

Vacuum Problems in the Evaporation Section

Ni Chaowei
Ningxia Petrochemical Company of PetroChina
Yinchuan, Ningxia, People's Republic of China

Summary

In general, urea solution is vaporized isothermally. The concentration of the urea solution increases gradually while water is continuously vaporized and expelled during evaporation. In the No. 1 Urea Plant of Ningxia Petrochemical Company in the People's Republic of China, urea solution evaporation is divided into two stages. Pressures of the first-stage and second-stage evaporations are 0.30~0.35 MPa (a) and 0.034 MPa (a) respectively. The Concentration is increased from 75 wt% to 99.7 wt%, meeting prilling requirements. However, to reach vacuum pressure in the evaporation system during startup or normal production often fails, or the vacuum degree in the evaporation system is too low, thus seriously affecting the startup progress or the quality of finished urea product.

Because many factors affect the vacuum of the evaporation section, corresponding measures should be taken to effectively solve problems like failure of vacuum pressure, low vacuum degree, etc. of the evaporation section which occur during startup or production, in order to ensure smooth startup of the evaporation system, and all urea products are up to standard quality.

Introduction

In general, urea solution is vaporized isothermally. The concentration of the urea solution increases gradually while water is continuously vaporized and expelled during evaporation. In the No. 1 Urea Plant of Ningxia Petrochemical Company in the People's Republic of China, urea solution evaporation is divided into two stages. Pressures of the first-stage and second-stage evaporations are 0.030~0.035 MPa (a) and 0.0034 MPa (a) respectively. The Concentration is increased from 75 wt% to 99.7 wt%, meeting prilling requirements. However, to reach vacuum pressure in the evaporation system during startup or normal production often fails, or the vacuum degree in the evaporation system is too low, thus seriously affecting the startup progress or the quality of finished urea product.



Figure 1: The heaters and separators of a two stage evaporation section

Process description

Urea solution from the urea solution pump flows into the tubes upwards of a rising-film evaporator heater under vacuum pressure by means of a flow control valve. During the evaporation of the light components like water, ammonia and carbon dioxide, the concentration of the urea solution increases finally up to about 95 wt%. The gas-liquid mixture from the heater is separated into a gaseous phase and a liquid phase in the first-stage evaporation separator. The gaseous phase is sent to the first-stage evaporation vacuum condenser from the top of the separator after entrained droplets are removed. The non-condensing gasses (inerts) from the vacuum condenser passes through a manually control valve and then together with secondary steam these gasses flow from the first stage

evaporator separator into the first stage vacuum condenser where it will be condensed by cooling water. The process condensate thus formed flows into the ammonia water tank by gravity while the non-condensing gasses go to the first-stage evaporation steam ejector and are ejected by low pressure steam into the final vacuum condenser. The pressure of the first-stage evaporator is controlled by the pressure control valve installed on the suction line of the first stage evaporator steam ejector and is generally controlled at 34 kPa(a).

Urea solution discharged from the bottom of the first stage evaporator separator flows automatically into the bottom of the second-stage evaporator heater. The two stages are connected by a pressure pipe to balance the differential pressure. The design and evaporation principle of the second stage evaporator heater are similar to those of the first stage although its dimension is smaller. During the second stage evaporation, the concentration of the urea solution is increased from 95 wt% up to 99.7 wt. The gas-liquid mixture discharged from the second stage evaporator heater flows into the second-stage evaporation separator where it is separated into a gaseous phase and a liquid phase. The gaseous phase passes through the demister and then flows to the booster ejector in order to boost up the pressure. After the booster the gasses flow into the second-stage evaporation vacuum condenser where the ejector steam from the booster is condensed together with gasses by cooling water. The condensate formed flows into the ammonia tank by gravity again. The non-condensing gasses (inerts) are sent to the second stage first ejector operated with low pressure steam to the second stage after vacuum condenser, where it is condensed again by cooling water. The condensate formed flows also into the ammonia tank and the non-condensed gasses pass through the second stage second ejector and then are sent together with gas from the first stage evaporator ejector into after vacuum condenser for further final condensation. The condensate formed flows also into the ammonia tank. The pressure of the second-stage evaporation is maintained below 10 kPa(a) jointly by three ejectors in serie (booster, second stage first ejector and second stage second ejector). Urea melt coming from the second stage separator flows through a sight glass to the inlet of urea melt pump and is then sent to prilling bucket in the prilling tower.

