A Study on the Causes and the Treatment Measures of Slack Line Flow at the Crossing-over Points of the Oil Pipeline

Siqi Xie *
Petroleum Engineering School, Southwest Petroleum University, Chengdu, China

*Corresponding author e-mail: verity5xie@outlook.com

Abstract. This paper points out the definition of the oil pipeline crossing-over points, and thereby identifies the existence and the position of crossing-over points by applying the graphical method and the analytical method. Besides, this paper analyzes the phenomenon of slack line flow from the perspectives of thermodynamics, structural mechanics and fluid mechanics. In order to analyze the motion characteristics of slack line flow, this study divides the control volume in stratified flow into several sections, and then carries out a mechanical analysis of the accelerating and the uniform flow section. Based on the analysis, the equations of the gas-liquid two-phase volume and other parameters in the pipeline are worked out. What’s more, with the time-averaged continuum equation, momentum equation, energy equation for turbulent flow, and RNG k − ε two-equation turbulence modeling, this paper works out closed-form simultaneous equations for gas-liquid two-phase flow in order to establish the calculation model of slack line flow section. This paper also introduces the calculation methods of fluid motion equations and some common simulation software. Furthermore, taking into account the fast velocity and instability of slack line flow, and its buffering effect, this paper points out its hazards, and puts forward the application of its buffering effect and the energy dissipation measures to prevent and control slack line flow.

1. Introduction
Due to the imbalance of energy supply and demand all over the world, it has become a trend to transport the oil and gas resources from resource-rich areas to less abundant areas. With economic efficiency and safety, pipelines have become the best way to transport large quantities of oil in long distances [1]. In recent years, China's long-distance pipeline construction has steadily advanced with the completion of crude oil pipelines, including Kunming-Chongqing, Lanzhou-Chengdu, China-Myanmar crude oil pipelines, and product oil pipelines, such as Nanning-Liuzhou and the product oil pipeline network of Zhejiang Province. However, crude oil pipelines are seriously aging. Up to now, the length of the retired crude oil pipelines is about 2,700km. In the future, it is planned to gradually abandon those aging pipelines. At the same time, the progress of constructing new pipelines has slowed down. Therefore, pipeline projects should be developed, aiming to improve the distribution network, strengthen pipeline construction and promote operation management level [2].

Generally, the geological and environmental conditions of the pipeline construction areas in China are diverse, featuring that there are many mountains undulating in the western and southwestern regions. The pipelines are usually constructed in accordance with the terrain, so there are many pipelines with
great elevation difference in China. According to the data, there are three typical pipelines with the greatest elevation difference, including China-Myanmar crude oil pipeline with an elevation difference of 2,470m, Shijiazhuang-Taiyuan product oil pipeline with an elevation difference of 1,394m, and Jingbian-Xianyang product oil pipeline with an elevation difference of 1,331m [3]. Because of the great elevation difference, there are many crossing-over points along the pipelines, which may lead to slack line flow (the increase of local flow velocity can consume the surplus energy) in the section after the peak. As a result, the energy of oil transportation will be wasted, and various undesirable consequences may be caused, such as the intensified water hammer and shock, and oil mixing in batch transportation [4]. Therefore, it is necessary to study whether there is a crossing-over point in the oil pipeline with great elevation difference under various throughput, and the motion characteristics of slack line flow, so as to propose measures to prevent slack line flow in oil pipelines.

2. The Definition and Identification of Oil Pipeline Crossing-over Points

2.1. The Definition of Oil Pipeline Crossing-over Points

Crossing-over points are primarily caused by the undulating terrain and great elevation difference of pipelines. Besides, after the crossing-over points, the gravity potential energy of the fluid will be rapidly converted into pressure energy and kinetic energy. With the assumption that the energy of the fluid is abundant, crossing-over points can be explained by two definitions:

1. If the liquid still contains surplus energy after automatically flowing from one high point to the ending point, and the surplus energy at this high point is greater than that of the other high points, this high point is the crossing-over point.

2. If the pressure head that a certain amount of liquid needs to flow through a high point is larger than the pressure head to flow from this point to the ending point, and the pressure head at this high point is the greatest one, this high point can be defined as the crossing-over point.

When bracketing off whether the fluid carries sufficient energy to flow through the crossing-over point, and taking the elevation difference between the starting point and the ending point as the hydraulic gradient line, this hydraulic gradient line in the section before the ending point will intersect with the pipeline route profile.

