ISSN: 2688-8645

Study on Pulsation Law of Gas-Liquid Two-Phase Flow in Produced Water Dissolved Gas System

Shuxuan Jiang, Peiyu Lu

School of Xi'an Shiyou University, Xi'an Shaanxi, 710018, China

Abstract

This study focuses on the pulsation characteristics of gas-liquid two-phase flow in undulating pipe networks and adopts a one-dimensional model. The results show that the pulsation of gas-liquid two-phase flow causes an increase in pressure at the manifold inlets of each well accompanied by a certain degree of pulsation. The pulsation exhibits a significant wide-frequency distribution feature, where high-frequency pulsations are mainly caused by the operation of pumping units, and low-frequency pulsations originate from random slug flow of two-phase flow in undulating pipelines. Meanwhile, the increase in single-well water production promotes the rise of pressure at the manifold inlets of each well, and the degree of pressure pulsation shows a decreasing trend. The results of this study can provide a theoretical basis for the stable operation and pressure regulation of gas-liquid two-phase flow in undulating pipe networks.

Keywords

Multiphase Flow; Simulation Analysis; Pulsation Law.

1. Introduction

Due to the differences in gas reservoir geology, mining technology, and production years of dissolved gas well sites, the quantity and quality of water discharged during dissolved gas extraction vary. Compared with oilfield produced water, dissolved gas produced water has lower contents of petroleum and organic matter but higher salinity, such as bicarbonate, sulfate, chloride, calcium, magnesium, sodium, etc., as well as small amounts of iron, sulfide, and other substances. Most dissolved gas well sites are located in hilly and loess tableland areas with sensitive environmental factors. After treatment, most of the produced water needs to be discharged into the environment, which has high requirements for indicators such as COD and NH_3. If it is directly discharged into the environment without effective treatment, it will lead to soil salinization, surface and groundwater pollution, and cause serious damage to the ecological environment and residents' lives. However, after appropriate treatment, dissolved gas produced water can be used for drilling and fracturing construction of dissolved gas wells, farmland irrigation, coal washing in mining areas, dust removal, etc., having good utilization value. Therefore, establishing an easy-to-manage dissolved gas produced water treatment system that meets environmental protection requirements according to the actual water quality and suitable geological conditions is an important prerequisite for the compliant and sustainable production and development of dissolved gas. With the deepening of production in a certain area, the operating conditions of the water treatment system have been constantly changing. It has been found that there is an obvious phenomenon of dissolved gas escape at the water inlets of pumping stations and water treatment stations, which affects the stable transportation of produced water, and there is energy waste and air pollution. The terrain in this area is undulating. During the pipeline transportation of gas-containing produced water, there is obvious pressure pulsation, which not only affects the operation safety of the pipe network but also affects the design of separators. Therefore, it is necessary to study the flow law of two-phase flow in the pipe network.

2. Numerical Analysis

2.1. 1D Multiphase Flow Model

In this study, OLGA software was used to establish a 1D pipeline model [1] (adopting the default miscible multiphase flow model, and the flow resistance model was modified through experiments/3D analysis). Multiphase flow model: Two-Fluid Model (TFM); flow pattern prediction model: Slug Tracking model; solution method: method of characteristics. The specific details are as follows:

The OLGA software adopts an extended two-fluid model [2], which is obtained based on the solution of 6 conservation equations, including 3 mass equations (gas phase, liquid phase or liquid film, liquid droplets), 2 momentum equations (gas phase containing liquid droplets, liquid phase or liquid film), and 1 energy equation (mixed system). The basic conservation equations in the model use the Eulerian method, but the Lagrangian front-tracking format is also adopted in the Eulerian format. The basic OLGA model is as follows:

2.1.1. Extended Two-Fluid Model

1) Mass Conservation Equations [3]

For the gas phase:

$$\frac{\partial}{\partial t}\left(V_g\rho_g\right)=-\frac{1}{A}\frac{\partial}{\partial z}\left(AV_g\rho_g v_g\right)+\psi_g+G_g$$

