Academic Symposium on

Slurry Transport with Pipeline and Deep Sea Mining

College of Life & Environmental Science
Central University for Nationalities
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- **PART ONE**

  Slurry transport with pipeline in China

- **PART TWO**

  Hydraulic lifting in deep-sea mining

Slurry transportation in China

Applications:

- **Ore tailings transportation and backfill;**
- **Refined mineral transportation.**

For the slurry transportation, the key parameters should be investigated:

- transportation concentration of slurry
- the working velocity
- the loss of resistance
- transportation pressure.

- In order to cope with the selection of transmission programs, the following two experiments should be carried out in the laboratory before slurry pipeline is designed:

- rheological experiment （流变试验）
- semi-industrial experiment(实验室半工业试验 ）

- the transport parameters of fine particles and highly viscous （高粘度 ）slurry were studied.

Tailing sand in Dahongshan Mine in Yunnan Province

the Filtration machines in Dahongshan Mine in Yunnan Province

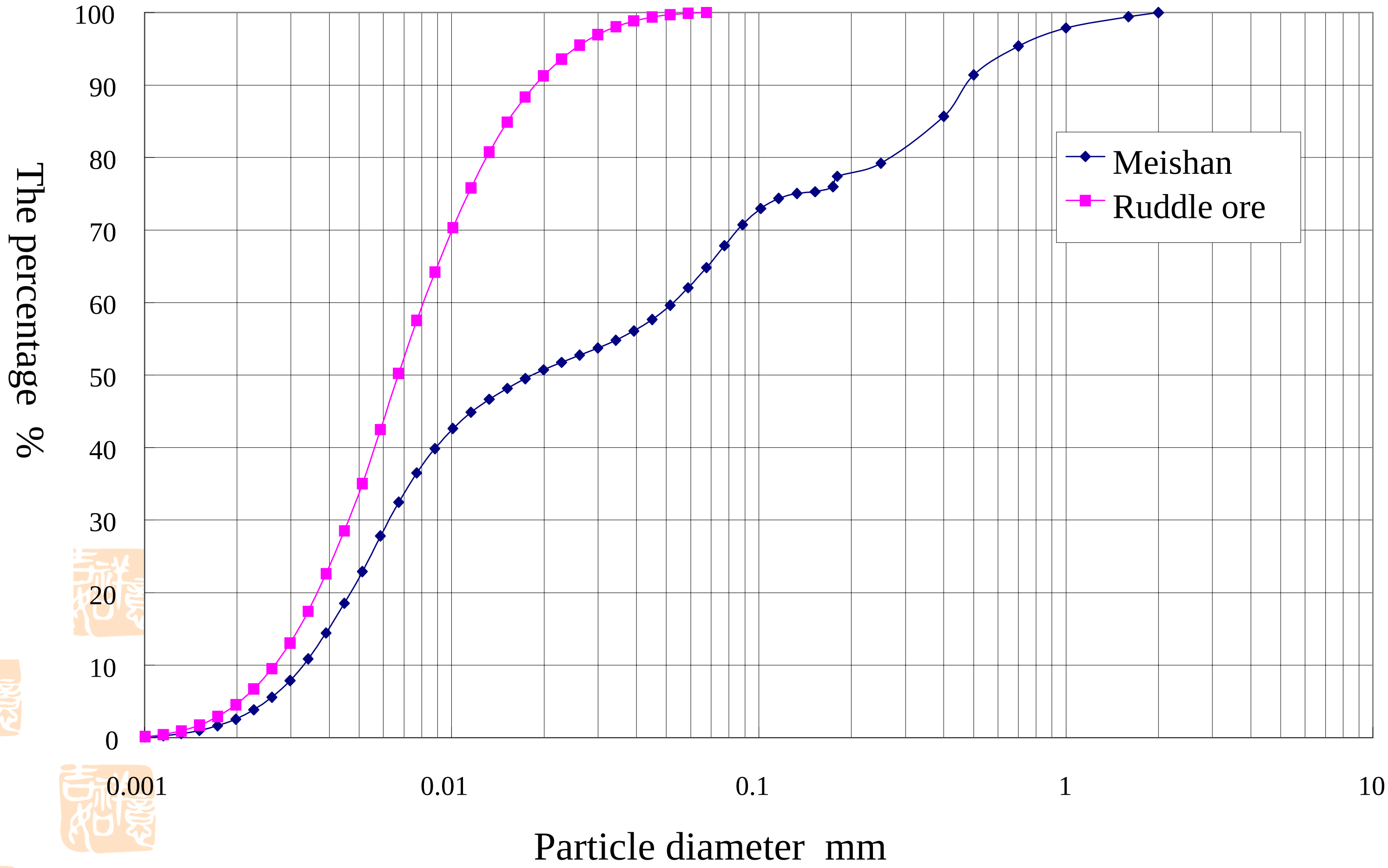


Fig.1 Particle Size Distribution in Slurry

there are more fine particles than other kinds

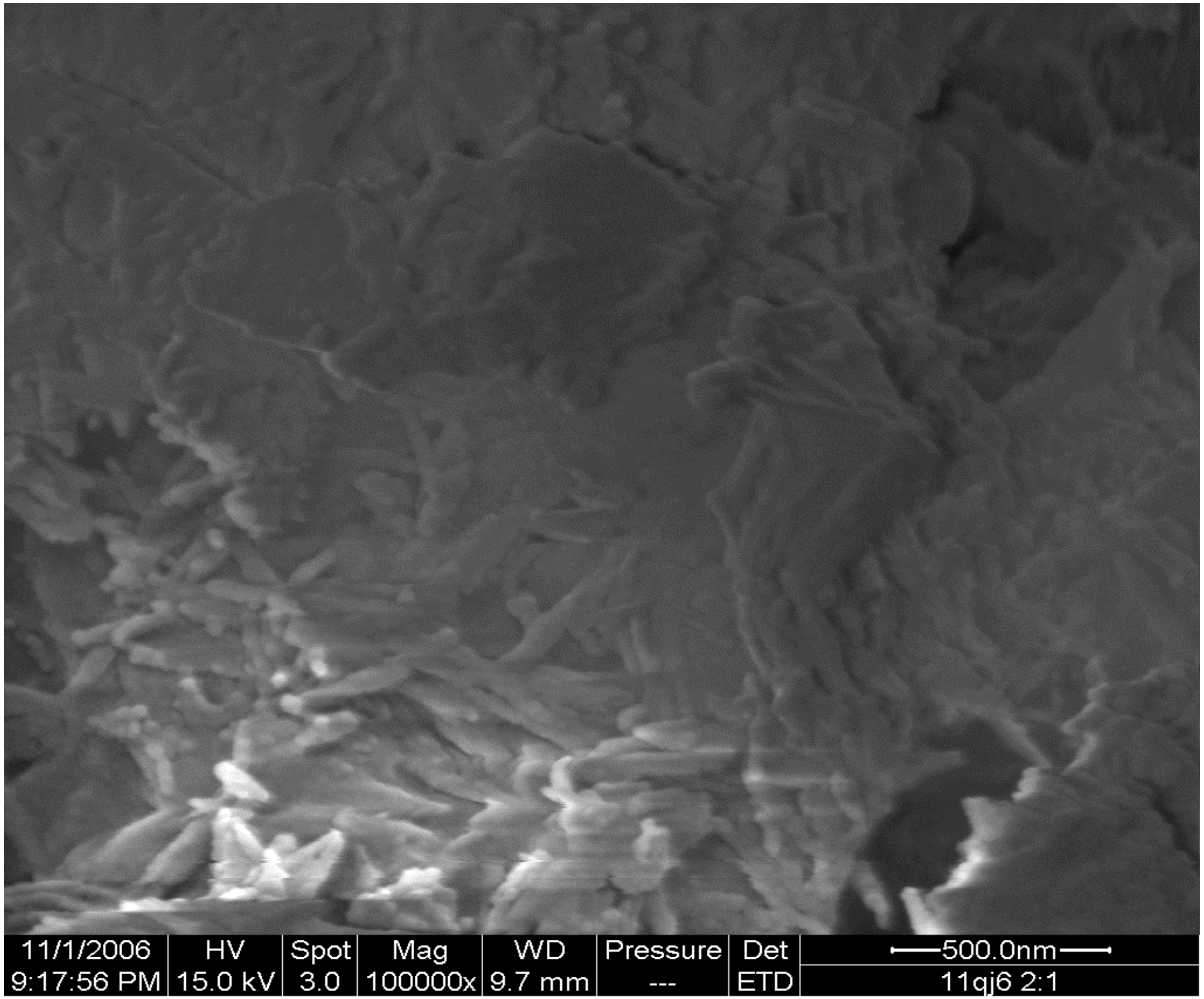


