressor, its pressure and temperature rise after the adiabatic compression in compressor, and the vapor after compression is superheated [9]. Eliminator of degree of superheat is necessary in order to reduce the negative influence of degree of superheat to evaporation and heat transfer; live steam system: in the initial operation period of heat pump evaporating system, it’s necessary to build the vapor circulation, and to build live steam system in order to protect the heat balance of evaporating system.

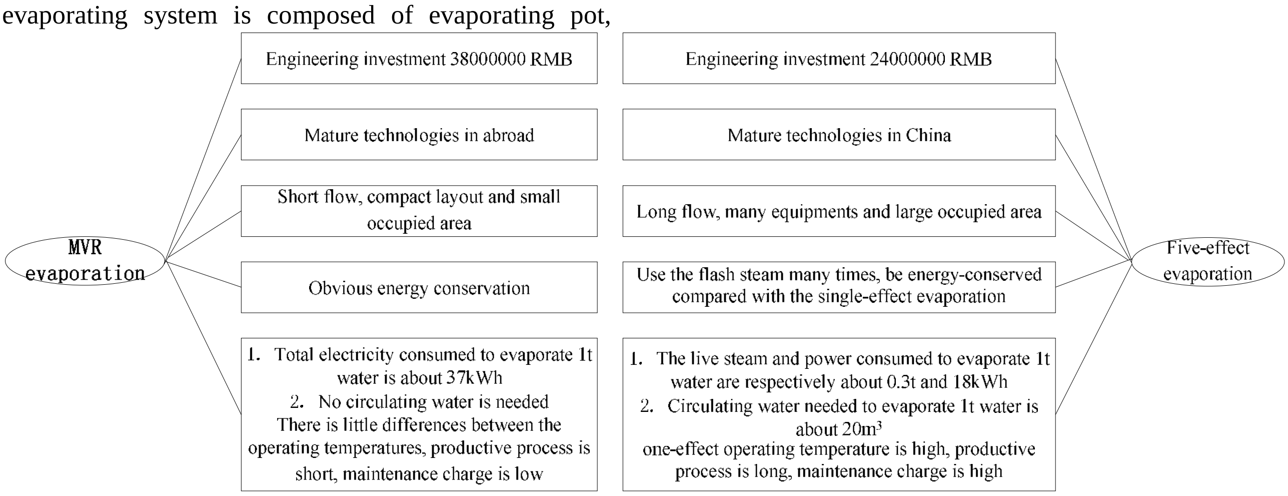

Figure 2. Contrast of concentration technology of dilute brine

At present China, the multi-effect evaporating technology is generally adopted in evaporating and concentrating operation. The principle of multi-effect evaporating technology is taking the flash steam generated by previous evaporation as the heat source of latter evaporator, then the one-effect steam passing by surface air cooler, circulating water condensates through vacuum pump and system load is produced[10]. Five-effect evaporation is usually adopted in vacuum salt making with brine. No matter what multi-effect evaporation is adopted, great quantity of live steam is consumed during the evaporating process. For five-effect evaporation, 0.3t live steam is consumed to evaporate 1t water. The simple contrast of five-effect evaporation with 150000 t/a ion-exchange membrane caustic soda equipment and with evaporating capacity of 60t water per hour and MVR evaporating technology is shown as Fig. 2:

3.Application Process of MVR Technology

The basic technological flow of traditional brine is shown as Fig3:

