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# The Pressure Drop Calculation Method in Oil-gas-water Horizontal Pipeline with Highly-water

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Abstract: With the deeply exploitation of oil field, majority of oil field have entered high water-cut developing bear stage. The water-cut of most oil wells exceeds by 85%. The flow in gathering and transferring pipeline belongs to mixed flow of oil-gas-water with super high water-cut. Calculating pressure drop exactly is significant for the operation and management of oil-gas gathering and transferring system. Baker pressure drop calculating model of slug flow are introduced, and calculating results are contrasted and analyzed with testing data. Basing on the testing data, we correct Baker model, provide the modified model and validate it in this paper. Make a conclusion that the modified model is fit for the slug flow pressure drop calculating of oil-gas-water three-phase horizontal pipeline with super high water-cut.

Key Words: Super high water-cut ；Oil production；Oil-gas-water；Mixed transportation；Flow pattern；Pressure drop；Temperature; Test; Model

## 1 Introduction

Generally, investment on transportation pipeline net almost occupies 1/3 in the total ground investment, while transportation energy consumption accountants for 2/5 in total production energy consumption. So both of studying on flow rule and predicting pressure drop of oil-gas-water pipeline is significant for operating and managing the oilfield production system.

Oil-gas-water three-phase flow became the hotspot in multiphase flow region in 1980s according to the requirement of production and technology advancement. After a long-range research, people have developed some mature method to predict pressure drop. Baker adopted Lockhart-Martinelli format that is two-phase pipeline pressure drop equals the product of gas converted coefficient of pressure drop and pressure drop that there is only gas [1]. According to his own flow pattern chart, Baker analyzed some experimental data and located measuring data in two-phase pipeline, and then concluded different experience associating equations according to different flow pattern. Data that Baker collected dates mostly from 152～253mm oil-gas pipeline, so the equation were more appropriate for the pipeline which diameter is bigger than 152mm. Baker thought that the slug flow counting precision is best of all, and the error could be about 10%. Baker pressure drop method is commended in «Oilfield Gas Gathering and Transferring Designation Rule», which is issued by Oil-gas Combined Company in china. Basing on more than 4000 experimental data, Mandhane modified the calculating expression of gas converted coefficient, provided pressure drop calculation for slug flow and dispersed bubble flow [2]. Neogi、Lee、Jepson put forward stratified flow mechanics model of oil-gas-water[3]. When superficial velocity liquid character and diameter are invariable, the model can predict the oil layer thickness and water layer thickness in stratified flow. Zhang Longjiang [4] used gas-liquid two-phase slug flow for reference, established hydraulic model to depict oil-gas-water three-phase slug flow. Some investigators think that if oil and gas mix evenly, some two-phase pressure drop calculation method, such as Brill or Dukler, can be used to predict three-phase pressure drop when mixture viscidity is exactly calculated[5，6]. Oil-gas-water pressure drop calculation is being explored, there is no recognized method. Testing result indicates that, oil-gas-water flow is slug flow in gathering and transferring pipeline during high-watery exploring in Daqing oilfield[7]. So we introduce Baker model, test the liquid output, gas output, water-cut, temperature and pressure drop, contraste and analyze with testing data, and provided a modified model that fit for the pressure drop calculating in oil-gas-water pipeline during super high water-cut exploring in this paper.

# 2 Baker slug flow pressure drop calculating model and errors

## 2.1 Model Introduction

Gas- water two-phase flow pipeline pressure drop equals the product of gas converted coefficient of pressure drop $\phi_g^2$ and pressure drop that there is only gas, that is:

$$\frac{dp}{dl} = \phi_g^2 \left(\frac{dp}{dl}\right)_g \tag{1}$$

Expression for Baker slug flow gas converted coefficient $\phi_g^2$ is like this:

$$\phi_g^2 = 1920 X^{1.63} \left(\frac{A}{G_l}\right) \tag{2}$$

$$X^2 = \frac{\left(\frac{dp}{dl}\right)_l}{\left(\frac{dp}{dl}\right)_g} = \frac{\phi_g^2}{\phi_l^2} \tag{3}$$

