Design and Application of Gas Permeability Measurement System

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Abstract: the permeability of porous media is an important index to characterize the permeability of fluid to porous media. In order to accurately determine the gas permeability of rock medium, a set of steady permeability measurement system is designed. The measurement and control part of the system is designed based on the Labview platform, and the functions of sensor control, acquisition, data processing and storage are realized. The experiment of gas permeability measurement and its uncertainty evaluation were carried out, and the results showed that the measurement system had good repeatability, and the extended uncertainty was 1.9%, which met the requirement of material permeability measurement.

1. Introduction

The permeability of porous media is an important index to characterize the permeability of fluid to porous media. The accurate determination of gas permeability in rock media is of great significance in the geological storage of greenhouse gases, the construction of energy gas storage reservoirs and the study of heat and mass transfer characteristics of strata [1-4].At present, the commonly used methods to measure rock permeability by gas include steady-state method, pressure pulse method and pore pressure vibration method [5-7]. Pressure pulse method is a method to calculate the permeability by analyzing the attenuation characteristics of the pressure pulse at the inlet with time in the rock sample, which belongs to the category of unsteady state measurement. The pore pressure vibration method is a testing method between steady state and unsteady state. The specific oscillation pressure is applied at the inlet end of the sample, and the permeability is obtained by measuring the phase and amplitude difference of the pressure at both ends of the sample.

In this paper, a set of gas permeability steady state measurement system is designed, which can be used to test the permeability of porous media such as rock and concrete. The measurement and control part of the system is designed based on the Labview platform, and the functions of sensor control, acquisition, data processing and storage are realized. The results of permeability measurement and uncertainty evaluation show that the system design is reliable and effective.

2. System Principle

The steady-state measurement method is based on the seepage theory. When the gas pressure and flow rate at both ends of the medium are stable, the permeability can be calculated by Darcy's law though measuring the pressure and flow rate at both ends of the specimen.

$$K = \frac{2Q_0 P_0 \eta L T c}{(P_1^2 - P_2^2) T_0 A} \tag{1}$$

Where, K is the gas permeability coefficient (m^2), L is the length of specimen (m), η is the aerodynamic viscosity (Pa·s), Q_0 is the indicated flow rate of the mass flow meter in the standard state (m^3/s), A is the seepage cross-sectional area of the test sample (m2), P1 and P2 are the inlet and outlet pressure (Pa), T is the test temperature (K), P_0 is the standard atmospheric pressure (101325Pa), T_0 is the standard temperature (273K), c is the gas mass flow meter conversion coefficient for different kinds of gases.

The permeability measurement system is mainly composed of air source, mass flow meter, measurement chamber, and pressure sensor and data acquisition module, as shown in Fig. 1. During the test, we used a high-pressure gas source to establish the suitable pressure difference to measure the gas pressure and flow at both ends of the specimen under a stable seepage state to obtain the gas permeability measurement results in a single test, and taken the arithmetic mean value of multiple measurements as the final measurement result of the specimen permeability.