Fig.2 Picture of slurry by Electronic microscope

In this picture we could find out that fine particles present a column shape, and a bigger surface area. Therefore, on the same concentration condition, fine particles slurry has a higher viscosity.

The tailing sand warehouse for slurry transportation in Dahongshan Mine in Yunnan Province

The pump in Dahongshan Mine in Yunnan Province

The pillar-plug pump in Dahongshan Mine in Yunnan Province

The transportation parameter monitor in Dahongshan Mine in Yunnan Province

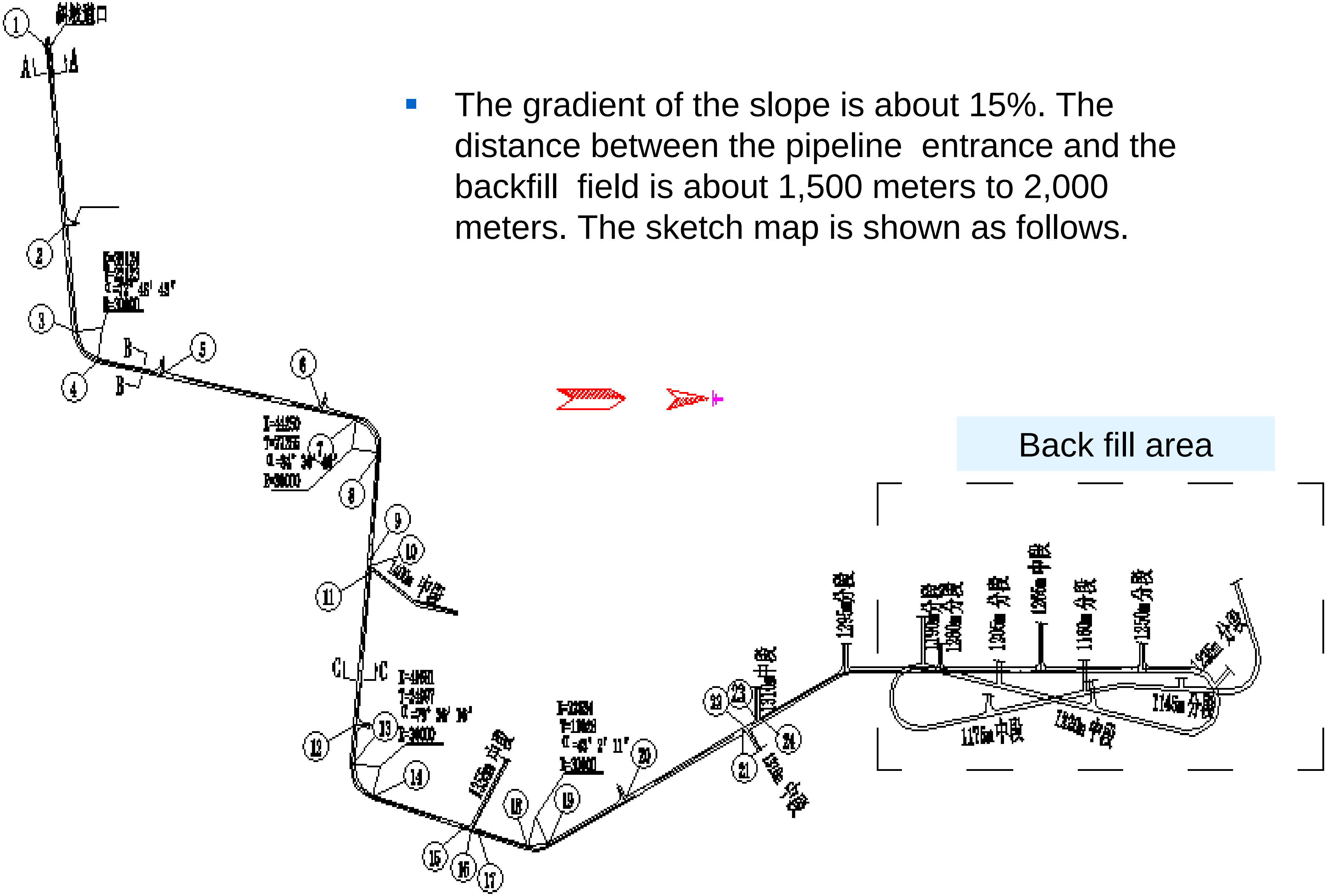
Slurry transportation experiments
——CAIJIAYING LEAD-ZINC MINE

