Effect of Monitoring Points on Detection Accuracy of Incomplete Blockage in CO2 Pipeline

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Abstract. Based on the transient pressure wave method, this paper uses OLGA simulation software to detect CO2 incomplete pipe blockage, sets different monitoring points in the pipeline, uses its pressure response data for the calculation of blocking position, blocking length and strength, and determines the best monitoring point by analyzing the relative error of specific blocking parameters. For blockage length, when the monitoring point is close to the blockage position, it has the highest measurement accuracy and a relative error of less than 0.535%. Therefore, the monitoring point should be set up separately at the pipe entrance and near the front of the blocking position, so that the internal blockage of the pipe can be detected more accurately and effectively.

1. Introduction

With the vigorous development of global CCUS technology, CO2 pipeline transportation has entered a new peak period. Due to the special properties and a series of factors of CO2 fluid, blockage of long-term pipeline in long-term operation will reduce the transportation efficiency of the whole pipeline. In serious cases, CO2 pipeline will be shut down or burst, endangering the safe and stable operation of pipeline [1-3].

In recent years, researchers at home and abroad have carried out some research on the detection of oil and gas clogging, and tested the blockage of pipelines according to the propagation characteristics of transient pressure waves. For example, in 2011, Based on transient pressure waves, a detection system was developed that can be applied to submarine pipelines [4], which can accurately detect the location of clogging, but cannot determine the strength and length of the blockage; In 2017, according to the propagation law of pressure waves, Xia Ruili [5] and so on studied the blockage parameters of natural gas pipelines, and simulated the corresponding operating conditions, and finally verified and analyzed them. However, there is less research on the detection of blockage of CO2 pipe [6], and this paper will carry out the research on the detection and blocking technology of CO2 pipeline on the basis of the research of scholars at home and abroad.

In engineering practice, CO2 blockage is mostly incomplete blockage, the probability of complete blockage is small, so this paper is based on transient pressure wave method to detect the CO2 pipe not complete blockage. Because the pressure wave propagation in the pipeline takes a certain amount of time, when other conditions are the same only the monitoring point in different positions, each monitoring point responds to the flow pulse distance of pressure propagation, the positive pressure wave and the negative pressure wave reflect the distance is different for the first time, the corresponding time is not the same, and then the measured blocking parameters are different, so analyze the impact of
different monitoring points on the detection accuracy, determine the best monitoring point to reduce the relative error of detection, improve the effectiveness of detection and practicality.

2. Causes of incomplete blockage and model simplification

2.1. Causes and hazards of blockage
Before establishing the blockage model, the causes of the blockage of CO2 pipes are analyzed first. There are many reasons for the blockage of the CO2 long pipeline, which can be divided into two main categories: one is the blockage formed by hydration in the process of transmission, when the pipe has free water and the appropriate pressure and temperature, in the low-lying area of the pipeline or at the elbow, it is easy to form CO2 hydrants and thus cause blockage. Due to the flushing of the pipe fluid, the blockage pattern will extend forward, which is the main reason for the formation of incomplete blockage. The other is that when the CO2 pipeline is laid, the impurities contained in the CO2 gas are gradually deposited and aggregation in the pipe due to the residual impurities after the internal water pressure test of the pipe and the corrosion of the material during the pipeline delivery process, which in turn causes the pipe to become blocked.

2.2. Simplified model for incomplete blockages
According to the characteristics of the CO2 pipe not completely blocked in this paper, that is, mostly by the CO2 fluid to the blockage of the effect of flushing, so the blockage form can be expressed as an extension of blockage shown in Figure 2-1:

![Figure 1. Extended Blockage Schematic](image1)

In order to describe the blockage in the pipe more completely, the basic parameters such as the clogging position, length and strength are studied. For the convenience of the complete calculation of the blocking parameters, the diameter pipe shown in Figure 2-2 will not be fully blocked further equivalent:

![Figure 2. Schematic diagram of equivalent variable diameter pipeline for a single blocked pipeline](image2)

Figure: D1——CO2 pipe diameter, m; D2——Blocked pipe diameter, m; L1——the length of the pipe starting point to the starting point of the blocked pipe segment, m; L2——Blockage length, m;

The diameter-changing pipe model, which reduces the incomplete blockage of CO2, combined with the specific operating conditions, finally uses OLGA software to perform numerical analysis.