2.2. The Identification of Crossing-over Points

The graphical method and the analytical method are often applied to identify crossing-over points.

2.2.1. The Graphical Method. The graphical method can visualize the object and show the difference between the energy that the fluid in the pipeline carries and the actual required energy.

As Figure 1 shows, place the hydraulic gradient line above the pipeline route profile and translate it toward the pipeline route profile. If the hydraulic gradient line can be tangent to the pipeline route profile at a high point “T” before intersecting with the ending point, the high point “T” will be the crossing-over point. On the contrary, if not, there will be no crossing-over point.
In the actual engineering design and judgment, the terrain of the pipeline construction areas is more complicated than that of Figure 1. Under such circumstance, the relation between the pipeline route profile and the hydraulic gradient line can be simulated by computer in order to exactly and quickly find out the crossing-over points.

2.2.2. The Analytical Method. The analytical method applies a mathematical calculation to compare the specific parameters of the objects.

Calculate the total pressure head \( H_j \) that the pipeline requires from the starting point to each high point, and then compare the result with the total pressure head \( H_f \) that the pipeline requires from the starting point to the ending point. If \( H_j > H_f \), there is a crossing-over point, and the point with the greatest pressure head is the crossing-over point; otherwise, there is no crossing-over point.

\[
H_j = iL_j + Z_j - Z_Q
\]

\[
H = iL + Z - Z_Q
\]

Where: \( L_j, L \) —— the length of the high point \( j \) and the total length of the pipeline.

\( Z_j, Z \) —— the elevation of the high point \( j \) and the ending point of the pipeline.

\( i \) —— the hydraulic gradient per unit length.

\( Z_Q \) —— the elevation of the starting point.

The analytical method is more precise than the graphical method because the length can be assumed as a variable to calculate the specific coordinate of the crossing-over point. However, when applying the analytical method in practice, the calculation process will be more complicated. In general, two methods can be combined to identify crossing-over points. First, the graphical method can be used to conduct interval estimation of the crossing-over point, and then the analytical method can be utilized to work out the specific position.

It should be noted that maybe the crossing-over point is not the highest point of the pipeline. In some situations, the crossing-over point may be a high point close to the ending point. At the same time, after finding out the crossing-over point, the energy required by the fluid to flow from the starting point to
the crossing-over point should be calculated in the process of designing the total energy pressurized by the pump station, in order to ensure that the fluid can flow through the crossing-over point to the ending point. In addition, whether the pipeline can still bear the pressure after the crossing-over point should be taken into account. Although the energy that the fluid carries at the crossing-over point or close to the crossing-over point is within the pressure-bearing capacity of the pipeline, after flowing through the crossing-over point, the fluid’s hydraulic head will dramatically increase due to the sharp decrease of the terrain, which will lead to overpressure or slack line flow.

3. The Causes, Motion Characteristics and Hazards of Slack Line Flow

3.1. The Causes of Slack Line Flow

Generally, the oil flows with pressure under full-pipe flow state in long-distance pipelines. However, after crossing-over points, the amount of the incoming oil in the pipeline remains unchanged, while the elevation difference is greater than the frictional resistance of the full-pipe flow with that throughput. As a consequence, the surplus potential energy will accelerate the flow velocity in part of the pipeline. Due to the continuity of the fluid, an increase of the flow velocity will lead to a decrease in the flow area of the cross-section, and thereby the cross-section of the fluid will reduce and slack line flow will appear.

Slack line flow can be analyzed from the perspectives of thermodynamics and structural mechanics. In thermodynamics, when the pressure of the liquid in the pipeline is lower than the saturated vapor pressure, both the standard volume of the fluid per unit in the pipeline and the pressure will increase, so that the system in the pipeline will keep steady. In structural mechanics, slack line flow is an open pipe flow, meaning that it has a free surface under its corresponding pressure [6]. Besides, slack line flow is in the dynamic fluid state instead of the hydraulic steady state or the uniform flow with the same flow rate. If the pressure in the pipeline falls below the saturated vapor pressure of the liquid, the liquid in the pipeline will be gasified into bubbles. As a result, the gas-liquid two-phase flow, also known as slack line flow, will occur in the pipeline [7].