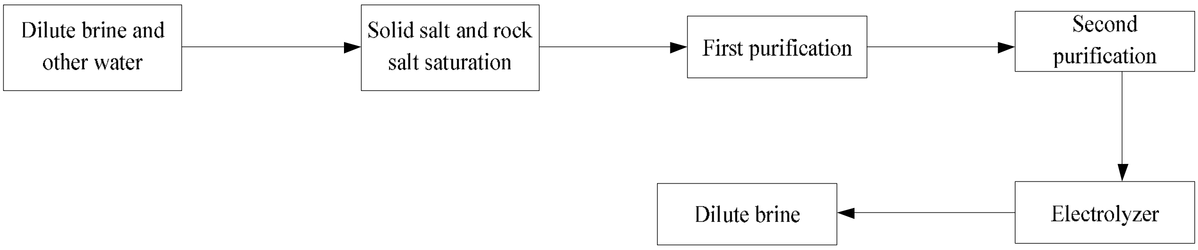

Figure 3. Basic technological flow of traditional brine

The biggest problem of the technology is that the high quality dilute brine generated by electrolyzer is saturated with low quality solid salt or rock salt, returning to secondary brine system and electrolytic system after brine purification [11]. Introducing the heat pump evaporating and concentrating technology (as shown in Fig. 2), Flow of MVR dilute brine concentration technology is shown as Fig4:

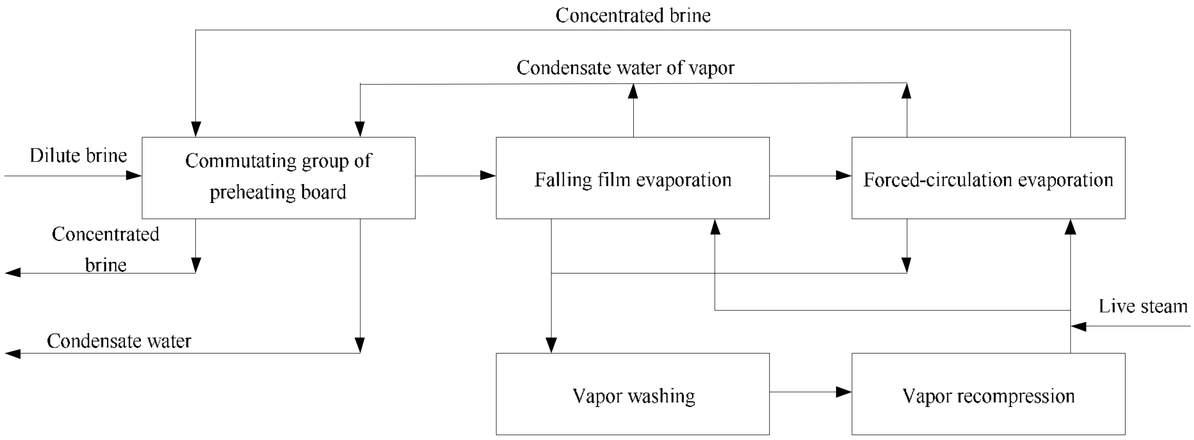

Figure 4. Flow of MVR dilute brine concentration technology

It's feasible to make the dilute brine generated by electrolyzer concentrated and circulated solely, without saturation and primary brine purification to improve the effective capacity of primary brine working procedure. Concentrating procedure of dilute brine: temperature within battery limit 55℃, the dilute brine which has content of NACL 220g/l is preheated through several heat exchangers. The heat source are condensate water of vapor, concentrated brine and washing water of vapor which are sent out the battery limit. The temperature of dilute brine is rising to 105℃ while transferring heat, the dilute brine is sent to falling film evaporator for circulation and preconcentration, part of the dilute brine flows to forced-circulation evaporator for evaporation and concentration, in which, the brine concentration reaches 315g/l; part flows out the system and transfers heat with the dilute brine to recycle the heat, the temperature decreases to 60℃ and the dilute brine enters into concentrated brine tank where pH value is adjusted and then into the secondary brine; Live steam and flash steam procedure: when MVR productive equipment cold boot starts, 0.3MPaG live steam entered and the temperature of circulating dilute brine in the evaporator rises to not lower than 100℃; when the dilute brine medium evaporates and flash steam is generated, the chloridion in the flash steam would be removed while passing by the defogger inside the falling film evaporator and forced-circulation evaporator; then in the vapor washing tower, the flash steam is further washed and it requires that the content of chloridion in flash steam should be smaller than l0ppm to ensure the steady operation of vapor compressor; qualified flash steam is pressurized and heated through the series connection of first and two stage compressors; at the same time, mist is sprayed to flash steam at the enter of compressor to humidify the steam in order to avoid the damage caused by superheat to equipment during the vapor compression process; the saturated flash steam after pressurization and heating enters into the falling film evaporator and tube still heater of forced-circulation evaporator; condensate water is generated after the flash steam transferred heat with dilute brine; at the same time, the flash steam is generated again from dilute brine to reach the recycle; condensate water of vapor procedure: the saturated flash steam transferred heat with dilute brine in the falling film evaporator and forced-circulation evaporator, then condensate water is generated and enters into condensate water tank; part of condensate water at high temperature enters into vapor washing tower to ensure the washing effect of vapor; the needless washing water in the tower is sent out the battery limit after transferred heat with dilute brine and after heat recycled; the rest transferred heat with dilute brine and heat is recycled, a small part of them as the washing water of interval of defogger, most of them are sent directly out the battery limit (conductivity <20μs/cm)[12].