For the liquid phase (liquid film) on the pipe wall:

$$\frac{\partial}{\partial t}\left(V_L\rho_L\right)=-\frac{1}{A}\frac{\partial}{\partial z}\left(AV_L\rho_L v_L\right)-\psi_g\frac{V_L}{V_L+V_D}-\psi_e+\psi_d+G_L$$

For liquid droplets:

$$\frac{\partial}{\partial t}\left(V_D\rho_L\right)=-\frac{1}{A}\frac{\partial}{\partial z}\left(AV_D\rho_L v_D\right)-\psi_g\frac{V_D}{V_L+V_D}+\psi_e-\psi_d+G_D$$

In the above equations: α is the volume fraction of each phase; G is the possible mass source of each phase; ρ is the density; v is the velocity of each phase; A is the cross-sectional area of flow in the pipe; Ψ_g is the gas-liquid mass transfer rate (positive when liquid phase evaporates into gas phase); Ψe is the droplet entrainment rate; Ψ_d is the droplet deposition rate; subscripts g, L, and D represent gas phase, liquid film, and liquid

2) Momentum Conservation Equations [4]

For the gas phase and liquid droplets, the momentum conservation equation can be expressed as:

$$\frac{\partial}{\partial t}\left(V_g\rho_g v_g+V_D\rho_L v_D\right)=-\frac{1}{A}\frac{\partial}{\partial z}\left(AV_g\rho_g v_g^2+AV_D\rho_L v_D^2\right)-\left(V_g+V_D\right)\frac{\partial P}{\partial z}$$
$$-\frac{1}{2}\lambda_g\rho_g\left|v_g\right|v_g\frac{S_g}{4A}-\frac{1}{2}\lambda_i\rho_g\left|v_r\right|v_r\frac{S_i}{4A}+\left(V_g\rho_g+V_D\rho_L\right)g\cos\alpha$$
$$+\psi_g\frac{V_L}{V_L+V_D}v_a+\psi_e v_i-\psi_d v_D$$

For the liquid phase (liquid film) on the pipe wall:

$$\frac{\partial}{\partial t}\left(V_L\rho_L v_L\right)=-\frac{1}{A}\frac{\partial}{\partial z}\left(AV_L\rho_L v_L^2\right)-V_L\frac{\partial P}{\partial z}-\frac{1}{2}\lambda_L\rho_L\left|v_L\right|v_L\frac{S_L}{4A}+\frac{1}{2}\lambda_i\rho_g\left|v_r\right|v_r\frac{S_i}{4A}$$
$$+V_L\rho_L g\cos\alpha-\psi_g\frac{V_L}{V_L+V_D}v_a-\psi_e v_i+\psi_d v_D-V_L d\left(\rho_L-\rho_g\right)g\frac{\partial V_L}{\partial z}\sin\alpha$$

3) Energy Conservation Equation

For the entire mixed system:

$$\frac{\partial}{\partial t}\left[m_g\left(E_g+\frac{1}{2}v_g^2+gh\right)+m_L\left(E_L+\frac{1}{2}v_L^2+gh\right)+m_D\left(E_D+\frac{1}{2}v_D^2+gh\right)\right]=$$
$$-\frac{\partial}{\partial z}\left[m_g v_g\left(H_g+\frac{1}{2}v_g^2+gh\right)+m_L v_L\left(H_L+\frac{1}{2}v_L^2+gh\right)+m_D v_D\left(H_D+\frac{1}{2}v_D^2+gh\right)\right]+H_S+U$$

In the equations: E is the internal energy per unit mass of fluid; h is the elevation; Hk is the enthalpy of the mass source; U is the heat transfer rate of the pipe wall; α is the angle between the pipeline and the vertical direction; P is the pressure; S is the wetted perimeter of each phase interface; g is the gravitational acceleration; subscripts g, L, and i represent gas phase, liquid phase, and the interface between gas and liquid phases respectively; the meanings of other parameters are the same as those in the mass conservation equations.

