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Analysis of Winter Freezing and Blockage of Natural Gas Gathering and Transportation Pipelines and Corresponding Measures

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Abstract

In response to the hydrate blockage problems occurring during the production of the Shaanxi Northern Gas Field in the winter of 2023, this paper conducts an in-depth analysis of the main causes of freezing and blockage, including the persistent low-temperature environment in winter, the relatively high hydrogen sulfide content in natural gas, and the mismatch between the process design of the gathering and transportation system and the existing production conditions. Meanwhile, it summarizes the actual implementation effects of various comprehensive anti-freezing and anti-blockage measures, and further puts forward the improvement direction and specific implementation paths for subsequent winter freezing and blockage prevention measures.

Keywords

Shaanxi Northern Gas Field; Hydrate Blockage; Anti-freezing and Anti-blockage Measures.

1. Introduction

During the transportation of natural gas through pipelines, affected by changes in flow regime and fluctuations in ambient temperature, condensate water is inevitably generated in the pipelines and gradually accumulates. With the increase of accumulated liquid, when encountering pipeline sections with large undulations or low temperatures in winter, natural gas hydrates are highly likely to form in low-lying areas of the pipelines and at components prone to throttling effects, such as valves, tees, and separator heads. Once hydrates are formed, they will reduce the cross-sectional flow area of the pipelines, thereby causing throttling effects that in turn accelerate the further formation of hydrates. This vicious cycle will eventually lead to pipeline blockage, pressure buildup, and even trigger safety accidents. In addition, during the blockage removal operation, measures such as venting and pressure reduction are required to resume production, which will also result in additional losses of natural gas volume. [1]

According to statistics, the pipelines and equipment with the most severe hydrate blockage, the highest frequency of blockages, and the most frequent pigging operations are mainly concentrated in high-sulfur natural gas gathering and transportation pipelines, as well as in some well stations located in alpine regions. In such well stations, components such as separator heads, filter separators, inlet elbows, and tees exhibit particularly prominent throttling effects. [2-3]

In addition to being closely related to the composition of natural gas and the content of free water, the formation of natural gas hydrates also requires specific thermodynamic conditions—namely, appropriate temperature and pressure. In summary, the formation of natural gas hydrates must satisfy the following four conditions simultaneously: a. The gas contains hydrate-forming molecules, such as small-molecule hydrocarbons and acidic components

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including hydrogen sulfide (H_2S) and carbon dioxide (CO_2); b. The presence of liquid water, and the temperature of natural gas must be lower than its own water dew point; c. A low-temperature environment, where the system temperature is lower than the phase equilibrium temperature for hydrate formation; d. A high-pressure environment, where the system pressure is higher than the phase equilibrium temperature for hydrate formation.

2. Analysis of the Causes of Hydrate Blockage

Low temperature in winter is the primary prerequisite and core driving force for hydrate formation. Thermodynamic theory indicates that the critical conditions for hydrate formation are negatively correlated with temperature—lower temperatures make hydrates easier to form and more stable. In the alpine regions of northern China, winter temperatures are generally below -20°C, and in some extreme areas, they even drop to below -40°C, which is far lower than the phase equilibrium temperature for natural gas hydrate formation. Under the continuous low-temperature environment, the temperature of natural gas in gathering and transportation pipelines decreases rapidly. When the temperature falls below the water dew point, the saturated water vapor in natural gas condenses into liquid water, providing the necessary material basis for hydrate formation. At the same time, low temperature significantly reduces the activation energy required for hydrate formation, accelerates the combination reaction between small-molecule hydrocarbons (such as methane and ethane) and water molecules, causing hydrate crystals to grow rapidly in a short period, adhere to the pipe wall, and gradually reduce the flow cross-sectional area.

The characteristics of high-sulfur media are an important factor that exacerbates hydrate blockage. High-sulfur natural gas is rich in acidic components such as hydrogen sulfide (H_2S) and carbon dioxide (CO_2), and these substances have a significant catalytic effect on hydrate formation. Compared with pure hydrocarbon gases, the molecular structures of H_2S and CO_2 are more likely to form hydrogen bonds with water molecules, reducing the phase equilibrium pressure required for hydrate formation. This allows hydrates to form under conditions of lower pressure and higher temperature. Data shows that when the H_2S content in natural gas exceeds 5%, the critical temperature for hydrate formation increases by approximately 3-5°C. This means that under the same environmental conditions, the risk of hydrate formation in high-sulfur pipelines is significantly higher than that in conventional natural gas pipelines. In addition, hydrosulfuric acid formed by the reaction of H_2S with water corrodes the inner wall of the pipeline, and the resulting impurities such as rust become heterogeneous nucleation centers for hydrate crystals, further accelerating the aggregation and growth of hydrates.

