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Case Report

Application of Supergravity Technology in a TEG Dehydration Process for Offshore Platforms

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Keywords: supergravity technology; TEG; natural gas dehydration; Higee

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1. Problem Description

Natural gas usually contains water vapor when it leaves the reservoir. When the pressure and temperature of natural gas change, water vapor easily forms the hydrate. Local accumulation of hydrate will restrict the flow rate of natural gas in the pipeline, increase pressure drop, reduce gas transmission capacity, and even block the pipeline seriously, leading to gas interruption. At the same time, moisture in natural gas is also the main factor causing corrosion of equipment, instruments, and pipelines. Therefore, in order to ensure the normal operation of pipelines, natural gas must be dehydrated. The GB50251 standard [1] states that the water dew point of natural gas must be 5 °C lower than the lowest temperature along the various sections of the gas pipeline.

The conventional natural gas dehydration processes in oil and gas fields are solvent absorption and solid desiccant adsorption. At present, glycol absorption dehydration and molecular sieve adsorption dehydration are widely used. The difference between the two methods is the depth of dehydration. Triethylene glycol (TEG) dehydration technology is the most widely used in the natural gas dehydration process. Usually, the main equipment of a TEG dehydration system includes a TEG absorption tower, TEG heating furnace, TEG regeneration tower, TEG circulating pump, and so on. Although the process is widely used, its shortcomings cannot be ignored: (1) When the regeneration tower is in normal production, some of the light hydrocarbons are inevitably contained in the water vapor discharged from the top of the tower. This part of the light hydrocarbons will be directly discharged into the atmosphere, causing pollution to the surrounding atmospheric environment and increased risk of fire accidents. (2) A TEG heating furnace generally uses a natural gas open flame heating furnace, and the decomposition temperature of TEG is 206 °C, so the burner performance directly affects the thermal efficiency of the furnace and easily causes damage to the furnace tube. (3) The tower equipment covers a large area, has low mass transfer efficiency, and limited treatment capacity [2].

At present, in the offshore gas field production operation, due to the lower control index requirements of the natural gas dew point, the TEG dehydration process is generally used. The conventional TEG dehydration process is shown in Figure 1. However, due to site constraints, the size of the absorption tower is generally relatively small. In the case of fluctuation of raw gas and large gas production, it is easy to cause large losses of TEG and tower flooding events [3]. With the continuous development of offshore oil and gas fields, the field conditions have changed. The instability of the traditional dehydration process results in the corrosion of platform equipment and pipelines. Therefore, it is not suitable to directly adopt the conventional triglyceride dehydration process and equipment for offshore platforms with a tight area and limited weight.

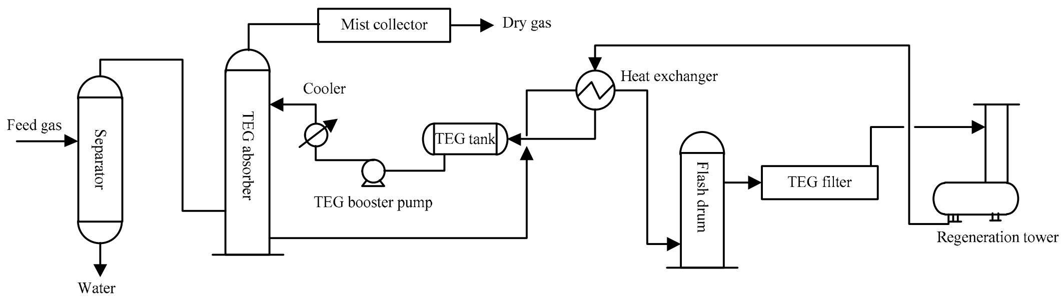


Figure 1. Conventional triethylene glycol (TEG) dehydration process.

Supergravity technology is a new generation of chemical separation technology [4]. Although developed in the 1980s, the high gravity machine (Higee) is a rapidly developing multi-media contact reaction equipment. Compared with the tower equipment, the mass transfer coefficient is one to three orders of magnitude higher. The size and weight of the equipment is only a few percent of the tower equipment. Furthermore, the footprint is greatly reduced, which is very suitable for offshore platforms. This paper takes the TEG dehydration system of an offshore platform as an example to verify the feasibility of replacing the original tower equipment with the super gravity equipment. According to field research, the TEG dehydration system of the offshore platform has the following specific problems:

(1) Gas composition changes

During the mining process, the composition of natural gas changes (Table 1), and the composition of C_3^+ increases, so that excessive light hydrocarbons are mixed with TEG, causing TEG to foam and affect the dehydration effect.

Table 1. Natural gas component.

Composition	Design Value	Actual Value
CH_4	90.47	79.78
C_2H_6	3.84	6.29
C_3H_8	2.13	2.51
i-C_4	0.48	0.41
n-C_4	0.81	0.88

Table 1. *Cont.*

Composition	Design Value	Actual Value
i-C_5	0.31	0.25
n-C_5	0.27	0.38
C_6	0.31	0.02
CO_2	1.03	7.86
N_2	0.35	1.63

(2) Insufficient operation capacity of dehydration tower

The TEG dehydration tower has a diameter of only 762 mm and a treatment capacity of 115 × 10^4 m^3/d under full load conditions. Now it needs to process 160 × 10^4 m^3/d of natural gas, which puts tremendous pressure on the operation of the tower equipment.

(3) Dew point is unqualified

Due to the increase in natural gas flow, the dew point is difficult to meet the requirements. In 2007, the dew point requirement was −24 °C, and in 2011 the dew point was 0 °C.

Therefore, it has been difficult to meet the requirements of the offshore platform using the conventional TEG dehydration system.

2. Literature Review

In supergravity technology, a rotating annular porous packed bed is used instead of a vertical stationary tower, so that gas–liquid contacts fully in the rotating packed bed. The process of mass transfer and heat transfer is strengthened by the high dispersion of the liquid phase, rapid surface renewal, and strong perturbation of phase interface in the Higee. Compared with the tower equipment, the volume mass transfer coefficient is one to three orders of magnitude higher. The volume and weight of the equipment is only a few percent of the tower equipment. It is called "the transistor of the chemical industry". The principle of the Higee is shown in Figure 2 [5].

