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Research Article

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Research on the Calculation Model of Negative Pressure Loss Considering the Influence of Drilling Instability Section

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Abstract: This study addresses the problem of borehole deformation and instability during gas extraction. An indoor similar simulation experiment was conducted, first establishing a negative pressure distribution testing system for extraction and then establishing five types of borehole instability models with gradually expanding, gradually contracting, suddenly expanding, suddenly contracting, and irregular cross-sections. The relationships between unit pressure drop, extraction flow rate, and orifice pressure were analyzed separately. The results show that with the increase of extraction flow rate and orifice pressure, the unit pressure drop of the five different instability conditions all increases, among which the pressure loss of the gradually expanding and gradually contracting instability conditions is the smallest, followed by the irregular cross-section instability condition, and the pressure loss of the sudden expansion and sudden contraction instability conditions is the greatest. Subsequently, the data obtained from the experiment were processed and analyzed, and it was found that the local pressure loss coefficient of the borehole instability section is approximately logarithmic in relation to the Reynolds number. Finally, the calculation formula for the local loss coefficient was deduced, and the pressure loss calculation model for the borehole instability section during extraction was improved.

Keywords: borehole gas extraction; deep coal seams; drilling instability model; unit pressure drop; negative pressure local loss coefficient.

1. Introduction

According to the "Statistical Communiqué on the National Economic and Social Development of the People's Republic of China in 2022" released by the National Bureau of Statistics on February 28, 2023, the total energy consumption in China in 2022 was 4.56 billion tons of standard coal, an increase of 2.9% over the previous year. Coal consumption accounted for 56.2% of the total energy consumption, up 0.3 percentage points from the previous year [1]. Coal has long accounted for a very important proportion of China's energy consumption [2]. For a long time, the frequency of mine gas disasters and the death rate have remained high. In particular, various disasters such as gas explosions and gas outbursts have always been the main factors that seriously affect the safety of coal mine production, and are major problems that need to be solved urgently in the safe and stable development of coal mining enterprises in China [3,4], which have had a great impact on the stable development of China's economy and society. Borehole gas extraction is the most important measure to prevent and control mine gas accidents. The instability and collapse of the extraction borehole is one of the key problems hindering the efficient extraction of coal seam gas (coalbed methane). The distribution of coal seam gas is directly related to the extraction effect of borehole gas, and the effect of borehole gas extraction is mainly related to the negative pressure and hole size of the extraction. Most of the coal seams in China are soft coal seams, and the deep soft coal seam extraction boreholes are prone to instability, which seriously affects the gas extraction effect of boreholes [5-7].

The process of instability and failure of the extraction borehole is actually the failure and instability process of the coal and rock mass around the borehole. Many scholars at home and abroad were the first to apply various mechanical theories to analyze the process and mechanism of deformation and failure of surrounding rock from different aspects. Zhang Xuebo et al [8] established a coupling mathematical model that comprehensively considers borehole deformation instability, coal seam gas migration and dynamic attenuation of borehole negative pressure along the hole length, numerically analyzed the influence mechanism of extraction borehole instability and collapse on gas extraction, and proposed a technology for detecting the instability and collapse characteristics of extraction borehole based on the negative pressure distribution test of extraction. Tezuka et al [9-12] proposed a linear elastic model, a viscoelastic model, an elastoplastic model, and other borehole stability models, and analyzed the stability of the borehole wall theoretically. Cheng Hongming [13] analyzed the influencing factors of the effective radius from two aspects: coal seam occurrence parameters and extraction parameters, based on the gas-solid coupling model of gas-solid extraction in bedding boreholes. Zhu Hongqing et al [14] established a full-scale borehole model based on the mechanical model of coal and rock around the borehole to simulate the stress and displacement distribution of the surrounding rock of the borehole and investigated the effect of regional measures to eliminate outburst at the test site, which indirectly proved that the borehole wall stability was good. Zhang Wenhao [15] used the COMSOL numerical simulation software to analyze the gas extraction effect and the effective radius of the gas under different initial in-situ stresses, initial permeability, and borehole diameters. Wang Zhen et al. [16] established a mechanical model of the instability of the anti-outburst borehole in the excavation face and obtained the failure form and instability characteristics of the coal body around the bottom and wall of the anti-outburst borehole. Zhao Yangsheng et al. [17] conducted experimental research and theoretical analysis on the deformation law of borehole and its critical instability conditions in the borehole granite body under constant temperature and pressure. According to the experimental research conclusions, the viscoelastic theoretical model and viscoelastic-plastic theoretical model of borehole deformation were established by using the viscoelastic-plastic mechanical theory. Zhai Cheng et al [18] analyzed the instability and deformation mechanism of the extraction borehole of the soft and outburst coal seam and pointed out that the main reasons for the weak structure of the hole wall and the easy damage and instability collapse after the construction of fracturing borehole are the surrounding rock stress of the roadway and the secondary stress of the borehole. The method of solidification and hole formation in the soft coal seam area was proposed, and the stress field and displacement change law around the soft coal seam and the borehole after solidification were numerically analyzed. Yi Lijun and Yu Qixiang [19] used ANSYS finite element software to numerically simulate the plastic zone and strain changes around the borehole under different coal strengths and obtained the variation law of the plastic zone. Sun Zehong, Tu Min [20] and others used FLAC software to numerically simulate the mechanical dynamics of borehole rocks, preliminarily studied the mechanical characteristics of borehole instability with weak structure in deep coal and rock and established the corresponding theoretical calculation model. The influencing factors of borehole stability were analyzed, and the method of hole stabilization was proposed. Based on UDEC software, Zhang Feiyan [21] carried out a numerical simulation study on the instability and failure of coal seam borehole and preliminarily discussed the distribution law of stress field and displacement field around coal seam borehole and its failure mode. Yao Xiangrong et al. [22] numerically analyzed the variation of the stress field, plastic failure zone and displacement field of the coal around the borehole based on the Kastner formula. Peng Zhuang et al. [23] used Fluent software to simulate the mixed flow in the horizontal wellbore of gas-water co-production, and analyzed the effects of flow velocity and hole roughness on the flow pressure drop in the horizontal section, and the results showed that the pressure loss in the horizontal section increased significantly with the increase of flow rate and mixing velocity. Ji Zhongchao [24] regarded the flow in the borehole as the flow of a straight pipe and considered the resistance loss along the way as the main resistance loss in the borehole and numerically analyzed the influence of factors such as coal seam permeability, pumping negative pressure, and borehole collapse on the negative pressure loss in the borehole.