Where：$\frac{dp}{dl}$—Pressure drop of gas-liquid transportation pipeline，Pa；$\phi_g^2$—gas converted coefficient；$\left(\frac{dp}{dl}\right)_g$—pressure drop that there is only gas in pipeline，Pa；$X^2$—Lockhart-Martinelli coefficient；$G_l$—Gas and liquid mass flux，kg/s；$A$—Section area，m$^2$。

## 2.2 Relative parameter calculation [8]

（1）0il-water emulsification liquid density

$$\rho_l = \rho_o(1-\phi) + \rho_w\phi \tag{4}$$

$$\phi = \frac{Q_w}{Q_w + Q_o} \tag{5}$$

（2）Gas density in transportation pipeline

$$\rho_g = \frac{pM_g}{TR} \times 10^3 \tag{6}$$

（3）Hydraulics friction coefficient when there is only gas flow in pipeline

$$\lambda_g = \frac{0.009407}{\sqrt[3]{d}} \tag{7}$$

（4）Hydraulics friction coefficient when there is only liquid flow in pipeline

$$\lambda_L = \frac{A_1}{\mathrm{Re}^m} \tag{8}$$

Where：stratified flow $A_1$=64，$m$=1；hydraulics smooth area $A_1$=0.316，$m$=0.25；mixed friction area $A_1 = 10^{\left(0.127\lg\frac{e}{d}-0.627\right)}$，$m$=0.123

（5）Pressure drop when there is only gas flow in pipeline

$$\left(\frac{dp}{dl}\right)_g = \frac{\lambda_g \cdot x^2 \cdot G^2}{d \cdot 2A^2 \cdot \rho_g} \tag{9}$$

Where：$x = \frac{G_g}{G}$.

（6）Pressure drop when there is only liquid flow in pipeline

$$\left(\frac{dp}{dl}\right)_l = \frac{\lambda_L (1-x)^2 G^2}{2dA^2 \rho_L} \qquad (10)$$

Where： $\mu$—Dynamical viscidity of liquid，mPa • s; Subscript l、o、w—Indicate mixture, oil, water; $\psi_w$—Mass water-cut, %; $\phi$—Volume water-cut, %; $\rho_l$—oil-water emulsification liquid density, kg/m$^3$; $\rho_o$—Oil density on ground at the same temperature, kg/m$^3$; $\rho_w$—Density of well extracting water, kg/m$^3$; $Q_w$—Volume flux of water in pipeline, m$^3$/s; $Q_o$—Volume flux of oil in pipeline，m$^3$/s。$\rho_g$—Gas density in transportation pipeline, kg/m$^3$; $M_g$—Gas relative molecule weight; $R$—Currency gas constant, that is 8.314kJ/(kg • K); $\lambda_g$—Hydraulics friction coefficient when there is only gas flow in pipeline; $x$—Gas mass ratio; $G$—Mass flux in pipeline, kg/s; $d$—Inner diameter, m; $A$—Section area of transportation pipelne，m$^2$; $\lambda_L$—Hydraulics friction coefficient when there is only liquid flow in pipeline.

## 2.3 Pressure drop test and Baker model error

In order to study on the pressure drop calculating method under different liquid production, different gas ratio and different water-cut, we do a series of tests on pipelines in No.4 Oil Extraction Factory of Daqing oil field.

The test had been done for 52 days. According to the testing data, we sum up the oil output, gas output, water-cut and gas oil ratio about 7 testing pipeline, showed in Table 1. The pressure drop testing result and calculating results with Baker slug flow pressure drop model is show in Fig. 1~7. The error analysis is showed in Table 2.

