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Research on Dynamic Venting Characteristics of City Gas Pipeline Networks and Analysis of Software Development

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Abstract. As an important part of the gas pipeline safety system, the venting pipe plays a role in protecting the safe operation of the network and reducing the consequences of accidents, and its design feasibility, rationality and safety are particularly important. In China, most of the online simulation software used for gas pipeline network venting simulation is limited to expensive, poorly controllable software and difficult to design for specific working conditions, so the application of dynamic simulation software for gas pipeline networks is of great importance. In this paper, simulation software is developed for city gas pipeline venting systems, simulations are carried out using a programming language, the usability of the developed software is verified and the influence of different influencing factors on the venting process is investigated using the control variable method of analysis.

Keywords: Gas Pipeline Networks; Pipeline Emptying; Software Development.

1. Introduction

Energy and environmental issues are currently two of the world's greatest concerns. Compared to resources such as oil and coal, natural gas has the advantage of high calorific value, better safety, and cleaner products after combustion [1]. In recent years, with the widespread deployment of gas pipeline systems in China, many complex issues have arisen and people are becoming aware of the importance of gas pipeline network simulation technology.

Western countries have started research on gas pipeline network simulation technology since the 1960s [2]. With the continuous development of numerical simulation technology, many foreign gas pipeline network simulation software has appeared one after another. Stoner in the USA invented the SPS software, which contains two modules for gases and liquids, enabling steady-state and transient simulations of gases and liquids respectively [3]. The British company FMI has developed Flow Master online simulation software, which has the capability of steady-state and transient analysis, and can also calculate the heat and mass transfer of compressible and incompressible fluids [4].

The research work on pipe network simulation technology in China started late, and it was not until the 1970s that research on the steady-state simulation of gas pipeline networks began. China's Pipeline Company Science and Technology Research Centre developed RealPipe-Gas 1.0, a software that can be used for the planning and design of natural gas pipeline networks, accident analysis, etc [5]. Overall, the domestic gas pipeline network simulation software is still in the stage of not yet fully commercialised, and there is still a large gap compared to foreign countries, specifically in that it has not yet fully mastered the core technology of large-scale gas pipeline network simulation [6].

Pipeline venting has not yet formed a complete and systematic theoretical system, and the related technology is not yet mature. The design of the venting system was first proposed in a paper by F.F.K Chen [7] at the end of the last century, and the dynamic design of the venting system was analysed for the first time based on the criteria in the change paper, and the formulae for calculating the venting volume, venting rate and other parameters were derived. In 2015, Zhang Wenli of Southwest Petroleum University obtained the calculation method of the height of the venting pipe for different venting methods through the study of three different ways of natural gas pipeline venting methods, which laid the foundation for the subsequent study [8].

In this paper, a parametric, intuitive and user-friendly software is developed to simulate the blow-off process of gas pipelines by using the basic flow relationship in natural gas pipelines combined with one-dimensional transient simulation method and programming language.

2. Dynamic Emptying Software Development Method

2.1. Software Analysis Methods

The flow of natural gas in the pipe is difficult to determine and, because of its compressibility, the pressure, density and velocity are constantly changing as it flows. At the same time, the temperature of the natural gas is constantly changing as it exchanges heat with the environment in the pipeline, which makes the simulation of gas network dynamics even more complex. Therefore, this paper mainly considers the change of parameters with the operation of the pipeline to carry out a one-dimensional simulation, and the following pipeline flow model is established according to three major conservation relationships.

1. Continuity *Equation*

$$\frac{\partial \rho}{\partial t} + v\frac{\partial \rho}{\partial x} + \rho\frac{\partial v}{\partial x} + \frac{\rho v}{A}\frac{\partial A}{\partial x} = 0 \tag{1}$$

Where: ρ is the gas density; v is the gas flow rate; t is time; A is the cross-sectional area of the pipe; X is the axial length of the pipe; m is the mass flowing into the control body.

2. Momentum Equation

$$\left(\frac{\partial v}{\partial t} + v\frac{\partial v}{\partial x}\right) + \frac{1}{\rho}\frac{\partial P}{\partial x} + g\frac{dz}{dx} + \frac{\lambda}{2D}v|v| = 0 \tag{2}$$

Where: v is the gas; τ is the shear stress; t is the time variable; x is the length variable in the axial direction of the pipe; ρ is the gas density; P is the gas pressure in the pipe; g is the acceleration of gravity; z is the gas pipe elevation; λ is the hydraulic friction resistance coefficient; D is the internal diameter of the gas pipe.

