# Research on Dynamic Monitoring and Analysis Model of Fracturing Fluid Injection

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## Abstract

**Hydraulic fracturing is the most direct and effective way to improve low productivity, low permeability oil and gas reservoirs, and to increase production of low permeability and ultra low permeability oil and gas reservoirs. In the process of hydraulic fracturing, the dynamic position of fracturing fluid injection and the monitoring of dynamic friction in fracturing column have great significance on the optimization of fracturing construction parameters and ensuring the safety of fracturing construction.Through the research on the domestic and foreign research, the analysis and evaluation of dynamic monitoring parameters of fracturing fluid injection and the theoretical research on the dynamic monitoring model of fracturing fluid injection,providingthe theoretical basis for the establishment of dynamic monitoring model of fracturing fluid injection.**

## Keywords

**Fracturing Fluid; Dynamic Monitoring; Model Investigation.**

## 1. Introduction

The quality of hydraulic fracturing construction directly affects the mining efficiency of dense oil and gas reservoirs and the economic benefits of oil and gas fields. Fracturing fluid in fracturing construction is an important part of hydraulic fracturing technology. Fracturing fluid injection dynamic position and dynamic friction monitoring of fracturing fluid column have important engineering significanceon the optimization of fracturing construction parameters and ensuring the safety of fracturing construction .In this paper, the Zielke model, Trikha model, Vardy-Brown model, Zarzycki model, IAB model, MIAB model and MIAB empirical model are summarized by study the dynamic monitoring of fracturing fluid injection in China and abroad, which provide a theoretical basis for the establishment of dynamic monitoring model of fracturing fluid injection.

## 2. Analysis and Evaluation of Dynamic Monitoring Parameters of Fracturing Fluid Injection

In the process of fracturing construction, there are many monitoring ground parameters of Instrument panel group. Through research and analysis of Dynamic Monitoring Machine for Fracturing Fluid Injection, the parameters collected and analyzed by the ground sensor mainly include tubing pressure, casing pressure, proppingagent, discharge and so on. According to the real-time monitoring of these parameters and the curve display, combined with the fracturing fluid injection dynamic monitoring model, to monitor the dynamic real-time position of fracturing fluid injection and real-time dynamic friction of fracturing string.

Among them, there are two main factors influencing the dynamic position and dynamic friction of the fracturing fluid: one is the controllable factors such as construction displacement, construction pressure, fracturing fluid, propping agent and construction scale. Uncontrollable factors such as ground stress field condition,rock'smechanical properties and so on. By understanding and evaluating these controllable and uncontrollable factors, to provide data supportfor establish a dynamic monitoring model of fracturing fluid injection.

## 3. Research on dynamic monitoring model of fracturing fluid

In the calculation of the traditional fracturing pipe friction hydraulics, the standard constant model is usually used to describe the friction change when the fracturing fluid is injected into the fracturing column. The most commonly used hydraulic model is the one - dimensional fluid hydrodynamic model.

Because the fracturing fluid is injected into the fracturing pipe string through the high pressure pipe of the ground, it is a fast transient flowing process. In the hydraulic calculation for the hydraulic pipeline, the traditional standard constant friction model can’t be described the process clearly. Therefore, in the face of a lot of non-constant fluid problems, the results of the standard constant friction calculation model of conventional hydraulic mechanics do not match with the actual experimental results.In the same time,a lot of experimental evidence suggests that the flow velocity profile of the pipe is a physical quantity that changes over time in a non-constant fluid flow in a pressurized pipe. Thus,the unsteady flow of the pressurized pipe fluid is handled by the fluid flow non-constant friction model, which can describe the unsteady fluid flow in the pressurized pipe more accurately. Non-constant friction research models include weighting function models such as Zielke model, Trikha model , Vardy-Brown model , Zarzycki model and other empirical revised model such as IAB model , MIAB model , MIAB revised model.