Table 1 The sum-up table of testing wells' basic circumstances

| Well No. | $L$ /m | $d$ /mm | $Q_l$ / m$^3$/d | $Q_g$ / m$^3$/d | $\phi$ /% | Gas Oil ratio /m$^3$/t |
|---|---|---|---|---|---|---|
| 217 | 70 | 76 | 84 | 1457 | 92 | 236.03 |
| 313 | 319 | 76 | 34 | 134 | 92 | 49.82 |
| 614 | 259 | 60 | 25 | 397 | 91 | 174.31 |
| 617 | 90 | 60 | 25 | 100 | 87 | 33.04 |
| 316 | 186 | 89 | 27 | 142 | 78 | 22.83 |
| 616 | 175 | 60 | 68 | 358 | 90 | 52.13 |
| 713 | 454 | 60 | 40 | 188 | 90 | 50.50 |

It can be seen from Table 2, when we predict oil-water-gas three slug flow pipeline pressure drop with the Baker oil-gas two phase slug flow pressure drop mode, its errors are very high.The364 groups calculating and test results were compared. There are 70 groups errors within ±10%, occupy 19.2%; There are 86 groups errors within ±10%~±20%, occupy 23.6%; There are 128 groups errors within ±20%~±30%, occupy 35.2; There are 33 groups errors within ±30%~±40%, occupy9.1%; There are 35 groups errors within ±40%~±50%, occupy9.6%; There are 12 groups errors higher than ±50%, occupy3.3%.

# 3 Modified Baker model and error

## 3.1 Modified Baker model

Analysis above indicate that oil-water-gas three slug flow pipeline pressure drop calculating errors with the Baker oil-gas two phase slug flow pressure drop mode are very high. So According to the testing data, we draw up the gas converted coefficient expression with the least two multiplication methods.The modified Baker models as follow:

For pipeline in which water-cut is higher than 85%, the oil output is constants from oil well:

$$\phi_g^2 = 3929 X^{2.3476} \left( \frac{A}{G_l} \right) \quad (11)$$

For pipeline in which water-cut is higher than 85%, the oil output high sometime and low sometime:

$$\phi_g^2 = 22674 X^{1.4772} \left( \frac{A}{G_l} \right) \quad (12)$$

For pipeline in which water-cut is between 80~85%:

$$\phi_g^2 = 1178673 X^{1.0021} \left( \frac{A}{G_l} \right) \quad (13)$$

### 3.2 Modified Baker model errors

The pressure drop calculation result of modified Baker model with testing data are compared and showed in Fig. 1~7, error analysis is showed in Table 2.

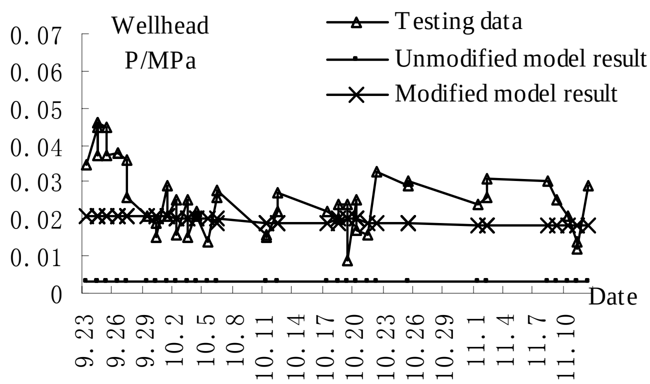


Fig1 The pressure drop comparison between calculated results and Experimental results of No.217 well

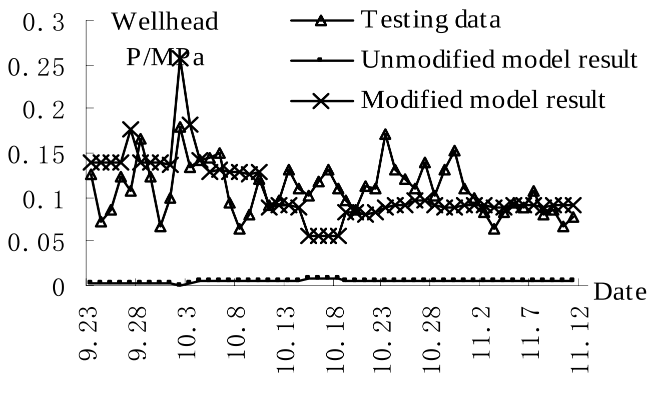


Fig. 2 The pressure drop comparison between calculated results and Experimental results of No.313 well