In actual pipeline engineering, slack line flow may occur when the pipeline crosses a high point, the sealed pipeline cools down, the valve is suddenly closed or the fluid flows downhill in accordance with the terrain. Under the circumstance that the pipeline crosses the high point, the pump station should be designed to ensure that the fluid can flow through the crossing-over point. Therefore, the actual total pressure head \( H_j \) will be greater than the pressure head \( H \) which can overcome the elevation difference between the starting and the ending point, and the frictional resistance of the pipeline. The difference between these two pressure head is the surplus energy, which can be represented as \( \Delta H = H_j - H \). If the surplus energy \( \Delta H \) is not consumed after crossing the crossing-over point, local liquid will consume it by increasing the flow velocity, resulting that the liquid with different flow velocity will be separated from each other by gaps, and thereby the gas will be generated.

3.2. An Analysis of the Characteristics of Slack Line Flow

3.2.1. The Motion Characteristics of Slack Line Flow. According to the experimental results, in the downhill flow, the stratified flow is the main flow pattern. However, only in some specific situations that the gas flows very fast, the two-phase fluid in the pipeline will change into an impact flow or an annular flow [8]. Therefore, the stratified flow will be the main focus of the following sections.

When slack line flow occurs, the hydraulic steady state of the whole pipeline can be divided into three parts [9]. First, in the full flow section before the slack line flow section, the energy is provided by the pump; second, in the slack line flow section, the hydrodynamic pressure is provided by the saturated vapor pressure of the liquid; third, in the full flow section after the slack line flow section, the energy is provided by the potential energy.

In the slack line flow section, based on the criterion whether the acceleration of the fluid “a” is 0, the flow of the fluid can be divided into two forms: acceleration flow \((a<0 \ or \ a>0)\) and uniform flow \((a=0)\). Assuming that the gas-liquid two-phase surface in the slack line flow section is a continuous smooth
curved surface, the cross-section of the slack line flow section can be shown as Figure 2, in which $L_1$ represents the acceleration flow section and $L_2$ represents the uniform flow section.

![Figure 2](image.png)

**Figure 2.** The acceleration flow section and the uniform flow section of the slack line flow

Taking the acceleration flow section as the control volume, when the fluid flows from the cross-section 1 to the cross-section 2, the momentum equation of the control volume can be obtained as:

$$
\sum F = \frac{d(mu)}{dt} + m'_2 u'_2 - m_1 u_1
$$

(3)

Where:
- $F$ —— the total force exerted on the fluid in the control volume;
- $m$ —— the mass of the fluid in the control volume;
- $u$ —— the average velocity of the fluid in the control volume;
- $t$ —— time;
- $m'_2, m_1$ —— the mass of the fluid crossing the cross-section 2 and the cross-section 1;
- $u'_2, u_1$ —— the velocity of the fluid crossing the cross-section 2 and the cross-section 1.

In the steady state, it follows that $\frac{d(mu)}{dt} = 0$. 
Figure 3. Force diagram of the control volume in the slack line flow acceleration section

Figure 3 is the force diagram of the control volume in the acceleration section. Based on the law of force balance and the momentum equation, an equation can be obtained as:

\[ \rho g h_1 A_1 - \rho g h_2 A_2 - \int \tau_0 dA - \int \rho g h dA' = A_2 u_2' - A_1 u_1' \]  

(4)

Where:
- \( \rho \) — the density of the fluid;
- \( g \) — the acceleration of gravity;
- \( h_1, h_2 \) — the potential energy of the cross-section 1 and the cross-section 2;
- \( h \) — the potential energy of a microsegment in \( L_1 \);
- \( A_1, A_2 \) — the flow area of the cross-section 1 and the cross-section 2;
- \( dA \) — the area of a microsegment on the flow cross-section of \( L_1 \);
- \( dA' \) — the area of a microsegment on the free surface of the acceleration flow section;
- \( \tau_0 \) — the shear stress at the pipe wall.

