Dynamic Simulation Model for Gas Transmission Pipeline Network System

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ABSTRACT

The dynamic simulation calculation of gas pipeline network is complicated. Usually, for each pipeline, energy conservation, mass conservation and momentum conservation are used to establish the non-linear equations[1-2]. For some complex pipeline network flow with multiple entries and outlets, the calculation is very slow, and cannot achieve real-time calculation. This study presents a new method for calculating the pressure between pipelines by assuming that the pipeline is a single vessel, calculating the flow rate between the pipelines by the pressure difference between the pipelines, and then using the flow rate as the intermediate coupling relationship to calculate pipe pressure. This method is simple, fast, with few boundary limitations, which can assist the design and operation verification of complex pipeline networks.

1. INTRODUCTION

The traditional hydraulic simulation model is very complex. A set of equations is used to describe the hydraulic model of a whole station. The equations are usually non-linear. The calculation amount of solving the equations increases exponentially with the complexity of the pipeline network [3]. When the pipeline network is complex to a certain extent, it is impossible to realize real-time pressure calculation [4-5].
This study presents a simple real-time simulation method, which has low computational complexity and can real-time calculate the pressure and flow in the pipeline network.

2. MATERIALS AND METHODS

2.1 Core Model

If each pipe is regarded as an independent container, the flow calculation of pipe network can be simplified to independent flow calculations between pipes. Pipe flow is assumed to be a set of multiple static pressure states as Figure 1.

Suppose there are two pipes, Pipe A and Pipe B are connected as Figure 2, and the volume of the pipes is large enough, pipes filled with gas, the pressure of Pipe 1 is \( P_A \), and the pressure of Pipe 2 is \( P_B \).

The equation of flow \( Q \) of pipe A to pipe B under standard pressure is as:

\[
P_A^2 - P_B^2 = K_{AB} Q_{AB}^2
\]
$K_{AB}$ is pipeline flow coefficient, according to the pipe type and media situation, $K_{AB}$ has many forms, for example in the form below[6]:

$$K_{AB} = 4.3599 \times 10^8 \frac{f G T}{D^5} \left(\frac{P_n}{T_n}\right)^2 L$$

$P$ [kPa], $T$ [K], $L$ [km], $Q$ [m$^3$/h] and $D$ [mm],

For pipe A and B, the general expression is used to express the flow rate between pipes as shown in the following formula, $Q$ is used to express the flow rate of gas from pipe A to pipe B (at standard atmospheric pressure).

$$\Delta Q = \left( P_A - P_B \right)^{1/2} \times K_{AB} \times P_A \times \Delta t$$

$$K_{AB} = f(D, L, \delta)$$

$K_{AB}$ is the flow coefficient of pipeline, which is related to the friction coefficient, diameter and length of pipeline.

- $P_{A1}$: Pipe A pressure at time $t$
- $P_{A2}$: Pipe A pressure at time $t+\Delta t$

After the time $\Delta t$

Pipe A pressure: $P_{A2} = \left( P_{A1} V_A - \Delta Q \right) / V_A = P_{A1} - \Delta Q / V_A$

Pipe B pressure: $P_{B2} = \left( P_{B1} V_B + \Delta Q \right) / V_B = P_{B1} + \Delta Q / V_B$

When $\Delta t$ is short enough, the ratio of $\Delta Q/Q$ is small, which will not lead to sudden change of pressure in the pipeline.

Pipeline energy equation:

- The first state, when time $t$. pipe A energy: $P_{A1} V_A$. pipe A energy: $P_{A1} V_A$
- System total energy: $P_{A1} V_A + P_{B1} V_B$

The second state, when time $t+\Delta t$. pipe A energy: $P_{A2} V_A = (P_{A1} - \Delta Q / V_A) V_A = P_{A1} V_A - \Delta Q$. Pipe B energy: $P_{B2} V_B = (P_{B1} + \Delta Q / V_B) V_B = P_{B1} V_B + \Delta Q$. system total energy: $P_{A1} V_A + P_{B1} V_B$.

In states 1 and 2, the total energy of the pipeline system is conserved.

Pipeline Mass equation:

- The first state at time $t$. The gas mass of Pipeline A is: $\rho V_{A1}$. The gas mass of Pipe B is: $\rho V_{B1}$. System total gas mass: $\rho V_{A1} + \rho V_{B1}$
- The second state, at time $t+\Delta t$. the flow from pipe A to pipe B is $\Delta Q$. the second state, when time $t+\Delta t$. Pipe A gas mass: $\rho V_{A1} - \Delta Q$. Pipe B gas mass: $\rho V_{B1} + \Delta Q$. System total gas mass: $\rho V_{A1} + \rho V_{B1}$

In states 1 and 2, the mass of the pipeline system is conserved.

