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Shale Gas-Hammer Mill Thermal System Safety Analysis Based on the HAZOP Method

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Abstract. The treatment of oil-bearing cuttings is a key factor affecting the safety and environmental protection in shale gas exploitation. Frictional heat treatment of oil-cuttings as the most effective method to solve the environmental problems, the safety of the process system is particularly important. At present, there is no safety analysis of the hammer mill thermal desorption device, in order to reduce the risk of hammer mill thermal desorption device due to downtime, and personal injury caused by oil and gas detonation, this paper introduces HAZOP analysis method to evaluate risk, combined with three-dimensional risk assessment methods, take CQ-TDU- 2.0 / 480 as an example, and a suitable deviation matrix for the set of devices is established. Based on the characteristics of the process, the influences of temperature, pressure and wear on hammer mill and other equipment are analysed. As the main risk device of the whole system is the hammer mill, vibration, leakage and blockage are the main risk points of the whole system. The suggestions for improving the operation of the system are put forward, which provide references for the safety analysis of similar solid-liquid gas treatment equipment.

1. Introduction

Shale gas exploitation is an important strategy of developing clean energy in China [1]. At present, oil-based drilling fluids are mainly used for domestic exploitation, which will generate a large amount of oil-bearing drill cuttings. In order to solve the problem of environmental pollution caused by oil cuttings [2], CNPC Chuanqing Drilling Co. Ltd, compares with the solvent extraction method, heat treatment method, centrifugal separation method [3,4],takes heat treatment method as the core technology and has developed a hammer-type drill cuttings disposal system. Compared with other treatment methods, this treatment system can efficiently recycles the base oil with less influence on the environment and simple treatment principle [5-8], which is one of the best treatments for drill cuttings at present in China. However, as a new research and development equipment, there are some operating safety hazards [6].

Compared with SCA analysis, FMECA analysis, ETA analysis and ATA analysis [9-11], HAZOP can distinguish the risk between deviation and process while ensuring the accuracy of the analysis, and it's easy to put it into use. Therefore, in order to reduce the risk of usage, this paper analyzes the safety of hammer-mill named CQ-TDU-2.0 / 480 based on HAZOP. Meanwhile, with a trend of quantitative measurement for HAZOP [12], this paper introduces a three-factor risk assessment to quantify the HAZOP analysis results. Through the analysis of the oily drill cuttings' disposal process, the paper concludes that the process involves risk factors such as high temperature, high pressure, flammable and explosive. On the other hand, the whole process contains both solid and gas-liquid treatment equipment, which may result in leakage, blocking, vibration and other accidents. And according to the purpose of each process stage and other factors, this paper divides the process with the nodes, establishes the corresponding deviation matrice, and traverses the deviation matrices for each device and pipeline. So it analyzes the reasons and consequences for the risk of each key deviation, and draws the conclusion that the whole cuttings disposal device is safe, some measures are proposed for some risks, and it provides the experiences and references for similar safety analysis application of vapor-liquid-solid three-phase processing equipment.

2. Process Flow Analysis of Oil-bearing Cuttings Disposal System

The thermal desorption processing system of oil-bearing cuttings separates the solid residue and the gaseous oil by means of thermal decomposition, took the thermal desorption technology as the core method. It could produces the drill cuttings with oil content less than 1%, and solve the problem with the pollution of the environment due to the difficulty of discharging oil-bearing cuttings. The safety analysis CQ-TDU-2.0/480 oil drill cuttings disposal system, it's easy skid-mounted, and cover a small area.

Cuttings' handling process was divided into four stages according to the purpose of the treatment. Stage I, while handling the drill cuttings, the spiral conveyor stirred the drill cuttings and sent it to the vibrating screen, broken drill and other objects that may damage the device structure were screened out, then the cuttings were mixed by the agitator tank and injected with the recovery of oil to change its mobility, the device was prone to blocking during this stage and it would affects the supply of downstream equipment. Stage II, well-mixed cuttings in agitator tank were pumped into the hammer mill, drill cuttings were driven thrown to the inner wall of the device, and friction in the hammer mill produced a lot of heat, oil and water of cuttings at high temperature vaporized into gas, this stage equipment was easy to wear and vibrate, and there was a risk of high temperature sealing failure. Stage III, after the hammer mill, the LPG were cleaned by the cyclone separator and the venturi tube, then it was separated by the condenser and the oil-water separator into light oil and water, and it was the main stage to suffer from high temperature and pressure risks. Stage IV, the solid residue from hammer mill and cyclone separator were discharged via a discharger, which was at risk of clogging under a high temperature dry cuttings surroundings. It can be seen from the entire process, the risk point of each stage is slightly different, and the process flow diagram is shown in Figure 1.