Analysis on factors causing failure of the vacuum pressure

Vacuum of the evaporation system is established by the action of steam ejector using steam as motive power. Factors causing a failure of the vacuum pressure or low vacuum degree in evaporation system can be summarized as follows:

Influence of compositions and flow rate of urea solution on evaporation vacuum pressure

In case the operating conditions in the High Pressure and Low Pressure systems is not optimum.

For example in case the conversion rate in the synthesis section or the stripping efficiency are lower than design, the efficiency of the recirculation section and flash tank will be poor and the contents of free ammonia and CO₂ contained in the urea solution flowing into evaporation system are high and the concentration of the urea solution decreases. The temperature of the solution at the bottom outlet of low pressure rectifier will be too low and this temperature can hardly be increased. The free ammonia and CO₂ content in the urea solution flowing into the flash tank are increased and the gas flow to the flash tank condenser is reduced. At this moment, the vacuum pressure in the first-stage evaporation section is lower, or the vacuum pressure cannot be increased by means of the ejectors during startup. In the evaporators more free ammonia and CO₂ are vaporized, leading to an additional load on the vacuum system and affecting the vacuum pressure. Sometimes carbonates are formed from the free ammonia and CO₂, which crystallize inside the inlet pipe to the steam ejector and the surface vacuum condenser, affecting directly the capacity of the steam ejector and the condensation efficiency.

During production, the urea solution from the urea solution tank is delivered by the urea solution pump to the first-stage evaporator section. A sampling point is available in this line, where the urea solution can be sampled per shift in order to analyse whether $\text{CO}(\text{NH}_2)_2=72.2\text{wt}\%$, $\text{NH}_3=0.6\text{ wt}\%$, $\text{CO}_2=0.2\text{ wt}\%$ in the urea solution and to check whether the contents of $\text{CO}(\text{NH}_2)_2$ and biuret exceed their design values. Compositions of the urea solution flowing into the first-stage evaporator must be monitored in time by taking samples at the sampling point per shift.

High evaporation load on the evaporation section due to excessive feeding as well as increasing load of low pressure steam and inerts are all factors imposing excessive load to the vacuum system, thus reduce the vacuum degree.

Influence of crystallization plugging on evaporation vacuum

The rising-film long-tube evaporator (film evaporator) with high efficiency is applied in our plant. The first-stage evaporator has a structure basically the same as that of the second-stage evaporator. The upper part of the evaporator is a separator while the lower part is an evaporation heater, which is connected together by a flange connection. A gas-liquid separating device of shutter type is installed inside the separator. Since the direction is changed when the evaporated vapor entrained with urea droplets flows through the shutter blades, the droplets crash on the surfaces of the upper blades due to inertia force and are flapped out. However, because of the short passage between the blades, satisfactory separation can be hardly obtained and dead corners are easy to be formed, resulting in urea crystallization plugging. Moreover, the export gas entrains a larger quantity of urea. Meanwhile, concentration of urea solution in the evaporation system is also higher. In such case, if vacuum degree and urea concentration are not compatible properly, crystals may be formed in crystallizing zone, thus affecting the vacuum degree.

Plugging of the inlet pipe of booster vacuum ejector

Because the gas flow from the second-stage evaporator entrains a larger quantity of urea, crystallization is easy to occur in the inlet pipe of the booster vacuum ejector, resulting in plugging and thus affecting the vacuum of the evaporation system.

Influence on evaporation vacuum pressure caused by the decrease of the capacity of the ejector

When the pressure of steam flowing into the ejector is decreased, the capacity of the ejector decreases as well. As the load increases, the motive steam should be increased accordingly to meet the high load requirements. However, it is just on the contrary in actual production. Low pressure steam is a byproduct of the high-pressure synthesis section. According to design requirements, as the load of high-pressure synthesis section increases, the pressure of the low pressure steam piping network will be reduced while the pressure in the high-pressure synthesis section is increased. In this case, the pressure of the motive steam sources of the vacuum ejectors in each stage reduces; the steam pressure of the ejectors may be obstructed due to plugging of impurities on the strainers upstream the steam nozzles of the steam ejectors; resistance in the exhaust pipe may be increased when foreign matters accumulate downstream the vacuum ejectors; corrosion, wear & tear caused to nozzles, increase of the resistance of the suction and exhaust pipes of the ejector may all decrease the pumping capacity of the ejectors. To realize vacuum pressure may also fail when condensate accumulates in steam pipes, which may cause water-hammer during startup.

Influence on evaporation vacuum caused by condensation inefficiency of surface vacuum condensers

Insufficient cooling water flow, higher temperature or lower inlet pressure of cooling water are common factors reducing the condensation efficiency of the surface vacuum condensers and slowing down the condensation process of the evaporated gasses, thus causing a decrease of vacuum degree.

