Design and Application of Automatic Dust-free Convey Equipment for Heavy Medium Solid Material on Offshore Drilling Platform

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Abstract: The Yingqiong Basin, a large high-temperature and high-pressure gas field in the South China Sea, is one of the three high-temperature and high-pressure areas in the world. According to incomplete statistics, from 1984 to 2013, a total of 30 high-temperature and high-pressure exploration Wells were drilled in the South China Sea. According to the drilling situation, there were 4 ultra-high temperature and high-pressure Wells with temperatures over 200°C and mud gravity over 2.20sg. With the increasing demand for oil and gas in China, the drilling operations of HP/HT Wells are also increasing, which is the inevitable trend of the development of oil and gas drilling technology. Due to the high pressure of Wells, drilling fluid need to be weighted by additives during cementing operations. In the past, these operations on offshore platforms were all done by manual. Therefore, we developed a set of positive-negative pressure conversion type continuous conveying device which integrated a weight medium negative pressure cutting device. The device consists of negative pressure dust-free feeding system, negative pressure conveying system, positive and negative pressure continuous conveying system, dust removal system and automatic control and detection system. It can realize flexible pipeline transmission through negative pressure and positive pressure. The device contains a variety of detectors to detect the operation situation in real time, and the control system can realize the functions of automatic control and automatic fault alarm. The results of experiment and field application show that the device can meet the high demand of heavy medium transportation.

1. Introduction
In the development of high temperature and high-pressure gas fields in the western South China Sea, it is usually necessary to carry out cleaning fluid and spacer weighting operation\textsuperscript{[1]}. In the past, the conventional practice is to manually cut the bag for weighting operation, which requires a lot of labor and has safety risks.

The research content of this paper is to develop a set of cement weighting agent configuration system specially used in HP/HT Wells based on the physical and chemical properties analysis of cementing weighting agent on offshore oil drilling platform. Its principle is to adopt the theory of negative pressure dust-free transport combined with modern control module to achieve dust-free automatic weight adding
operation

At present, domestic offshore oil drilling platforms have not put in weighted medium adding equipment. High-end offshore oil drilling platforms in the world are all equipped with customized material adding system, which has automatic process from front-end transportation of materials to material mixing.

In order to solve the shortage of existing weighting operations and ensure more environmentally friendly and efficient weighting material transportation, this paper developed a heavy medium negative pressure dust-free conveying equipment, and verified the reliability of the equipment through experiments. The main innovation point of the equipment is the use of HMI human-computer interaction interface control, and the integrated skid design. It can realize patrolling inspection, dust-free bag cutting and automatic operation during operation. This method can fundamentally reduce the labour intensity, safety risk and other problems. At the same time, accurate measurement and delivery guarantee the performance of weighting agent, avoid weighting agent stratification, and effectively improve the quality of cementing operation.

2. Process design

According to the use environment such as the use space of the drilling platform and the physical characteristics of the commonly used powder materials, the initial conditions of the process were determined and the process plan was made.

2.1. Physical characteristics of the powder materials

In order to make the conveying system design more reasonable, the research group of the author fully analyzed the physical characteristics of the materials to be transported:

(1) particle size distribution: 250-mesh sieve $\leq 3\%$; 1200 mesh sieve $\leq 3\%$;

(2) Bulk density: 250 mesh 2.7~2.8t/m$^3$; 1200 mesh 1.5~1.6t/m$^3$;

2.2. Operating environment

At present, the ambient temperature of the slurry blending operation on the drilling platform is -15°C ~45°C, and the relative humidity is less than 95%. According to the conditions of DF13-2B platform and the main deck of HYSY944 platform, the operating space of equipment should be less than 4500mm×2500mm×3200mm; The working area is in the platform danger zone 2, and the explosion-proof requirements are IIB T4; No dust can be seen.