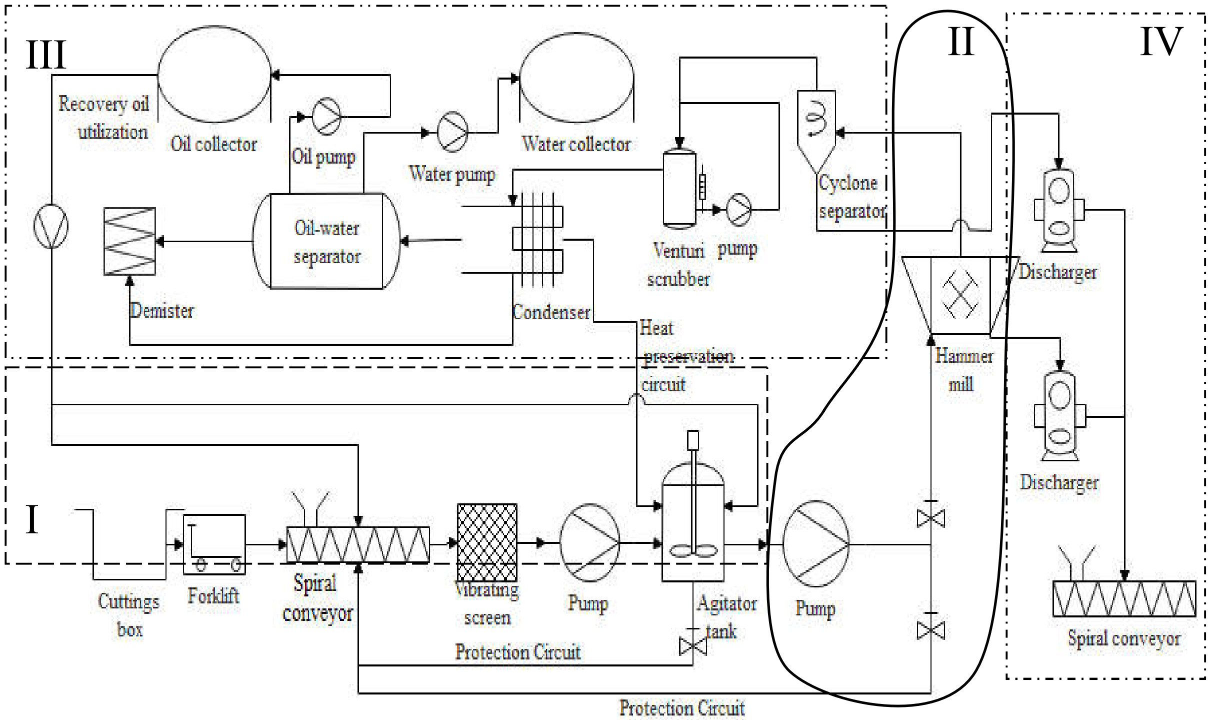

Figure 1. Oil Cuttings Thermal Desorption System Diagram of the Process

2.1. HAZOP Analysis of Oil Cuttings Disposal System

HAZOP (Hazard and Operability) analysis is a systematic analysis that identifies possible defects and hazards in traditional design. By analyzing the variation of the parameters and the deviations in the process, this method explores the causes and evaluates the consequences, and countermeasures should be arose to finding dangers in advance. With the development of HAZOP analysis, this method has become a widely used for safety assessment analysis in petroleum and chemical industry [13-16].

A multi-expert team should be established before the HAZOP analysis, and prepared with the design intent, process flow charts and other informations, so that team members can be familiar with the cuttings disposal system. And then they will discuss and analyze. The analysis steps are as follows, first of all, the team leader divides the disposal system into a plurality of nodes. Secondly, the team leader sets up the deviation which would effects the equipment operation. Thirdly, the team exchange ideas with each other about nodes, deviations, and find out the cause of the deviations, then, analyze the consequences of each deviations. Lately, put forward some corrective measures, and implements the recommendations. According to the analysis flow, the HAZOP analysis flow of cuttings disposal shown in Figure 2 is given specifically for the analysis in this paper.