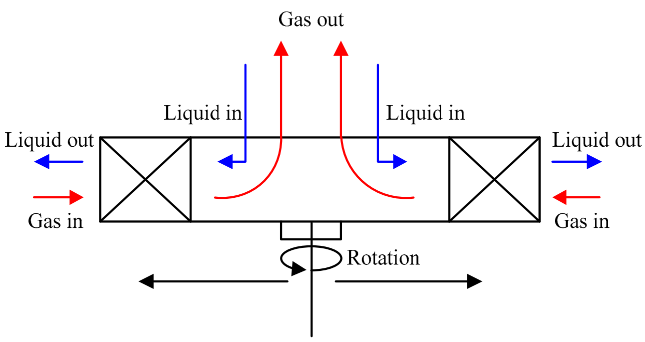


Figure 2. Working principle diagram of the high gravity machine (Higee).

At present, the research of high gravity fluidized bed technology focuses on the application of different materials in the drying process, including the initial fluidization behavior of different materials and the study of mass transfer and heat transfer rate in the drying process. Qi et al. [6] used high gravity equipment to desulfurize, and analyzed the influence of rotational speed, temperature, and other factors on desulfurization rate. The results showed that the desulfurization rate of this method was higher than 99% and proved that the equipment had the characteristics of high efficiency and small volume compared with traditional tower equipment. Xing et al. [7] studied the removal efficiency of carbon dioxide from flue gas of boilers by using a high gravity rotating bed. The effects of absorption liquid concentration and liquid flow rate on the absorption efficiency were investigated. It was found that the removal efficiency of carbon dioxide could reach 85.81%, which was 25% higher than that of tower equipment. Wang [8] used the mixture of air and sulfur dioxide to simulate the flue gas and studied the desulfurization in a rotating packed bed by double alkali method. The optimum technological conditions for the absorption of sulfur dioxide by sodium hydroxide solution in a rotating packed bed were determined. Liu et al. [9] used water, calcium hydroxide, and magnesium hydroxide suspension as absorbents to carry out flue gas desulfurization experiments in a rotating packed bed. The effects of absorbent concentration, flow rate of absorbent, rotating speed of rotating packed bed, and concentration of sulfur dioxide in inlet gas on mass transfer rate were investigated. The effects of various factors on mass transfer rate of sulfur dioxide and their causes were analyzed. The results show that under the known experimental conditions, the reaction rate of sulfur dioxide absorption by alkaline liquids is three to four times that of water. At the same time, the reaction rate of sulfur dioxide can be greatly increased by increasing the flow rate of alkaline liquids and the rotating speed of the high gravity rotating bed.

High gravity technology can be used not only in desulfurization and decarbonization, but also in denitrification and ammonia absorption industries. However, this technique is rarely used in TEG dehydration systems. A new process for gas drying based on the supergravity technology applied to the offshore platform is proposed, in which the high-gravity machine replaces the absorber unit of the conventional TEG dehydration device. Consequently, the retention time of the absorbent is reduced and the apparatus like the holding tank downsized. The developed process is a low-cost method for water removal from the natural gas and it is significant progress to apply the supergravity technology to gas dehydration.

3. Theory and Method

3.1. Structure of the Higee

A Higee uses a rotating packed bed and an annular porous packing for gas and liquid contact. The structure of the high gravity machine is shown in Figure 3. The gas phase is introduced into the outer cavity of the rotating shaft by the gas inlet pipe under the action of the pressure gradient and enters the packing through the outer edge of the rotating shaft, and the liquid is sprayed on the inner edge of the rotating shaft by the inlet pipe through the nozzle under the action of the pump. The packing rotor rotates at high speed under the driving of the motor to form a super-gravity environment far greater than the gravitational acceleration. The liquid entering the rotating shaft is affected by the packing in the rotating shaft, and the circumferential speed increases and the centrifugal force generated pushes it toward the outer edge of the rotating shaft. During this process, the liquid is dispersed, broken up by the filler, and forms a large, constantly renewed surface area, and the tortuous flow path exacerbates the renewal of the liquid surface [10]. Therefore, excellent mass transfer and reaction conditions are formed inside the rotating shaft. The liquid is thrown into the outer casing by the rotating shaft and then exits the rotating packing bed through the liquid outlet pipe. The gas rotates away from the rotating shaft at the center of the rotating shaft and is led out by the gas outlet pipe to complete the mass transfer [11].

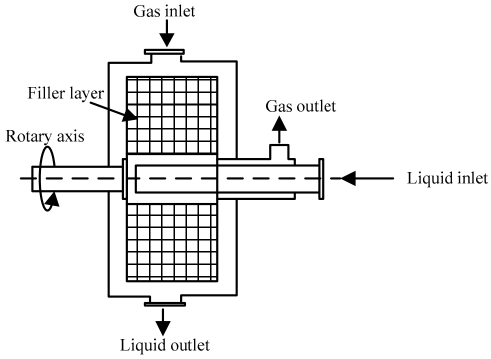


Figure 3. Structural sketch of the Higee.

3.2. Mass Transfer Model

3.2.1. Liquid Phase Mass Transfer Coefficient

The effect of gas volume change on the flow of liquid during countercurrent operation of the rotating packed bed is not particularly obvious. Therefore, the influence of the gas phase on its flow is ignored during the discussion of the liquid phase mass transfer coefficient. In the supergravity field, the surface renewal speed of the liquid is quite fast due to the impact of the liquid on the rotating packing [8,9]. Therefore, the surface renewal theory is used to calculate the liquid phase mass transfer coefficient. According to the surface renewal theory of Danckwerts [12], the theoretical formula for calculating the liquid mass transfer coefficient is:

$$K_L = \sqrt{DS} \tag{1}$$

where K_L is the liquid phase mass transfer coefficient, m/s; D is the liquid diffusivity, m^2/s; S is the surface renewal rate, 1/s.