2.1.2. Numerical Solution Scheme

The above physical model generates a series of coupled first-order nonlinear one-dimensional partial differential equations with quite complex coefficients. Most two-fluid models are solved using the finite difference staggered grid control volume method [5].

3. Simulation Analysis

According to the pipe network system diagram provided in the data, based on basic information such as system layout and pipeline parameters, the OLGA software was used to build a pipe network model. The actual pipe network structure such as the pipe network around No. 1 water tank was converted into a virtual pipe network model architecture through the software, and each wellhead, pipeline, node, facility, etc., were converted into unit modules in the model. Reasonable boundary conditions were set (such as wellhead water flow rate, pressure boundary, water level boundary of the water tank, etc.). Among them, the 24-year average wellhead pressure of each well was taken as a reference; the 24-year average water production of each well was taken as the benchmark input (the total pipe network was 822 m^3/day); the water production was calculated to change between 0.2 and 3 times the benchmark value; the single-well gas seepage volume was calculated to change between 5 and 60 NL/min (the total pipe network was 655-7862 m^3/day).

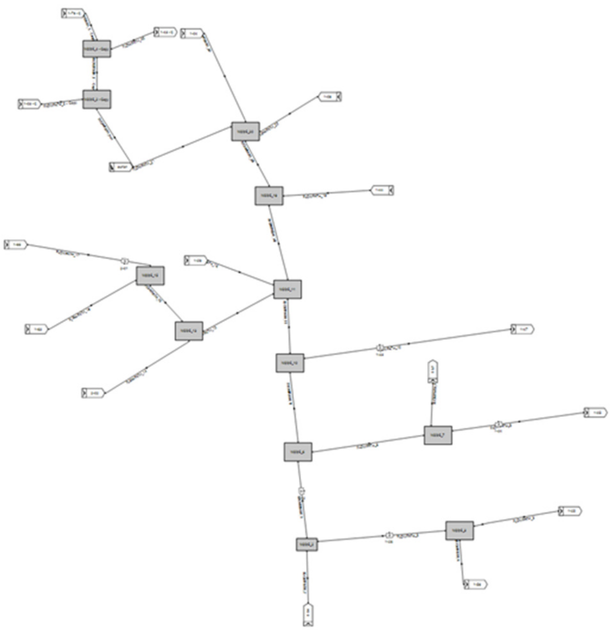
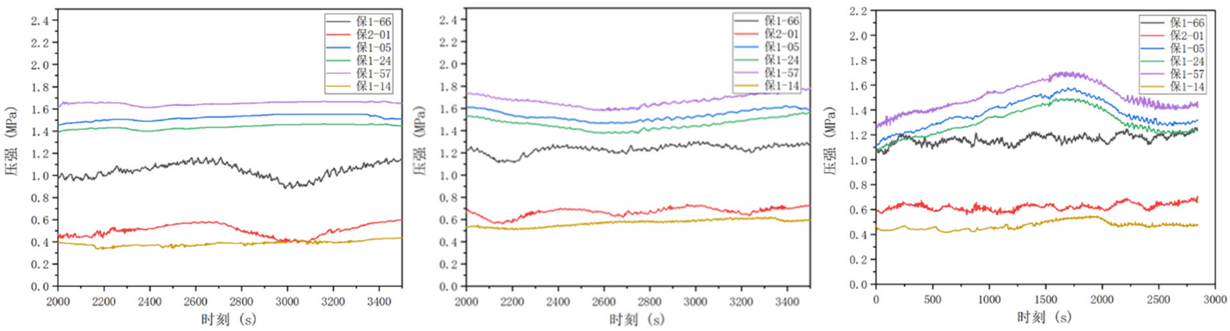