In case too much inert gas accumulates on the tube-side of surface vacuum condensers, the condensation efficiency decreases the condensation process of evaporated gasses, thus causing decrease of vacuum degree.

Carbonates or foreign matters can obstruct the surface vacuum condensers, reducing the condensation efficiency of the surface condensers and slowing down the condensation process of evaporated vapor, thus causing decrease of vacuum degree.

The down comer pipes of the vacuum condensers are blocked, or the manual valve between the vacuum condenser and the ammonia water tank is closed, causing liquid accumulation in the vacuum condensers thus vacuum degree is affected.

Influence on evaporation vacuum caused by malfunction of instruments

The pressure indicators in the evaporation section are often blocked by crystallization, especially at the inlet of the pressure indicator of the second-stage evaporation separator. At this moment, indication of the vacuum pressure indicator drops rapidly while the vacuum degree in the evaporation system remains unchanged.

Influence up evaporation vacuum caused by leaks of pipeline/equipment, excessively low liquid level control and/or gas leaks

- Liquid level of ammonia tank is too low, gas leaks into the barometric leg set for maintaining the liquid seal in the surface condenser, thus vacuum disappears;
- Leaks of equipment and/or pipelines in evaporation system cause leak-in of outside air, thus vacuum decreases or even disappears;
- The manual vacuum pressure control valve may be opened too widely, allowing large volume of air to come in, thus affecting the vacuum;
- The vacuum of the second-stage may be influenced by the leak-in of outside air through the urea melt pumps due to the inhalation resulted from the leakage of urea melt pump packing;
- Liquid level of the liquid seal of the flash tank to the urea solution tank is too low and air is drawn in from the inlet of urea solution pump, flowing into the first stage evaporator section together with the urea solution, causing vacuum decrease or even disappearance in the first-stage evaporation. Unstable vacuum in the first-stage evaporation may also affect greatly the stability of the vacuum in the second-stage evaporation;
- Check all vacuum-breaking valves to see if they are closed or any leaks existed. Vacuum can be easily reduced or even disappear if air enters into the inside of the equipment through these valves.
- Water can flow directly into the second-stage separator or pipes when the flush water valve of the booster steam ejector leaks, affecting severely the stability of the second-stage vacuum, thus causing vacuum decrease or even disappearance.

Control Measures

The following corresponding measures are recommended to be taken based on the above-mentioned factors analyzed.

Compositions and flow rate of the urea solution

Stabilize and optimize the operation conditions of the High Pressure and Low Pressure sections, so that the concentration of the urea solution can be kept at maximum level while the content of free ammonia and CO₂ is minimum in the bottom liquid seal of the flash tank, thus alleviating the load of the evaporation section. During startup, the pressure of the rectifier should be increased in time under the condition that sufficient steam is available, in order to avoid that the bottom outlet temperature of the low pressure rectifier is too low. Otherwise the poor rectification may cause an increase of free ammonia and CO₂ in the urea solution flowing to the flash tank, thus affecting the vacuum of the evaporation section. In normal production, the bottom outlet temperature of the low pressure rectifier is controlled around 135 °C, thus keeping the highest concentration of urea solution flowing into the flash tank and the lowest content of free ammonia and CO₂.

Excessive load on the evaporation section may be caused by various factors, resulting in higher feed flow. Therefore, vacuumization should be carried out using medium pressure steam instead of low pressure steam when the pressure of low pressure steam is insufficient, in order to ensure a normal vacuum pressure in the evaporation section. Evaporation capacities and pressures of low pressure steam network corresponding to different loads of the system are listed in Table 1 below.

Table 1: List of evaporation capacities and pressures of low pressure steam network corresponding to different loads of the system

Load of the system (m ³ /h)	Evaporation capacity (m ³ /h)	Pressure of low pressure steam network (MPa)
24000	71.8	0.446
25000	74.9	0.431
26000	78.1	0.423
27000	80.8	0.392
28000	84.1	0.383
29000	86.7	0.374
29400	89.0	0.350

Crystallization plugging

Crystal forms easily in the evaporation separator installed with shutters. The existence of such crystals affect the flow of the gasses and increases the resistance. Such accumulated crystals can be cleaned with process condensate through flush water piping of the separator. However this problem can be hardly solved during normal operation and can be removed only in the plant shutdown period, when crystals can be removed manually or dissolved by steam condensate. For crystals inside the equipment or piping, the preferable approach is to dissolve these by filling up the system with hot steam condensate during a short shutdown of the evaporation system, through which better result can be obtained generally. However crystallization plugging in the inlet pipe of the booster ejector of the second-stage evaporator, which easily occurs, can be removed through purging without shutdown.