Temperature control: the temperature of dilute brine out of the battery limit should be not lower than 50℃, if the temperature is too low, the vapor compressor cannot maintain MVR heat flow balance, in such case, live steam needs to enter constantly to maintain the operation; at the same time, too low temperature of dilute brine may result in crystallisation of strong brine while transferring heat, and plate heat exchanger may be blocked [13]. When the compressor is launched, it requires that the temperature of circulating brine in system is not lower than 100℃ to ensure that the dilute brine can evaporate enough flash steam to maintain the stability of system pressure, and to avoid the influences of great load suddenly generated to static equipment and operation of compressor.

Flow control during operation: on the initial operating period of vapor compressor, great quantity of water in dilute brine is evaporated, which results in rapid change of liquid level in evaporator; it's necessary to set the fluid infusion valve in manual operation and to timely replenish the dilute brine and exhaust the strong brine to avoid the excessive concentrations of strong brine which result in precipitation of salt crystal, and plate heat exchanger may be blocked. The fluid infusion valve could be set in automatic operation when the system is steady.

Liquid level control of evaporator: reasonable liquid level is necessary for both falling film evaporator and forced-circulation evaporator, with too low liquid level, great fluctuation in concentration of strong brine may influence the steady operation of system, even block the plate heat exchanger; with too high liquid level, small vapor space may result in decreases of productive capacity, and brine with low concentration cannot meet the productive requirements, at the same time, the operating effect of defogger is influenced, which results in excessive ion in flash steam, thus the corrosion of equipment is accelerated and quality of condensate water of vapor is influenced.

Exhaust of noncondensable gas in system: when MVR system operates, it should open the exhaust valve of noncondensable gas in shell side and monitor of equipment, and close it when the compressor operates steadily and exhausted gas is vapor; after long operation of system, accumulation of noncondensable gas may result in the decreases of evaporative capacity, therefor the exhaust valve should be open for a period to exhaust the noncondensable gas.

Interlocking device for compressor vibration: there is interlocking protect for operation and vibration of vapor compressor, in normal case, it's effective, but when the compressor is launched, "resonance" is formed by the equipment under certain rotate speed during acceleration; it's normal to have a over-vibration during short period, therefor while operating, the interlocking delay settings should be added to avoid the tripping of compressor; the delay settings would be cancelled when the compressor operates steadily.