Most of the above studies use the theory of elastoplastic mechanics to study the deformation and instability of boreholes (or coal and rock mass), but the change of borehole shape from deformation and instability to the process of borehole deformation and instability has not been studied. At present, the research of domestic and foreign researchers is to directly convert the borehole section after instability into the borehole diameter reduction to study, but it does not take into account the changes of different shapes after borehole instability and does not consider the influence of different cross-section shapes on gas extraction.

In this paper, five experimental models of borehole shape change before and after instability are constructed through laboratory simulation experiments, namely: gradual expansion, gradual reduction, sudden increase, sudden reduction and irregular cross-section. By measuring the changes of pressure and pumping flow under different instability conditions of several boreholes, the influence of different instability sections of boreholes on the negative pressure of borehole pumping in the borehole is explored, which has important guiding significance for improving the effect of gas extraction.

2. Analysis of Cross-Sectional Shape After Instability and Collapse of Extraction Borehole

The factors that cause borehole deformation, instability and failure can be roughly divided into two categories: natural factors and engineering factors. Natural factors include in-situ stress, geological structure, mechanical properties of coal and rock mass, gas pressure, etc., and engineering factors include the disturbance of the drill pipe on the hole wall, the erosion of the hole wall by high-pressure water, and the mining influence of the working face. However, fundamentally speaking, the instability failure of the borehole, that is, the instability and failure of the coal and rock mass around the borehole, is a process of mechanical instability, and the essence is the instability failure induced by the inability of the coal and rock mass to withstand the applied stress due to its own strength. The instability and collapse of the borehole during the gas extraction process are shown in 1. As can be seen from Figure 1, the shape change before and after the borehole instability is not fixed, and the borehole instability section will undergo shape changes such as hole diameter enlargement and irregularity. The study of the influence of shape change on the negative pressure of coal seam extraction borehole after instability has important theoretical guiding significance for solving the problem of coal seam borehole instability and collapse and effectively improving the gas extraction effect. In order to study the variation law of the negative pressure of the pumping borehole under different instability sections, the shape change of the borehole after instability is divided into five categories, and five borehole instability models are constructed as shown in Figure.