The shear stress \( \tau_0 \) at the pipe wall is related to Fanning friction factor \( f \), which can be expressed as:

\[ \tau_0 = \frac{1}{2} f \rho u^2 \]  

(5)

Fanning friction factor \( f \) is a function of the Reynolds number of the fluid and the roughness of the pipe wall, so different equations can be applied in accordance with the flow regime and fluid characteristics [10]. The Reynolds number of slack line flow is the function of the hydraulic radius, fluid properties, and flow velocity. In addition, the area of the cross-section is defined as the flow area \( A \). Setting the radius of the pipeline as \( R \), and the radian corresponding to the wetted perimeter as \( \theta \), the flow area of the cross-section \( A \) and the wetted perimeter \( \chi \) can be obtained as:

\[ A = \frac{1}{2} R (\theta + Rsin\theta) \]  

(6)

\[ \chi = R \theta \]  

(7)
Therefore, the shear stress at the pipe wall in the differential element section can be expressed by a function of the radian corresponding to the wetted perimeter and the flow velocity. The characteristic equation of slack line flow acceleration flow section can be simplified calculation.

\[ \rho g h_2' A_2 - \rho g h_2 A_2 - \tau_0 L_2 \chi = 0 \]  

Figure 4. Force diagram of the control volume in slack line flow uniform flow section

As Figure 4 shows, taking the uniform flow section as the control volume, an equation can be derived with the law of force balance:

\[ \rho g h_2' A_2 - \rho g h_2 A_2 - \tau_0 L_2 \chi = 0 \]  

The potential energy of each cross-section in the acceleration and the uniform flow section is the elevation of the pipe at that point. Therefore, in conformity with the similar triangle principle, the potential energy relationship among the three cross-sections can be derived as:

\[ \frac{h'_2 - h_2}{L_2} = \frac{h_1 - h_2}{L_{12}} \]  

With the above equations from (3-1) to (3-7), the flow velocity and the radian corresponding to the wetted perimeter of each points in the slack line flow section can be derived, and thereby the gas phase volume in the pipeline can be obtained.

3.2.2. Establishment of Slack Line Flow Calculation Model. To simplify the model, this study assumes that the pipeline of slack line flow section is adiabatic. For the fully-developed turbulent flow (with high Reynolds number) in the model, the flow regime under the circumstance of slack line flow can be simulated based on the time-averaged continuum equation, momentum equation and energy equation for turbulent flow, as well as RNG \( k - \varepsilon \) two-equation turbulence modeling[11]. The closed-form simultaneous equations for gas-liquid two-phase flow are as follows:

Continuum equation:

\[ \frac{\partial \rho}{\partial t} + \frac{\partial (\rho u_i)}{\partial x_i} = 0 \]  

Momentum equation:

\[ \frac{\partial (\rho u_i)}{\partial t} + \frac{\partial (\rho u_i u_j)}{\partial x_j} = - \frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_j} \left( \mu \frac{\partial u_i}{\partial x_j} - \rho u_i u_j \right) + S_i \]
Energy equation:

\[
\frac{\partial (\rho \overline{T})}{\partial t} + \frac{\partial (\rho u_i \overline{T})}{\partial x_j} = - \frac{\partial}{\partial x_j} \left[ \left( \frac{\mu}{\rho R} + \frac{\mu_t}{\sigma_f} \right) \frac{\partial \overline{T}}{\partial x_j} - \rho u'_i T' \right] + S_r
\]  

(12)

k-equation:

\[
\frac{\partial (\rho \overline{T})}{\partial t} + \frac{\partial (\rho u_i \overline{T})}{\partial x_j} = - \frac{\partial}{\partial x_j} \left[ \left( \frac{\mu}{\rho R} + \frac{\mu_t}{\sigma_f} \right) \frac{\partial \overline{T}}{\partial x_j} - \rho u'_i T' \right] + S_r
\]  

(13)

epsilon-equation:

\[
\frac{\partial (\rho \overline{T})}{\partial t} + \frac{\partial (\rho u_i \overline{T})}{\partial x_j} = - \frac{\partial}{\partial x_j} \left[ \left( \frac{\mu}{\rho R} + \frac{\mu_t}{\sigma_f} \right) \frac{\partial \overline{T}}{\partial x_j} - \rho u'_i T' \right] + S_r
\]  

(14)