4.Application Results of MVR

In order to ensure the effectiveness of application method of MVR in concentration of dilute brine, experimental demonstration is done through the brine with the same volume. Traditional concentrating method is adopted as contrast to ensure the preciseness of experiment. The concentrating efficiency of dilute brine is compared and contrast results are shown as Fig5:

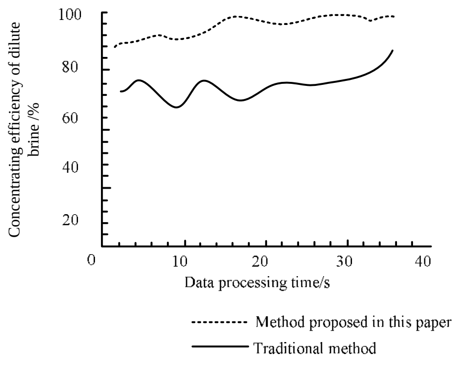

Figure 5. Curve of experimental demonstration results

Fig5 represents the concentrating efficiency of dilute brine of two methods. By analyzing above figure, it can be obtained that there are great differences between the application method of MVR in concentration of dilute brine and traditional method. From the perspective of efficiency of compression time, the application method of MVR in concentration of dilute brine has obvious advantages, especially if there is great quantity of dilute brine to be compressed and processing takes long time; from the data in above figure, it can be known that compared with the traditional method, the application method of MVR in concentration of dilute brine can finish the effective compression to dilute brine, through weighted analysis, it's proved that the working efficiency of application method of MVR is improved 40%.

Following features of MVR evaporation can be obtained by analysis: in order to improve the utilization efficiency of live steam, the traditional multi-effect evaporation adopts generally three-effect, even four-effect or five-effect evaporation which are complicated in technology [14]. MVR evaporating technology is simple and has short flow as it adopts only single-effect evaporator; little equipment has little volume and occupied area; little vapor consumption: when the live steam consumed is mainly used in change of operation and production load, the live steam consumed to evaporate 1t water is lower than 0.04t which is much lower than that of the traditional method (0.24t for five-effect evaporation); it's unnecessary to consume great quantity of circulating condensate water; as few live steam is consumed by MVR evaporation, it's unnecessary to build steam generator with great volume and thus the investment is reduced.

As MVR evaporation consumes little circulating condensate water, it's unnecessary to build large circulating condensate water equipment and thus the investment is reduced; low operating cost: the dynamic electricity consumed to evaporate 1t water may be lower than 46kW·h. The productive equipment of MVR is arranged compactly, DCS interlocking control, for example, liquid level and flow, proportion of dilute and strong brine and rotate speed of compressor (energy input), compressor and vibration, temperature and oil mass are set with automatic adjustment or interlocking protection, which improves the stability of system and decreases the workload of operation staff; compared with the multi-effect evaporation, the temperature differences of MVR are small, the productive conditions are moderate, therefor the corrosion to equipments and pipes is light [15]. Three ceramic membrane equipment are open when the primary brine which adopts the crude salt dissolving technology is on normal operation. MVR technology adopts the brine as raw material. The dilute brine is concentrated directly without returning to the salt dissolving procedure, which reduces the operating load of ceramic membrane equipment, operation of two ceramic membrane equipment with low load can meet the productive requirements; in MVR technology, the temperature of strong brine sent to secondary brine is about 63℃, which meets the requirement that resin tower temperature of secondary brine is not lower than 60℃; compared with the crude salt mining technology which requires that the brine temperature is about 55℃ and that vapor needs to be heated, MVR technology reduces the production control point and economizes the consumption of live steam; since gone into operation, after eight months of examination on material and energy consumption, MVR soda manufacturing equipment gains significant economic benefits by replacing the crude salt with brine to reduce the raw material cost. Economic contrast of MVR soda manufacturing technology is shown as Fig. 6 and Tab. 1:

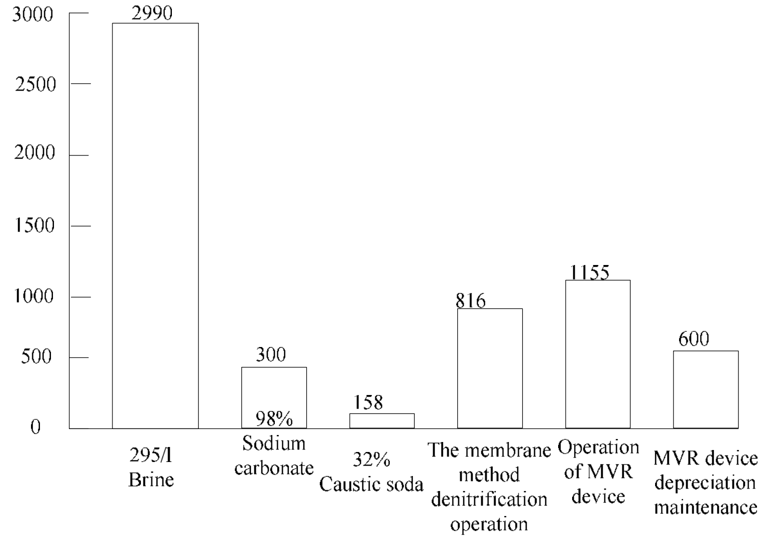

Figure 6. Economic contrast of soda manufacturing technology

Table 1. Economic contrast of crude salt dissolving technology in brine unit

Raw material / operation	Unit	Unit price	Salt dissolving technology	
			Unit consumption	Amount (ten thousand Yuan / year^{-1})
94% crude salt	t	260.00	1.70	6630
295g/L brine	m³	34.00		
98% soda	t	2000.00	0.025	750
32% caustic soda	t	700.00	0.030	315
Membrane denitration operation	m³	5.00	146	584
MVR equipment operation	kWk	0.65		
MVR equipment depreciation maintenance				
Sub-total				8279

From the above, it can be known that ion-exchange membrane caustic soda with scale of 150000t/a adopts the MVR soda manufacturing technology. Recycle of condensate water (480000m³/a) are not taking into account, reducing the heated vapor of secondary brine (12000t/a), simple calculation is done. It indicates that the raw material and operating cost saved every year are about 22000000 Yuan. MVR soda manufacturing technology adopts the direct concentration of brine, apart from its own advantage of energy conservation, it saved great quantity of energy consumption of brine → vacuum solid salt in vacuum salt manufacturing and of chlor-alkali salt (liquid → solid → liquid), according to estimation, adopting the MVR soda manufacturing technology to produce 150000t/a ion-exchange membrane caustic soda can save 20000 standard coal each year.

During the application process of MVR in concentration of dilute brine, most problems exist in liquidometer of evaporator and iron pollution of water. Liquidometer of evaporator: falling film evaporator adopts originally radar level transmitter, as the condensate water is easy to congeal in detecting element, which results in abnormal detecting data, the control valve and liquid level cannot be set as automatic, and thus the workload of DCS operation staff is increased, differential pressure type level gauge well resolves the problem; iron pollution of water: the pipe for flash steam exhausted from the evaporator is made in carbon steel, in production operation, the ferruginous condensate water falls into the evaporator, which results in the excessive iron content in brine medium and pollution and corrosion of carbon steel. A weir with certain height is added below the exit of flash steam of evaporator, as the pipe is upward, in order to avoid the back flow of condensate water to evaporator, several pores are open on the bottom of pipe of flash steam to place the pipe which leads to the vapor washing tower, thus the condensate liquid flows automatically into the washing tower due to the position difference.

5. Conclusions

Replacing the crude salt with the brine increases processing scale and operating cost of membrane denitration. The Iodine content in brine is high, there is no efficient and economic removing technology, which may results in productive difficulties to latter procedures. MVR soda manufacturing technology help the brine in system to form closed cycle, some foreign ion as silicon, iodine and nickel in brine get enriched, thus the operation of secondary brine unit and service life of ionic membrane may be influenced. Therefor, the application of MVR technology in concentration of dilute brine can effectively improve the concentrating efficiency of dilute brine.