Flush the booster ejector regularly as this the one to be plugged easiest among all the individual ejectors in the evaporation system because more urea is entrained in the evaporated gasses in second-stage evaporator, causing crystallization near the throat of the ejector. In normal operation, the booster must be flushed intermittently, i.e. twice per shift at the interval of every 3-4 hours for 35–40 minutes each time. Changes of the second-stage evaporation vacuum before and after flushing the booster ejector are shown in Table 2 below, which indicates that the second-stage evaporator vacuum pressure can be improved by flushing the booster ejector. The booster ejector can be flushed and cleaned completely by injecting a large volume of steam condensate during the shutdown period.

Table 2: List of changes of the second-stage evaporator vacuum pressure before and after flushing the booster ejector

Time	Jan. 1	Jan. 16	Feb. 1	Feb. 16	Mar. 1	Mar. 16	Apr. 1
Before flushing	-84.72	-84.81	-85.07	-84.92	-84.77	-85.17	-85.11
After flushing	-86.24	-86.12	-86.23	-85.97	-86.17	-86.30	-85.84

Time	Apr. 16	May 1	May 16	Jun. 1	Jun. 16	Jul. 1	Jul. 16
Before flushing	-85.21	-85.13	-85.07	-84.83	-84.81	-85.02	-85.11
After flushing	-86.24	-86.19	-86.22	-85.97	-86.17	-86.30	-86.27

Decrease of suction capacity of ejectors

Experience has shown that the pressure of the low pressure steam network cannot be lower than 3.50×10^3 Pa when evaporation flow is 89 m³/h, or medium pressure steam can be used for realizing vacuum pressure if the pressure of the low pressure steam network decreases while the evaporation load increases. Pressures of the low pressure steam network corresponding to different evaporation capacities (evaporation loads) are listed in Table 1 above.

Clean the strainers upstream the vacuum ejectors and purge the pipelines of the individual ejectors during the maintenance shutdown; meanwhile, check ejectors for severe damages and replace in time if necessary.

Liquid accumulated in the steam pipes should be drained completely during startup.

Condensation efficiency decrease of surface vacuum condensers

Increase the inlet pressure of the circulation cooling water and decrease its temperature as much as possible in order to enhance the condensation efficiency of surface vacuum condensers in each stage;

Check the vacuum condensers to see if inert gases exist and remove them in time if any; completely fill the equipment with cooling water so as to enhance the condensation efficiency of surface vacuum condensers in each stage;

Clean the surface vacuum condensers in each stage with chemicals to remove any carbonates or other foreign matters inside them during a shutdown so as to improve greatly the heat-exchange efficiency of surface vacuum condensers in each stage;

Check and confirm that the valves between the vacuum condensers and the ammonia water tank are open prior to startup in order to prevent the accumulation of a large quantity of liquid in the condensers, which may otherwise affect the vacuum condition in the system.

Malfunction of instruments or blockage of pressure indicators

Contact responsible instrumentation professionals in time for treatment in case of malfunction of instruments;

When crystallization plugging occurs in a pressure indicator tubes, disassemble the connection between the pressure indicator and the tubes, put condensate on the tubes and dissolve the crystals by creating vacuum pressure in the evaporator separator; or connect the tubes with steam for purging out the crystals. However, it must be noted to close the valve between the tubes and pressure transmitter during purging process, otherwise the instruments may be damaged.

Leaks of pipeline/equipment, excessively low liquid level control and/or gas leaks

Vacuum can be restored after shutting down and repairing the equipment when a failure occurs. In order to check the tightness of the evaporation system, vacuum pressure test should be performed before each startup of the evaporation system to find any problems (such as leaks, etc.) and solve these in time.

Strictly control the position of the pressure control valve and the liquid level in the ammonia water and urea solution tanks in order to prevent leak-in of air.

Check the vacuum-breaking valves to see any leaks and solve leakage problem if any.

Conclusions

Because many factors affect the vacuum of the evaporation section, corresponding measures should be taken to effectively solve problems like failure of vacuum pressure, low vacuum degree, etc. of the evaporation section which occur during startup or production, in order to ensure smooth startup of the evaporation system, and all urea products are up to standard quality.

Translator notes:

This is a Technical Paper originating from our Chinese partner: www.Ureanet.cn. The paper was original in Chinese language and it is translated and interpreted into English with care and as much as reasonable possible accuracy, all to the best of our abilities.