### 3.1 Zielke model

The main considerate variable quantity of the Zileke model is the distance along the pressure pipe(x) and the head pressure (H) as an independent variable quantity and the average cross-sectional flow rate (V) of the pressurized pipe. Zileke argues that the viscous effect of laminar flow and turbulent flow of the pipeline is mainly concentrated on the thin layer near the inner wall of the pipe. If the pressure gradient of the fluid flow is different, it will inevitably affect the flow state of the fluid around the pipe wall. The fluid with a certain acceleration and pressure gradient flows in the vicinity of the pipe wall, the inertial force is smaller than that of the center of the pipeline, and the fluid flow friction is larger than that of the center of the pipeline. At this time, the fluid flow resistance is the dominant factor.

According to lots of experimental datas, Zielke summed up that the function W has two different forms in the neighborhood of $\tau = 0.02$, which can be expressed as:

When $\tau > 0.02$,there are:

$$W(\tau) = \sum_{i=1}^{5} e^{-A_i \tau} \tag{3-1a}$$

In the formula, $A_i = (26.3744; 70.8493; 135.0198; 218.9216; 322.5544)$

When $\tau < 0.02$,there are:

$$W(\tau) = \sum_{i=1}^{6} B_i e^{\frac{i-2}{2}} \tag{3-1b}$$

$B_i = (0.282095; -1.25; 1.058755; 0.9375; 0.396696, -0.351563)$

Zielke first creatively put forward a non-constant friction model for rapid transient of pressurized piping fluid, and proposed the non - constant expression of unsteady friction by a large number of physical experiments. By comparing the theoretical results with the actual experimental results, it is proved that the model can calculate the unsteady friction of fluid flow accurately. Zielke's non-constant friction model provides a theoretical basis for the study of unsteady fluid flow research.

### 3.2 Trikha model

Trikha used a one-dimensional hydraulic flow equation and a continuous equation for Laplace transform to obtain the draught lossper unit length cross section of the pressurized pipe. And the use of historical storage data through a large number of experiments, and ultimately get:

$$\text{When}\left\{\begin{array}{l}(1)\int_0^\infty W_{app}(\tau)d\tau=\int_0^\infty W(\tau)d\tau\\ (2)W_{app}(\tau)=W(\tau),\tau\approx 0.0001,0.001,0.01\\ (3)\left|\dfrac{W_{app}(\tau)-W(\tau)}{W(\tau)}\right|<0.02,\tau>0.1\end{array}\right\}\text{,there are:}$$

$$W_{app}(\tau)=40.0e^{-8000\tau}+8.1e^{-200\tau}+e^{-26.4\tau} \tag{3-2}$$

### 3.3 Vardy-Brown model

Vardy and Brown argue that the non-constant friction of the pressurized pipe is related to the Reynolds number(Re) of the fluid in the pipe. The relationship between the average velocity of the fluid flow of the pipe, the velocity of the fluid near the pipe wall and the shear force of the unsteady fluid flow in the pipe is obtained by Laplace transformation analysis of the unsteady friction of the pipeline fluid flow.

In order to better reflect the relationship between the attenuation coefficient(C*) of the cross-section shear force of the pressurized pipe and the reynolds number(Re), Vardy and Brown obtained the 2002 model and the 1995 model through the experimental analysis of the pressure pipeline, as is shown in Fig3-1:

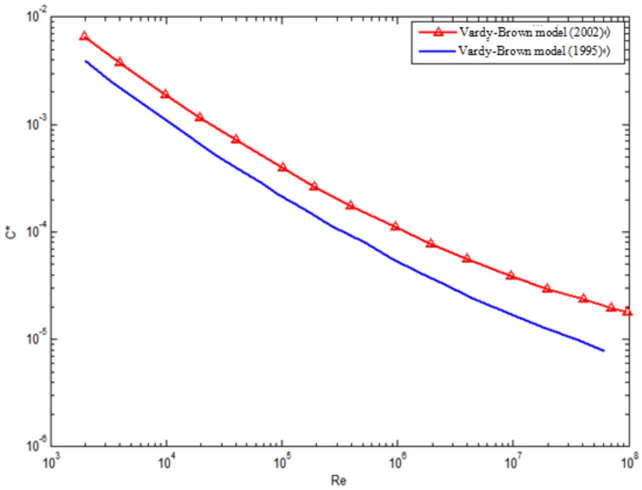

Fig 3-1 the relationship between the attenuation coefficient(C*) of the cross-section shear force of the pressurized pipe and the Reynolds number (Re)

As can be seen from Figure 3-1, when the Reynolds number’s (Re) value is small, the attenuation coefficient’s value(C*) changes rapidly; when the value of the Reynolds number (Re) is large, the attenuation coefficient numerical change is relatively slow. At the same time, by comparing the 1995 model with the 2002 model, it is found that the value of the 2002 model is bigger, which means that the 1995 model overestimate the decay rate when estimating, especially for large Reynolds numbers.

As shown in Figure 3-2, under two different models, Reynolds numbers are $\mathrm{Re}=10^5$ and $\mathrm{Re}=10^7$ respectively, there is the numerical relationship of non - constant friction coefficient $f_u$ and dimensionless time $\psi_T$ under uniformly accelerated condition.

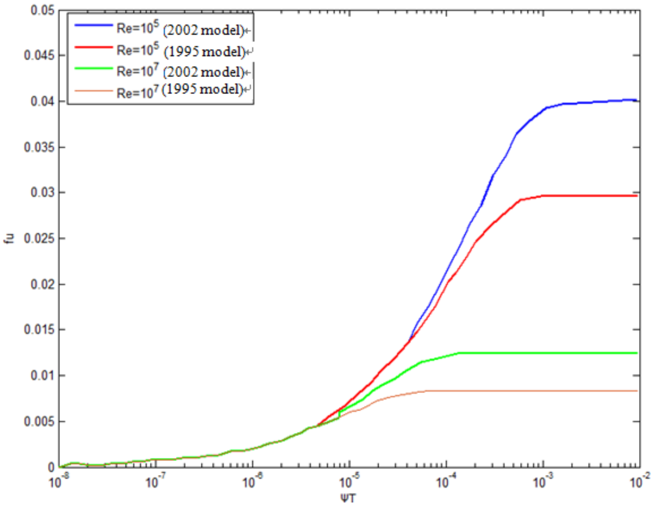

Fig 3-2 The growth trend of thenon - constant friction coefficient $f_u$ and dimensionless time $\psi_T$ under uniformly accelerated condition

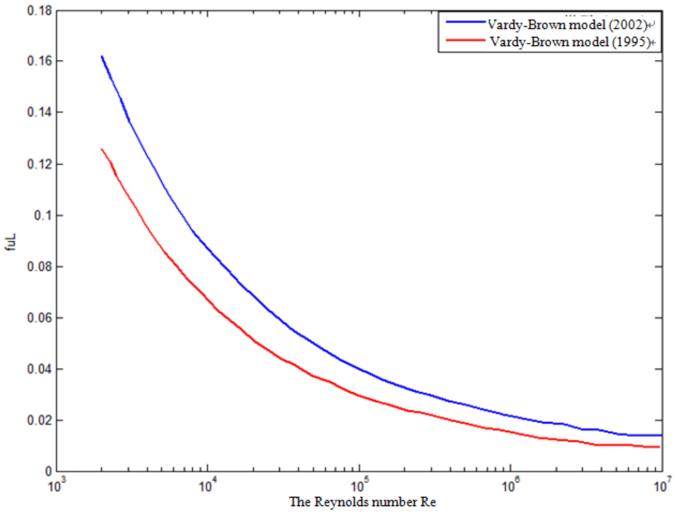

Fig 3-3 The numerical relationship between the correlation coefficient of the non - constant friction coefficient $f_u$ and the Reynolds number Re