- The lead-zinc mine of Caijiaying in Hebei province locates the north edge of the North China mesa. The main content of the ore is the zinc blended with much ironstone.
- The designed capacity of the mine is 0.52 million tons per year.
- Mining methods:

  Mine later shallow-hole filling (浅孔留矿嗣后充填)

  Sub-section later filling(分段空场嗣后充填)

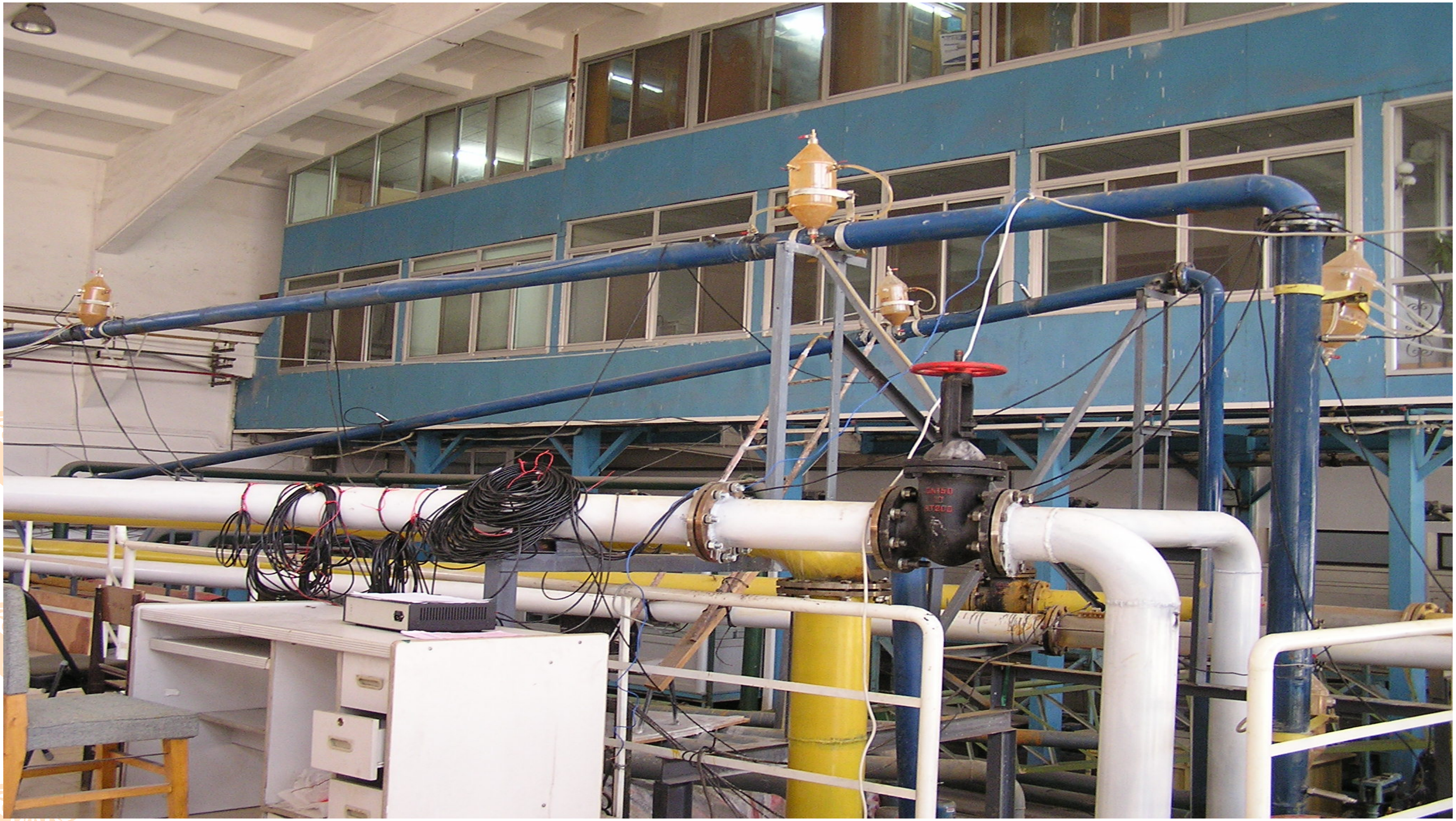
- The gradient of the slope is about 15%. The distance between the pipeline entrance and the backfill field is about 1,500 meters to 2,000 meters. The sketch map is shown as follows.