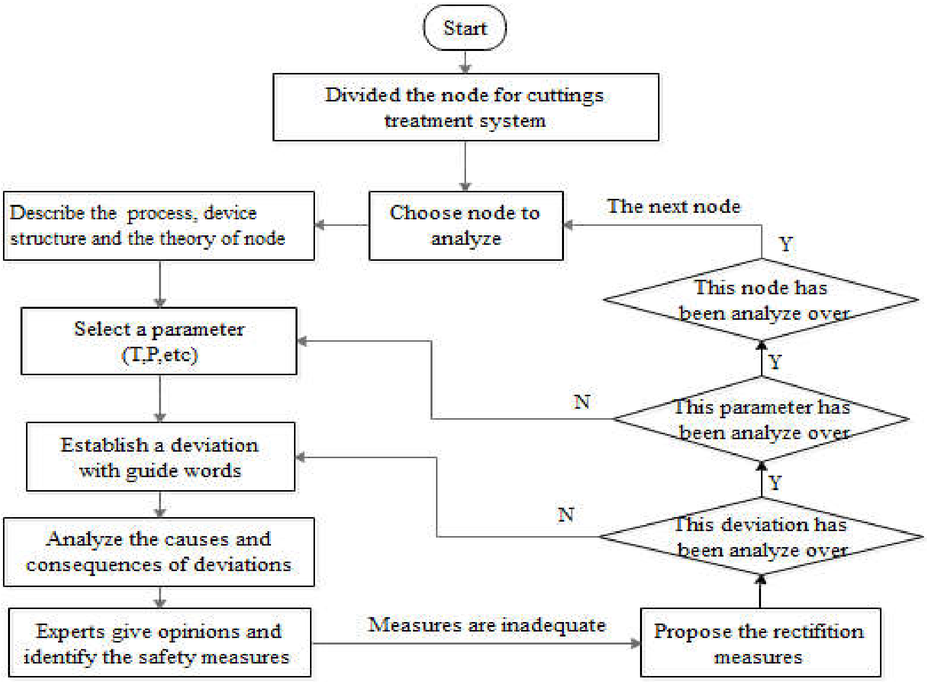

Figure 2. Analysis Process of HAZOP

2.2. Node Division and Deviation Settlement in Drilling Cuttings Disposal System

Generally speaking, the node of HAZOP was divided according to the process, and each device could be a node, there could also be more than one device in a node. According to the design intention and characteristics of different treatment stages and other factors, the process of the whole treatment system in this paper was divided into four nodes, pretreatment, thermal desorption, fluid treatment and solid treatment. The details were shown in Table 1. To ensure the comprehensiveness of the analysis, deviations were separately analyzed for each device and main pipeline in each node.

The common deviation was usually established according to the key parameters that ensure the normal work in a good working condition. In order to avoid omission of the establishment deviation in the analysis, it based on the common analysis deviation and the existing standard (AQ/T: 3049-2013, Q/SY 1364-2011). And the excerpts deviation matrix were shown in Table 2 was established for cuttings disposal system, which eliminated the meaningless deviation such as reaction abnormality, it increased the accuracy and efficiency of the analysis. During the analysis, the deviation of each device is considered with deviation matrix, and then chose the key deviation to analyze. At the same time, this paper considered the deviation of the key parts that affect the use of the equipment. This paper established 146 deviations from this deviation matrix.

Table 1. Nodal division of thermal cuttings processing system for oil cuttings

Node	Keywords	Meaning
1	Drilling cuttings pretreatment	Let drilling cuttings recovered from the well into slurry with good fluidity, particle size, and no impurity such as metal gloves.
2	Thermal desorption	Using custom hammer mill to separate the oil-bearing cuttings into non-chemically decomposed hydrocarbons and dry cuttings.
3	Fluid treatment	Clean up the tiny cuttings particles in the oil and gas, and condensate to obtain light oil and water.
4	Solid treatment	Timely discharge the high temperature solids from the hammer mill and cyclone separator.