To calculate the liquid phase mass transfer coefficient, the liquid diffusivity D and the surface renewal rate S must be calculated. The liquid diffusivity D is obtained according to the Wilke–Chang formula [13]:

$$D = \frac{1.173 \times 10^{-13} T \sqrt{\phi M}}{\mu V_m^{0.6}} \tag{2}$$

where T is the temperature, K; Φ is an association factor for the solvent; M is the molecular mass of solvent; μ is the viscosity of solvent, $mN{\cdot}s/m^2$, V_m is the molar volume of the solute at its boiling point, m^3/kmol.

In the rotating packings, the surface renewal rate is fast, and it is dictated by two components in the radial direction and tangential direction, respectively [14].

It is assumed that the surface is renewed once the liquids pass through a layer of the rotating packing in the radial direction. The renewal rate of the radial surface S_{radial} is:

$$S_{\text{radial}} = u_{\text{radial}} \frac{N}{R_1 + R_2} \tag{3}$$

where u_{radial} is the average radial surface velocity of the liquids, m/s; R_1 and R_2 are the inner and outer diameters of the packed column, respectively, mm; and N is the number of the layer.

It is assumed that the surface is also renewed every time the liquids collide with the rotating packing in the tangential direction. According to the time consistent principle in the radial and tangential direction of the packing, the renewal rate of the tangential surface $S_{\text{tangential}}$ is:

$$S_{\tan\text{gential}} = \frac{u_{\tan\text{gential}}}{u_{\text{radial}}} \frac{l_{\text{radial}}}{l_{\tan\text{gential}}} \cdot S_{\text{radial}} \tag{4}$$

where $u_{\text{tangential}}$ is the average tangential velocity of the liquids, m/s; u_{radial} is the average radial velocity of the liquids, m/s; $l_{\text{tangential}}$ is the circumferential center distance between the adjacent layers, mm; and l_{radial} is the radial center distance between the adjacent layers, mm.

3.2.2. Gas Phase Mass Transfer Coefficient

The gas phase mass transfer coefficient is calculated using the empirical correlation equation [15]:

$$k_G = C\left(\frac{G}{a_p \mu_G}\right)^{0.7} \left(\frac{\mu_G}{D_G \rho_G}\right)^{1/3} \left(a_p d_p\right)^{-2.0} \left(a_p D_G\right) \tag{5}$$

where k_G is the gas phase mass transfer coefficient; C is the coefficient constant; G is the mass flow of vapor phase, kg/s; ρ_G is the gas density, kg/m^3; a_p is the specific surface area of packing, m^2/m^3; μ_G is the gas viscosity, kg/m·s; D_G is the TEG diffusion coefficient, m^2·s; R is the gas constant, 8.314; T is the gas temperature, K; and d_p is the effective diameter of packing.

4. Laboratory Experiment

4.1. Experiment Conditions

In order to verify the feasibility of the proposed method, a laboratory experiment was used. The flow chart of the experiment is shown in Figure 4. The experiment can be divided into five systems: TEG regeneration system, TEG dehydration system, dew point control system of the feed gas, detection system, and Higee. The description of each system is shown in Table 2.

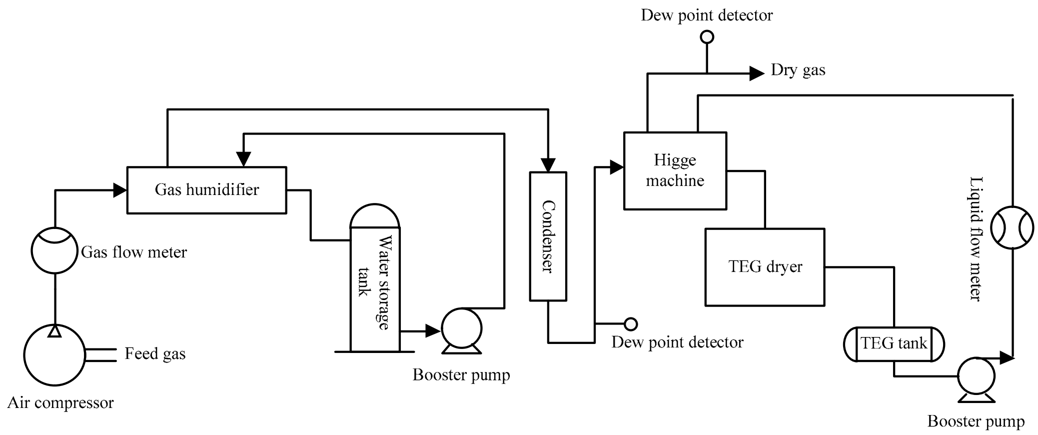


Figure 4. Experiment flow chart.

Table 2. Description of each system.

System	Description
TEG regeneration system	The conventional way for TEG regeneration is heating. Since the heating is not well controlled in the laboratory, a dryer is used to regenerate TEG in this experiment.
TEG dehydration system	A small air compressor is used to supply gas source and a booster pump is used to supply poor TEG for the Higee.
Dew point control system of the feed gas	Control the feed gas dew point by a combination of artificial humidification and condensation.
Detection system	A gas phase flow meter, a liquid phase flow meter, air inlet and outlet dew point detector of Higee are arranged on the TEG treatment process for detecting the parameters of each point and evaluating the treatment effect. The liquid phase flow rate is 100–800 L/h, and the gas phase flow rate is 2–20 m^3/h. Liquid phase flow and gas phase flow are controlled by valves.
Higee	The selected Higee is a small-scale test machine with a filler of steel mesh, with an axial length of 80 mm, a rotor inner diameter of 70 mm, and a rotor outer diameter of 206 mm. Operating parameters: rotor speed is 0–1300 r/min.

In the TEG dehydration experiment, the influence of the TEG flow rate, the super-gravity packed bed rotation speed, and the gas flow rate on the air dew point were analyzed. The experimental conditions are shown in Table 3.

Table 3. Experimental conditions.