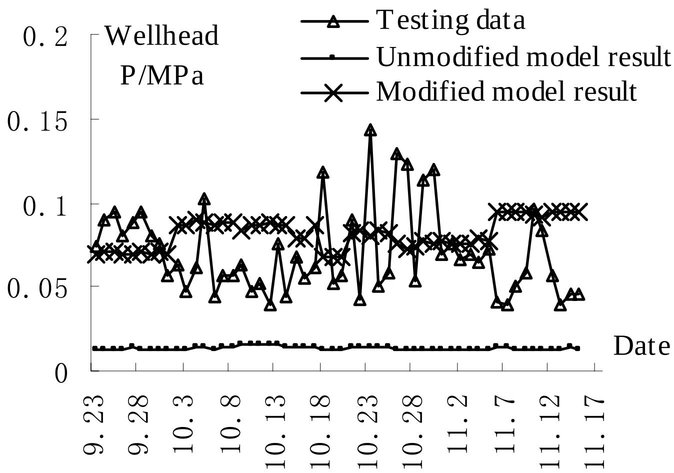


Fig.3 The pressure drop comparison between calculated results and Experimental results of No.614 well

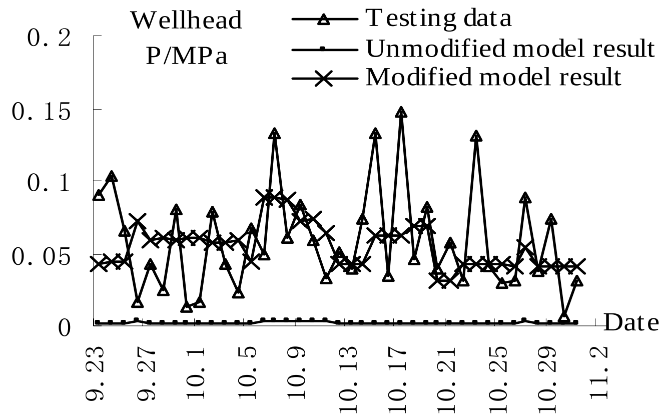


Fig. 4 The pressure drop comparison between calculated results and Experimental results of No.617 well

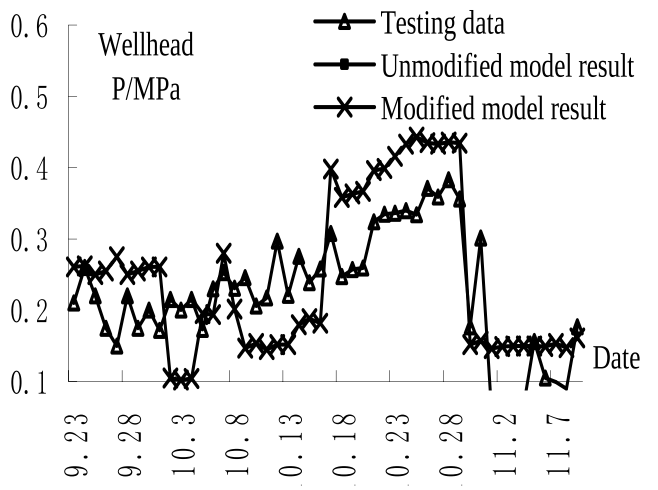


Fig. 5 The pressure drop comparison between calculated results and Experimental results of No.316 well

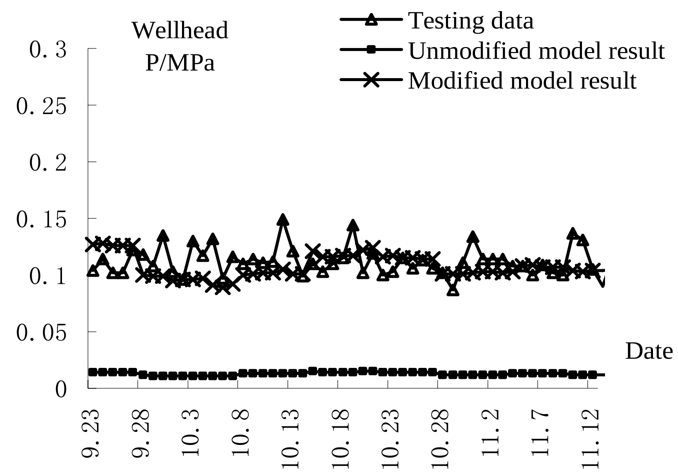


Fig. 6 The pressure drop comparison between calculated results and Experimental results of No.616 well