The values of each terms in the two-equation are as follows:

\[
\begin{aligned}
k &= \frac{\overline{u_i u_j}}{2} \\
\varepsilon &= \frac{\mu}{\rho} \left( \frac{\partial u_i'}{\partial x_i} \right) \left( \frac{\partial u_j'}{\partial x_j} \right) \\
G_k &= \mu_t \left( \frac{\partial u_i}{\partial x_i} + \frac{\partial u_j}{\partial x_j} \right) \frac{\partial u_i}{\partial x_j} \\
\mu_{eff} &= \mu + \mu_t \\
\mu_t &= \rho C_\mu \frac{k^2}{\varepsilon} \\
C_\mu &= 0.0845, \alpha_k = \alpha_\varepsilon = 1.39 \\
C_{1e} = C_{1\varepsilon} &= \frac{\eta (1 - \eta/\eta_0)}{1 + \beta \eta^3} \\
C_{1e} &= 1.42, C_{2e} = 1.68 \\
\eta &= \sqrt{\frac{2 E_{ij} \cdot E_{ij}}{k}} \\
E_{ij} &= \frac{1}{2} \left( \frac'(x_j + \frac{\partial u_j}{\partial x_i}) \right) \\
\eta_0 &= 4.377, \beta = 0.012
\end{aligned}
\]

Where: \( u_i \) — the component of instantaneous space velocity, m/s;  
\( \overline{u_i}, \overline{u_j} \) — the component of time-averaged space velocity, m/s;  
\( u'_i, u'_j \) — the component of time-averaged space velocity fluctuation, m/s;  
\( \overline{T} \) — the time-averaged temperature, K;  
\( \overline{T'} \) — the time-averaged temperature fluctuation, K;  
\( k \) — turbulent kinetic energy, J;  
\( \varepsilon \) — turbulent dissipation rate;  
\( G_k \) — the production of turbulent kinetic energy \( k \) caused by the average velocity gradient;  
\( \mu \) — the viscosity of laminar flow, Pa·s;  
\( \mu_t \) — the viscosity of turbulent flow, Pa·s;  
\( C_\mu, C_{1e}, \alpha_k, \alpha_\varepsilon, \eta_0, \beta \) — empirical constants.

With the time-average continuum equation, momentum equation, temperature variable equation, and \( k \)-equation and \( \varepsilon \)-equation of \( k - \varepsilon \) two-equation turbulence modeling, the governing equations of
gas-liquid two-phase flow in slack line flow section has been worked out. However, when local turbulence features that $Re_t = \frac{\rho k^2}{\eta \epsilon} < 150$, a low Reynolds number $k-\epsilon$ model should be applied in order to take the viscous sublayer in the pipe wall area into account.

3.2.3. An Introduction to the Calculation Method of Fluid Motion Equation. The calculation methods of the established fluid model mainly contain experimental test, theoretical analysis, and numerical simulation.

The experimental test is to establish an experimental system which is similar to the engineering system model, collect the system, record the experimental data, and finally work out a data processing method for calculation to process a large number of experimental data. With experimental test, the solution and dynamic characteristics of the system model can be derived. However, it is difficult to ensure the accuracy in the process because it is more likely to be influenced by the model size, external interference and measurement accuracy. Apart from that, due to high-level requirements on equipment and personnel, the cost of time, human and material resources is much greater than other methods [12].

As the basis of the experimental test and numerical simulation, the theoretical analysis features that its results are universal. However, because of the limited calculation capacity, the model should be simplified in practice. Besides, it is hard to solve the actual nonlinear problems.

Without the limitation of the physical model and the experimental model, the numerical simulation features high flexibility and low cost, and can accurately simulate the model under ideal conditions. However, this method often carries out complex calculations with the help of computers, so it will be limited by the personnel and the computing power of equipment. The commonly used simulation software mainly includes OLGA, PLAC, TACITE, TUFFP, PeTra and so on.

(1) OLGA software: When carrying out calculations, the software will divide the pipeline into several control volume, and store the non-quality variables in the center of the control volume. With the difference scheme of the donor, the Euler method is employed for the transient two-phase flow. However, when the liquid-phase is discontinuous, the results will deviate from the real data. With the focus on averaging the discontinuous liquid-phase, the standard OLGA model can only solve the pressure drop and liquid holdup rate, whereas it cannot work out the per unit length and the frequency of the slug flow.

(2) TACITE software: The algorithm of this software is relatively simple, which can flexibly deal with the transient flow of complex pipelines by adopting a three-point prediction and correcting the finite volume method. The result derived by this software shows high front-end traceability. What’s more, this software embraces many relative advantages. First, the transport equation can guarantee the continuity of the flow pattern transition. Second, the law of closure can be widely applied. Third, the variable continuity in the flow pattern transition is required to be calculated.