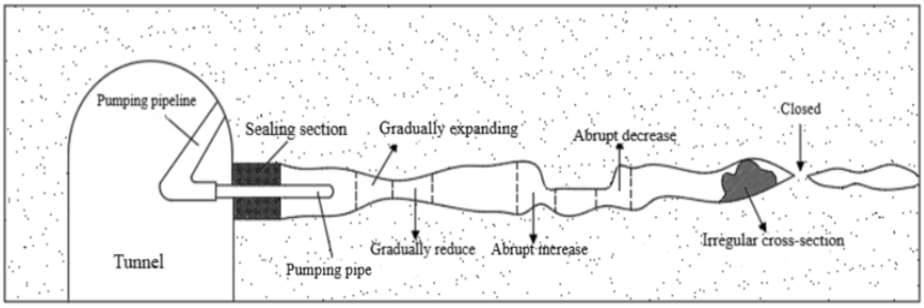
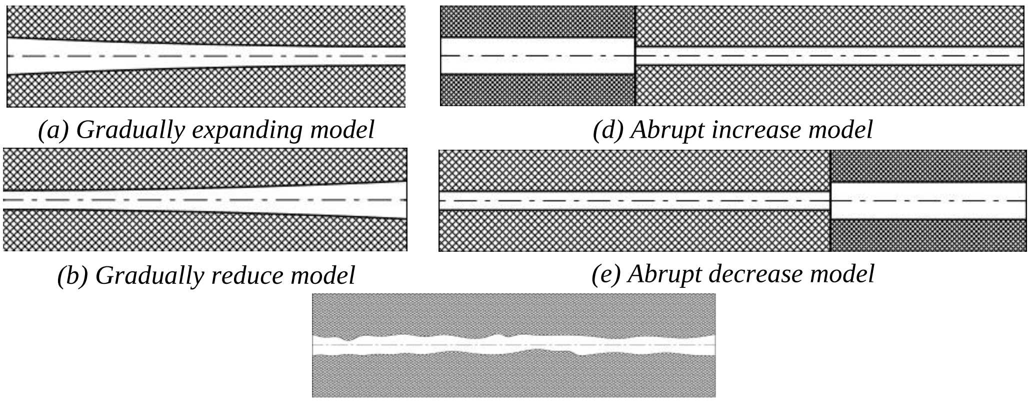


Figure 1: Schematic diagram of destabilization and collapse of extraction borehole



(a) Gradually expanding model *(d) Abrupt increase model*

(b) Gradually reduce model *(e) Abrupt decrease model*

(c) Irregular cross-section model

Figure 2: Five borehole instability models

3. Experimental System Construction

The purpose of this test system is to simulate the process of pumping coal seam gas through experiments, to grasp the influence of borehole deformation instability on the negative pressure distribution and flow distribution in the extraction borehole, and to determine the calculation method of borehole extraction negative pressure under different deformation degrees of borehole.

The coal seam gas extraction process is under the action of negative pressure of borehole extraction, so that there is a pressure difference in the coal seam around the borehole, and the surrounding coal seam gas flows to the borehole and then extracts it under the action of pressure difference. Generally speaking, the permeability coefficient in the coal seam that is not affected by mining can be regarded as isotropic homogeneity, and the permeability coefficient affected by mining should be considered as a variable. If the permeability coefficient of the coal seam around the borehole is regarded as isotropic homogeneity, that is, the permeability of the coal seam is fixed, the gas flow velocity in the coal seam is only related to the coal seam gas pressure gradient, and the gas flow field in the coal is basically uniform. Based on this, a negative pressure loss test system for borehole extraction was designed, which was composed of a gas pumping system, a pressure regulation system, a pipeline system, and a pressure/flow test system.

The experimental system uses air as the medium, and the gas pressure in and around the filling is one atmosphere, and when the system is running, the air around the system continuously enters the filling through the sieve hole under the action of the pressure difference caused by the negative pressure of extraction, and then pours into the borehole.

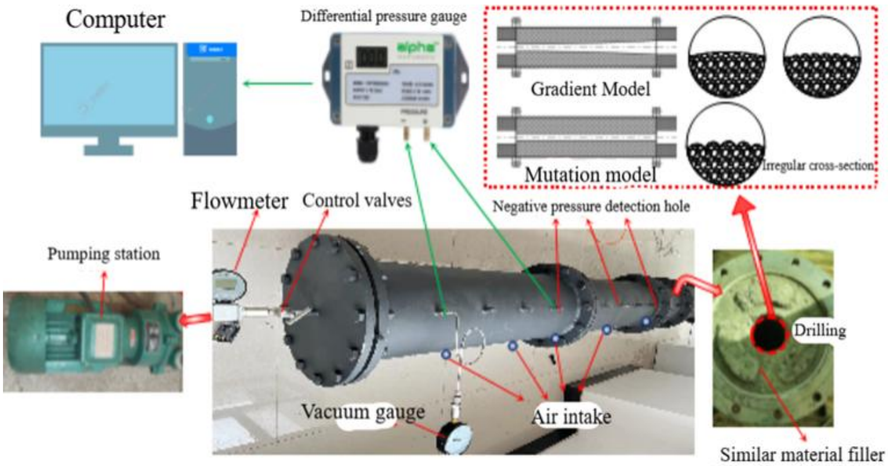


Figure 3: Testing system for negative pressure loss in boreholes

Combined with the theory of variable mass flow pressure loss, considering the irregular influence of the borehole collapse section, the calculation model of negative pressure loss under the condition of borehole deformation is perfected, and the negative pressure loss calculation model under the condition of borehole deformation is accurately mastered, which has important theoretical guiding significance for accurately monitoring the borehole instability area and instability degree. The negative pressure distribution test system in different deformation boreholes is composed of a pumping system, a pressure regulation system, a pipeline system and a pressure and flow test system.