Working Contents

- Physical Characteristics Experiment
- Clear Water Pipeline Transportation Experiment
- Tailings Backfill Pipeline Experiment
- Parameter Calculation of Pipeline Backfill

Pipeline Test System管道试验系统

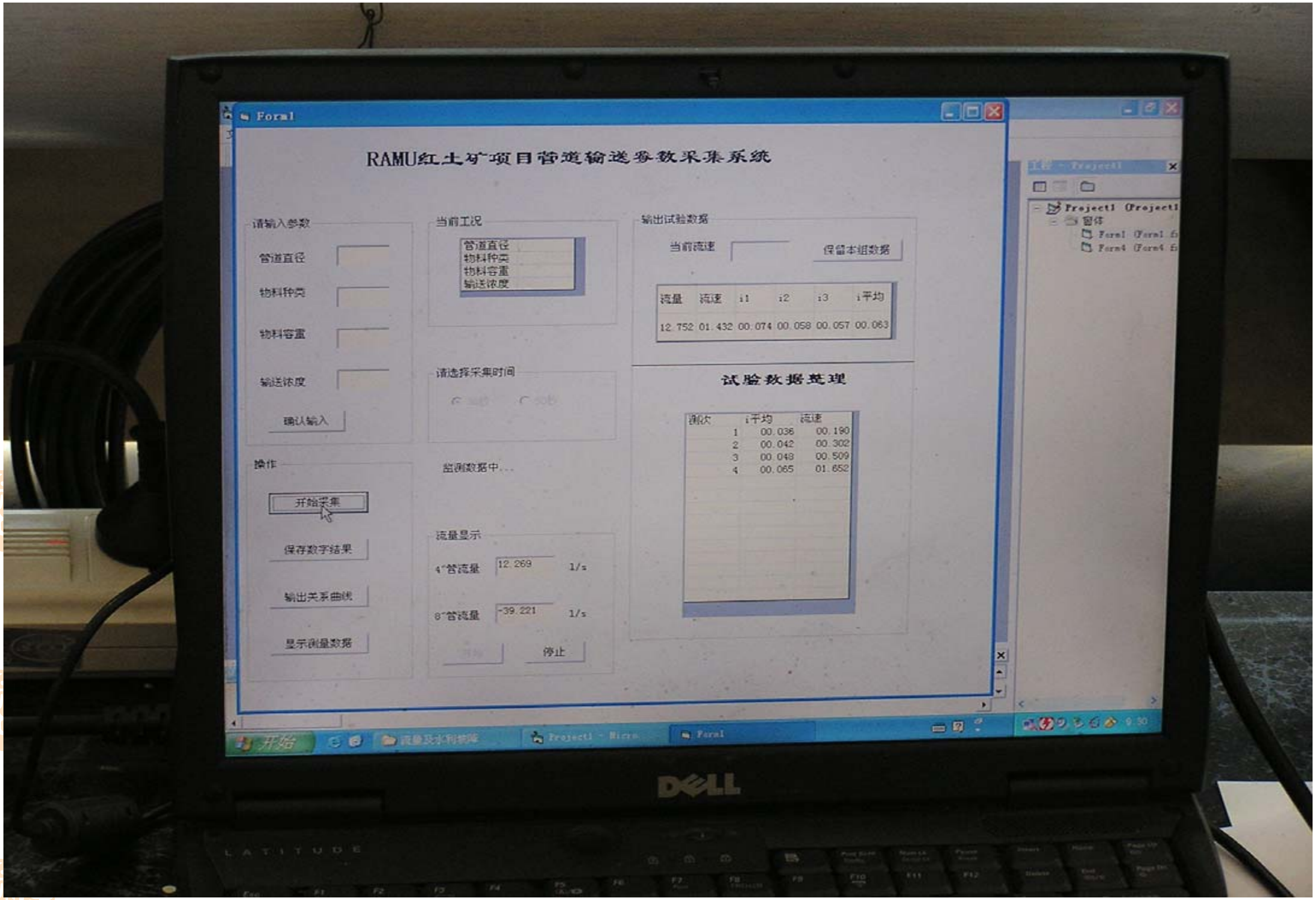


Sensor(传感器)

the isolation pot and differential pressure sensor

The electromagnetic flow meter for the discharge and the flow velocity test

Data collecting system



Backfill Experiment Results Analysis

充填参数试验

- The bending pipeline resistance loss coefficient of is calculated by the following formula：

$$\zeta = \frac{i_{\mathrm{b}}}{u^2/(2gD)}$$

- The horizontal pipeline resistance loss coefficient is calculated by:

$$\frac{i_m - i_0}{i_0 c_v} = k\left(\frac{u}{\sqrt{gD}}\right)^m$$

- Lean and vertical resistance loss

$$i_{\mathrm{t}} = (i_m \times L - i_{\mathrm{p}} \times \gamma_m \times L)/L = i_m - i_{\mathrm{p}} \times \gamma_m$$