3. Method for measuring plug by transient pressure wave method
A mass pulse is applied at the starting point of the CO2 pipeline and the pressure change at the entrance is analyzed. The specific process is shown in Figure 3-1, the left side is the starting point, the right side is the end of the pipe, in the inlet input along the direction of the pipeline mass flow pulse, because the
blockage will make some pressure waves in the form of transient positive pressure waves, while the other part in the form of negative pressure waves exist in the form of a negative pressure wave, and then through the pressure wave changes to determine the location, intensity and length of the blockage [7-8].

Pipe inlet pressure is recorded as $p_0$, mass pulse, positive pressure wave caused by the pressure peak is recorded as $P_1$, $P_2$, pressure wave velocity $a$ is 238m/s. The time when the mass flow reaches its maximum value is recorded as $t_1$, the time at which the first peak is caused by a positive pressure wave is recorded as $t_2$, and the time at which the negative pressure causes the first trough is $t_3$. Blocking parameters can be calculated according to the time difference between mass pulses and crests. The formula is as follows:

$$L_1 = \frac{a(t_1 - t_2)}{2}$$  \quad (1)$$

$$L_2 = \frac{a(t_1 - t_2)}{2}$$  \quad (2)$$

$$B = \frac{P_2 - P_0}{P_1 - P_0}$$  \quad (3)$$

4. Numerical simulation of incomplete pipe blockage

In this paper, the principle of reflection of transient pressure waves in CO2 blocked pipe is used to understand the internal blockage of pipeline by analyzing the data of pressure response. Based on the 2.2 simplified model for numerical simulation, according to the specific operating conditions, OLGA software is used to detect the response data at different monitoring points, and then derive the corresponding blocking characteristic parameters according to the formula, calculate the relative error and analyze the impact on the measurement accuracy, the steps are as follows:

4.1. Basic settings

The basic parameters of a CO2 pipeline in an oil field are shown in Table 4-1, a single insulation extension blocking model in the OLGA software module is set, and the transient calculation uses the original steady-state data, and the pipe is divided by 5m interval. At the initial moment, the pipeline inlet flow increases and then decreases, and then remains in place.

| Length L/m | Diameter d/mm | Pressure P/MPa | Flow rate q/kg/s | Medium Temperature t/°C | Wave velocity m/s | Blocking strength B | Blockage length L_2/m |
|-----------|--------------|---------------|------------------|-------------------------|------------------|------------------|---------------------|
| 5000      | 426          | 4             | 11.9             | 30                      | 238              | 50%              | 100                 |
4.2. Model of Incomplete Blocking Section

The transient flow model selects the basic steady-state model, studies and detects incomplete segment plugs, controls the inlet flow of CO2 pipeline, and can set the action at different points in time, and can get the process parameters of the whole pipeline, different times and different nodes. The study selected the pressure of different monitoring points as the research object, the blocking model is to set the NODE intermediate node pipe diameter, the two NODEs are connected to three pipe segments to form a single extension incomplete blocking model, the blockage segment is FLEPATH-2, PIPELINE1 and FLEPATH-3 are normal non-clogging horizontal pipes, as shown in Figure 4-1:

![Figure 4. Not completely clog the model](image)

4.3. Impact analysis of monitoring points

Using the basic parameters set in 4.1, the pipe is blocked at 1km, the blockage length L2 is 100m, the blockage intensity B is 50%, the different monitoring points are set, 0m, 200m, 400m, 600m, 800m, 950m from the pipe entrance, and then the blockage characteristic parameters under each monitoring point are calculated, the data error is analyzed, and the optimal monitoring point is obtained by comparison.

4.3.1. Simulation results. Using OLGA software to simulate this condition, the pressure at different monitoring points changes over time as shown in Figure 4-2:

![Figure 5. Pressure varies over time at different monitoring points of the CO2 pipeline](image)

4.3.2. Results Analysis and Calculation and Error Calculation.

(1) Description of the simulation result curve.

First of all, the pressure fluctuation curve of the monitoring point at the entrance is analyzed, and the pressure increases sharply at the beginning, reaching a peak of 4.032MPa at t1=0.55s; It is then reduced to 4.012MPa, held for a few seconds before increasing again, peaking again at t2=8.836s, and then decreasing again. As pressure waves travel back and forth between the inlet of the pipe and the blockage, the pressure in the curve fluctuates repeatedly.
(2) The error calculation of clogging feature parameters

Analysis of Figure 4-2, 0m monitoring point pressure change curve over time, due to the increase of pipeline inlet mass flow, monitoring point at a number of pressure peak troughs. The time when the pressure wave reaches the first peak $t_1$ is 0.55s, the second peak time of positive pressure wave reflection is $t_2$ is 8.836s, and the length $L_1$ from the monitoring point to the blocking point is calculated by formula (3-1):

$$L_1 = \frac{a(t_2 - t_1)}{2} = \frac{238(8.836 - 0.5)}{2} = 991.98\text{m}$$

(4)