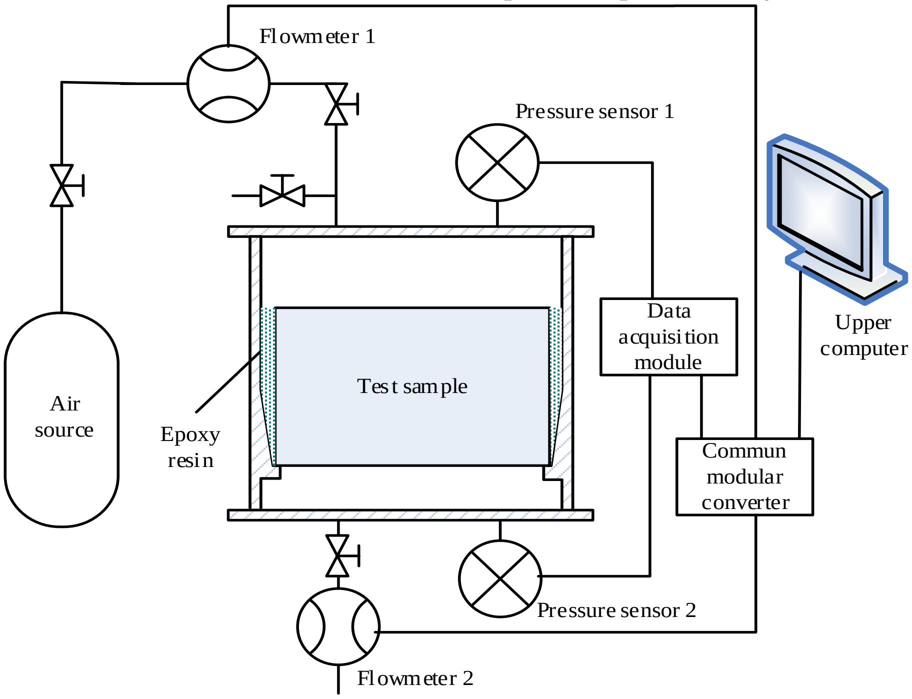

Figure 1. Structure of permeability measurement system

3. Hardware Design

3.1 Framework Design

The hardware measurement control system is shown in Fig. 2. The hardware system selection: pressure sensor measurement range is (0~1)MPa, the accuracy is 0.1%FS, and the analog signal output is (4~20)mA. The flow meter specification is (0~20)mL/min, the accuracy is ±1.0%SP (35%FS) and 0.35%FS (<35%FS), the working pressure difference range is 0.1Mpa~0.35Mpa, and the digital signal output is RS485. We use the ADAM4117 module to collect the output signal of pressure sensor. The ADAM4520 module is used to convert the signal to RS-232 interface between the ADAM4117 module and interface of flow controller RS-485.

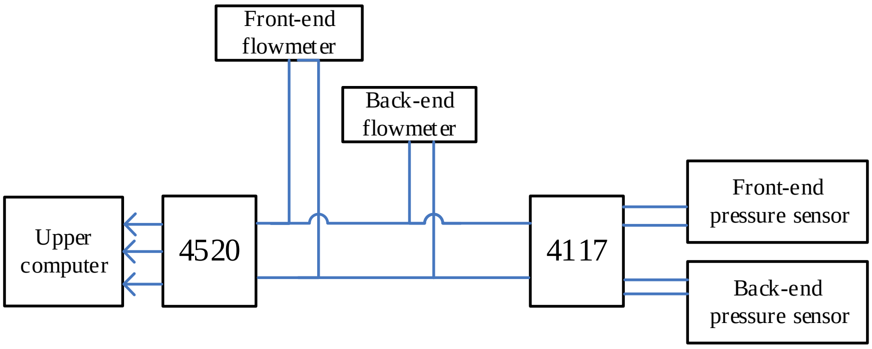

Figure 2. Hardware framework of measurement control system

3.2 Hardware Settings

Before setting up the hardware system, it is necessary to configure the address, communication rate, range, communication protocol and other parameters of ADAM4117 module, and check whether each channel can collect data normally. Module is initialized by Utility, which is setting the dial switch on the right side of the module to INIT (initialization), and then setting parameters by Utility of software tools. The configuration of this module is shown in Table 1.

Table.1. Module configuration contents

Address	Baud rate	Protocol	Input variable
Dec: 1.	9600 BPS	MODBUS	Ch0-ch7: (4 ~ 20) mA

4. Software Design

With the help of virtual panel user interface and block diagram, Labview is the first graphic programming system to establish virtual instrument, which is widely accepted by industry, academia and research laboratory, and is regarded as a standard data acquisition instrument and instrument control software.

On the basis of Labview driver installed flow meter and data acquisition module and VISA driver, and combined with Labview function visualization software, the measurement control software in the system developed by Labview platform, which has the function of serial communication, parameter setting, data record storage, computing results, and other functions. It mainly includes serial communication, parameter setting, data display, data collection, data storage and data processing. The software flow is shown in Fig. 3.

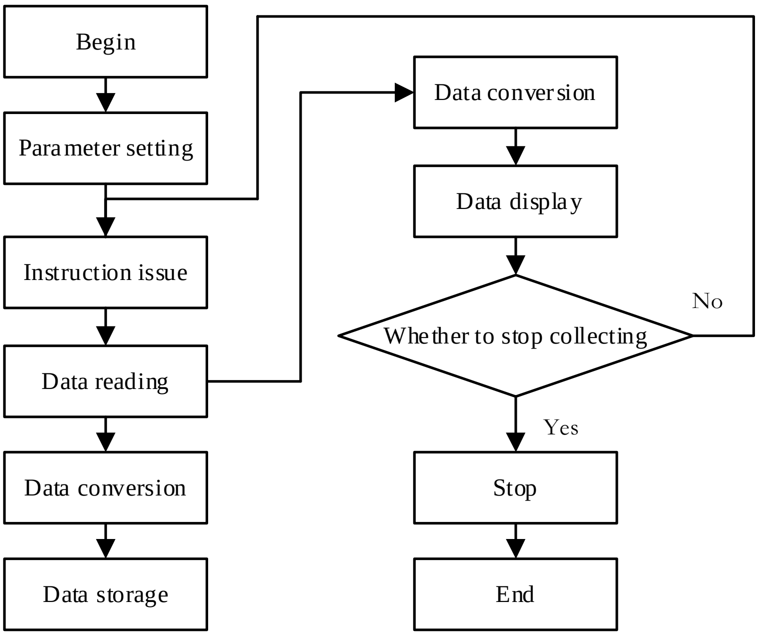

Figure 3. Software structure diagram

Considering the practicability and openness of the Software, we adopt VISA (Virtual Instrument Software Architecture) interface module for programming. VISA is a standard I/O application program interface, which is applied to instrument programming, and is an instrument driver standard API (application program interface) commonly used in the industry. It adopts object-oriented programming and has good compatibility, expansibility and independence. Flow meter control acquisition part of the program diagram is shown in Fig. 4.