$$i_{\mathrm{v}} = i_m - \gamma_m$$

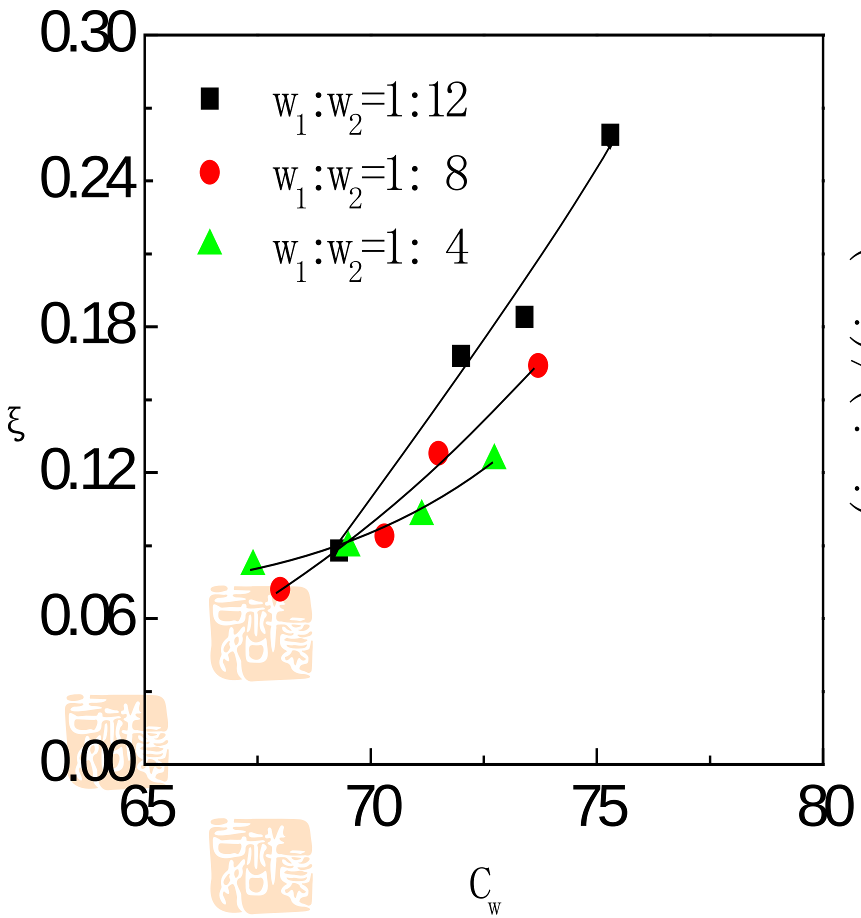


Fig. 2 The relationship between the resistance coefficient and concentration of the bending section

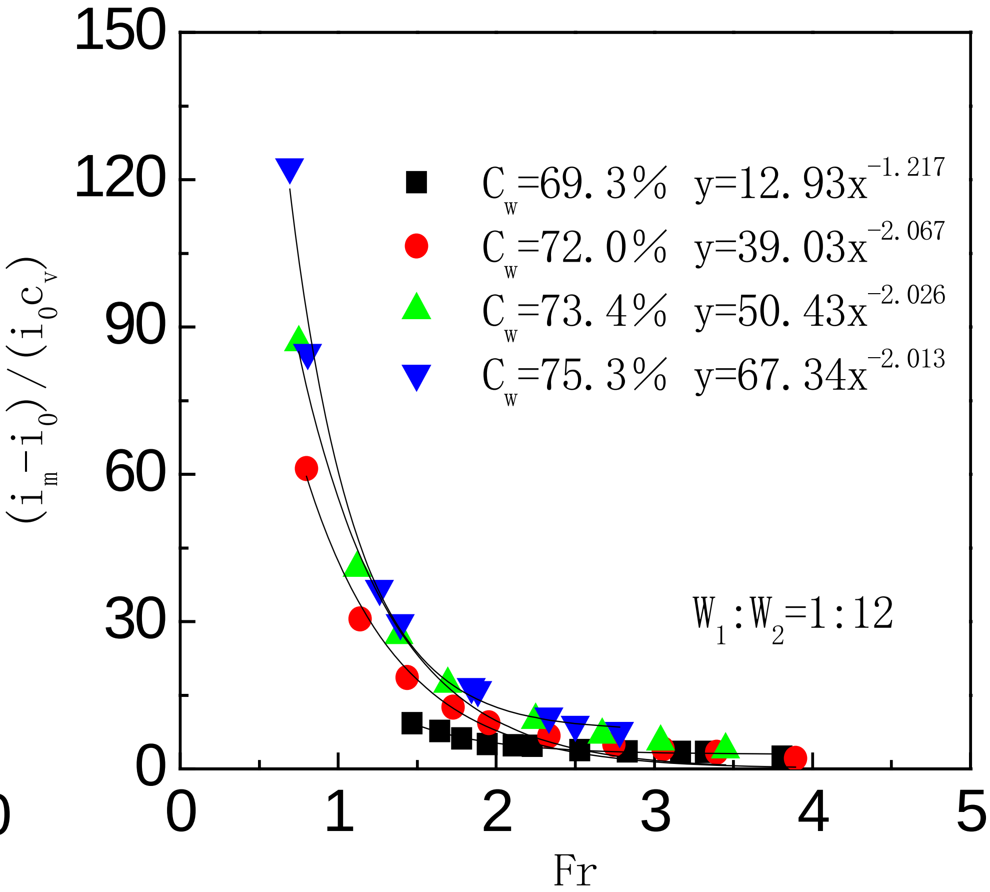


Fig.3 The relationship between additional loss of horizontal section and *Fr*

PART TWO

Deep-sea Mining

- Optimize the lifting pipeline parameters
- Analysis the emergent discharge process