Influence Factor	Variation Range	Experimental Condition
TEG flow rate	100–600 L/h	TEG concentration: 99%–99.7% TEG concentration: 98%–99% TEG concentration: <98%
Super-gravity packed bed rotation speed	400–1200 r/min	TEG concentration: 99%–99.7% TEG concentration: 98%–99% TEG concentration: <98%
Gas flow rate	6–16 L/h	TEG flow rate: 200 L/h TEG flow rate: 400 L/h TEG flow rate: 600 L/h

4.2. Conventional Analysis

(1) TEG flow rate

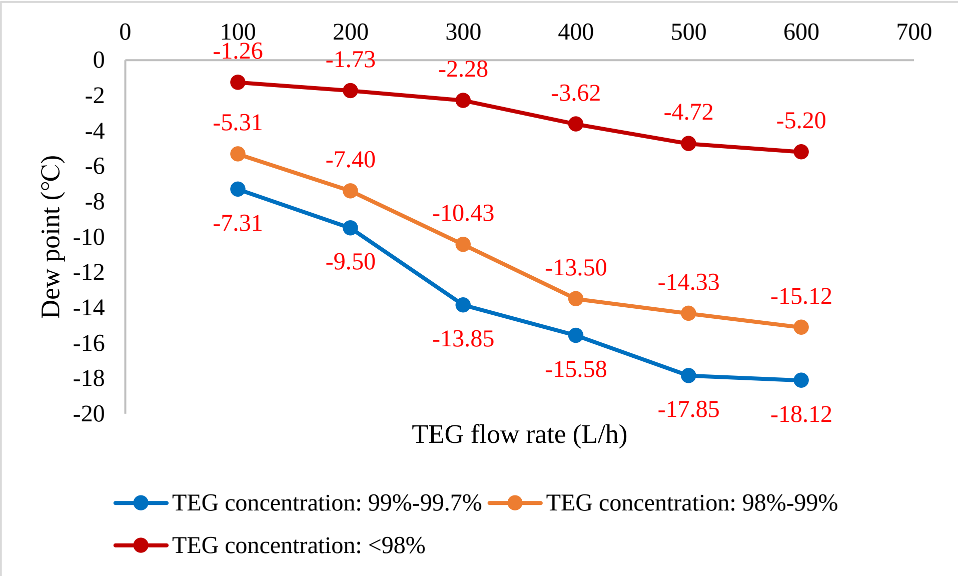
As can be seen from Figure 5, the influence of TEG flow on dew point was very significant. Under a certain rotational speed, dew point decreased with the increase of TEG flow rate. This was because the increase in flow rate increased the chance of gas–liquid contact and increased the impetus of mass transfer. In addition, the absorbent liquid rotated with the rotor and achieved a higher tangential velocity when moving along the packing layer. The liquid was dispersed into small droplets, liquid film or liquid filament in the packing layer, which reduced the mass transfer resistance of the gas–liquid phase and improved the mass transfer coefficient.

The effect of concentration of TEG solution on dew point was also obvious. The effect of mass transfer at high concentration was much stronger than that at low concentration. The water content in poor solutions should be less than 1%, and the water content in rich solutions should not be more than 5%–6%. Therefore, the concentration of poor TEG solution was between 98% and 99.5%, and that of rich TEG solution was between 93% and 97%.

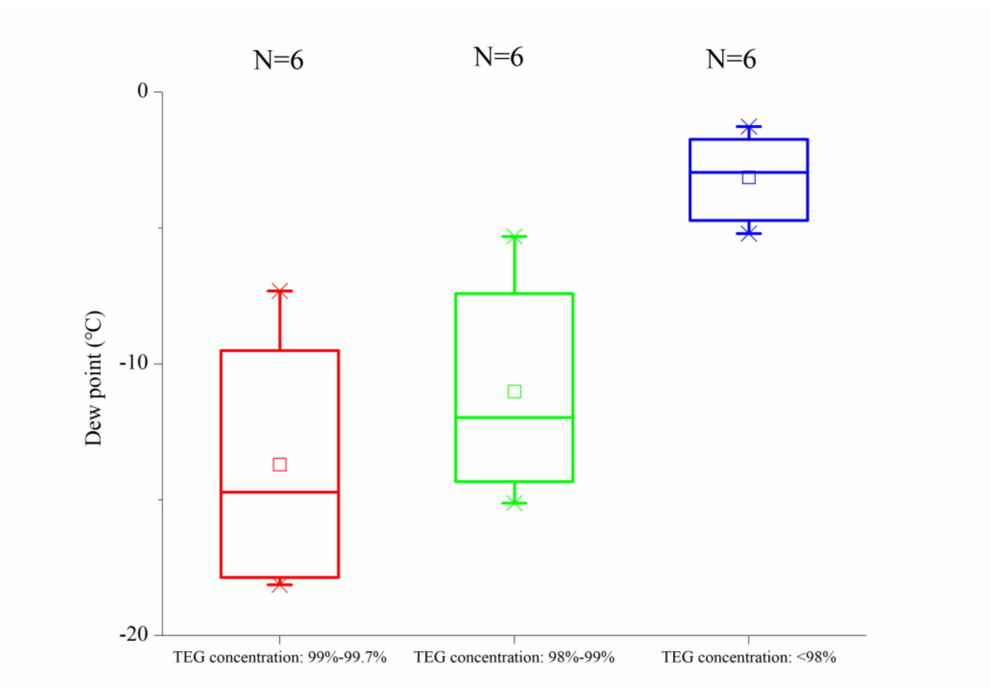
When the flow rate was less than 400 L/h, the dew point decreased very little; even if the concentration of TEG was higher, the effect was not ideal. The main reason was that when the flow rate was too low, the pressure head of the TEG solution was low. After entering the Higee, the liquid could not flow out in a jet but flowed down at a low speed. In this way, the liquid could not all enter the high-speed rotating wire mesh packing; on the contrary, it increased the mass transfer resistance between the gas phase and liquid phase and reduced the absorption of TEG. When the flow rate was above 400 L/h, the dynamic pressure head of TEG was large enough. However, when the flow rate of TEG was too large because the viscosity of TEG was too high, the flow requirement was higher and the increased power undoubtedly increased the consumption of electricity. Therefore, it was very important to find out the optimal liquid flow rate for industrial implementation and operation.

(2) Super-gravity packed bed rotation speed

As shown in Figure 6, when TEG flow rate was constant, the mass transfer coefficient increased with the increase of rotating speed of the rotating bed rotor. This was because it accelerated the movement of liquid in the packing layer, increased the turbulence of liquid, enlarged the gas–liquid contact area, enlarged the mass transfer coefficient, and decreased the dew point of gas significantly. When the rotational speed exceeded a certain range, the increase of rotational speed made the gas–liquid contact time less, and the influence of rotational speed on mass transfer coefficient was not obvious, so the change of dew point tended to be stable. Considering comprehensively, the rotating speed of the rotating bed of the Higee was determined to be greater than 800 rpm.