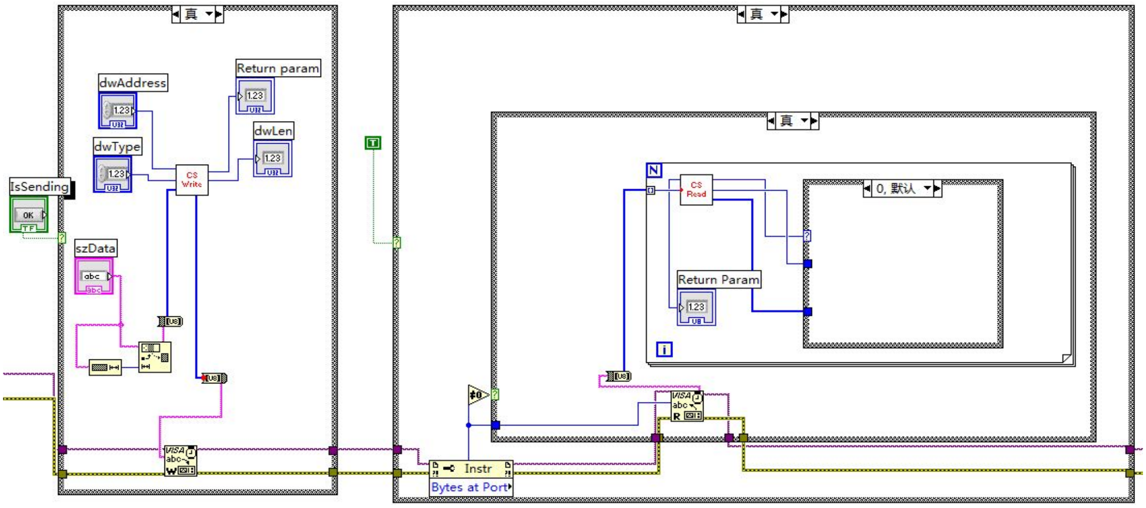

Figure 4. Block diagram of flow meter control acquisition part

After starting the software, the parameters are setted, including communication parameters, sample parameters, sampling interval frequency and data storage address. Among them, serial communication Settings include serial number, baud rate, data bit, stop bit, and check bit, etc. The setting process is completed and saved automatically when the software is first used. Click the start measurement button, the interface displays the pressure and flow reading values, and the chart mode can display the change trend of the values visually. When the pressure value tends to be stable and the flow readings are similar, the permeability results can be read, whose datas are under calculating and processing. The system works as shown in Fig. 5.

Figure 5. System work diagram

5. System Application

5.1 Experimental Process

We carry out the permeability test with the measurement system at 20℃ environment. The specimen is a cylinder with 150mm length and 50mm diameter. The experimental medium is helium gas. Before the experiment, the sealing test results showed that the system had no leakage at the pressure of 0.54Mpa. During the experiment, open the helium cylinder valve door and adjust the pressure value to 120kPa between the system inlet valve and the inlet end of the specimen. When the inlet pressure tends to be stable, check the gas flow at both ends. If the difference is no greater than the preset value, it indicates that the gas seepage has entered the steady state, and then the measurement can be started. The experiment was repeated for 6 times, and the permeability test results were summarized according to equation (1), as shown in Table 2. Among them, the dynamic viscosity of helium is 1.96×10^{-5}Pa·s at 20℃, the conversion coefficient *c* from thermal mass flowmeter to helium takes 1.415.

Table.2. Sample measurement data

Number of measurements	1	2	3	4	5	6
Q (% FS)	58.31	58.33	58.35	58.36	58.37	58.38
P_1 (kPa)	120.2	120.2	120.2	120.2	120.2	120.2
P_2 (kPa)	92.9	93.0	92.9	92.9	93.1	92.9
K (m^2)	5.70×10^{-16}	5.72×10^{-16}	5.71×10^{-16}	5.71×10^{-16}	5.75×10^{-16}	5.71×10^{-16}

5.2 Evaluation of Uncertainty of Measurement Results

It can be seen from the analysis of the principle and testing process of the gas permeability measuring device that the uncertainty of measurement results mainly comes from the length L of the specimen, the sectional area A, the gas dynamic viscosity, the flow rate value Q, the gas temperature T, and the pressure value P1And P2.