According to the experimental data of Vardy and Brown, the relationship between the final weight function $W(\tau)$ and the Reynolds number (Re)is obtained as follows:

$$W(\tau)\approx W_{\mathrm{app}}(\tau)=\frac{A^{*}e^{-\frac{\tau}{C^{*}}}}{\sqrt{\tau}} \tag{3-3}$$

In the formula, $A^{*}=\frac{1}{2\sqrt{\pi}}$=0.2821 , $C^{*}=\frac{12.86}{\mathrm{Re}^{\kappa}}$ , $\kappa=\lg(\frac{15.29}{\mathrm{Re}^{0.0567}})$

The scope of the Vardy-Brown model is: $2000<\mathrm{Re}<10^{8}$. Large-scope of Reynolds numbers makes the model applicable to the calculation of non-constant friction for most of the fluid flowing in pressurized pipelines. Vardy and Brown creatively introduce Reynolds number Re, which is favorable for the comparative Study of laminar flow and turbulent flow of pressurized pipeline fluids.

### 3.4 Zarzycki model

Like Vardy and Brown, Zarzycki also argues that the non-constant friction of the pressurized pipe is related to the Reynolds number(Re) of the fluid in the pipe, and the model is based on further analysis of the axisymmetric flow, the difference is the hypothesis model used by Zarzycki is a four-layer velocity distribution, and a new algorithm of critical Reynolds number $\mathrm{Re}_{c-u}$ is introduced. The weight function of the theoretical model $W_{app}(\tau)$ is defined as:

(1) When the fluid flow in the pressurized pipe is in the laminar flow state ($\mathrm{Re} \le \mathrm{Re}_{c-u}$),there are:

$$W_{app}(\tau) = C_1\tau^{-0.5} + C_2 e^{-m\tau} \tag{3-4}$$

Among them, $C_1 = 0.2812, C_2 = -1.5821, m = 8.8553$

(2) When the fluid flow in the pressurized pipe is in a turbulent state( $\mathrm{Re} > \mathrm{Re}_{c-u}$ ),there are:

$$W_{app}(\tau) = C\frac{1}{\sqrt{\tau}}\mathrm{Re}^n \tag{3-5}$$

Among them, $C = 0.299635, n = -0.005535, \tau = \dfrac{4\nu t}{D^2}$

Zarzycki creatively proposed a calculation of the critical Reynolds number $\mathrm{Re}_{c-u}$ for distinguishing the fluid flow from a pressurized pipe, which is used to distinguish whether the fluid flow is laminar or turbulent. Using Zarzycki's innovation to define:

$$\mathrm{Re}_{c-u} = 800\sqrt{\Omega} \tag{3-6}$$

Among them, $\Omega = \dfrac{\omega D^2}{4\nu}; \omega = \dfrac{2\pi}{T}; T = \dfrac{4\nu t}{D^2}$, so:

$$\Omega = \frac{\pi D^4}{8\nu^2 t} \tag{3-7}$$

### 3.5 IAB model

Brunone et al. studied and analyzed the data results of the non-constant friction test of the pressurized pipe. It was found that there was a certain relationship between the unsteady friction of the pressurized pipe and the local acceleration and convective acceleration. The formula can be expressed as:

$$f_u = f_q + \frac{kD}{V|V|}\left[\frac{\partial V}{\partial t} - a\frac{\partial V}{\partial x}\right] \tag{3-8}$$

In the formula, $f_u$ is friction coefficient of non-constant term, $f_q$ is the first quasi-constant friction coefficient, $a$ is fluid flow velocity of pressurized pipe, $k$ is Brunone's model coefficients.