(a)



(b)

Figure 5. Effect of TEG flow rate on dew point. (**a**) Experimental data; (**b**) Box-plot.

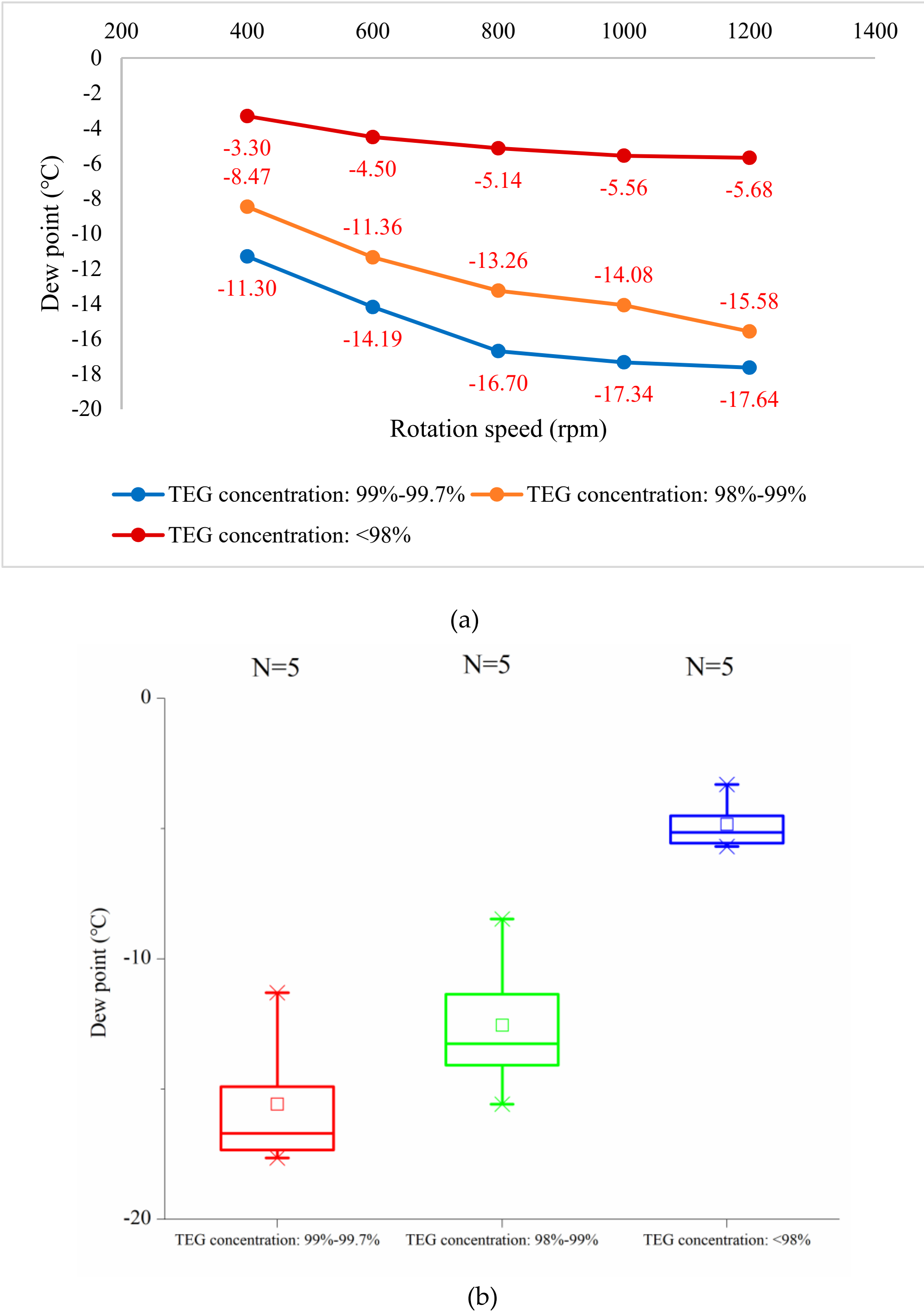
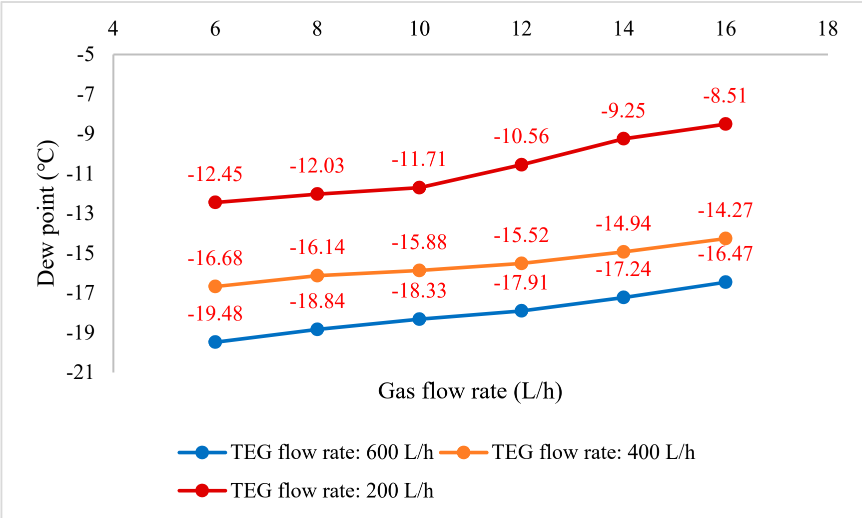