2.3. Process

Pneumatic conveying is mainly divided into negative pressure (vacuum) conveying and positive pressure conveying[2]. In negative pressure conveying, the medium is transported in a closed space under the action of negative pressure, which has good dust removal effect. However, when gravity blanking is used, the equipment should be placed above the receiving tank, and the overall height exceeds the requirements of the platform. Moreover, the unpacking components and feeding components of the equipment cannot be integrated into the skid, and the integration degree is not high. Positive pressure conveying has the advantages of large conveying capacity and long conveying distance, but the dust-free operation is worse than negative pressure conveying, so it cannot play the greatest role in protecting the environment and the health of the workers[3]. Based on the comprehensive analysis of the actual use environment and the technical characteristics of pneumatic conveying, the process scheme of "negative pressure feeding + positive pressure conveying" (as shown in Figure 1) was developed to realize the automatic and dust-free conveying of heavy media materials.
The vacuum pump is used as the vacuum power source to keep the material transfer pump in a vacuum state, and the powder material is fed with negative pressure and dust-free in combination with the special ton bag unpacking machine with micro-negative pressure dust removal structure. Then the material is fluidized in the material transfer pump with compressed air and transported to the specified position. Under the control of the automatic control system, the two material transfer pumps alternate between feeding and conveying, realizing automatic and continuous conveying of materials.

3. Equipment design

According to the determined process scheme and design requirements, the material density is 5.15t/m³, the bulk density is 2.8t/m³, the particle size is 0.06mm, the moisture content is less than 10%, the throughput is 12t/h, the mixed system of "negative pressure feeding + positive pressure conveying" is adopted.

3.1. Key parameter calculation

3.1.1. Negative pressure feeding

According to the process plan, the vertical length of the negative pressure feeding section is less than 3m, the horizontal length is less than 4.5m, the total length is less than 10m, and there are six 90° elbows with a curvature radius of 400mm.

(1) According to the throughput of 12t/h, determine the calculated productivity:

\[ G_s = \frac{G_d K_1 K_2}{T} = 13.2 \text{t/h} \] (1)

Where \( T \)- the working hours of the device day and night, h; \( K_1 \)-Non-uniformity coefficient of material transmission, take 1.1; \( K_2 \)- Consider the long-term development coefficient, Take 1; \( G_d \)- average day-night throughput, t.

(2) According to the conveying process and material characteristics, the solid-gas ratio \( m=5.2 \text{kg/kg} \), then the calculated air volume is determined:

\[ Q_a = \frac{G_a}{\rho_a} = 1950 \text{m}^3/\text{h} = 32.5 \text{m}^3/\text{min} \] (2)

Where \( G_a \)-the calculated productivity of the device, kg/h; \( \rho_a \)- air density, 1.3kg/m³ in standard state.

(3) Calculate the inner diameter of the feed pipe \( D \)

According to the physical properties of the material, the reasonable average speed of conveying material is estimated:

\[ v_t = \alpha \sqrt{\rho_m g} + \beta L = 31 \text{m/s} \] (3)

Where \( \alpha \)-the particle size of the material is in the Newtonian resistance region[5] according to the particle size coefficient of the transported material, then \( \alpha = 5.9 \); \( \rho_m \)-bulk density of the material,
be equipped with a vacuum pump and the air should be transported, \( \beta = (2-5) \times 10^{-5} \), a smaller value is desirable for dry powder; L-conveying distance, \( \Delta L = 15.4 \times 10^3 \) m. Therefore, the size of pleated cloth bag is \( \phi_1 = 130 \text{mm} \times 1200 \text{mm} \), and the number is 21 pieces.

(3) Calculation of dust removal equipment for negative pressure system

The drape cloth bag is used as the main dust removal device. According to the total calculated air volume of the system, the total air volume of filtration is determined as follows:

\[
Q = \frac{2125}{\sqrt{3600 \pi \rho_{\text{a}}}} = 0.149 \text{m}
\]  

(4) Calculation of pressure loss of negative pressure system

Other pressure loss (including vacuum pump intake pipe, exhaust pipe and muffler pressure loss)

\[
\Delta P_{\text{C}} = 25200 \text{ Pa}
\]

(5) Pressure loss caused by pure air

\[
\Delta P_{\text{a}} = \lambda_a \frac{l}{D} \times \frac{\rho_a v_a}{2}
\]

Where \( \lambda_a \) -friction resistance coefficient when pure air moves; \( l \)-pipe length, m; \( D \)-inner diameter of pipeline, m; \( \rho_a \)-air density, kg/m³; \( v_a \)-flow velocity, m/s.

(6) Local pressure loss

\[
\Delta P_{\text{a2}} = \xi \frac{\rho_a v_a^2}{2}
\]

Where \( \xi \)-Local drag coefficient.