Since the IAB model does not take the effect of the convective term in the pressurized pipe on the positive or negativeinto account, when the fluid in the pipe is flowing, and the acceleration rate is opposite to the instantaneous acceleration direction at that time, the difference between the calculated results and the real value is large. At the same time, Brunone's model coefficients are generally calculated by experimental methods, and the values of the coefficients have a great effect on the different site construction conditions. Therefore, the IAB model cannot be described the transient state of fluid flow well.

### 3.6 MIAB model

For the IAB model, when the fluid in the pipeline is flowing, and the local acceleration is opposite to the instantaneous acceleration direction,in the case of the transient state of the fluid flow can not be described well. So Vitkovsky, Bergantd et al. proposed the MIAB model. The formula can be expressed as:

$$f_u = f_q + \frac{kD}{V|V|}\left[\frac{\partial V}{\partial t} + a\,\mathrm{sign}V\frac{\partial V}{\partial x}\right] \tag{3-9}$$

In the case of different circumstances $a\mathrm{sign}V$ can be expressed as:

$$a\mathrm{sign}V=\begin{Bmatrix} 1, V\dfrac{\partial V}{\partial x}\geq 0; \\ -1, V\dfrac{\partial V}{\partial x}<0. \end{Bmatrix} \tag{3-10}$$

Although the MIAB model eliminated the influence of the coordinate system on the unsteady friction coefficient of the pressurized pipe to a certain extent, in order to ignore the effect of the non-constant friction of the fluid during deceleration process, the MIAB model also ensures that the non-constant friction of the fluid during the acceleration process is sufficiently large, and compared the resulting value of the non-constant friction coefficient with the IAB model, there is a certain range of promotion in accuracy, but the MIAB model only considered the interaction of the flowing fluid in the pressurized pipe with the boundary does not take the friction along the pipe into account, so the function of the MIAB model for calculating the unsteady friction coefficient of the pressurized pipe is to be improved.

### 3.7 MIAB empirical revised model

For the defect situation of IAB model of Brunone et al. and the MIAB model of Vitkovsky et al. in the calculation of the non-constant friction coefficient of the pressurized pipe,some scholars have introduced two non-constant friction coefficient $K_A$ and $K_P$ .The non-constant friction coefficient of the pressurized pipe can be expressed by the formula :

$$f_u = f_q + \frac{D}{V|V|}\left[\frac{K_P\partial V}{\partial t} + a\mathrm{sign}V\,\frac{K_A\partial V}{\partial x}\right] \tag{3-11}$$

In the formula, $K_A$ and $K_P$ expressed as a different physical quantity, the physical essence is not the same. $K_A$ is the physical quantity of extra friction in the non-constant friction of the pressurized pipe , usually $K_A$ can be expressed as:

$$K_A = 0.166\sqrt{f_q} \tag{3-12}$$

In the formula, $f_q$ is Darcy-Weisbach friction coefficient.

$K_P$ is the physical quantity of the wave velocity in the non-constant friction of the pressurized pipe, it is usually associated with the momentum corrected factor( $\beta$ ), expressed as the formula:

$$K_P = \beta - 1 \tag{3-13}$$

Under different construction conditions, the values of $K_A$ and $K_P$ in the model need to be calibrated, whether it is correct or not is still arguing. At the same time, the MIAB revised model has the same computational defects as the MIAB model, but the MIAB revised model brought the great convenience on the non-constant friction coefficient correction, making the calibration between the non-constant friction coefficient and the actual value become more convenient.

## 4. Conclusion

In this paper, the monitoring parameters of fracturing fluid injection dynamic monitoring system are optimized by analyzing the monitoring parameters of fracturing fluid injection dynamic monitoring system. Based on the research of the empirical models such as Zielke, Trikha, Vardy-Brown, Zarzycki and IAB, MIAB and MIAB correction models, the characteristic law of the weight function in the unsteady coefficient of non-constant friction is obtained, which provide theoretical basis for the improvement and optimization of the monitoring model.

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