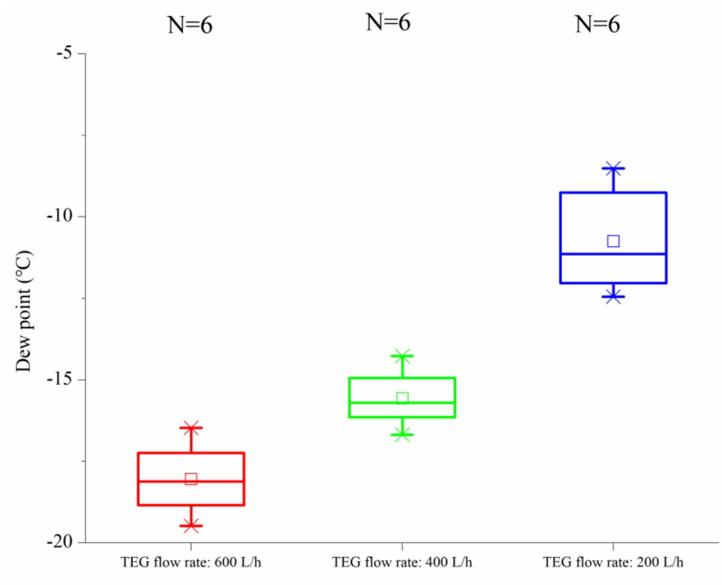
Figure 6. Effect of rotation speed on dew point. (**a**) Experimental data; (**b**) Box-plot.

(3) Gas flow rate

Figure 7 shows that when TEG flow rate was greater than 400 L/h, the gas flow rate had little effect on dew point, but when TEG flow rate was 200 L/h, the gas flow rate had a significant effect on dew point, and dew point increased with the increase of gas flow rate. When the rotational speed and the water content in the gas flow were constant, the increase of gas flow rate had little effect on dew point under the large TEG flow rate. Under the small TEG flow rate, the dew point increased with the increase of gas flow rate, and the effect was significant.



(a)



(b)

Figure 7. Effect of gas flow rate on dew point. (**a**) Experimental data; (**b**) Box-plot.

(4) Dehydration balance

Based on the above experimental results, the dehydration balance of the rotating packed bed in the modified TEG dehydration process was defined to evaluate its dehydration performance. Dehydration balance is defined as:

$$\alpha = \frac{P_v}{P_s} \times 100\% \tag{6}$$

where α is the dehydration balance; P_v is the saturated vapor pressure of the poor TEG solution; and P_s is the saturated vapor pressure of the gas at the outlet.

Figure 8 shows the dehydration balance obtained from a set of experiments. The experimental conditions were as follows: the rotating speed of the rotating bed rotor was 1000 rpm, the liquid–gas ratio was 1:20, the temperature was 20 °C, and the water content of inlet air was 13 g/L. It can be seen that the dehydration balance of the dehydration by using rotating packed bed was above 95%, which was much higher than the dehydration balance of about 80% of the traditional tower dehydration equipment. It is fully explained that the dehydration performance of the rotating packed bed was far superior to the ordinary tower dehydration equipment. Under the same dehydration conditions, the rotating packed bed could also meet the dew point drop required for gas transportation.

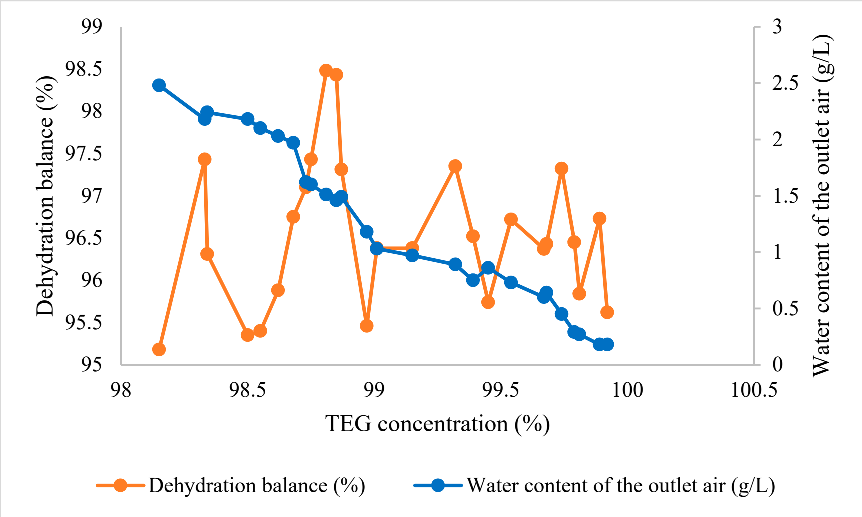


Figure 8. Effect of gas flow rate on dew point.

Through laboratory experiments, the following key parameters or conclusions can be drawn:

(1) The concentration of TEG should be more than 98%.
(2) The circulation of TEG should be greater than 300 L/h.
(3) The rotating speed of the rotating bed should be greater than 800 rpm.
(4) With the increase of gas flow rate, the dehydration effect becomes worse.

4.3. Analysis Based on Actual Working Conditions

In order to determine the benchmark conditions of field experiments under sudden change of gas flow conditions, laboratory experiments were carried out first, and the conditions of field experiments were selected by comparing the experimental results with the actual situation in the field. The three conditions to be determined included: water content in the gas, flow rate of TEG, and rotational speed of the Higee. In this experiment, air was used instead of natural gas. The specific experimental conditions are shown in Table 4. The experimental results are shown in Table 5.

Table 4. Experimental conditions.

Influence Factor	Variation Range	Basic Conditions
Water content in the air	1500–5000 mg/L	Air flow rate = 5000 L/h Pressure = 5.4 MPa Temperature = 50 °C Rotational speed of packed bed = 800 rpm Flow rate of TEG = 6 L/h
Flow rate of TEG	4.5–7 L/h	Air flow rate = 5000 L/h Pressure = 5.4 MPa Temperature = 50 °C Rotational speed of packed bed = 800 rpm Water content in the air = 2300 mg/L
Rotational speed of the Higee	600–1000 rpm	Air flow rate = 5000 L/h Pressure = 5.4 MPa Temperature = 50 °C Flow rate of TEG = 6 L/h Water content in the air = 2300 mg/L

Table 5. Experimental results.