The insufficient adaptability between pipeline structure design and operating conditions is a key inducement leading to localized and frequent hydrate blockages. Throttling components in the gathering and transportation system are high-risk areas for hydrate blockage, such as valves, tees, separator heads, and inlet elbows. When fluid passes through these components, the sudden change in cross-section causes a throttling effect, leading to a sudden drop in local pressure and temperature, and forming an ideal "low-temperature and high-pressure" environment for hydrate formation. At the same time, undulating sections and low-lying areas in some old pipelines are prone to accumulate condensed water in winter, forming "dead water zones". These zones have slow water flow and poor heat exchange, becoming "hotbeds" for hydrate formation. Furthermore, fluctuations in pipeline transportation pressure also increase the risk of hydrate blockage. When the pipeline pressure is higher than the phase equilibrium pressure for hydrate formation, hydrates will form rapidly and block the pipeline once the temperature meets the required condition. Moreover, the Joule-Thomson effect generated during the sudden pressure drop further lowers the temperature inside the pipeline, accelerating the growth and aggregation of hydrate crystals. [4-6]

2.1. Traditional Regasification Processes and Their Limitations

Traditional open-cycle regasification processes use seawater as the heating medium, realizing LNG gasification through Submerged Combustion Vaporizers (SCV) or Open Rack Vaporizers (ORV). Among them, SCV directly heats LNG by using high-temperature flue gas generated from natural gas combustion. Although it has high gasification efficiency, it consumes a large amount of natural gas and results in high carbon emissions. ORV, on the other hand, uses the sensible heat of seawater to heat LNG. While it does not require additional fuel consumption, its winter operation stability is poor in some regions due to the limitation of seawater temperature. Moreover, the large temperature difference between seawater and LNG leads to significant irreversible losses, resulting in low system exergy efficiency.

Closed-cycle regasification processes achieve heat transfer through the circulation of intermediate media, with typical equipment including Intermediate Fluid Vaporizers (IFV) and Shell-and-Tube Vaporizers (STV). This process is not limited by seawater temperature and has high operational stability. However, the heat exchange process of the intermediate medium increases system complexity, and heat exchange efficiency is greatly affected by the thermal conductivity of the medium. In addition, traditional regasification processes generally suffer from insufficient cold energy recovery. A large amount of cold energy released during LNG gasification is directly carried away by seawater or air, causing energy waste and potentially exerting low-temperature impacts on the marine ecological environment.

3. Effect of Anti-Freezing and Anti-Blockage Measures

Shaanxi Northern Gas Field experiences extremely cold winters (minimum temperature drops below -30℃), making natural gas gathering and transportation, processing, and transmission systems prone to hydrate formation, pipeline freezing cracks, and equipment failures. Anti-freezing and anti-clogging is a core task for safe winter production. Based on oil and gas storage and transportation engineering expertise and on-site practical applications, the measures are systematically listed under the principle of "prevention first, remediation supplemented, and full-process control" from four dimensions: **process optimization, equipment protection, operation management, and emergency support**.

3.1. Natural Gas Dehydration and Hydrocarbon Removal (Fundamental Measure)

Deep Dehydration: Adopt molecular sieve dehydration units at gas gathering stations/ processing plants to reduce the water dew point of natural gas below the minimum winter ambient temperature (typically required to be ≤ -20℃~-30℃ in Shaanxi Northern areas) to prevent free water condensation in pipelines. [7-8]

Condensate Recovery: Recover liquid hydrocarbons (condensate oil, light oil) from natural gas through cryogenic separation, throttling refrigeration, and other processes to reduce viscosity increase or freezing caused by hydrocarbon condensation.

Wellhead Pretreatment: Install wellhead separators for high-yield water wells or alcohol-containing wells to initially separate free water and mechanical impurities, reducing the processing load of subsequent pipelines.

