# Study on the Flow Testing Instrument for Bingham Ink

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## Abstract

*This paper studied the self-designed testing instrument which could test the Bingham type ink flow characters according to the fluid dynamics characteristic of the Bingham fluid. The testing instrument took high-pressure gas as power source, and used the advanced sensor technology, virtual instrument technology and self-developed software. The testing instrument could achieve the signal of the fluid flow parameters, and then the data was automatically collected, filtered and preserved. The experimental results on this instrument showed that the flow characters of the Bingham type ink could be observed in the testing tube and the corresponding yield stress could be also achieved, it would provide the accurate testing data for the scientific research and the engineering practice.*

## Introduction

The ink widely used in the printing ink industry, oil industry is non-Newtonian viscous fluid speaking from the rheological properties, and is usually Bingham fluid, there is a starting pressure (also called the minimum yield stress) for it, the measurement of flow resistance started in science and engineering is very important because this kind of fluid is conveyed by pipeline[1].However, we have seldom seen the small flow testing instrument for Bingham ink, the operation of the existing instrument is too complex and the price is expensive, so it is important to design the simple, accurate measurement and low-cost instrument for Bingham ink. This paper studied the flow testing instrument and software for Bingham fluid based on the hydrodynamics, this instrument would provide the experimental research method for printing ink and high-viscosity oil.

## The design of testing instrument

### *The constitutive equation of Bingham ink*

When the Bingham ink is in the stationary state, it must rely on the external force to flow. When ink flows steadily in pipeline, it likes a plug, the radial velocity gradient of across the plug (du/dr) is zero, all the friction generates in circulation area near the wall. Usually we have used Bingham fluid equations to describe the stably plug-flow of this type of ink[2][3]:

$$\begin{aligned} \tau &= \tau_y + \tau_w \qquad \tau > \tau_y \\ \tau &= \tau_y \qquad\quad \tau < \tau_y \end{aligned} \tag{1}$$

Where: τ—shear stress of ink plug-flow(Pa).
$\tau_y$—minimum yield stress of ink flow(Pa).
$\tau_w$—shear stress of fluid flow in water ring(Pa).

When the Bingham ink flows in pipeline, the flow region will be divided into two parts. It shows in figure 1.

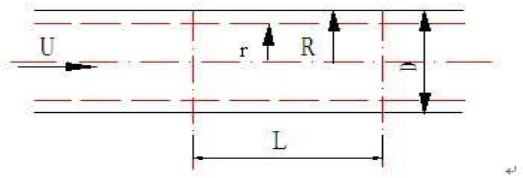


***Figure 1**. The stratified region of ink stable plug flow*

The flow shear stress $\tau_w$ of fluid in water ring can be calculated as below(r-radius of ink plug, R-radius of pipe):

$$\tau_W = (\mu + \varepsilon)\left(-\frac{du}{dr}\right) \tag{2}$$

Where: $\mu$ —dynamic viscosity of water（Pa·s）.
ε— eddy viscosity of turbulent generated（Pa·s）.
$du/dr$ — radial velocity gradient of fluid

When the external force is reached the minimum yield stress $\tau_y$, ink plug starts to slide. When the water ring is stable, the flow shear stress is calculated as below:

$$\tau = \tau_y + \tau_W \tag{3}$$

If the status of fluid in water ring is laminar flow, eddy viscosity is 0, the shear stress is below:

$$\tau = \tau_y + \mu\left(-\frac{du}{dr}\right) \tag{4}$$

### *The design of testing instrument*

Figure 2 is the diagram of flow testing instrument for Bingham ink. This instrument is made of gas buffer tank, horizontal pipe, sensor and computer, In figure 2: 1-high pressure tank, 2,3-control valve, 4-flow pipe, 5- photoelectric sensor, 6-DAQ, 7-computer, 8-pressure transmitter, 9- gas flow meter,10-gas buffer tank.

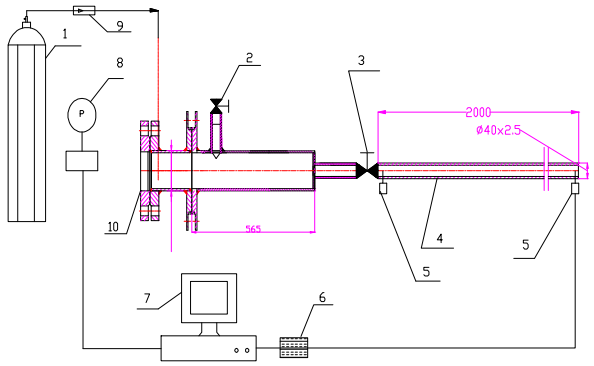


***Figure 2**. Testing instrument for Bingham type ink*

Ink flowed in the pipe which diameter was 35 mm and it was made of plexiglass. Because the start flow resistance of Bingham fluid was large in the flow experiment, traditional sources of power could not meet the needs of this fluid flow, we used high pressure gas as power producer[4], it could control the yield stress of Bingham ink. High pressure gas went into gas buffer tank 10 through gas flow meter 9, the gas pressure in the buffer tank was controlled by valve 2,3, the valve was controlled by the comparator chip, the differential pressure of ink flowing in the pipe was measured by the pressure sensor, the time of ink flowing in the pipe was measured by the photoelectric sensor, all the signal was collected into the computer by DAQ system.