The time $t_3$ for the first negative pressure trough value is 9.684s. The length $L_2$ of the blocked segment is calculated from the equation (3-2):

$$L_2 = \frac{a(t_3 - t_1)}{2} = \frac{238(9.684 - 8.836)}{2} = 100.912\text{m}$$

(5)

Because the inlet flow pulse increases, the pressure wave of the pipe at 0m reaches a peak of 4.032MPa, the wave peak caused by the positive pressure wave is 4.022MPa, and the pressure after the inlet stabilizes is 4.012MPa, and the blockage intensity $B$ is calculated according to the formula (3-3):

$$B = \frac{P_1 - P_0}{P_1 - P_0} \times 100\% = 50\%$$

(6)

When the monitoring point is 200 m, 400m, 600m, 800m, 950m, the analysis pressure varies with time, and the calculation of each parameter value is shown in Table 4-1:

| Parameter | Monitor Points | $t_1$/s | $t_2$/s | $t_3$/s | $P_0$/MPa | $P_1$/MPa | $P_2$/MPa |
|-----------|----------------|---------|---------|---------|------------|------------|------------|
|           | 200m           | 1.247   | 7.891   | 8.725   | 4.012      | 4.028      | 4.017      |
|           | 400m           | 2.039   | 7.043   | 7.891   | 4.011      | 4.025      | 4.017      |
|           | 600m           | 2.942   | 6.264   | 7.098   | 4.011      | 4.025      | 4.018      |
|           | 800m           | 3.762   | 5.403   | 6.237   | 4.011      | 4.023      | 4.018      |
|           | 950m           | 4.485   | 12.575  | 5.750   | 4.011      | 4.026      | 4.017      |

Consistent with the algorithm at 0m of the monitoring point, the blockage characteristic parameters under each monitoring point are calculated by using formulas 3-1, 3-2 and 3-3 respectively, and the relative error is calculated according to the results of the blockage characteristic parameters at each monitoring point and the true blockage parameter values, and the results are found in Table 4-2:

| Parameter error | Monitor Points /m | $L_1$/m | $L_1$ Relative error | $L_2$/m | $L_2$ Relative error | $B$     | $B$ error |
|-----------------|-------------------|---------|----------------------|---------|----------------------|---------|-----------|
|                 | 0                 | 991.98  | 0.8016%              | 100.912 | 0.912%               | 50%     | 0         |
|                 | 200               | 790.636 | 1.17%                | 99.246  | 0.754%               | 46.67%  | 6.66%     |
|                 | 400               | 595.476 | 1.17%                | 99.246  | 0.754%               | 46.67%  | 6.66%     |
|                 | 600               | 395.32  | 1.1705%              | 99.246  | 0.754%               | 46.67%  | 6.66%     |
|                 | 800               | 195.275 | 2.36%                | 99.246  | 0.754%               | 46.67%  | 6.66%     |
|                 | 950               | 975.42  | 2.458%               | 100.535 | 0.535%               | 41.18%  | 17.64%    |

Table 4-2 shows that the blockage characteristic parameter error at different monitoring points is small, the blocking position error range is 0.8016%-2.458%, and the blocking length error range is 0.535%-0.912%. When the monitoring point is set at the entrance of the CO2 pipe, the accuracy of the
blocking position and the clogging intensity is the highest, and the error is as low as 0.8016% and 0,
respectively. The relative error is as low as 0.535% when the monitoring point is closer to the blocked
position.

5. Conclusion
(1) The CO2 pipeline can determine the blockage position by using the time difference between peak
and blocking caused by peak and blocking of flow pulses in the pipeline, the blocking length by the time
difference between the peak of positive pressure wave and the time difference caused by blocking
causing the negative pressure wave valley, and the amount of mutation of transient pressure wave to
determine the blocking intensity, and then calculate the blocking characteristic parameters.

(2) The clogging position and clogging intensity obtained by setting the monitoring point at the
entrance of the CO2 pipeline are the most accurate, the relative error of positioning in the simulation is
less than 0.8016%, and the closer the monitoring point is to the blockage, the greater the error. In contrast
to the clogging length, the closer the monitoring point is to the clogging position, the higher the accuracy
of the blockage length measurement and the smaller the error. When the CO2 pipe is blocked, in order
to effectively measure the extent of the blockage in the pipe, the corresponding monitoring points should
be set at the pipe inlet and near the blockage.

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