

The Influence of Unstable Flow on the Pipeline and its Elimination Measures

Na Yang¹, Kexi Liao¹ and Guoxi He¹

¹Southwest Petroleum University, Chengdu 610500, China.

Abstract

During the operation of the natural gas pipeline, the system is in an unsteady state due to the changes in the user's gas consumption with the production load, the connection or closure of the pipeline inlet/distribution branch, and the start and stop of the compressor station. According to the characteristics of the unsteady state of the gas pipeline system, according to the fluid continuity equation, the equation of motion and the energy equation, the mathematical models of the unsteady fast transient process and the slow transient process are established respectively. The formula central difference method respectively solves the fast transient and slow transient models, and analyzes the mathematical method of solving partial differential equations by the characteristic line method and the implicit central difference method and the processing method of the boundary conditions. The established model was applied to the fast transient operating case and the slow transient operating case of the gas pipeline system. The simulation results are the same as the pressure change trend at the end of the pipeline described in the literature value, which can better reflect the gas pipeline. The unstable operating state of the gas pipeline proves the reliability of the model and can be used to guide the actual operation of natural gas pipelines. At the same time, when the National Pipeline Network Company was established, the influence of unstable flow in the natural gas pipeline and the elimination measures were analyzed to facilitate the better operation and management of the National Pipeline Network Company.

Keywords

Dissatisfied flow; Gas-liquid two-phase flow; Cavitation; Elimination measures.

1. Introduction

On December 9, the National Petroleum and Natural Gas Pipe Network Group Co., Ltd. (referred to as the National Pipe Network Company) was formally established in Beijing. This is a major measure for China to deepen the reform of the oil and gas industry and ensure the safe and stable supply of oil and gas. It will break the long-standing highly monopolistic operation in the oil and gas industry, promote the market-oriented allocation of energy industry factors, and promote "effective property rights incentives, free flow of factors, and flexible price response." "Competition is fair and orderly, and enterprises survive the survival of the fittest". It is of great significance and is a key step in the market reform of China's natural gas industry [1]. It is worth noting that unstable flow can also cause major problems for the operation of the pipeline network. How to promote the smooth transition of the national pipe network company, and truly operate smoothly, has become the focus of the current industry.

The establishment of the National Pipe Network Company is of great significance:

(1) Separation of pipeline transportation from production and sales, and fair opening to third-party market entities will help promote market competition, improve resource allocation efficiency, better reflect the attributes of energy commodities, and give play to the decisive role of the market in resource allocation To further promote market-oriented oil and gas price

mechanism reforms, stimulate market vitality, and better serve economic and social development;

(2) It will promote the interconnection of pipeline networks and build a "national one network", which will help better allocate oil and gas resources nationwide, improve the efficiency of oil and gas resource allocation, and ensure the safe and stable supply of oil and gas energy;

(3) Overall planning, construction and operation of the national oil and gas trunk pipeline network will help reduce repeated investment and pipeline resource waste, speed up the construction of the pipeline network, and enhance the oil and gas transportation capacity [2].

When designing a piping system, it is not enough to consider only steady-state conditions such as pressure drop, corrosion, erosion and distribution coefficient, because some forces generated by the fluid may also affect the normal operation of the equipment and piping system when the flow starts and stops. Running. The mechanical force generated by the common unstable flow can cause the instantaneous pressure in the system to be too high, deformation and displacement:

(1) Close and open the valve too quickly, or stop and open the pump;

(2) Improper design of two-phase flow system, especially when continuous gas phase and discontinuous liquid phase are combined;

(3) There is local liquid flashing and condensation. Obviously, it is very important to prevent these problems in the design stage.

2. Sudden Start and Stop

When opening the valve, it is usually required to open a bit first, and then slowly open to the required opening. When closing, it also requires slow operation to minimize the impact of the rapid change of fluid momentum on the pipeline system.