(1) Pumping system: It is composed of a high-reliability vacuum pump. The vacuum pump adopts the V-i280SV high-reliability vacuum pump produced by Zhejiang Feiyue Vacuum Technology Co., Ltd., and its parameters are shown in Table 1.

Table 1: Parameters of V-i280SV High-Reliability Vacuum Pump

Name	Model	Evacuation rate/m^3/h	Ultimate vacuum/Pa	Rated voltage	Power/W
High reliability vacuum pumps	V-i280SV	14.4	2×10^{-1}	220V-/50HZ	750

(2) Pressure regulation system: The negative pressure adjustment of the pipeline system can be realized by rotating the pressure regulating valve at the outlet of the high-reliability vacuum pump.

(3) Pipeline system: As shown in Figure 3, the pipeline system is composed of a filling box, a filler and a borehole on the outside. Considering that there is gas inflow throughout the actual drilling process, the drilling in the system is used for five instability situations designed in advance, which is located in the middle of the pipeline system; A sieve hole is arranged on the filling box as an air intake. The same length of pipeline system is filled with the same simulated coal seam filler to ensure the same air permeability of the filler around the borehole, and then the filling box needs to be arranged with a sufficient number of evenly distributed screen holes to ensure that the flow field in the pipeline system is evenly distributed.

(4) Pressure and flow test system: A pressure measurement point is arranged at every interval in the pipeline, and the differential pressure and flow rate are tested through equipment such as pitot tubes, precision differential pressure gauges and gas mass flow meters. The negative pressure measurement of the orifice is measured by the pressure vacuum gauge produced by Qingdao Huaqing Group Co., Ltd. The gas mass flow meter adopts the AMS2106 produced by Guangzhou Aosong Electronics Co., Ltd., and its parameters are shown in Table 2. The precision differential pressure gauge adopts the GM520 precision differential pressure gauge produced by Shenzhen Jumaoyuan Technology Co., Ltd., and its parameters are shown in Table 3.

Table 2: Parameters of Gas Mass Flow Meter Model AMS2106

Product model	Range/L/min	Precision	Response time/s	Maximum operating pressure/MPa
AMS2106	0~25	±3%F.S.	≤2.00	0.80

Table 3: Parameters of GM520 Precision Differential Pressure Gauge

Product model	Measuring range/KPa	Measurement accuracy	Response time/s	Operating temperature/℃
GM520	±35	±0.3%FSO	0.50	0-50

4. Analysis of experimental results

In order to study the different effects of pressure loss on different deformation and instability conditions of bedding boreholes, the flow rate and pressure loss before and after deformation instability of five types of borehole deformation instability (gradual expansion, gradual reduction, sudden increase, sudden decrease and irregular section) were measured, and the specific schemes are as follows:

1) The borehole instability is measured by the pumping flow rate when it gradually expands and the pressure loss measurement before and after the instability change. The filling box is evenly filled with similar materials of the coal seam to ensure the uniform air permeability of the pipeline system, and the borehole diameter is 47 mm to 94 mm, and the distance between the measuring points before and after borehole instability is 0.6 m.

2) The borehole instability is measured by the pumping flow rate when it is gradually shrinking and the pressure loss measurement before and after the instability change. The borehole diameter of the borehole is 94 mm to 47 mm, and the distance between the measuring points before and after borehole instability is 0.6 m.

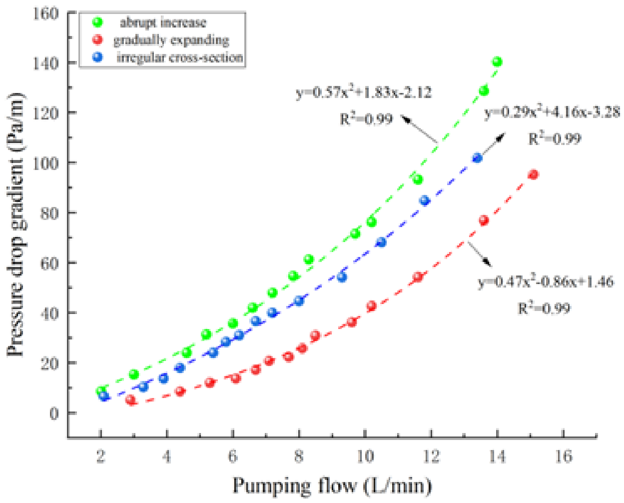
3) The instability of the borehole is the measurement of the pumping flow rate when the instability increases suddenly and the pressure loss measurement before and after the instability change. The filling box is uniformly filled with similar materials of the coal seam to ensure the uniform air permeability of the pipeline system, and the borehole diameter increases suddenly from 47 mm to 94 mm, and the distance between the measuring points before and after borehole instability is 1.165 m.