(7) Friction pressure loss

\[
\Delta P_p = \lambda_a \frac{l}{D} \times \frac{\rho_a v_a^2}{2} (1 + m k_p)
\]

Where \( k_p = 81 \frac{\rho_D}{v_a} \times \frac{\rho_a}{\sqrt{C}} \), \( C = C_d \phi \), \( C_d \)- The drag coefficient of equivalent spherical particles, which can be determined according to Re. \( \phi \)-The shape coefficient of the particle, when it is sphere, \( \phi = 1 \).

(8) Acceleration pressure loss

\[
\Delta P_j = \xi_j m \frac{\rho_a v_a^2}{2}
\]

Where \( \xi_j \)-Acceleration pressure loss coefficient.

(9) Lifting pressure loss

\[
\Delta P_{\text{sh}} = m \rho_a g h \frac{v_a}{v_m}
\]

(10) Internal pressure loss of bag dust collector and transfer pump

\[
\Delta P_{\text{CC}} = 25200 \text{ Pa}
\]

(11) Other pressure loss (including vacuum pump intake pipe, exhaust pipe and muffler pressure loss)

\[
\Delta P_{\text{Q}} = 1400 \text{ Pa}
\]

To sum up, the total pressure loss \( \Delta P_e = 39463 \text{Pa} \). Considering the 20% margin, the system should be equipped with a vacuum pump and the air should be \( \Delta P_e = 1.2 \Delta P_e = 47355 \text{Pa} \).

At the same time, considering the 20% rich air volume, the air volume of vacuum pump is about \( 1.2 Q_a = 39 \text{m}^3/\text{min} \). The negative pressure conveying distance of the system should not be greater than
10m.

3.1.2. Positive pressure conveying
According to the process plan, the height of the positive pressure conveying part is 996mm, the Angle of the cone is 70°, the bottom fluidized diameter is 325mm, the vertical distance of conveying is less than 5m, the horizontal distance of conveying is less than 35m, and there are three 90° elbow.

(1) Calculation of fluidized gas volume
The Archimedes number of particle flow is obtained according to the working condition:
\[ A_r = \frac{d^2 g (\rho_m - \rho_a)}{v^2 \rho_a} \] (11)

The synthetic critical fluidization velocity was obtained by combining the A.H. Planovsky universal Re number and the critical fluidized voidage in fluidized bed[7]:
\[ \varepsilon = \left( \frac{18Re + 0.36Re^2}{A_r} \right)^{0.21} \] (12)

\[ v_f = \frac{150(1-\varepsilon)\mu}{3.5 \cdot d_s \rho_a} \left[ 1 + \frac{7}{150^2 (1-\varepsilon)^2} \frac{d_s^2}{\mu^2} \frac{(\rho_m - \rho_a) \rho_a g}{1} \right] \] (13)

The calculated fluidized velocity is 0.32m/s, so the calculated fluidized gas volume is about 1.6m³/min.

(2) Calculation of conveying air volume and conveying pipe diameter
The solid-gas ratio was selected as 19kg/kg to determine the calculated air volume:
\[ Q_a = \frac{G_s}{\rho_a} = 489 m^3/h = 8.15 m^3/min \] (14)

According to the empirical formula, the transmission wind speed was selected to be 11m/s. According to the formula (3-4), the inner diameter of the conveying pipe could be calculated to be 0.123mm. The seamless steel pipe with wall thickness of 5mm and outer diameter of 133mm was selected.

(3) Pressure loss calculation of positive pressure system
The corresponding pressure loss was calculated by formulas (3-6) ~ (3-10), and considering the elbow pressure loss and margin, the pressure loss of the positive pressure system was calculated to be about 60kPa. The reserve coefficient of pressure is set as 1.1, then the wind pressure of compressed air required for positive pressure conveying should be no less than 66 kPa.

Considering the air volume leakage rate of 6%, the total air volume of positive pressure conveying is at least
\[ Q_T = (1 + 6\%) (8.15 + 1.6) = 10.34 m^3/min, \text{ take } 10.5 m^3/min. \]

3.2. Equipment
The device uses the design concept of miniaturization, integration and skid-mounted integration. Due to the limited space of the offshore oil platform, the miniaturization integrated skid-mounted equipment can meet the demand of frequent movement and increase the space utilization rate of the offshore oil drilling platform.