The opening and stopping of the pump is equivalent to the rapid opening and closing of a valve. When the resulting pressure wave is reflected back, it may adversely affect the shut-off valve of the pump. Positive displacement pumps are especially piston pumps and diaphragms.

The so-called fast here usually refers to stopping the flow in less than $2L/c$, where L represents the distance from the source of the fluid to the device (such as a valve being closed) that is blocking the flow; c is the sound in the fluid The speed of propagation. $2L/c$ is the time it takes for the pressure wave to reach the end of the tube from the starting point and then be reflected to the starting point.

If a rapidly closing valve generates a pressure wave, the pressure wave will expand in the upstream direction of the valve through the fluid and generate a sudden increase in pressure in the pipe. In order to prevent the pipe from rupturing under this condition, in addition to the normal operating pressure, such a surge pressure must be included in the design. There is an additional reaction force at the turning point, and this reaction force increases with the increase in the normal force of the pipe and support under operating conditions. The impact force generated by water hammer at the corner can be calculated by Joukowsky's formula:

$$F = cv\rho A \quad (1)$$

In the formula, c is the speed of sound in the fluid; v is the fluid velocity; ρ is the fluid density; A is the cross-sectional area through which the fluid flows in the tube.

The normal force is ρAv^2 , so the ratio of the impact force to the normal force is c/v . The general flow velocity of the fluid is 3-14m/s, and the sound propagation velocity in the fluid $c \approx 1400$ m/s, so the impact force of the fluid due to water hammer can reach up to 450 times the normal force.

3. Pulsation

Flow fluctuations can produce a lower degree of water hammer, but can also cause failure of valves, pipes, pumps, and other equipment. The metering pump is one of the main vibration sources that produce this mechanical vibration [3].

Vibration force is a function of tube cross-sectional area and amplitude. When the vibration frequency resonates with the natural frequency of the system, the vibration force is significantly amplified. The data shows that the pulsation resonance amplification factor can reach 40. If there is mechanical resonance at the same time, and the two overlap, the amplification factor can even be as high as 800 times. To avoid stop-open and pulsating water hammer, the following measures can be taken:

- (1) Ensure that the closing time of valves and other components is much longer than $2L/c$.
- (2) Place the pulsation buffer, shock absorber and riser as close as possible to the pump, valve or other fast-acting equipment to reduce the impact amplitude.
- (3) Install the pulsation buffer near the downstream of the shut-off valve of the centrifugal pump outlet pipe to minimize the pump's stopping effect.
- (4) Keep the fluid flow rate as low as possible while considering the economic flow rate. When the flow velocity is not higher than 1.6m/s, there is almost no water hammer effect.
- (5) Design piping and equipment supports correctly. In particular, the longer the pipe extends and the larger the pipe diameter, the greater the kinetic energy generated.
- (6) Install shock absorbers or pulse dampers at the sensitive instruments of pipelines or equipment.

4. Gas-liquid Two-phase Flow

When opening the steam valve to the cold pipeline, you can often hear the sound of bangs in the pipe. The drastic change in temperature caused part of the steam to quickly condense in the tube, causing two problems:

- (1) Liquid plug appears [4];
- (2) Steam flows at high speed.

The combination of the two allows the liquid plug to be accelerated to a very high flow rate, so the bang sound heard is the sound of a fast-flowing liquid plug hitting an elbow, valve or other pipe fittings. The kinetic energy released by this impact generates local high pressure, which can cause displacement or even rupture of the impacted part. Although water vapor is the most common cause of this phenomenon, any other hot vapor can cause both of these problems.

According to calculations, when the gas velocity in the horizontal pipe is lower than 13m/s, the gas flows in the upper space of the pipe, while the liquid is located in the lower space of the pipe. When the flow rate increases, the gas will form waves in the liquid in the pipe, thereby forming a liquid plug. The gas with a pressure difference of 5atm can accelerate the liquid plug to nearly 25m/s. The weight of a 20cm faucet in a 20cm inner diameter pipe is equivalent to a bowling ball. It is not difficult to imagine a bowling ball impacting an elbow or valve at a speed of 25m/s, which would have consequences for the elbow, valve and pipe frame.