4) The borehole instability is measured by the pumping flow rate when the instability is abruptly reduced and the pressure loss is measured before and after the instability change. The filling box is uniformly filled with similar materials of the coal seam to ensure the uniform air permeability of the pipeline system, and the

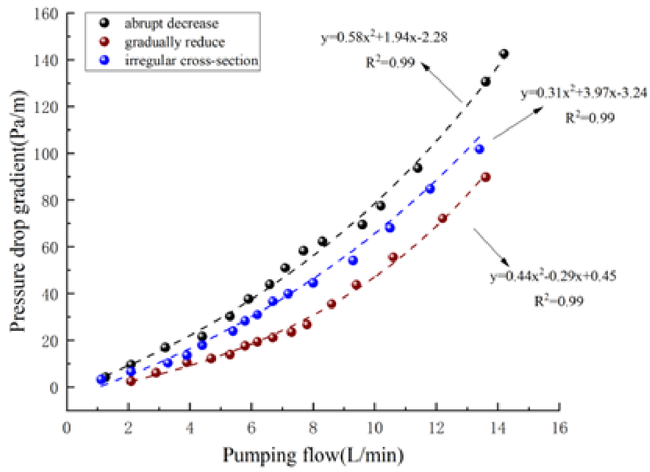
borehole diameter of 94 mm to 47 mm decreases suddenly, and the distance between the measuring points before and after borehole instability is 1.165 m.

5) The instability of the borehole is the measurement of the pumping flow rate when the irregular section and the pressure loss measurement before and after the instability change. The filling box is uniformly filled with similar materials of the coal seam to ensure the uniform air permeability of the pipeline system, and the borehole diameter is 47 mm, but the borehole deformation and instability are irregular deformation. The distance between the measuring points before and after borehole instability is 0.6 m.

By adjusting the pressure regulating valve at the outlet of the pumping pump, the negative pressure of the system was adjusted to 10 kPa, 15 kPa, 20 kPa, 25 kPa, 30 kPa, 35 kPa, 40 kPa, 45 kPa, 50 kPa and 55 kPa, respectively, and the flow rate in the 10 pipelines under negative pressure and the pressure difference before and after borehole instability and deformation were tested, and then the negative pressure distribution and flow distribution of the system were obtained. Since the distances between the measuring points are not the same, the measured differential pressure is uniformly converted into a unit pressure drop (Pa/m). Through experiments, according to the data obtained from the measurement, the relationship between the pumping flow, the negative pressure of the orifice and the unit pressure drop is drawn as follows:

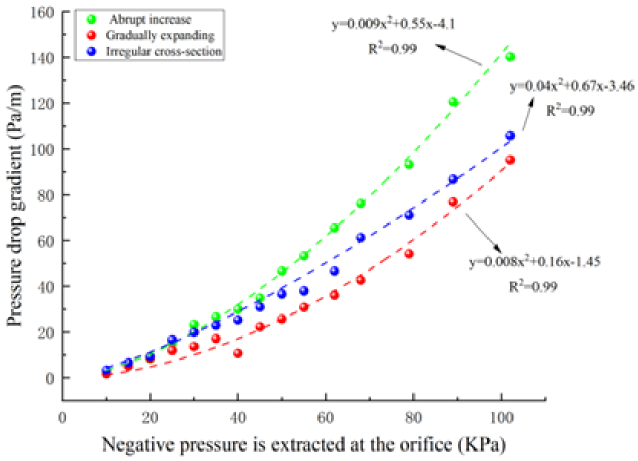


(a) The relationship between unit pressure drop and pumping flow under the condition of gradual expansion, abrupt increase and irregular cross-section.

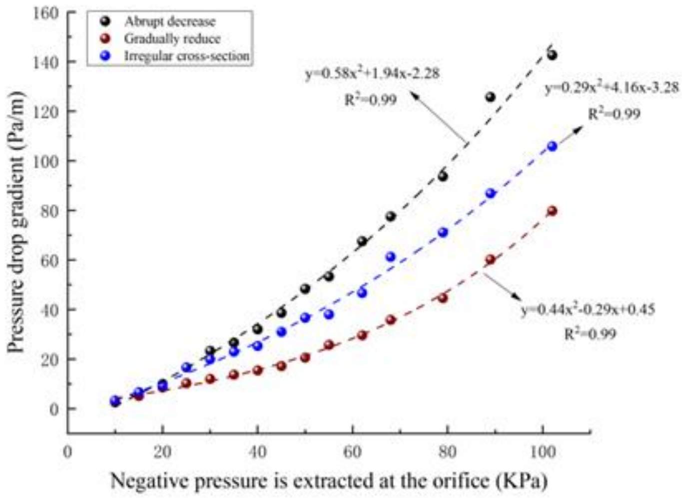


(b) The relationship between unit pressure drop and pumping flow under the condition of gradual reduction, abrupt decrease and irregular cross-section.