### *The design of DAQ system*

The analog output quantity of the sensors in experiment was 4—20mA current, so we used virtual instrument to collect and dispose signal. Virtual Instruments technology is the combination of modern computer technology and instrument technology[5][6].

PC-DAQ measuring system is the basic pattern of constituting VI, it is widely used in lab, and it is the virtual instruments made of DAQ card, signal conditioning circuit and computer. We used PCL-818HG DAQ card in experiment, 12-bit analog input, single-channel sampling frequency100kHz, transfer time 10s. We used differential (DIFF) wiring and software trigger A/D conversion in the instrument measurement by means of analyzing the dynamic spectrum of physical parameters. We used LabWindows/CVI programming languages to design the software program. Figure 3 was the interface map of the DAQ software.

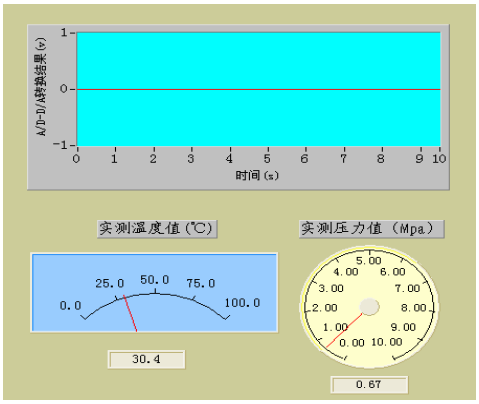


***Figure 3**. The software interface of data acquisition*

In order to ensure the accuracy and reliability of test data, we used FFT technology to dispose the original acquired signal by low-pass filtering method.

### *The process of using testing instrument*

At first, we loaded a certain quality of Bingham ink into experimental pipe, stared the DAQ software, set the signal channel and opened the control valve and sensors slowly, the sensors would measured the pressure change in the gas buffer tank. The ink in the pipe started to flow from the static state, we could observe the flow of ink through the glass pipe. The time of ink flowing was measured by the photoelectric sensor, in the whole testing experiment, DAQ program collected the data and saved the computer as the text formatting. So this instrument could studied the flow characteristics of Bingham ink flowing in the pipe, it would provide the reliable data for scientific research and engineering practice.

## Results and Discussion

Figure 5 showed the change of resistance for Bingham ink flowing in the pipe, from the figure 5, we could conclude that the Bingham ink still keep stationary from the pressure beginning to the point A; When the differential pressure reached the point A, the external force reached the minimum yield stress, the whole ink began to move, there is no relative motion in the ink, from point A to point B, ink flowed stably; When the ink flowed reach point B, the whole ink ejected from the pipe, Bingham ink flowing in horizontal pipe was ended. So, the results measured by this testing instrument reflected the Bingham fluid dynamics. There was the minimum yield stress for the Bingham ink, only if the external force reached the minimum yield stress, the Bingham ink would flow.

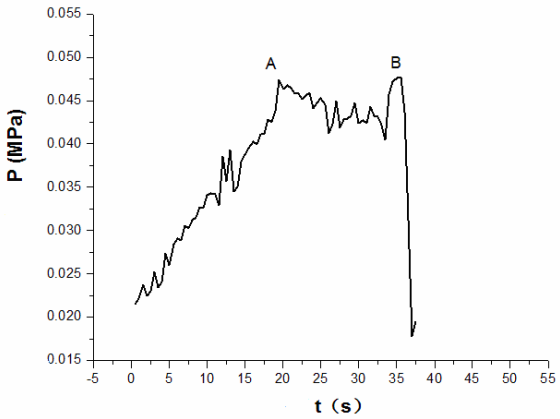


***Figure 4**. The changes of the Bingham ink flow resistance*

## Conclusions

Based on the fluid dynamics characteristic of the Bingham ink, this paper studied the self-designed testing instrument which could test the Bingham type ink flow characters in the pipe, Including the design of hardware and software .The testing instrument took high-pressure gas as power source, and used the advanced sensor technology, virtual instrument technology and self-developed software. The testing instrument could achieve the signal of the fluid flow parameters, and then the data was automatically collected, filtered by FFT and preserved. The experimental results on this instrument showed that the flow characters of the Bingham type ink could be observed in the testing tube and the corresponding yield stress could be also achieved, it would provide the accurate testing data for the scientific research and the engineering practice.

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