Many gas-liquid two-phase flows will produce liquid plugs, and water hammer will occur as long as the gas flow velocity is high. Wet compressed air is a typical example.

To avoid the above problems, the following measures can be taken:

- (1) Install low-point drain valves or steam traps on the front of the riser pipe, the end of the main pipe, the pressure control valve, and every 90-150m long pipeline;
- (2) Install Y-type filter and basket filter horizontally to prevent the liquid from being carried away by steam;

- (3) Avoid installing a vertical riser pipe in the hot condensate return pipe;
- (4) Install a device capable of completely draining liquid to avoid storing liquid in the pipe;
- (5) Pay attention to the maintenance of steam traps, pressure control valves, safety valves and safety diaphragms;
- (6) Equipment and pipeline materials should have appropriate tensile strength to resist possible dynamic transients. Try not to use cast iron materials;
- (7) Check the heat preservation condition to minimize the production of condensate;
- (8) The support design must have good transient adaptability;
- (9) When there is condensable gas, first open the low-point discharge valve, and then slowly open the gas valve.

5. Liquid Flashing and Cavitation

If the cooling water in the jacket of the reactor is not exhausted, open the heating steam valve and condensate drain valve of the reactor, you will hear loud popping and knocking noises from the jacket. This is the cavitation water hammer phenomenon. The steam entering the jacket quickly replaces and compresses the water in the jacket, and the steam is quickly cooled and condensed, thereby creating a gap, which is backfilled by liquid at a high speed. This can cause local high pressure in the jacket to damage the jacket.

The rapid condensation of steam is one of the causes of water hammer. If the valve is opened on the pipe full of condensate and pressurized steam (usually water vapor) is passed in, the steam will pressurize the condensate pipe and replace the condensate, thereby generating noise. If the valve is closed again, the condensate will quickly condense the incoming steam, and the pressure in the pipe will decrease. The condensate will backfill the gap with great force. The momentum generated by the impact on the valve is enough to destroy the valve.

Cavitation may also occur in systems with non-condensable gas but soluble in a certain liquid. However, this happens only when the dissolution kinetics and solubility of the gas are sufficiently high [5].

Cavitation also occurs when the liquid close to the boiling point flashes and then condenses instantaneously. Any dissolved gas in the liquid can increase the strength of the cavitation force. This kind of cavitation may occur if the pressure at the upstream and downstream of the narrow part of the pipe is greater than the vapor pressure of the liquid, but the pressure at a certain point between the upstream and downstream is lower than the vapor pressure.

Flash evaporation occurs when the upstream pressure is higher than the vapor pressure in the narrow part, but the downstream pressure is lower than the vapor pressure. Erosion caused by flash evaporation often produces groove marks on the metal surface, while cavitation often produces dents.

The damage caused by cavitation is more serious than flash evaporation. When choosing a centrifugal pump, technicians often pay attention to the outlet pressure and flow rate, while ignoring the condition of the suction port. If the suction pressure of the pump is low to a certain level, the liquid will vaporize locally, and the gas microbubbles will be transported to the higher pressure area of the pump. These bubbles will re-condensate into liquid, causing local high pressure and the generation and re-condensation of more bubbles. These pressure cycles occur in microsecond time intervals and can generate partial pressures of up to 4000 kg/cm² and high temperatures of 800°C. This phenomenon often occurs in the pump inlet and pump casing, orifice plates, valves, Venturi flowmeters, suction pipes, and vanes [6].

Partially opened valves (mainly butterfly valves), but also other types of control valves) and other objects protruding in the fluid, act like an aerodynamic surface, on which unstable forces will cause cavitation. The butterfly valve can generally be used for flow regulation when the

opening degree is 30% to 70%. Beyond this range, the pressure drop will not be sufficient for control. However, if the opening degree is lower than 30%, cavitation, high torque and wear will occur. This is the cause of local pitting and wear, noise and mechanical failure. Even if the manufacturer takes measures to eliminate this phenomenon when designing the product, poor installation design will also affect the use effect. Suddenly closing the valve can create a gap downstream of it, which will cause a pressure imbalance whose value is equal to the pipeline pressure minus the vapor pressure at the gap [7].