Figure 4: Relationship diagram between unit pressure drop and pumping flow rate.



(a) The relationship between unit pressure drop and orifice extraction negative pressure under the conditions of gradual expansion, abrupt increase and irregular cross - section.



(b) The relationship between the unit pressure drop and the negative pressure of orifice extraction under the condition of gradual reduction, abrupt decrease and irregular cross-section.

Figure 5: The relationship between the pressure drop gradient and the negative pressure of orifice extraction

As can be seen from Figure 4 and Figure 5:

1) With the increase of the negative pressure of pumping, the pumping flow rate gradually increases, which is consistent with the gas extraction law that increasing the negative pressure of borehole extraction in the field can increase the gas extraction volume. The unit pressure drop and the pumping flow rate are roughly quadratic. The unit pressure drop is roughly quadratic with the negative pressure of orifice extraction.
2) With the continuous increase of pumping flow rate and orifice negative pressure, the unit pressure drop of the five instability conditions is gradually increasing.
3) There is not much difference in the pressure drop change at the beginning of several instability models, but with the continuous increase of pumping flow and orifice pumping negative pressure, the unit pressure drop change range of the borehole instability is gradually expanding and gradually narrowing. The borehole instability is the least variable per unit pressure drop of the two types of instability: sudden increase and sudden decrease. When the borehole instability is an irregular section, the variation amplitude of the unit pressure drop is between the gradual and abrupt instability cases. From the analysis, it can be seen that the instability of the borehole is the largest when the borehole gradually expands and shrinks. The instability of the borehole is that the pressure loss is greater when the irregular section is

irregular, but the degree of pressure loss is less than the pressure loss when it gradually expands and gradually shrinks. Borehole instability occurs with a sudden increase and a sudden decrease in pressure loss.

5. Discuss

Extraction negative pressure dynamic attenuation model

Wang Kai [25] proposed that the pressure loss of the gas fluid in the borehole will occur during the flow process, and the pressure loss is mainly caused by four factors: frictional resistance loss along the way, acceleration pressure drop, mixed loss caused by gas inflow in the borehole wall, and local resistance loss (Figure 6).

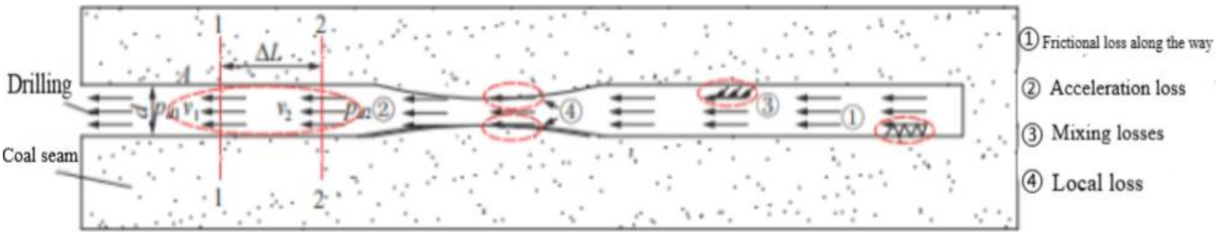


Figure 6: Classification of negative-pressure-loss in extraction within boreholes

In the negative pressure dynamic attenuation model established in Ref. [7] and [8], the calculation formula of pressure loss in the process of gas extraction and the calculation formula of resistance coefficient along the hole wall are analyzed:

$$\Delta P_{d12} = f'\frac{\Delta L}{2}\frac{\rho\bar{v}^2}{2} + \rho(v_1^2 - v_2^2) + \xi\frac{\rho v^2}{2} \quad (1)$$

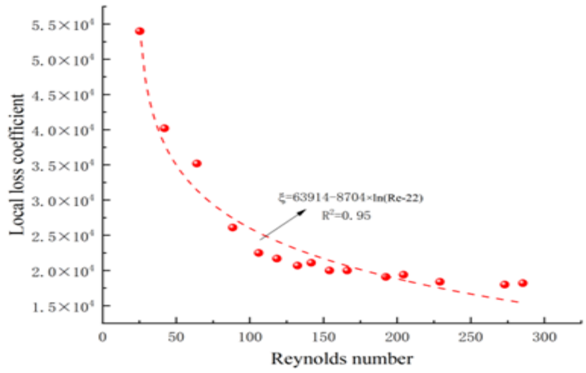
$$f' = \begin{cases} \frac{64}{Re}(1+0.04304\,\mathrm{Re}^{0.6142}),\ Re \le 2000 \\ \left[1.14 - 2\lg(\frac{\varepsilon}{d} + 21.25 Re^{-0.9})\right]^{-2} \\ \times(1+0.0163 Re^{0.2278}),\ Re \ge 4000 \end{cases} \quad (2)$$