5.2.1 Class A uncertainty assessment

The class a evaluation of standard uncertainty can be carried out according to any statistical calculation method of measurement data processing and characterized by the experimental standard deviation obtained by calculation. The permeability measurement result K was evaluated for class a uncertainty, and the experimental standard deviation was calculated by Bessel formula. The results show that the mean value of the experimental results is $5.72 \times 10^{-16}m^2$, the experimental standard deviation was $1.75 \times 10^{-18}m^2$, the standard uncertainty *u* introduced by repeated measurement of permeability KA3.1×10^{-3}.

5.2.2 Class B uncertainty assessment

(1) Evaluation of standard uncertainty component $u(L)$

The size and shape of the test pieces in the system are fixed and made by standard molds. The length error of the test pieces is estimated to be (50±1) mm according to the mold precision, which is subject to triangular distribution. Then the uncertainty introduced by the length L of the test pieces is:

$$u(L) = 0.01/\sqrt{6} \approx 4.1 \times 10^{-3} \tag{2}$$

(2) Evaluation of standard uncertainty component u(A)

The size and shape of the test pieces in the system are fixed and made by standard molds. The sectional area error of the test pieces is estimated to be (17427 233) mm according to the mold precision2, follows the triangular distribution, then the uncertainty introduced by the sample cross-sectional area A is:

$$u(\mathrm{A}) = 0.013/\sqrt{6} \approx 5.3 \times 10^{-3} \tag{3}$$

(3) Evaluation of standard uncertainty components $u(\eta)$

The gas source of the system is Helium. As the gas viscosity is almost only related to temperature in the lower pressure range, the relationship between the gas dynamic viscosity and temperature changes in stages. When the temperature is less than 50℃, it is not very obvious that the gas viscosity is influenced by temperature. Therefore, according to the actual working condition of the system, the uncertainty introduced into the aerodynamic viscosity can be neglected. As follows:

$$u(\eta) = 0 \tag{4}$$

(4) Evaluation of standard uncertainty components u(Q)

Q is the reading value of the gas flow meter, whose specification is (0~20)mL/min, and the accuracy is 1.0%FS. Assuming uniform distribution, so the uncertainty component introduced by the gas flow value Q is:

$$u(\mathrm{Q}) = 0.01/\sqrt{3} \approx 5.8\times10^{-3} \tag{5}$$

(5) Evaluation of standard uncertainty components u(T)

T is the system working gas temperature, the results given by the metrology laboratory environment temperature and humidity table, its accuracy is (20±0.1)℃, according to the triangle distribution, so the uncertainty component introduced by the gas temperature temperature is:

$$u(\mathrm{T}) = 0.005/\sqrt{6} \approx 2.0\times10^{-3} \tag{6}$$

(6) Evaluation of standard uncertainty components $u(\mathrm{P}_1)$

P_1 is the pressure sensor reading value at the inlet end of the system. The measurement range of the pressure sensor is (0~1)MPa, the accuracy is 0.1%FS, and the output is (4 ~ 20)mA analog signal. Assuming uniform distribution, so the uncertainty component introduced by the pressure P_1 at the air inlet is:

$$u(\mathrm{P}_1) = 0.001/\sqrt{3} \approx 5.8\times10^{-4} \tag{7}$$

(7) Evaluation of standard uncertainty components $u(\mathrm{P}_2)$

P_2 is the pressure sensor reading value at the air outlet of the system. The type and specification of the pressure sensor are the same as that at the air inlet, so the uncertainty component introduced by the pressure P_2 at the air inlet is:

$$u(\mathrm{P}_2) = 5.8\times10^{-4} \tag{8}$$

5.2.3 Combined standard uncertainty

Since the inputs are not correlated, according to the uncertainty propagation rate:

$$u_c = \sqrt{u_A^2 + u^2(L) + u^2(A) + u^2(\eta) + u^2(Q) + u^2(T) + u^2(P_1) + u^2(P_2)} \approx 9.6\times10^{-3} \tag{9}$$

5.2.4 Extended uncertainty

Take the confidence probability p=95% and k=2, so the relative extended uncertainty is:

$$u_{95rel} = 2\times9.6\times10^{-3} = 1.9\% \tag{10}$$

6. Conclusion

On basis of Darcy's Law, we design a steady permeability measurement system for porous media, complete the structure design and the front-end measurement sensor device selection, from two aspects of hardware construction and software design, with Labview platform, realize sensor control, acquisition, data processing and storage, and carry out the permeability measurement experiment with the measuring system. The experimental results have good repeatability, and the extended uncertainty is 1.9% (k=2), which indicate that the measurement system can meet the requirements of material permeability measurement.

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