Influence Factor	Value	Water Content of Air at Outlet (mg/L)
Water content in the air	5000 mg/L	189
	3000 mg/L	163
	2500 mg/L	95
	2300 mg/L	82
	2000 mg/L	75
	1500 mg/L	40
Flow rate of TEG	4.5 L/h	142
	5 L/h	126
	5.5 L/h	105
	6 L/h	83
	6.5 L/h	62
	7 L/h	41
Rotational speed of the Higee	600	90
	700	88
	800	81
	850	79
	900	75
	1000	69

According to the actual situation on site, the gas–liquid ratio in natural gas was 833:1, so it was appropriate to select 2300 mg/L for the water content in the gas. By analyzing the factor of TEG flow, it can be seen that the TEG flow had a great influence on the water content of the outlet air. Based on the field data, the flow rate of TEG was selected to be 6 L/h. Finally, the rotational speed of the supergravity machine had little effect on the dewatering effect, so a moderate parameter of 800 rpm was chosen.

5. Field Experiment

5.1. Experiment Conditions

According to the characteristics of oil and gas treatment process on the offshore platform, the high gravity TEG dehydration process was simplified and field experiments were carried out. The experimental process is shown in Figure 9. TEG from the pharmaceutical tank was pumped into the liquid inlet of the Higee through the pharmaceutical circulation pump, and the liquid entered the rotating packed bed; the natural gas to be treated entered the rotating packed bed from the gas inlet of the Higee; under the action of the rotating packed material, the gas and liquid were broken into fine particles and fully contacted on the wire mesh packing. The purified gas entered the separator from the gas outlet of the Higee and then into the gas pipeline. The liquid phase entered the TEG regeneration system from the liquid outlet of the Higee. The interface parameters of Higee are shown in Table 6.

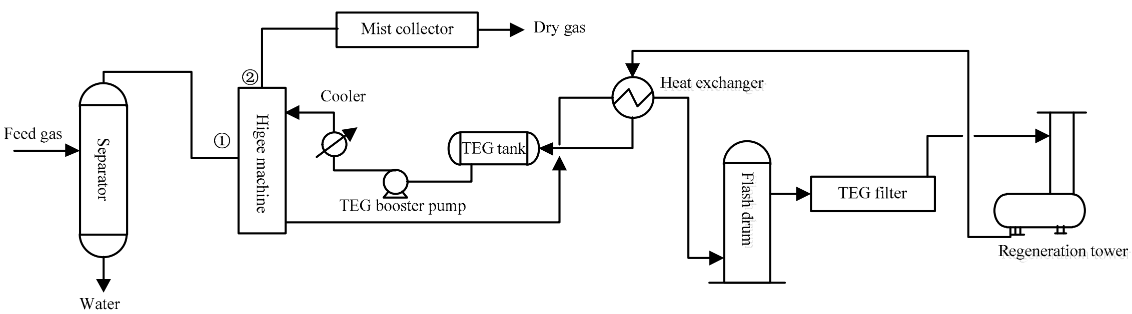


Figure 9. Flow chart of field experiment.

Table 6. The interface parameters of the Higee.

Name	Location (In Figure 9)	Flange Diameter (Inch)	Temperature (°C)	Pressure (MPa)	Dew Point (°C)
Inlet of the Higee	①	3/4	50–60	≤0.7	10.46
Outlet of the Higee	②	1/2	/	0.1	/

Before the on-site experiment, the field device needed to be modified, including process connection, pipeline pressure testing, tank cleaning, equipment debugging, and so on. Two barrels of TEG medicinal agent were prepared, and after the dehydration test, the TEG rich liquid in the supergravity apparatus was sampled and analyzed to observe the loss of the TEG medicinal agent. The monitoring instrument inspection included whether the various instruments were complete, whether they were properly connected, and whether the display data was abnormal. The air tightness of the equipment was rechecked and a pressure holding test was performed.

In the experiment, the operating pressure of feed gas was 0.7 MPa, the operating temperature was 50–60 °C, and the flow rate of natural gas was controlled by a valve. The purity of TEG was 98%–99%. Dry gas was vented through the torch to avoid direct discharge of combustible gas into the atmosphere. Since the distance between the TEG booster pump and the separator was 60 m, in order to avoid the temperature drop of TEG affecting the dehydration effect, the necessary insulation measures were taken in the experimental process. The specific parameters of Higee are shown in Table 7.

Table 7. The specific parameters of the Higee.

Parameter	Value
Processing capacity	160×10^4 m^3/d
Water content at the inlet	1400 mg/L
Water content at the outlet	<150 mg/L
Equipment size	2.0 m × 1.0 m × 3.0 m (length × width × height)
Motor power	37 kW
Drive mode	Magnetic drive
Filler volume	0.1 m^3
Filler material	316 L

In this paper, four working conditions were selected as the research objects: 1. conventional working condition; 2. sudden change of gas flow condition; 3. dry gas source condition; and 4. continuous operating condition.

5.2. Experiment Results

5.2.1. Conventional Working Conditions

The data of field experiments were monitored by the dew point detector and collected every 20 min. The data are shown in Table 8.

Table 8. Experimental results under conventional working conditions.

Operating Pressure	Time	TEG Flow Rate (m^3/h)	Gas Flow Rate (m^3/h)	Dew Point at the Inlet (°C)	Dew Point at the Outlet (°C)	Gas Bubble
0.32	13:40	5.2	12.0	10.45	−25.43	Not found
	14:00	5.0	12.5	10.31	−25.26	Not found
	14:20	4.0	11.0	11.09	−24.71	Not found
	14:40	4.1	12.5	10.88	−24.82	Not found
	15:00	3.0	13.0	10.26	−24.41	Not found

Table 8. *Cont.*

Operating Pressure	Time	TEG Flow Rate (m^3/h)	Gas Flow Rate (m^3/h)	Dew Point at the Inlet (°C)	Dew Point at the Outlet (°C)	Gas Bubble
0.32	15:20	2.9	12.4	10.42	−24.35	Not found
	15:40	2.1	12.2	10.35	−24.02	Not found
	16:00	1.9	11.8	10.67	−23.95	Not found
	16:20	1.0	13.2	10.04	−23.83	Not found
	16:40	1.1	12.8	10.31	−23.67	Not found
	17:00	0.6	11.9	10.49	−24.78	Not found
0.30	8:30	0.5	12.5	10.65	−25.67	Not found
	8:50	0.5	13.1	10.43	−25.26	Not found
	9:10	0.4	11.0	10.37	−26.05	Not found
	9:30	0.4	11.6	10.69	−26.12	Not found
	9:50	0.3	12.2	10.74	−26.31	Not found
	10:10	0.3	12.4	10.35	−26.42	Not found
	10:30	0.2	12.8	10.50	−27.45	Not found
	10:50	0.2	13.0	10.21	−27.03	Not found
	11:10	0.1	12.7	10.93	−25.73	Not found
	11:30	0.1	12.5	10.82	−25.86	Not found