The transmission mode of positive and negative pressure conversion realizes the closed and continuous conveying of materials. The equipment includes dust-free feeding system, negative pressure conveying system, positive and negative pressure continuous conveying system, dust removal system, automatic control and detection system, etc. The equipment is assembled as a whole skid-mounted equipment to meet the requirements of integration, modularization, small volume of equipment, convenient transportation.

The device structure is shown in Figure 2.
3.2.1. Dust-free feeding system

The dust-free feeding system is mainly composed of dust-free feeding bin, automatic cutting device, negative pressure dust collecting device around the upper part, dust collecting circulation hopper, negative pressure fan, etc. The dust-free feeding system can realize the automatic cutting of tons of bags and meet the dust-free treatment in the cutting process. The dust collection circulation hopper can promote the recycling of materials collected in the negative pressure dust-free treatment, which saves space and guarantees the material utilization rate.

3.2.2. Negative pressure conveying system

The negative pressure conveying system is mainly composed of star type quantitative conveying device, material gas mixing acceleration chamber, negative pressure vacuum pump and so on. The negative pressure conveying system allows the whole process of feeding to the storage tank to be completed under the negative pressure environment, which effectively controls the risk of air leakage during the positive pressure conveying and completes the dust-free operation during the feeding process.

3.2.3. Continuous conveying system

Continuous conveying system adopting the scientific research team to develop the manufacture HGMRI 1000 type pneumatic conveying pump. HGMRI 1000 type pump is a set of sending negative pressure suction and positive pressure conveying functions integrated equipment, the set of conveying system is composed of A and B pump together, two pump in the form of alternating work achieve the purpose of continuous work, to finish at the same time, the purpose of the negative pressure and positive pressure, is a key equipment in the system.

The continuous conveying equipment mainly has two functions: separation function is through the design and manufacture of cyclone offset structure to make the material in the pump efficient separation, at the same time greatly reduce the wear of the equipment and increase the conveying efficiency, and can collect the material stored in the pump; The conveying function is to design an appropriate fluidized pressurizing device by adopting the principle of material flow and fluidized unloading, and then to separate material and gas after conveying the material to the receiving point through the accelerating device at the bottom. Positive pressure pipeline specifications for Φ 133 mm x 5 mm, reasonable and effective size of HGMRI 1000 type pump for 1160 mm diameter, height is 3100mm. The pump needs to be equipped with pneumatic pressurization valves, pneumatic conveying valves, pneumatic fluidized valves and other regulating valves, and is equipped with a check valve, check filter parts, various soft connection and other supporting process pipe.

The structural of continuous conveying system is shown in Fig. 3.
3.2.4. Automatic control and detection system
The automatic control and detection system implements sequence control for the HGMRI 1000 A/B composite pump, and its alignment logic design completely conforms to the control requirements of offshore oil weighting operation. The system automatically adjusts the various working states of the continuous conveying system, measures the relevant process parameters, and according to the measurement results, carries on the closed-loop control to the warehouse pump. The control system is equipped with weighing material level, timing material level, manual material level three material level mode, weighing material level mode, supplemented by timing material level mode and manual material level mode, to ensure the stability of system operation. The detection system measures the working pressure of the warehouse pump conveying pipeline and the air source pressure of the gas supply pipeline. According to the requirements of the process, the system carries out interlocking control of the pump valve and pipe valve of each warehouse.

Sensors and Instruments: The measurement system is equipped with two sets of continuous on-line adjustable weighing control devices. The weight is displayed in the secondary instrument and can output digital and analog signals. The weighing system can accurately detect the weight of materials in the pump. Equipment installed at the same time supporting pressure transmitter, pressure secondary instrument can display continuously instantaneous value and can output digital signals, the form a complete set of sensor that can automatically detect the pressure and vacuum degree, so as to realize the chain material level control to run automatically, cooperate with the use of this kind of sensor control system can automatically alarm and shutdown functions, automatic judgment in the process of conveying pump empty state. The transmission capacity of the equipment integrated with sensor technology should be able to accurately set the throughput within the operating range of 80%~110%, and realize automatic transmission.

Control system includes: 1 set of touch screen system, 1 set of PLC main control system, warehouse pump local operation box (including solenoid valve). The PLC main control system selects the latest SMART programmable controller of Siemens.