3.2. Alcohol Injection for Anti-Freezing (Targeted Anti-Clogging)

Alcohol Types: Prioritize methanol (low cost, high volatility) or ethylene glycol (low toxicity, high recovery rate), with dosage controlled based on "on-demand injection".

Injection Point Layout: Install alcohol injection points at critical freezing-prone nodes such as wellheads, junctions of gathering branch lines and main lines, and before/after throttling valves.

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Precisely inject alcohol via metering pumps to form an alcohol-wrapped natural gas flow system, reducing hydrate formation probability.

Alcohol Recovery: Equip gas gathering stations with alcohol recovery units (e.g., flash tanks, rectification towers) to recover and regenerate rich alcohol solution for reuse, lowering operational costs.

3.3. Pipeline Heat Tracing and Thermal Insulation (Active Temperature Control)

Heat Tracing Methods: Electric Heat Tracing: Suitable for short-distance pipelines, instrument pipelines, and valve bodies. Provide continuous heating via electric heat tracing cables with controllable temperatures (set at 5℃~15℃) and flexible installation.

Steam Heat Tracing: Suitable for long-distance pipelines or equipment (e.g., separators, heat exchangers) in gas gathering stations and processing plants. Utilize waste steam heat for low-cost heating, with corrosion prevention measures (to avoid condensed water corrosion).

Thermal Insulation Design: Wrap rock wool, polyurethane foam, or other insulation materials (thickness calculated based on ambient temperature, typically ≥50mm) outside the heat tracing layer, protected by an outer iron sheet to reduce heat loss. Increase insulation thickness at key locations (e.g., pipeline elbows, valves) to prevent local excessive heat dissipation. [9-10]

4. Key Insights and Opinions

4.1. Select the Anti-freezing Agent Injection System based on Operating Conditions.

Currently, the injection of hydrate inhibitors remains one of the primary measures to prevent natural gas hydrate formation. Its hydrate prevention effectiveness is closely related to the natural gas transmission temperature, inhibitor type, dosage, injection timing, and injection method. The key lies in mastering the injection timing, dosage, and cycle; during on-site practical operation, dynamic adjustments must be made according to different operating conditions.

Currently, there are two main types of hydrate inhibitor injection methods: continuous injection and intermittent injection, with continuous injection yielding the best results. For the injection process, pump injection equipped with an atomization device is recommended to facilitate full contact between the inhibitor and natural gas flow, thereby achieving better anti-freezing performance. When selecting the pump displacement, it should be suitable for adjusting the inhibitor injection volume. It is advisable to use the MROYB series diaphragm metering pump with a displacement of 5–10 L/h to realize small-displacement continuous injection and enhance the anti-freezing agent injection effectiveness.

The injection cycle and timing shall be determined based on the hydrate formation temperature of the gathering and transportation pipelines. If the hydrate formation temperature is relatively high, it is feasible to inject 2–3 times per day or appropriately extend the injection duration during the low-temperature nighttime period to ensure injection effectiveness. For high-sulfur gathering and transportation pipelines, an injection mode of 30 minutes of injection followed by a 2–3 hour shutdown is adopted; continuous injection shall even be implemented when temperatures are lower. For general gathering and transportation pipelines, injection shall be performed once per day or once every 2–3 days according to production conditions, preferably scheduled around 22:00 at night or 06:00 in the early morning, with each injection duration guaranteed to be 30–60 minutes as much as possible.

4.2. Implement Process Adaptability Modifications

a. Install bypass pipelines for gas-liquid separators. Due to the special structure of the separation head of gas-liquid separators, this part is highly prone to hydrate blockage. It is recommended to add bypass pipelines to the gas-liquid separators at some stations.

b. Conduct adaptability modifications on gathering and transportation pipelines and station equipment: reduce the number of elbows, U-tubes, and reducer pipes; alternatively, increase the diameter of the separator's separation head to mitigate the throttling effect.

c. Achieve co-transportation of high-sulfur and low-sulfur natural gas through adaptability modifications to the gathering and transportation system, thereby reducing the sulfur content of natural gas in the pipelines and effectively lowering the hydrate formation temperature.

d. For high-sulfur well stations, to reduce the risk of freezing and blockage in the automatic blowdown system, it is recommended to replace the control valve at the front end of the automatic blowdown valve with a slab gate valve to minimize the throttling effect. Meanwhile, select automatic blowdown valves with large nominal diameters.

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