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Dynamic Simulation of Compressible Fluid Network

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Abstract
Oil and gas transmission is a very complex industrial process. To improve system security and reduce costs, pipeline network simulation has been developed. The classical approach is to establish mathematical models and solving method, however, solving is complicated and slow. In this paper, we proposed a new method which can be used in simulation for analyzing compressible fluid network dynamically. The proposed method is simple and easy to implement, which can compute the pressure and flow of pipeline network in real time, and let the system reach steady state quickly. The simulation example verifies the accuracy of the algorithm. The experimental results indicate that our method is efficient, and the simulation data can truly reflect the changing process of the real pipeline network system.
Key words: COMPUTER SIMULATION, COMPRESSIBLE FLUID, PIPELINE NETWORK, FLUID COMPUTATION

1. Introduction

From the mid-1980s, many research institutions have developed fluid network computing software, Such as American Electric Power Research Institute of MMS software, LINK's FLOWNETS software. Some scholars studied fluid network model and achieved good results. Lv Zian [1], who developed a method using fluid pressure node network system simulation package THNP, Wu Jing [2], who established the simulation training system suitable for chemical process fluid network. Ma Yinhui [3] use network analysis tools, arbitrary topology derived a compressible fluid network modeling. However, these conventional simulation techniques [1-11], is usually composed of conservation equations and thermodynamic equations, those equations is nonlinear, equations solving is difficult and time-consuming, it is impossible to simulate in real time.

In this paper, we proposed a new method can be used in simulation and training system for analyzing compressible fluid network dynamically. The proposed method is simple and easy to implement. It can compute the pressure and movement of pipeline network in real time.

2. Simulation Introduction

Oil and gas pipeline network system is composed of a large number of pipeline and non-pipeline equipment including pumps, valves, separators, heater, and etc. These equipment form a complex fluid network system. Inside the pipeline network phenomenon is fluid diversion and confluence. This paper presents a simple simulation method for dynamic analysis of compressible fluid in the fluid flow network. The method called as “pipeline flow coupling analysis”, which use flow relationship between adjacent pipelines to calculate each pipeline’s pressure and flow direction dynamically.

In order to analyze problems easier, we propose the following hypothesis.

1) Fluid density will change with the fluid flow.

2) The entire fluid system is located in a two-dimensional plane, which does not consider potential changes caused by the height difference.

3) Fluid in the pipeline uniform state (internal pipeline pressure, temperature everywhere equal), without regard to the heat exchange system and the outside world in any form.

4) Each pipeline fluid is in uniform state, pipeline pressure is equal and flow temperature is equal, without regard to the heat exchange between pipelines and environment in any form.

3. Simulation Algorithm

This chapter introduces the core idea of the algorithm, including fluid pressure analysis, pipeline network flow calculation, and pipeline network storage.

3.1. Analysis of compressible fluid pressure

Gas is compressible, the density of the gas will change while the pressure change. In a sealed container, gas pressure and gas volume is depend on temperature, which consistent of Klapper Long equation PV = nRT. It can be considered inversely proportional to the pressure and volume of gas when the gas volume changed little. When increasing the gas to a sealed container, the gas pressure will not mutated, but changes linearly. Its curve shown in Figure 1.

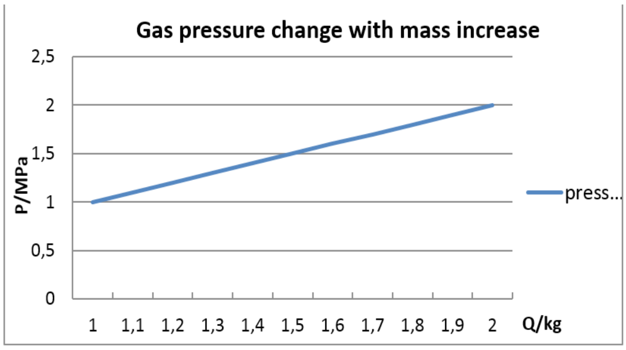

Figure 1. Gas pressure change with mass increase

Figure 1 shows that: When the fluid is a compressible, within a very short time, pipeline pressure and the inflow, outflow of fluid mass values are proportional relationship, which is the fundamental basis of the proposed algorithm.

3.2. Pipeline network flow calculation

The flow of the pipeline network is very complex, its status changes all the time, such as fluid flow, pressure, temperature and etc. If we can predict the actual running state, then we can provide advice for pipeline design and maintenance.

Pipeline network flow analysis involves two issues, 1) determine the flow direction in each pipe; 2) calculate flow parameters in all pipelines.

Determining pipeline flow direction in pipeline networks is a very important issue. Many operation (such as Pipeline diversion, confluence situation, valve opening change, multiple entrances and exits, pipeline loops) will cause flow direction change and parameter change within the system.

The algorithm, network flow calculations include two steps, Step 1: In a very short time, the pressure is assumed to be constant for each pipeline, pipeline inflows and outflows is proportional to the pressure difference of each pipeline. Formula (1) (2) is used to calculate the flow between adjacent pipelines; step 2: calculate the entire pipeline system pressure in the next time according to the last inflow and outflow of each pipeline. Fluid calculation process shown in Figure 2.