In equation (1), ΔP_{d12} is the pumping pressure difference between the two sections 1 and 2 in the borehole，Pa; ΔL is to calculate the length of the unit segment, m; $\bar{v}$ is used to calculate the average gas velocity of the unit segment, m/s; f' 、 ξ is the resistance coefficient and local loss coefficient along the modified hole wall, respectively, N·s 2 /m4.

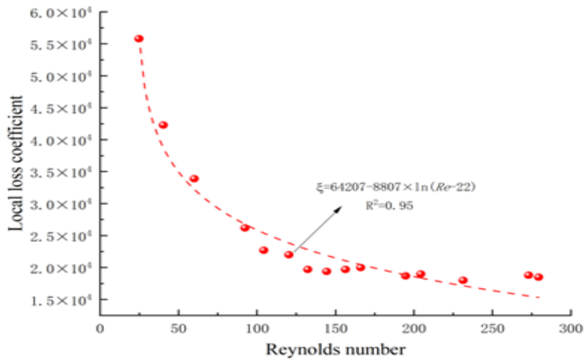
In equation (2), the **ε** is the roughness of the pipe wall. The drag coefficient along the transition (2 000≤Re≤4 000) fluid can be obtained using Eq. (2) using linear interpolation.

The relationship between the Reynolds number and the local loss coefficient after borehole instability changes

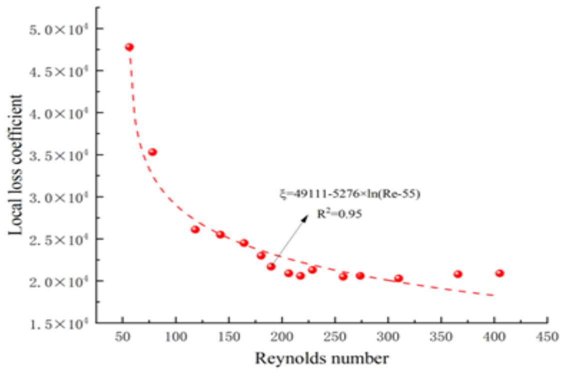
Through the above formula, according to the experimental data, the Reynolds coefficient and the local loss coefficient in each borehole instability case are calculated, and the relationship between the Reynolds number and the local loss coefficient in the five borehole instability cases of gradual shrinking, gradual expansion, sudden increase, sudden reduction and irregular section is shown in Figure 7.



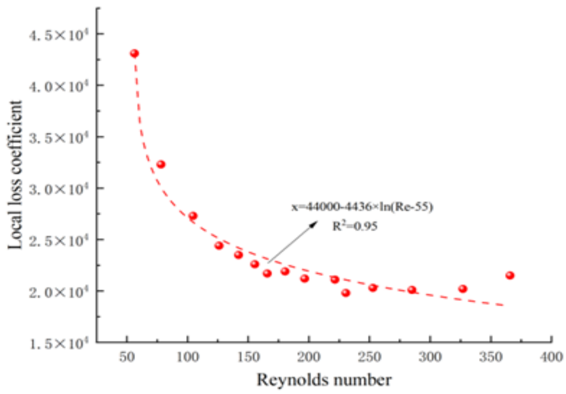
(a) Relationship diagram between Local loss coefficient and Reynolds number under the condition of gradual reduction.



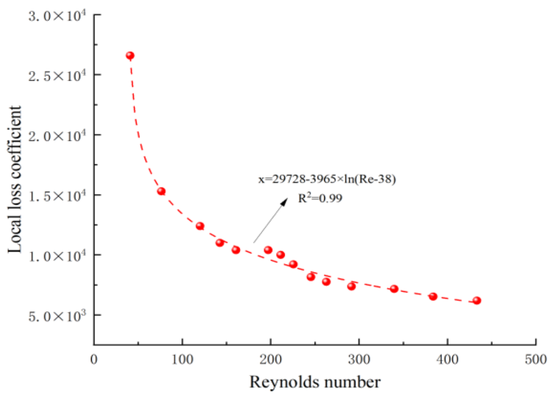
(b) Relationship diagram between Local loss coefficient and Reynolds number under the condition of gradual expansion.



(c) Relationship diagram between Local loss coefficient and Reynolds number under the condition of abrupt increase.