Cavitation can cause noise, vibration, material damage, and low flow rates at higher pressure drops. The destructive effect of cavitation on the material occurs when the cavitation bubbles condense near the surface of the material. The damage forms include high-speed erosion, excessive stress [overstress], cold deformation and fatigue. The location of cavitation can move upstream or downstream of the system, depending on the back pressure. Moreover, the size of the back pressure also affects the severity of cavitation (lower back pressure increases the amount of cavitation formed, but because the pressure difference between the downstream pressure and vapor pressure is reduced, the damage is reduced).

In order to reduce and control the occurrence and impact of cavitation, the following principles can be followed when designing the piping system:

- (1) Ensure the net positive suction head of the centrifugal pump to adapt it to the actual working conditions;
- (2) A straight pipe section with a length of at least 7 times the pipe diameter is installed upstream of the pump, otherwise the fluid flow rate of the suction pipe should not exceed 3m/s. Generally speaking, the highest flow rate should be controlled within 1.5~1.8m/s;
- (3) Do not pass condensable gas into the sealed liquid. The drain device should be installed, and its size should be able to match the expected condensate drain rate. There have been cases in which accidents occurred after someone removed the heat insulation of the steam pipe due to insufficient water separation capacity of the original water separator;
- (4) Tilt the steam pipe down at a slope of 1:24 along the fluid flow direction. The study found that vapor voids are not easy to generate in the pipe at this time;
- (5) Special anti-cavitation equipment can be used. This type of equipment has a structure to eliminate cavitation on the surface of the equipment, or can gradually reduce the pressure step by step, or contain specially designed consumable parts, thereby playing a role in resisting cavitation [8].

6. Conclusion

- (1) A related mathematical model was established for the flow equation of natural gas in the process of transportation;
- (2) The model was simplified according to the relevant characteristics of the unstable conditions, and finally the mathematical model in the case of fast transients and slow transients was obtained [9];
- (3) The influence of unstable flow on the pipeline and the elimination measures were analyzed and applied to the actual operation and management of the national pipeline network company.

References

- [1] X.W. Cao, X.J. Wang and L.Q. Hou: Research on Key Influencing Factors of Flow Instability in the Process of Gravity Water Injection, Atomic Energy Science and Technology, Vol. 53 (2019) No.1, p.132-139.

- [2] Z.Y. Wang, X.B. Chen and Y. Huang: Experimental study on heat transfer characteristics under unstable conditions of natural circulation, Atomic Energy Science and Technology, Vol. 53 (2019) No.4, p.632-640.
- [3] Y.Y. Ling: Research on Elastic Unstable Flow in Viscoelastic Fluid Microchannels and Its Application in Enhanced Mixing, Harbin Institute of Technology, (2018).
- [4] B.L. Zhou: Study on the Unsteady Flow of Axial Fans and the Mechanism of Induced Noise, Jiangsu University, (2017).
- [5] X.Q. Jia: Research on Unstable Flow and Vibration Characteristics in Centrifugal Pump, Zhejiang University, (2017).
- [6] J. Lai, D. Zhang, L. Sun, L.X. Gao, T.C. Tan and P.Z. Li: Investigation on fluidelastic instability of tube bundles considering the effect of slip ratio of air-water two-phase flow, Annals of Nuclear Energy, Vol, 144 (2020).
- [7] J.L. Liu: Numerical Simulation and Experimental Research on Flow Instability Characteristics of Diagonal Flow Pump, Jiangsu University, (2017).
- [8] H. Yang: Simulation of gas-liquid two-phase flow in horizontal elbow in chemical process, Chemical Management, Vol. 33 (2016) No.60.