Pipeline inflow model:

$$M_{i(in)}{}^{(k)} = \sum_{j=1}^{m}[(P_{j,i-1}{}^{(k)} - P_i{}^{(k)}) * C] \quad (1)$$

Pipeline outflow model:

$$M_{i(out)}{}^{(k)} = \sum_{j=1}^{m}[(P_i{}^{(k)} - P_{j,i+1}{}^{(k)}) * C] \quad (2)$$

i: i-th pipeline;

i-1: i-th pipeline's upstream pipeline;

i+1: i-th pipeline's downstream pipeline;

k: Discrete time stamp, the time step is short enough.

$M_{i(in)}{}^{(k)}$: *Time k, the mass flow into i-th pipeline;*

$M_{i(out)}{}^{(k)}$: *Time k, the mass flow out i-th pipeline;*

m: The number of other pipelines connected

C: Constant for each pipeline, determined by the degree of opening of the pipeline friction, flow rate and the valve.

$P_i{}^{(k)}$: *Time k, i-th pipeline pressure;*

$P_{j,i-1}{}^{(k)}$: *Time k, the j-th upstream pipeline pressure;*

$P_{j,i+1}{}^{(k)}$: *Time k, the j-th downstream pipeline pressure;*

Pressure calculation model:

$$P_i{}^{(k+1)} = (V_i^{(k)} * P_i^{(k)} + M_{i(in)}{}^{(k)} - M_{i(out)}{}^{(k)})/V_i^{(k)} \quad (3)$$

$V_i{}^{(k)}$: *Time k, the volume of i-th pipeline;*

$P_i{}^{(k)}$: *Time k, the pressure of i-th pipeline;*

$P_i{}^{(k+1)}$: *Time k+1, the pressure of i-th pipeline;*

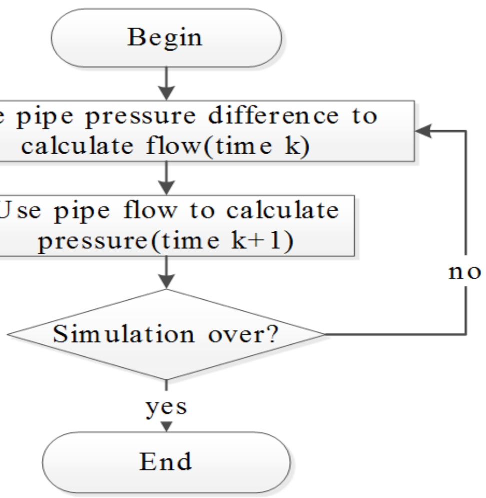

Figure 2. Network flow calculation Process

The following examples explain the algorithm. As shown in Figure 3, there are three pipelines, pipeline 1 and pipeline 2 is connected, pipeline 2 and pipeline 3 is connected, Suppose all pipelines volume are large enough, the interior is filled with gas. Within time Δt, mass inflow form pipeline 1 to pipeline 2 is $\Delta m1 = (P1 - P2) * C$, mass inflow form pipeline 2 to pipeline 3 is $\Delta m2 = (P2 - P3) * C$.

In the next period, pipeline 1 pressure is $P1 = P1 - \Delta m1/V1$, pipeline 2 pressure is $P2 = P2 + \Delta m1/V2 - \Delta m2/V2$, pipeline 2 pressure is $P3 = P3 + \Delta m2/V3$. When Δt is short enough, $\Delta m/V$ is relatively small, it does not cause the pipeline pressure mutation.

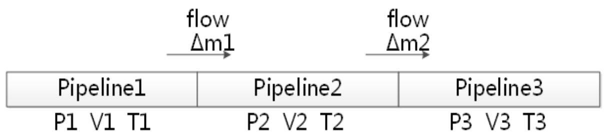

Figure 3. Examples of pipeline connection

3.3. Valve settings

Valve controls the flow between the pipes, Valve opening will also affect the mass flow of two pipes connected to this valve. If a valve is connected to pipe1 and pipe2. Valve opening will affect the constant C in formula $\Delta m = (p1 - p2) * C$. Valve opening impact the parameter C of pipeline 1 and pipeline 2. Depending on the valve type, the impact of C value approach may be linear or quadratic.

3.4. Pipeline storage

Pipeline network storage using the following method:

1. The pipeline is viewed as a single node, each node has its own volume, and flow can be input and output.
2. In Pipeline intersection, Pipeline must be split into multiple Pipelines.
3. Each pipeline is connected to up to three adjacent pipelines, two triples array is used to record adjacent pipelines, one is used to record head adjacent pipelines, another one is used to record tail adjacent pipelines;
4. Each valve is connected to adjacent two pipelines, setting a binary array for each valve, used to record adjacent pipelines;
5. If there is a valve on a pipeline, the pipeline must be split into two pipelines from the valve position.