3. Energy Equation

$$\frac{\partial}{\partial t}\left[\rho A\left(h - \frac{P}{\rho} + \frac{v^2}{2}\right)\right] + \frac{\partial}{\partial x}\left[\rho v A\left(h + \frac{v^2}{2}\right)\right] + \rho v A g\frac{dz}{dx} + K\pi D(T - T_0) = 0 \tag{3}$$

Where: ρ is the density of the gas; W is the work done by the force acting on the micro element; h is the enthalpy of the gas P is the pressure in the pipe; v is the gas flow rate; K is the total heat transfer coefficient of the gas pipe; T is the temperature of the gas in the pipe; T0 is the ambient temperature of the pipe; g is the acceleration of gravity; z is the elevation of the gas pipe; d is the internal diameter of the gas pipe.

2.2. Software Functional Design

In this paper, a one-dimensional dynamic simulation algorithm is used as the basis for building a gas pipeline model, which is then packaged and developed in a high-level programming language to design a stand-alone pipeline venting software. The main operating interface of the software is shown in Figure 1.

The leftmost interface is for selecting the model to be used for dynamic simulation, including the venting model and pipeline system maintenance, while the middle interface is for parameter input, where basic parameters are entered according to the different models, including the length of the main, the internal diameter of the main, the temperature and pressure of the pipeline during normal operation, the length of the venting pipe and the internal diameter of the venting pipe. The results include the duration of the venting process, the venting volume (the volume of gas released during the entire venting process), the hourly venting volume (the volume of gas released per unit hour), and the initial volume of gas. The graphs of flow rate, pressure, volume of gas in the pipe and temperature are also displayed for easy analysis.

Fig 1. Natural gas pipeline venting software operating interface

3. Analysis of Factors Influencing Emptying

3.1. Analyze the Basic Parameters of Pipe Network

The real emptying data of a section of the West-East gas transmission pipeline was selected for verification, and the designed software was compared and verified. the main length of this section of the pipeline is 10.20km, the pipe diameter is 1219×18.4mm, the pressure in the pipe before the start of emptying is 4.5MPa, and the pressure in the pipe after the end of emptying is 0.05MPa. the pipe parameters can be seen in Table 1 below.

Table 1. Basic parameters of the emptying pipeline

Gas main line	Pipe diameter	1219×18.4mm
	Pipe length	10.02km
	Initial pressure	4.5MPa
Emptying of pipeline	Pipe diameter	406×12.5mm
	Pipe length	450m

3.2. Effect of Emptying Tube Length on the Emptying Process

Different venting pipe lengths were selected to analyse the effect of venting pipe length on the venting process of natural gas pipelines. The diameter of the venting pipe was taken as DN400, the initial pressure was 4.5MPa and the initial temperature was 20℃, and the venting ended when the pressure inside the pipe was reduced to the external atmospheric pressure.

As can be seen from Figure 2, the greater the length of the venting pipe, the longer the duration of the venting process, when the venting pipe length is 500 m, the venting duration is 14 h, when the venting pipe length is 1000 m, the venting duration is 16.3 h. It can be seen that the venting time variation range is small, which is mainly because the venting pressure and temperature and the venting pipe diameter have been determined and other basic This is mainly because the basic data such as venting pressure and temperature as well as venting pipe diameter have been determined, and these data do not change with the change of venting pipe length, so the impact of venting pipe length on the venting process is small, and the venting process is a fast flow process, its flow form is complex, in a shorter period of time the pressure inside the pipe has been reduced to a lower level, the flow rate is also gradually reduced, and it can be seen from the figure, the venting process in low pressure conditions still lasted a long time, will This has an impact on the reasonable calculation of the emptying time and brings great inconvenience to production and maintenance.