(3) PLAC software: The software can establish a typical two-fluid model. When dealing with compressible fluid, structural equations that are difficult to be determined in oil and gas systems should be provided in order to solve the gas-liquid two-phase momentum equations. Apart from that, the Newton iteration method used by this software increases the difficulty in fluid property derivation, so it becomes more complicated to identify the fluid properties.

(4) PeTra software: By applying Euler method on the fixed grid, all of the simulation software listed above can calculate the pipeline pressure drop and liquid holdup rate, but when calculating the slug flow in the pipeline, the numerical dissipation will occur. Therefore, it is difficult to work out the front-end characteristics of the liquid slug, gas content, the movement speed of bubbles. Different from the above software, PeTra utilizes the Lagrangian method to simulate the slug flow and the pipe cleaning pig in the tracking section [13]. So that the above problems can be avoided.

3.3. Hazard Analysis of Slack Line Flow
Slack line flow is harmful to the production management and operational control of the pipeline as follows [14]:

(1) In terms of the leak detection system, the gas-phase in the slack line flow pipeline will hinder the flow of the liquid-phase pressure wave throughout the pipeline, which makes it difficult for the leak
detection system to find out the pipeline leakage point in time and accurately, and thereby increases the
response time to deal with the problems occurring in the section after the crossing-over point.

(2) In terms of the pipeline safety, slack line flow is often accompanied by water hammer in a form
of the collision of upstream and downstream flows, which may make the pressure in the pipeline increase
to the limitation. At the same time, in the transition from low to high pressure, and from slack line flow
to full flow in the downhill section, a constrained hydraulic jump or a tumbling flow will be formed to
consume the surplus energy, and the vacuum in the pipeline will be alternately filled up with backflows.
In this process, the created bubbles will collapse or flow downstream with excessive vibration and
cavitation, which will damage the pipeline.

(3) In terms of the pipeline corrosion, because the flow area of slack line flow becomes much smaller
and the flow velocity is larger, it is more likely for the local inner wall of the pipeline to be corroded.

4. Slack Line Flow Treatment
There are mainly two methods to treat slack line flow.

1) The Use of Slack Line Flow
Although slack line flow has negative impacts on transporting oil, the gas-liquid two-phase flow can
weaken and delay the pressure wave. Therefore, slack line flow can also alleviate the pressure
fluctuation, and form a buffer zone of pressure change, which can be utilized in the decompression
station or pressure reducing valve at the end of the pipeline. For example, Kinder Morgan's Trans
Mountain pipeline in Canada, provides service in slack line flow state [15]. However, it should be noted
that the length of the hydraulic line should be increased when applying slack line flow to buffer pressure
wave in order to extend the adjustment time of flow velocity [16].

2) The Prevention of Slack Line Flow
The measures commonly used in practice to prevent slack line flow are as follows.

(1) Applying reducing pipe: In the downhill flow section with great elevation difference, a reducing
pipe with a smaller inner diameter can be used to consume the surplus energy by increasing the friction
loss. This method can save pipes and cut down engineering investment, but it is not convenient for the
operation of the pipe cleaning pig.

(2) Changing the way of crossing: In the area with great elevation difference, the pipelines can be
constructed through tunnels instead of being arranged in accordance with the terrain. Besides, the
method of extending the length of the pipeline can be applied to make the pipeline bypass the area with
great elevation difference. However, due to topographical factors and construction difficulty, the cost of
this method is relatively high. At present, this method has been utilized in the construction of China-
Myanmar pipeline, Lanzhou-Chengdu-Chongqing pipeline, and Lanzhou-Zhengzhou-Changsha
pipeline.

(3) Setting pressure reducing valve: The pressure reducing valve can reduce the incoming water and
the pressure, and thereby consume the surplus energy. The method has been applied in the construction
of the pipeline at the third oil transportation station by Changqing Oilfield Company.

(4) Using back pressure device: This method is to arrange energy dissipation facilities in the pipeline.
These energy dissipation facilities can be automatically opened or closed by the control of computer
programming in accordance with different working conditions [17]. The back pressure devices
commonly used in practice includes orifice plate energy dissipation devices and spiral flow energy
dissipation devices [18]. Compared with using reducing pipe, changing the way of crossing mode, and
setting pressure reducing valve, this method is more flexible and can adapt to the back pressure
requirements in different working conditions, but it requires a high degree of automation.