Observing the effect of different gas–liquid ratios on dehydration, it was found that the dew point of gas decreased when the concentration was high, but it also decreased when the flow rate was low. This was because the viscosity of TEG was relatively high. Under the condition of high liquid flow rate, the reflux was not as fast as expected, resulting in the high liquid level inside the Higee, which resulted in the effect of accelerated mass transfer not being obvious, but the effect was better when the flow rate decreased. When the flow rate was 0.6 m^3/h, the dew point was better when the gas–liquid ratio was close to 70:1.

Compared with the experimental results in the laboratory, the dehydration effect of the high gravity machine was obviously improved in the field experiment, because there was no heating of TEG in the laboratory; but under the heating conditions of the field experiment, the temperature of poor TEG solution was higher, the viscosity was relatively low, and the accelerated mass transfer effect of the Higee was more obvious. The dew point of the TEG in the field was about −26 °C, so the dew point of natural gas met the requirements.

5.2.2. Sudden Change of Gas Flow Conditions

Similar to the laboratory experiment, the dehydration effect of the Higee under the condition of sudden increase or decrease of gas flow was observed. The field data are shown in Table 9. Table 9 shows that the dew point at the outlet of the Higee increased slightly with the sudden increase of gas flow rate, but the dew point was still below −24 °C. In the case of sudden reduction of gas flow rate, the dew point of the gas continued to decrease, and the dehydration effect was better. Therefore, the dehydration effect was good in the case of sudden increase or decrease of gas flow.

Table 9. Experimental results under sudden change of gas flow conditions.

Operating Pressure	Time	TEG Flow Rate (m^3/h)	Gas Flow Rate (m^3/h)	Dew Point at the Inlet (°C)	Dew Point at the Outlet (°C)	Gas Bubble
0.30	13:30	1.0	50.3	10.38	−24.61	Not found
	13:50	1.0	30.7	10.46	−24.69	Not found
	14:10	1.0	31.6	10.69	−24.58	Not found
	14:30	1.0	12.5	10.27	−24.92	Not found
	14:50	0.2	12.9	10.62	−24.95	Not found
	15:10	0.2	31.8	10.03	−24.09	Not found
	15:30	0.2	30.5	10.44	−23.89	Not found

5.2.3. Dry Gas Source Conditions

In order to further verify the dehydration effect of Higee, low-pressure fuel gas (dry gas) was used as the gas source to observe the dew point change of the outlet gas from the Higee, as shown in Table 10. The analysis shows that the dew point of the dewatered gas continued to decrease after entering the Higee, which showed that the effect of supergravity dehydration was better.

Table 10. Experimental results under dry gas source conditions.

Operating Pressure	Time	TEG Flow Rate (m^3/h)	Gas Flow Rate (m^3/h)	Dew Point at the Inlet (°C)	Dew Point at the Outlet (°C)	Gas Bubble
0.30	16:00	0.2	12.5	−16.37	−26.21	Not found
	16:20	0.2	11.9	−16.11	−26.45	Not found
	16:40	0.5	12.3	−16.56	−25.89	Not found
	17:00	0.5	12.8	−16.27	−25.77	Not found

5.2.4. Continuous Operating Conditions

Due to the deposition of solid particles and coke hydrocarbons, the decrease of the pH value of TEG formed a black, viscous, and corrosive colloid, which reduceed the quality of TEG. Therefore, the dehydration effect of the continuous operation of Higee was analyzed, and the results are shown in Table 11. It can be seen that the dew point at the outlet of Higee changed little, all below −24 °C, indicating that supergravity dehydration was more stable under long-term operation.

Table 11. Experimental results under continuous operating conditions.

Operating Pressure	Time	TEG Flow Rate (m^3/h)	Gas Flow Rate (m^3/h)	Dew Point at the Inlet (°C)	Dew Point at the Outlet (°C)	Gas Bubble
0.69	14:10	1.2	12.5	10.18	−24.62	Not found
	14:30	1.1	25.3	10.76	−24.64	Not found
	14:50	1.1	52.5	10.29	−24.52	Not found
	15:10	0.9	71.3	10.37	−24.95	Not found
	15:30	1.0	92.5	10.32	−26.96	Not found
	15:50	0.7	91.3	10.43	−24.08	Not found
	16:10	0.5	92.0	10.54	−23.87	Not found
	16:30	0.3	90.5	10.28	−23.56	Not found
	16:50	0.3	91.6	10.46	−23.64	Not found

In order to reduce the drop in pH, the glycol was completely recovered into a clean container after shutdown and protected by natural gas or nitrogen. The seal of the pump packing was often checked to prevent oxygen from entering the circulation system with the pump plunger. The pH was maintained between 7.0 and 7.5. When the pH was too low, triethanolamine was added to adjust it.

6. Conclusions

In view of the limited space of offshore oil production platforms and the low efficiency of traditional tower equipment treatment, super-gravity technology was used to improve the conventional TEG dehydration process, and the feasibility of engineering applications of super-gravity TEG dehydration treatment was studied. Laboratory experiments and field experiments showed that the Higee can completely replace the traditional tower equipment for the TEG dehydration of natural gas. Furthermore, it can greatly improve the efficiency of dehydration and effectively control the dew point range of natural gas.

The analysis shows that in a certain range, increasing the rotational speed of the Higee, increasing the flow rate of TEG, and reducing the flow rate of natural gas are conducive to enhancing mass transfer in the gas–liquid reaction process. When the critical point is exceeded, the effect of dehydration is not obvious. In addition, through the analysis of various working conditions in the field experiments, it is shown that the Higee has obvious advantages over the traditional tower equipment.

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