Fig 1. Pipe Network Model

 Volume 8 Issue 1, 2026

In the undulating pipe network, the pulsation of gas-liquid two-phase flow is a key factor affecting the pressure at the manifold inlets of each well. This pulsation not only causes an increase in the pressure at the manifold inlets but also brings a certain degree of pressure fluctuation. To accurately grasp the pressure characteristics, several wells with high pressure in the pipe network were selected for analysis. It was found that the pressure amplitude of each well is affected by both gas-liquid flow rate and nearby terrain. When the gas-liquid flow rate is large, the momentum transfer of the fluid is enhanced, which will impact the pressure at the manifold inlets; if the nearby terrain has elevation differences, turns, etc., it will change the fluid flow resistance and flow pattern, further disturbing the pressure amplitude. The combined effect of the two shapes the complex pressure change pattern at the manifold inlets. From the pressure curves of "different multiples of single-well water production", the fluctuation characteristics of pressure with operating conditions can be intuitively seen.



(a) 0.5 times single-well production (b) 1 time single-well production (c) 2 times single-well production

Fig 2. Single-Well Production Pressure Curves

During the operation of the manifold inlets of each well, there is a continuous frequency pulsation phenomenon, showing the characteristic of "high frequency + low frequency". Among them, high-frequency pulsations are mainly affected by the operation of pumping units, which will generate high-frequency pressure pulses in the fluid in the pipe network, like "periodic external disturbance", driving the rapid fluctuation of pressure at the manifold inlets; while low-frequency pulsations originate from random slug flow of two-phase flow in undulating pipelines. Due to the effects of gravity and flow resistance, gas-liquid two phases in undulating pipelines are prone to form slug flows with random sizes and positions. These slugs move slowly and pass through the manifold inlets alternately, causing low-frequency pressure pulsations. The superposition of the two frequencies constitutes the unique time-domain characteristics of pressure fluctuation at the manifold inlets.

With the increase in single-well water production, the pressure at the manifold inlets of each well shows a trend of "increasing pressure and decreasing pulsation". From the comparison of pressure curves of "0.5 times single-well water production", "1 time single-well water production", and "2 times single-well water production", it can be seen that the increase in water production leads to an increase in the liquid phase proportion in the fluid, enhanced flow continuity, and improved "constraint" effect on the gas phase, thereby suppressing the pulsation amplitude of gas-liquid two-phase flow and reducing pressure pulsation. At the same time, the increase in fluid mass flow rate caused by the increase in water production leads to a subsequent rise in the pressure at the manifold inlets under the action of pipe network resistance.

4. Summary

(1) The pulsation of gas-liquid two-phase flow in undulating pipe networks can cause an increase in pressure and a certain degree of pulsation at the manifold inlets of each well, and the pulsation shows an obvious wide-frequency distribution. Among them, high-frequency pulsations are mainly affected by the operation of pumping units, and low-frequency pulsations are mainly affected by the random slug flow of two-phase flow in undulating pipelines.

(2) With the increase in single-well water production, the pressure at the manifold inlets of each well also increases, and the pressure pulsation shows a decreasing trend.

References

[1] Sun Zhanwei, Zhu Xiangze. Numerical Simulation of Gas-Liquid Two-Phase Splitting Characteristics of T-shaped Multi-branch Pipe [J]. Journal of Liaoning University of Petrochemical Technology, 2021, 41(02): 65-72.

[2] Ye Yin, Zhong Xinglong, Gao Shuangwu. Numerical Simulation of Oil-Water Two-Phase Flow in T-type Gathering Pipeline [J]. Petroleum Engineering Construction, 2025, 51(01): 59-63. Author 1, Author 2, Author 3, et al. Book Title. Publisher, xx year, p. 231-236.

[3] Sang L, Hong Y P, Wang F J. Investigation of viscosity effect on droplet formation in T-shaped microchannels by numerical and analytical methods[J]. Microfluidics and Nanofluidics, 2008, 6(5): 621-635.

[4] Zhang X, Liu S, Qian J, et al. Research on the identification of the two-phase flow pattern of gas-liquid in a vertical rising tube based on BP neural networks[J]. arXiv preprint, 2024: arXiv: 2410.13906.

[5] Ayala L F, Adewumi M A. Low-Liquid Loading Multiphase Flow in Natural Gas Pipelines[J]. Trans. ASME 125. 2003. 284-293.