(d) Relationship diagram between Local loss coefficient and Reynolds number under the condition of abrupt decrease.



(e) Relationship diagram between Local loss coefficient and Reynolds number under the condition of irregular cross-section.

Figure 7: Diagram of the local loss coefficient versus the Reynolds number

As can be seen from Figure 7:

1) The Reynolds number is roughly logarithmic with the local loss coefficient. With the increasing Reynolds number, the local loss coefficient gradually decreases and finally tends to be stable.
2) From (a) and (b), it can be seen that when the borehole instability is gradual, the local loss coefficient gradually decreases with the increase of Reynolds number. When the Reynolds number is 0-100, the local loss coefficient decreases to a greater extent, and then with the increase of the Reynolds number, the local resistance coefficient gradually tends to be stable. From (c) and (d), it can be seen that when the borehole instability is abrupt, the local loss coefficient gradually decreases with the increase of Reynolds number. When the Reynolds number is 0-125, the local loss coefficient decreases to a great extent, and then with the increase of the Reynolds number, the local resistance coefficient gradually tends to be stable. It can be seen from (e) that when the borehole instability is an irregular section, the local loss coefficient gradually decreases with the increase of the Reynolds number. When the Reynolds number is 0-150, the local loss coefficient decreases to a greater extent, and then with the increase of the Reynolds number, the local resistance coefficient gradually tends to be stable.

Negative pressure loss calculation model considering the influence of borehole instability section

In Eq. (1), the local loss coefficient ξ is unknown. In this paper, through the analysis of experimental data, ξ can be obtained. Thus, the formula has been refined to a certain extent. According to the experimental test results, the formula for calculating ξ is as follows：

$$\xi = a - b \times ln\,(Re + c) \tag{3}$$

In Eq. (3), a, b, and c are the fitting coefficients, and ξ is the local loss coefficient.

Comprehensive equation (1)~(3) can establish a complete negative pressure loss calculation model considering the influence of borehole instability section, as shown in equation (4).

$$\begin{cases} \Delta P_{d_{12}} = f' \dfrac{\Delta L}{2} \dfrac{\rho \bar{v}^2}{2} \\ + \rho(v_1^{\,2} - v_2^{\,2}) + \xi \dfrac{\rho v^2}{2} \\ f' = \begin{cases} \dfrac{64}{Re}(1 + 0.04304\,\mathrm{Re}^{0.6142}),\ Re \le 2000 \\ \left[1.14 - 2\lg(\dfrac{\varepsilon}{d} + 21.25 Re^{-0.9})\right]^{-2} \\ \times(1 + 0.0163 Re^{0.2278}),\ Re \ge 4000 \end{cases} \\ \xi = a - b \times ln\,(Re + c) \end{cases} \tag{4}$$

The negative pressure loss calculation model considering the influence of borehole instability section can be used to calculate the negative pressure loss and distribution of borehole under different instability conditions, which can provide important support for the identification of the instability and collapse area and instability degree of the extraction borehole.

6. Conclusion

1) An experimental system for differential pressure measurement and flow measurement before and after borehole instability was designed and constructed, and the law of unit pressure drop change under five different deformation and instability conditions of borehole was tested and analyzed.
2) With the increase of negative pressure in pumping, the pumping flow rate and negative pressure loss gradually increase, which is consistent with the gas extraction law that increasing the negative pressure of borehole extraction in the field can increase the gas extraction volume. The higher the negative pressure of pumping, the greater the pumping flow, and the unit pressure drop of the five borehole instability cases gradually increased, among which the pressure loss degree of the two instability cases of gradual reduction and gradual expansion was the largest. In the case of sudden increase and sudden decrease, the degree of pressure loss is relatively small. The degree of pressure loss in the case of irregular section instability is between the two types of instability in the case of gradual change and abrupt change.
3) The local loss coefficient of negative pressure in the borehole instability section is roughly logarithmic with the Reynolds number. With the increasing Reynolds coefficient, the local loss coefficients of the five instability cases gradually decreased, and finally gradually stabilized. In the case of gradual instability, when the Reynolds number is 0-100, the local loss coefficient decreases to a greater extent. In the case of abrupt instability, when the Reynolds number is 0-125, the local loss coefficient decreases to a greater extent. When the Reynolds number is 0-150, the local loss coefficient decreases to a greater extent. Through the processing and analysis of the experimental data, the relationship between the local loss coefficient and the Reynolds number is obtained, and the calculation formula of the local loss coefficient is deduced, and the negative pressure loss calculation model considering the influence of the borehole instability section is improved. The negative pressure loss calculation model considering the influence of borehole instability section can be used to calculate the negative pressure loss and distribution of borehole under different instability conditions, which can provide important support for the identification of the instability and collapse area and instability degree of the extraction borehole.

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