3.3. Structural strength check of the skid
A simplified solid model was established. The size of the model was 4500mm (length) × 2500mm (width) × 3200mm (height), and the main material was 150mm×150mm×10mm and 150mm×120mm×10mm square tube. The skid bottom surface is applied with fixed constraints. 2t load is applied at the A/B pump support, 1.5t load is applied at the ton bag unloader support, and 3.31t load is applied at the vacuum pump.
The results of operation calculation are shown in Fig. 6 and Fig. 7. The maximum stress occurs at the intersection of the square pipe of the middle column and the middle beam of the structure, with a size of 98MPa, which is far less than the yield strength of the material. The maximum displacement appears in the middle beam partial B pump, the displacement size of 2.33mm, meet the requirements.
3.4. Working principle and process

Working principle: heavy medium bags after torn bags into the cache clean material into the bin, after frequency conversion constant feeder into the negative pressure conveying speed device, in the hybrid accelerating room material mixed with air, powered by vacuum pump produced by negative pressure, material mixture gas through the pipeline to HGMRI1000 type absorber, material gas separation in the pump at the same time, the filtered air from the vacuum pump discharge, again through the positive pressure after pressurized fluidized conveying to the designated receiver.

Workflow: pneumatic conveying system is turned on, vacuum pump produced by HGMRI1000 type A negative pressure suction pump will heavy medium material into the pump suction of sedimentation separation, suction heavy media content material needs to use the frequency conversion feeding machine to accelerate indoor quantitative feeding, uniform acceleration indoor mixed with air dense medium logistics within was sent to A pump absorption. When the weighing device on pump A reaches the set weight, the vacuum system will be switched to pump B to extract the material immediately, and pump A will start the positive pressure conveying process at the same time. When the positive pressure conveying process is finished, the vacuum system will be switched to pump A, and then pump B will start the positive pressure conveying process, so that the workflow continues in A continuous cycle.

Bulk heavy media materials are transported to the receiving tank by HGMRI1000 A/B pump. Material particle size distribution: 250-mesh screen \(\leq\) 3%, 1200-mesh screen \(\leq\) 3%; Bulk density of conveying material: 250 mesh is 2.7 \(\sim\) 2.8t/m\(^3\), 1200 mesh is 1.5 \(\sim\) 1.6t/m\(^3\); Transport capacity: iron ore powder 10 \(\sim\) 12t/h (design value).
4. Application
In January 2019, the equipment was applied on the CNOOC HYSY944 platform, and the effectiveness of the equipment was verified and the optimal operating parameters were determined.

![Application of the equipment on HYSY944](image)

The negative pressure vacuum value is the key parameter of the equipment. The influence of the negative pressure vacuum degree on the operation of the equipment was recorded in the application process.

![Vacuum degree varies with equipment operation](image)

The application results show that the operation process of the equipment is stable, the main performance is less affected by the operating environment, and can fully meet the requirements of the offshore drilling platform.

5. Conclusion
In this paper, a dust-free negative pressure conveying method of heavy medium for offshore oil drilling platform is proposed, and a set of negative pressure conveying equipment is designed. The device has the advantages of automatic control, small occupation and high environmental protection grade.

The field application results show that the equipment has excellent performance, can significantly reduce the workload of personnel, and meet the high requirements of the platform for iron ore powder conveying.

References:
[1] Li, Y.J., Wu, J., Huang Y., Luo M. (2015) Key technology and application of HTHP drilling in mid-deep formations in Yinggehai Basin. China Offshore Oil and Gas, 27: 102–106.
[2] G.E. Klinzing, F., Rizk, R., Marcus & L.S. L. (2010) Pneumatic Conveying of Solids. Springer,
Dordrecht.

[3] Gao, B.S., Zhu, S.Y., Yang, J. (1999) Pneumatic transport of solid materials. Fluid Machinery, (10):24-27.
[4] Yu, Z.S., Zhao, L.C., Huang, G.C. (1979) Calculation and measurement of some parameters of pneumatic conveying. Journal of Shanghai Maritime University, (02):33-47.
[5] Yang, L., Xie Y.H. (2006) Pneumatic Conveying Engineering. China Machine Press, Beijing.
[6] Zhou N.R., Zhu F.D., (1981) Pneumatic Conveying Principle and Design Calculation. Henan Science and Technology Press, Zhengzhou.
[7] Ding, D.C. (2015) A Simple Calculation of Fluidization Condition of Powder Granules. Chemical and Pharmaceutical Engineering, 36: 6-10.