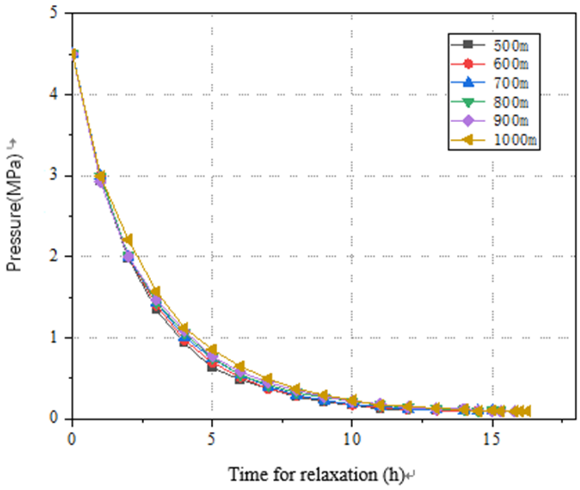

Fig 2. Pressure drop curves for different venting tube lengths

3.3. Influence of Emptying Pipe Diameter on the Emptying Process

Different venting pipe diameters were selected to analyses the effect of venting pipe length on the venting process of natural gas pipelines. The length of the venting pipe was taken to be 400m, the initial pressure was 4.5MPa, the initial temperature was 20°C, and the venting ended when the pressure inside the pipeline was reduced to the external atmospheric pressure.

As can be seen from Figure 3, under the premise that the pressure in the main line is 4.5MPa and other basic data remain the same, the emptying time gradually decreases as the diameter of the emptying pipe increases, and when the diameter of the emptying pipe is DN400, the corresponding emptying time is 14h, while when the diameter of the emptying pipe is DN900, the emptying time is 10.2h, the time is reduced by about 4h, and the smaller the diameter of the pipe, the more the The smaller the pipe diameter, the smaller the pressure drop in each time period. The main reason is that when the diameter of the emptying pipe becomes larger, the fluid flow per unit time through the emptying pipe will increase, so it will reduce the emptying time, but this does not mean that this can increase the diameter of the emptying pipe infinitely to reduce the emptying time, because when the diameter of the pipe increases will increase investment costs, etc., resulting in unnecessary waste. Therefore, the most suitable pipe diameter should be designed by simulation, taking into account a number of influencing factors.

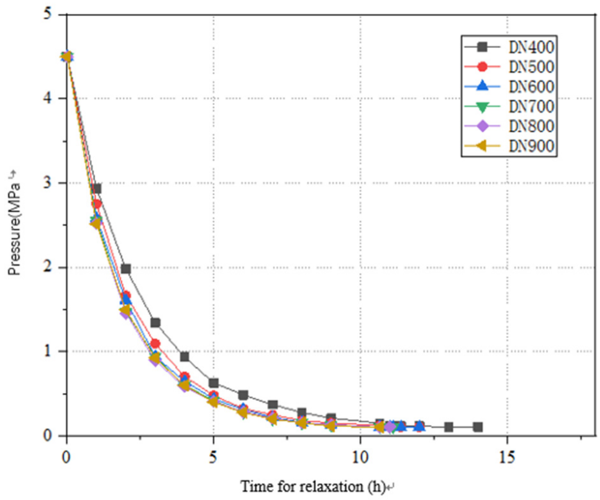

Fig 3. Pressure drop curves for different venting pipe diameters

4. Conclusion

This paper introduces the pipeline flow model and the pipeline venting calculation software developed using a high-level programming language, and gives a brief introduction to its main functions, carries out example verification, and draws the following main conclusions:

(1) This paper defines the continuity equation, the energy equation and the momentum equation for fluid flow in a pipeline based on three conservation laws, and establishes a mathematical model for dynamic simulation of natural gas pipelines by combining these three equations.

(2) The accuracy of the pipeline venting calculation software is verified through comparison with data in the literature, and the rate of pressure drop in the early stages of venting is significantly higher than in the later stages of venting, indicating that the venting time can be too long under low pressure conditions, bringing great invariance to the actual emergency repairs, so accurate estimation of the venting time is required and corresponding measures are taken to minimise the venting time.

(3) The influence of the diameter of the emptying pipe on the emptying time of the pipe is negatively correlated, the larger the diameter of the pipe the shorter the emptying time. Therefore, in the actual emptying design, the length of the main pipe, the diameter of the main pipe, the diameter of the emptying pipe and the pressure of the main line should be considered to ensure the reasonableness and safety of the pipeline emptying design and to save resources to the greatest extent.

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