In addition to the energy dissipation devices for rapids listed above, the operating principle of the
devices for eliminating water hammer in the pressure water pipeline can be adopted, such as
bidirectional surge tower, single-phase surge tower, air pressure tank, water hammer eliminator, slow
closure check valve and so on [19].
5. Conclusion

Based on the definition of the crossing-over point, this paper systematically analyzes the identification, causes, motion characteristics, calculation methods and hazards of crossing-over points. Besides, this paper also comprehensively summarizes the utilization and elimination of slack line flow. Therefore, this study can provide a reference for technical and scientific research personnel in oil pipeline engineering.

References

[1] Wang Hongju, Zhu Quezhi, Zhang Yanping. Overview of oil and gas pipelines in the world [J]. Oil and Gas Journal, 2015, 34(1): 15-20.
[2] Zhu Quezhi, Wu Chao, Li Qiuyang, etc. Development status and trend of global oil and gas pipelines [J]. Oil and Gas Journal, 2017, 36(4): 375-380.
[3] Liu Xirao. A study on safe pigging program of China-Burma natural gas pipeline [D]. Chengdu: Southwest Petroleum University, 2017.
[4] Gong Jing, Yan Dafan. The characteristics of batch transportation pipeline through the area with great elevation difference [J]. Pipeline Technology and Equipment, 1995, 6(19): 65-72.
[5] Jiang Huayi. Design and Management of Oil Pipelines [M]. Beijing: Petroleum Industry Press, 2010.
[6] Nicholas R E. Simulation of Slack Line Flow-A Tutorial[A]; proceedings of the PSIG Annual Meeting, Albuquerque, 1995[C]. Pipeline Simulation Interest Group: 19-20.
[7] Modisette J. A Slack Flow Model with Moving Regime Boundaries[A]; proceedings of the PSIG Annual Meeting, Deer Valley, 2018[C]. Pipeline Simulation Interest Group: 1-15.
[8] Han Wei. Study on two-phase gas-liquid flow technology in pipeline [D]. Chengdu: Southwest Petroleum University, 2004.
[9] Gong Jing, Yan Dafan. An analysis of the characteristics of slack line flow in downhill section of the pipeline with great elevation difference [J]. Journal of China University of Petroleum, 1995, 19(6): 65-72.
[10] Zeng Zuoxiang. Principle of transfer process [M]. Shanghai: East China University of Science and Technology Press, 2013.
[11] Yao Rentai, Guo Dongpeng. Fundamentals of computational fluid dynamics and application of STAR-CD engineering [M]. Beijing: National Defense Industry Press, 2015.6.
[12] Wang Jing. Study on dynamic characteristics of gas-Liquid two-phase flow [M]. Shanghai: Shanghai Jiao Tong University Press, 2012.
[13] Li Yuxing, Feng Shuchu. Oil, gas and water multiphase flow in pipelines [M]. Qingdao: China University of Petroleum Press, 2011.
[14] Zhang Dawei, Zhang Guangyi, Lu Xingxin. The hazard and prevention of slack line flow in the first section of Jing'an-Hui'an Oil Pipeline [M]. The thirteenth Ningxia Young Scientist Forum on Petrochemical. Yinchuan of Ningxia Province; Proceedings of the thirteenth Ningxia Young Scientist Forum on Petrochemical. 2017.
[15] Zhang Qiang, Gong Jing. Research on process control technology to the end section of west products pipeline [J]. Oil and Gas Journal, 2008, 27(1): 1-4.
[16] Chen Yuanhua G J, Li Xiaoping, Zhou Tong. Study Improves Control of Slack Line Flow[J]. Oil and Gas Journal, 2012, 110(12): 124-131.
[17] Han Wenliang, Zhang Zhiping. Vacuum-unfall flow in the long-distance transportation pipeline and its prevention [J]. Metal Mine, 1994, (11): 48-53.
[18] Wen Hui, Yan Yaoxing. Test analysis of influencing factors of spiral flow energy dissipation for orifice plate of rotary vane [J]. Water Resources and Power, 2015, 37(7): 101-104.
[19] Guo Xiaoning. Study on the effect of multi-orifices spiral flow energy dissipation equipment [D]. Taiyuan: Taiyuan University of Technology, 2008.