4. Simulation example

In this paper, we use the same instance in article [9] to test this algorithm. Fluid network structure shown in Figure 4. The system has a constant pressure source, its pressure is 3MPa. Tank 1, tank 2 and tank 3 volume are 300L. Set the volume size of each pipeline 1L. Initially, the valve 1 open, valve 2, 3,4,5,6 closed, all tank pressure are 0MPa.

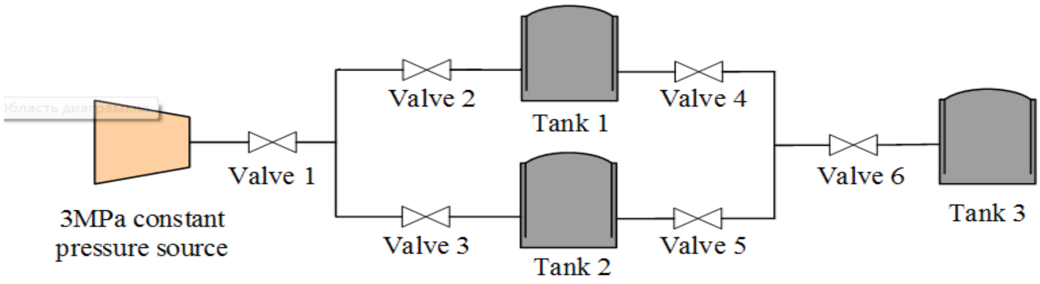

Figure 4. Fluid network simulation structure

The following operations of this simulation: 1) Open valve 2, valve 3, use constant pressure source to fill tank 1 and tank 2 until the tank pressure reaches 2MPa, and then close pressure source, valve 2 and valve 3. 2) After a while, open the valve 4, the valve 6,use tank1 to fill tank3 until pressure balance; 3) After a while, open the valve 5, use tank2 to fill tank1 and tank3 until pressure balance.

During the simulation, tank 1 pressure shown in Figure 5, tank 2 pressure shown in Figure 6, tank 3 pressure shown in Figure 7.

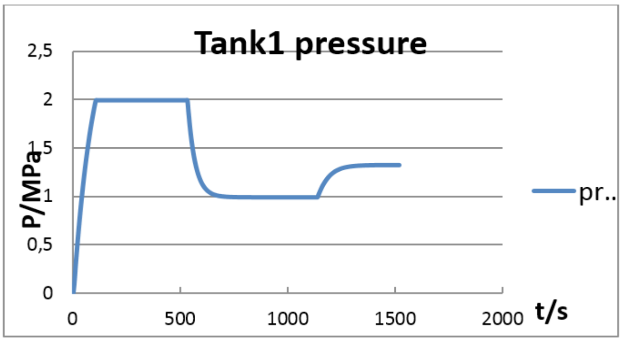

Figure 5. Tank 1 pressure change graph

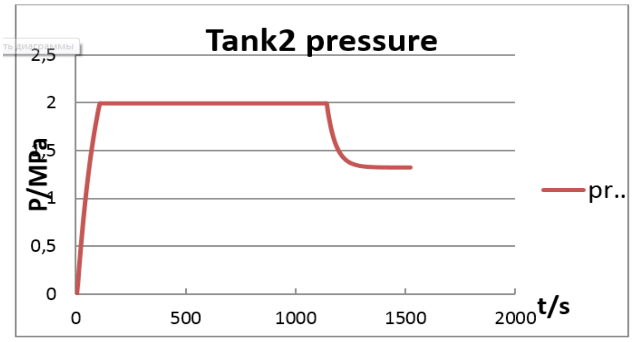

Figure 6. Tank 2 pressure change graph

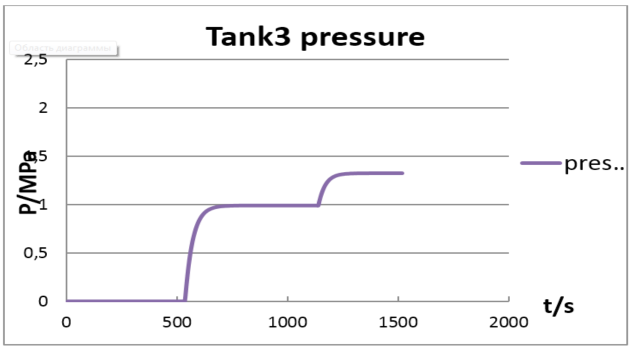

Figure 7. Tank 3 pressure change graph

Figure 5-7 shows that at the beginning of valve open or close, tank pressure change rapidly, the slope of the pressure change is relatively large. With the balance of the tank pressure, the pressure difference becomes smaller, the pressure change trend are becoming slow, and at last all pressure is balanced.

5. Conclusions

Pipeline flow coupling analysis is a new method for compressible flow pipelines network. Compared with traditional method, it is simple and easy to comprehend. With this method, simulation can reflect the flow direction inside the pipeline network system, and also correctly simulate the pressure changes within the system.

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Architecture Plane Layout Simulation Model Based on Probability Optimization Genetic Algorithm

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