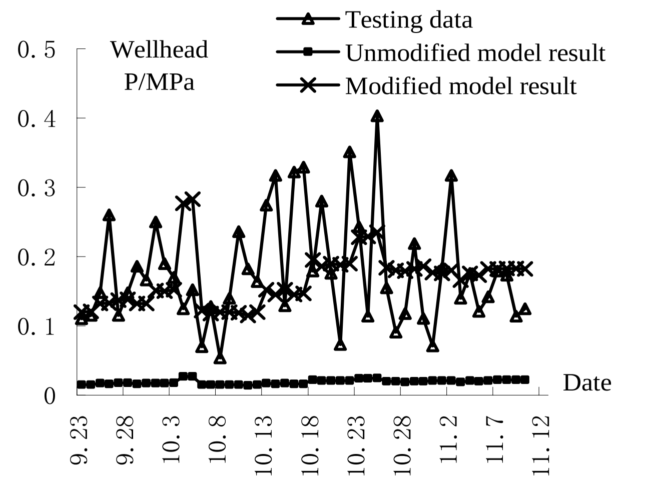


Fig. 7 The pressure drop comparison between calculated results and Experimental results of No.713 well

Table 2 The error comparison between calculated results using Baker model and corrected Baker model and experimental results

| Error scope | | ±10% | ±10%~±20% | ±20%~±30% | ±30%~±40% | ±40%~±50% | >±50% |
|---|---|---|---|---|---|---|---|
| unmodified | 217 | 45 groups | 13 groups | / | / | / | / |
| | 313 | / | 11 groups | 33 groups | 6 groups | / | / |
| | 614 | 12 groups | 34 groups | 12 groups | 1 group | / | / |
| | 617 | 13 groups | 18 groups | 7 groups | 3 groups | 1 group | / |
| | 316 | / | 3 groups | 4 groups | 10 groups | 24 groups | 9 groups |
| | 616 | / | 2 groups | 53 groups | 1 group | / | / |
| | 713 | / | 5 groups | 19 groups | 12 groups | 10 groups | 3 group |
| | total | 70 groups | 86 groups | 128 groups | 33 groups | 35 groups | 12 group |
| modified | 217 | 58 groups | / | / | / | / | / |
| | 313 | 36 groups | 14 groups | / | / | / | / |
| | 614 | 38 groups | 16 groups | / | / | / | / |
| | 617 | 28 groups | 17 groups | 1 group | / | / | / |
| | 316 | 17 groups | 27 groups | 8 groups | / | / | / |
| | 616 | 60 groups | / | / | / | / | / |
| | 713 | 22 groups | 9 groups | 13 groups | / | / | / |
| | total | 259 groups | 83 groups | 22 groups | | | |

It can be seen from Table 2 that the modified model errors are better than unmodified model. The modified results are more close to testing values. The errors are all within 30%.There are 259 groups errors within ±10%, occupy 71.2%; There are 83 groups errors within ±10%~±20%, occupy22.8%; The rest 22 groups errors within ±20%~±30% occupy 6.0%. So the modified model is fit for the pressure drop calculating in oil-gas-water pipeline during super high water-cut.

## 4 Conclusion

1. Test pressure drop and correlative parameter of oil-gas-water transportation pipeline with super high-watery in Daqing oilfield.

2. Make use of Baker model to calculate wellhead pressure with super high-watery. Within 364 groups data, errors within ±10% occupy 19.2%, errors within ±10%~±20% occupy 23.6%, errors ascend ±20% occupy 57.5%. So unmodified Baker gas-liquild slug flow pressure drop model is unfit for the pressure drop calculating of oil-gas-water three flow pipeline with super high water-cut.

3. According to a mass of testing data, provide modified Baker pressure drop model. Analysis and contrast indicate that the modified pressure drop model is more close to testing value. The errors are all within 30%, errors within ±10% occupy 71.2%, errors within ±10%~±20% occupy22.8%. The rest errors within ±20%~±30% occupy 6.0%. So the modified model is fit for the pressure drop calculating of oil-gas-water pipeline with super high water-cut.

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