Table 2. Deviation Matrix of Oil Drilling Cuttings Processing System (excerpt)

Guide words / Variable	More	Less	Accompany	Abnormal
Fluidity	Good fluidity of cuttings.	Bad fluidity of cuttings	—	—
Flow	Large amount of gas and cuttings.	Small amount of gas and cuttings.	—	There is countercurrent
Liquid level	High liquid level of parting device	Low liquid level of parting device	—	—
Seal	—	—	—	Seal failure
Instrument	Measurement is higher.	Measurement is lower.	—	Instrument failure
Abrasion	—	—	—	Wear of pipe/parts.
Others	—	—	Mixed with impurities	Vibration/Wrong operation

2.3. The Introduction of Three-factor Risk Level

HAZOP analysis was not only used to identify potential risk points in the drill cuttings system, but also to determine the severity of the risk, so that risk reduction measures could be put into effect by prioritize targeted. The general risk level was evaluated by the severity and the possibility. However, in the application, each equipment might have safety measures, it could reduce some risk of projects, so this paper introduced it as a third parameter, the degree of safety control U [17], it was compared with FMECA's risk priority number [18] and it's DDR, which was similar to the degree of safety control. Therefore, the introduction of this parameter could be used more rationally in combination with the equipment and the situation to score the risk level of each deviation.

Therefore, the severity of the consequences (S) was to determine each deviation's severity in each node and the whole process, the level of likelihood (L) meant how much each deviation causes might happe, and the existing safety precautions that prevented each deviation from occurring resulted Control degree (U), with index above, the results of risk evaluation ($R=S\times L\times U$) were obtained. The grading of the severity and the possibility was simplified according to the existing standard (Q / SY 1364-2011), the details of severity, likelihood and uncontrollability was in Table 3, they were divided into five levels. The results were multiplied into 4 levels four levels, few, less, medium, and high, and was used as the basis for decision. Tthe specific measures to be taken were shown in Table 4.

Table 3. Criteria of Level Classification

Level	Guidelines Of Severity (S)	Guidelines Of Possibility(L)	Guidelines Of Uncontrollability(U)
5	Affect the safety of system operation, resulting in the huge loss of life and property.	Happens at least once a year	No instrumentation, control or protective measures
4	System loses main function, and works in a bad condition.	Happens once in each maintenance cycle	Only passive protection system
3	Property goes down, affect the use and operation of system	Happens only once in history	Have measuring instrument or emergency stop
2	A slight impact on system performance	It has happened in this industry.	Instrumentation with alarm or active protection system
1	The system will not have an impact	Never happened	Automatic control and alarm instrumentation

Table 4. Risk Level and Action Decision Table

Risk Level	Score	Keywords	Measures to be taken.
I	1—24	Few risk	There is no need to take action.
II	25—49	Less risk	Strengthen the maintenance of preventive measures.
III	50—74	Medium risk	Improve the prevention and control measures, and choose the right time to implement the action.
IV	75—125	High risk	Improve the prevention and control measures, and implement the action immediately.

3. Deviation Causes, Consequences and Protection Measures

The HAZOP analysis of this paper mainly took the process flow, device structure and operation safety, device arrangement and protection measures of the entire set of oil shale hammer mill thermal desorption system into consideration, it analyzed four nodes and more than 140 deviations, and schematic diagram of hammer mill was shown in Figure 3. The causes, consequences and protection measures of each deviation were analyzed, and more than 30 suggestions for improvement were put forward. Table 5 listed a typical deviation and analysis result.