The calculation method satisfies the conservation of energy and mass in the pipe network system.

The whole flow process is regarded as a set of multiple stationary states, in which there is no flow in the pipeline, which conforms to the conservation of momentum.
2.2 Pipe Joint Model

There are three pipes connect to joint A: pipe A, pipe B, pipe C, calculation process is shown in Figure 4.

Assuming that the flow direction is pipe A flowing into pipe B and pipe C. The outflow of pipe A contains two parts, the flow from pipe A to pipe B $Q_{AB}$ and the flow from pipe A to pipe C $Q_{AC}$

$$Q_{A_{out}} = Q_{AB} + Q_{AC}$$

The inflow of pipe B contains only one parts, the flow from pipe A to pipe B $Q_{AB}$

$$Q_{B_{in}} = Q_{AB}$$
The inflow of pipe C contains only one part, the flow from pipe A to pipe C $Q_{AC}$

\[ Q_{C_{in}} = Q_{AC} \]

As for the joint A, the inflow of pipe A is the flow to pipe A, it is positive. The inflow of pipe B and pipe C is the flow from pipe A, it is negative. As for joint A, the sum of flow is:

\[ \sum Q = Q_{A_{out}} - Q_{B_{in}} - Q_{C_{in}} \]

\[ \sum Q = Q_{AB} + Q_{AC} - Q_{AB} - Q_{AC} = 0 \]

At Joint A, the $\sum Q$ is zero, which satisfy mass conservation. By using this method, the problem solving can be extended to a large system.

2.3 The Inlet and Outlet of Pipe Network

![Pipe inlet and outlet](image)

Figure 5. Pipe inlet and outlet.

The entrance of the pipe network is represented by a pipe whose pressure is constant.

The outlet of the pipe network is also represented by a pipe, and the pressure of the pipe is also constant.

2.4 Valves Model

![Valve model](image)

Figure 6. Valve model.

The head and tail of each pipe may be connected with a valve. The opening of the valve will affect the flow coefficient $K_{AB}$ between the pipes. $f(V)$ indicates the influence of the opening of the valve on the flow of the pipe. $f(V)$ is 0 when
the valve opening is 0, and \( f(V) \) is 1 when the valve opening is 100.

\[
\Delta Q = (P_A - P_B)^{1/2} \times K_{AB} \times P_A \times \Delta t
\]

\[
K_{AB} = f(D, L, \delta) \times f(V)
\]

3. SIMULATION APPLICATION

The typical # shaped pipe network is used to test this algorithm.

![Shaped pipe network system](image)

The flow direction of the red pipeline in the figure above depends on the flow and pressure of the upper and lower pipelines. The opening of the valves V-1, V-2, V-3 and V-4, V-5 and V-6 determines the flow direction and pressure of the pipelines P-7 and P-8. In this system, the atmospheric source pressure is 2 Mpa and the atmospheric outlet pressure is 0.1 Mpa.

In the process of dynamic calculation, all pipes are divided into hydraulic systems of multiple pipes and valves, as shown in the following figure.

1 if there is a valve in a pipeline, this pipeline must be divided into two pipes.
2 if there is a node in a pipeline, this pipeline must be divided into several pipes.

A typical division is shown in Figure 8.

![Shaped pipe network system pipes](image)
The inlet and outlet are abstracted into pipes with constant pressure, and the opening of all valves is corresponded to the opening of the head and tail of the pipes. For example, for pipes P-3, the opening of the head is as follows: because the head is not connected to the valve, the opening of the head is $K_{P3H}$ as follows:

$$K_{P3H} = f(D, L, \delta) \times 100\%$$

$f(D, L, \delta)$: The pipe P-3 feature factor

The tail of P-3 is connected to valve V-2, Valve V-2 opening value is 50%, the pipe tail opening value is $K_{P3T}$:

$$K_{P3T} = f(D, L, \delta) \times 50\%$$

$f(D, L, \delta)$ : The pipe P-3 feature factor

The pressure of each pipeline is shown in the following figure. The program is written in C#. The pipe color is used to express the pressure level. The blue text near the pipeline represents the pressure value of the pipeline. The triangle in the pipeline represents the pipe flow direction.

4. CONCLUSIONS

This algorithm can solve the flow problem of complex pipeline network quickly, and the computational time complexity is low. But the algorithm has some disadvantages:

(1)When the volume difference between the two pipes is too large, it will cause pipe pressure jump under the same flow rate. It needs to increase the calculation times per unit time.
The algorithm is only suitable for the calculation of gas with large pipe volume. For the high-speed flow with small diameter, more parameters need to be used to fix this model.

This algorithm is not suitable for the simulation of liquid flow in small volume pipes.

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