References

[1] Zhou Haiyun, Jiang Weili, Xu Chen. Experimental research on the treatment of wastewater from Aspartame production by mechanical vapor recompression process[J]. Industrial Water Treatment, 2017, 37(9) : 60-63.

[2] Zhao Yuanyang, Liu Guanshan, Li Liansheng. Performance Analysis on Mechanical Vapor Recompression System[J]. Fluid Machinery, 2017, 45(6) : 16-20.

[3] Cao Rongkai, Qian Desong, Yin Shihai. Simulation Analysis of Mechanical Vapor Recompression Used in Synephrine Aqueous Extract Concentration Process[J]. Chinese Journal of Pharmaceuticals, 2017, 48(9) : 1318-1324.

[4] Shen Jiubing, Zhang Kai, Xing Ziwen. Experimental Study of Mechanical Vapor Compression Wastewater Distillation System using Twin Screw Compressor[J]. Journal of Mechanical Engineering, 2016, 52(10) : 185-190.

[5] Qu Rui, Zhang Zhanmei, Fu Ting. Pilot study on mechanical vapor recompression technology for treatment of saline wastewater[J]. Chinese Journal of Environmental Engineering, 2016, 10(7) : 3671-3676.

[6] YuYang , Si Menglan , Gao Xuedi. Aspen Numerical Simulation Based Energy-saving Optimization for the Concentration Process of Trad1tional Chinese Medicine (TCM) w1th Mechanical Vapor Recompression (MVR)[J]. Chinese Journal of Pharmaceuticals, 2017, 48(11) : 1610-1616.

[7] Ma Rui, Wu Yuting, Du Chunxu. Experimentall performance of vapor compression heat pump wlth inverted compressor [J]. Acta Energiae Solaris Sinica, 2017, 38(5) : 1254-1260.

[8] Wang Gang, Hao Liang, Zhang Guanfeng. System simulation of mechanical vapor compression seawater desalination plant using wind power[J]. Journal of Thermal Science and Technology, 2017, 16(1) : 40-46.

[9] Li Zhengjun, Guo Jinxian, Chen Liqing. Observation of Generation Process for a Pulsed Vacuum-squeezing Light in Hot Rubidium Vapor[J]. Acta Sinica Quantum Optica, 2017, 23(3) : 232-240.

[10] daiwenzhi, Chen Yuehan, Yang Xinle. Operation Optimization Study on Steam Power System Based on Adjustment Rules and Particle Swarm Optimization Algorithm With Inertia Weight Logar1thmic Decrement[J]. Journal of Mechanical Engineering, 2017, 53(10) : 145-150.

[11] Cheng Fujiang, Zhang Yun, Jiang Qinyin.Influence of Operating Parameters on Performance of Two-stage Compression AirSource Heat Pump System at Low Temperature[J]. Fluid Machinery, 2017, 45(3) : 56-60.

[12] Liu Bingshen, Gong Yulie, Lu Zhenneng. Performance analysis and optimization of a coupling sub-cooler heat pump steam system in a quasi two-stage compression cycle[J]. Chemical Industry and Engineering Progress, 2017, 36(7) : 2360-2367.

[13] Ma Guoyuan, Fang Lei, Xu Shuxue. Comparison Study of Energy Ratio of ORC Compound W1th Vapor Compression Heat Pump System Using Different Working Fluid[J]. Journal of Beijing Univers1ty of Technology, 2016, 42(2) : 296-301.

[14] Liu Bignshen, Gong Yulie, Lu Zhenneng.Performance analysis and optimization of a coupling sub-cooler heat pump steam system in a quasi two-stage compression cycle[J]. Chemical Industry and Engineering Progress, 2017, 36(7) : 2360-2367.

[15] Hou Chao, Zhan Hufu, Zhang Yu.Characteristics of mechanical vapor recompression technology for treatment of liquid radioactive wastes in nuclear power stations[J]. Modern Chemical Industry, 2018(2).