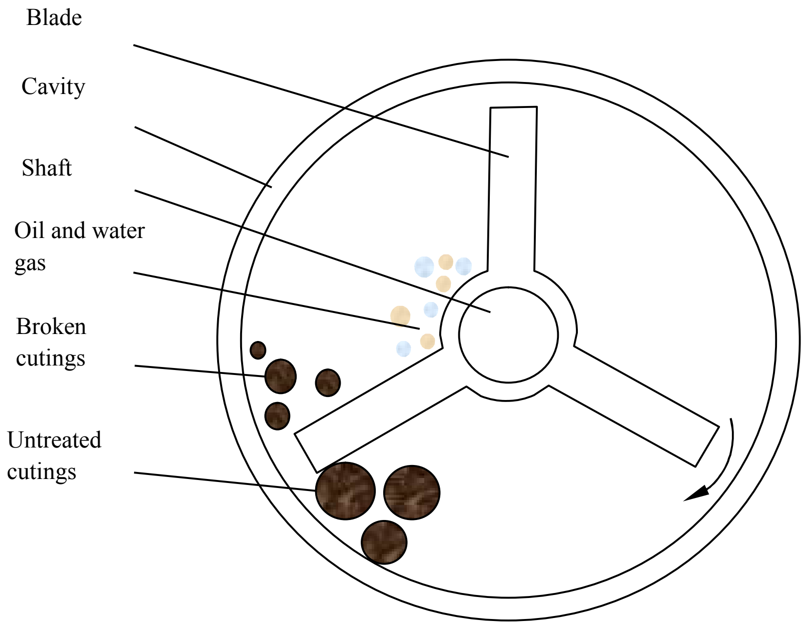

Figure 3. Working Principle Diagram of Hammer Mill.

Table 5. Analysis Table of HAZOP (excerpt)

No	Guide word	Deviation	Causes	Consequences	Protection measures	Corrective measures	Risk			
							U	S	L	R
1	Drilling fluidity	The cuttings fluidity is poor.	1. Drill cuttings were previously dried 2. Cuttings were stirred uneven	Subsequent pipeline suffered from blockage	1. Add the recovery oil to the premix tank	—	2	3	3	I
2	Vibrati on	The mixing tank vibrates.	1. The device reached the resonance frequency 2. Eccentricity shaft and tank was too large	Device might collapse. It was easy to have pipeline leakage and welding failure.	1. Handle the cuttings after the resonance frequency happened.	1. Set a suitable damping device 2 Assemble equipment should ensure concentrici ty	4	3	4	I I
3	Wear and Tear	Wear of hammer mill blades.	1. There were tough waste in the cavity 2. Strength of blade was poor 3. The law of blade wear couldn't be mastered	The property of hammer mill was affected When the blades couldn't drive cuttings effectively, shaft wear would be serious.	1.None 2. Use layer for blade.	3. Analyze the law of blade wear, optimize the structure of the blade	5	3	3	I I
4	Clogge d	The cyclone separator is blocked.	1. Vapor was chilling 2. There were too much cuttings in the gas and path was narrow 3. Seal failure	The turbulence arose, many dust discharged from the exhaust port, cyclone separator didn't work.	-	2. Set up cleaning mouth at gas inlet parts ,set regular maintenanc e of equipment.	5	3	3	I I
5	Temper ature	High temperature of unloader bearing.	1. Lack of seal oil 2. Cuttings' temperature were too high	Bearings were damaged, it was easy to beat Sealing were expanded, it couldn't reach expectancy life	1. Add lubricants regularly	2 .Use temperatur e measureme nt to monitor it regularly.	5	3	2	I I

4. Conclusion

By analyzing the HAZOP of the oil-bearing cuttings treatment system, the potential risk of the system of these set of equipment were identified .At the same time, measures were put forward to reduce the risk level of the accident, which helped to improve the safety of the entire process and provide the reliability approach advice and assistance. This paper mainly completed the following works:

(1) The process flow of treatment system was analyzed, it clarified the characteristics of different stages, and node 2 with hammer mill was the main risk of the system.

(2) The four nodes were divided according to the characteristics, the deviation matrix was established to avoid the omission in the analysis. The idea of establishing the deviation based on the processing characteristics was provided, and the paper established 146 deviations by it.

(3) The three-factor risk assessment criterion has been introduced, which considered the protection measures of a project, and analyzed the risk results of the system. And finally distinguished 0 high-risk, 6 medium-risk, 28 less-risk, and more than 100 few-risk deviations. The main reasons for medium-risk deviations included: 1) Large vibration due to resonance would happen without suitable vibration damping devices. 2) Cuttings of high-temperature had a poor fluidity, it was easy to plug the pipe. 3) High speed and high temperature for sealing structure resulted in hammer mill leakage. 4) The testing facilities for solid handling were not as well-equipped as the gas-liquid handling.

According to the analysis results of different deviations, some suggestions for the use of cuttings disposal system were as follows:(1) Set additional vibration damper and vibration isolation facilities for vibrative devices.(2) Pay attention to the welding and layout of pipeline.(3) Enhance detection measures about the pipeline and equipment leak in stage I and stage II.(4) Take actions for the concentrated discharge of non-condensable gases.(5) Enhance the repair and maintenance of high temperature equipment.And those action of suggests should be taken at the right time.

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