Parameters Optimization

In this section, we mainly

- Analyses the original experimental data of hydraulic lifting system
- the calculation methods of hydraulic parameters
- a mathematic model
- Find out the most suitable parameters, including the lifting velocity, solid concentration, and the pipeline diameter

2.1.1 Optimization Principle and Previous Speculation Data

- Here, speculation and optimization is analyzed and calculated on the ground of energy consumption and technology rationality of nodule lifting.

Table 1 Preliminary design lifting system parameters

Parameters	Data
Exploitation depth	5000m
Wet density of nodules	2.04kg/L
Density of seawater	1.028kg/L
Nodule diameter/ Average diameter	＜50mm/30mm
Pilot production (dry nodule)	30t/h
Industrial mining production (dry nodule)	300t/h (1,500,000t/y)

2.1.2 Parameters Calculation Method in Hydraulic Lifting System

- Parameters calculation in hydraulic lifting system includes lifting diameter, flow velocity, concentration, hydraulic gradient, etc.

- In order to ensure the safety of the lifting system formula about the minimum lifting flow velocity is defined as follows:

- Minimum lifting velocity:

$$V_{min} = 2V_f$$

- Where $$\frac{V_f}{V_{f0}} = e^{-(2.65C_v - 3.32C_v^{2.2})}$$

$$V_{f0} = 1.1W_t$$

$$W_t = \left(\frac{4}{3}\frac{gd}{C_D}\cdot\frac{\rho_S - \rho_W}{\rho_W}\right)^{1/2}$$

$$C_D = 0.52S_f^{-1.63}$$

- And the total lifting hydraulic gradient is:

$$i_t = i_s + i_m$$

2.1.3 Calculation method of System Lifting Efficiency and Energy Consumption

- Calculation of system lifting efficiency

The effective power of lifting solid particle E_s is:

$$E_s = Q_s[(r_s - r_w)\cdot L_b + r_s L_a] \qquad *$$

Energy costs by the lifting of solid-liquid E_m is:

$$E_m = Q_m \cdot (\Delta P - r_w L_b) \qquad * \quad *$$

And the system lifting efficiency is:

$$\eta = \frac{E_s}{E_m} = \frac{Q_s}{Q_m}[(\frac{(r_s - r_w)\cdot L_b + r_s L_a}{\Delta P - r_w L_b}]$$

- In formula (＊), the elements and the denominator divided at the same time, it is available that:

$$\eta = \frac{Q_s}{Q_m}\{[(\frac{r_s}{r_w} - 1) + \frac{r_s}{r_w}\frac{L_a}{L_b}]/[\frac{\Delta P}{r_w L_b} - 1]\}$$

- In formula (＊＊), $L_a >> L_b$, $L_a / L_b \approx 0$,and $Q_s / Q_m = C_V$, $\Delta P / r_w L_b - 1 = i_t$,

so which can be shorten as:

$$\eta = C_v [\frac{r_s / r_w - 1}{i_t}]$$

- **Calculation of unit energy consumption of nodule lifting**

- **Energy consumption of hydraulic lifting N：**

$$N = H \cdot Q_m r_w / 102$$

- **When the volume flow is Q_m， the sum nodule lifting Gs in every hour is ：**

$$G_s = Q_s \cdot r_s$$

- **Where the unit of G_s is t/h. So for sea trail exploitation，G_s＝30t/h； while for industrial trail exploitation， G_s＝428t/h.**

- **Per unit energy consumption** W

$$W = \frac{N}{G_s} = \frac{HQ_m r_w}{102Q_s r_s}$$

- **Where W represents the energy consumption when lifting a ton of dry nodules (kwh/t)**

- **The calculation of pipe diameter D and lifting pressure P in industrial exploitation**

- For D, because of

$$Q_m = V_m \cdot \pi D^2 / 4$$

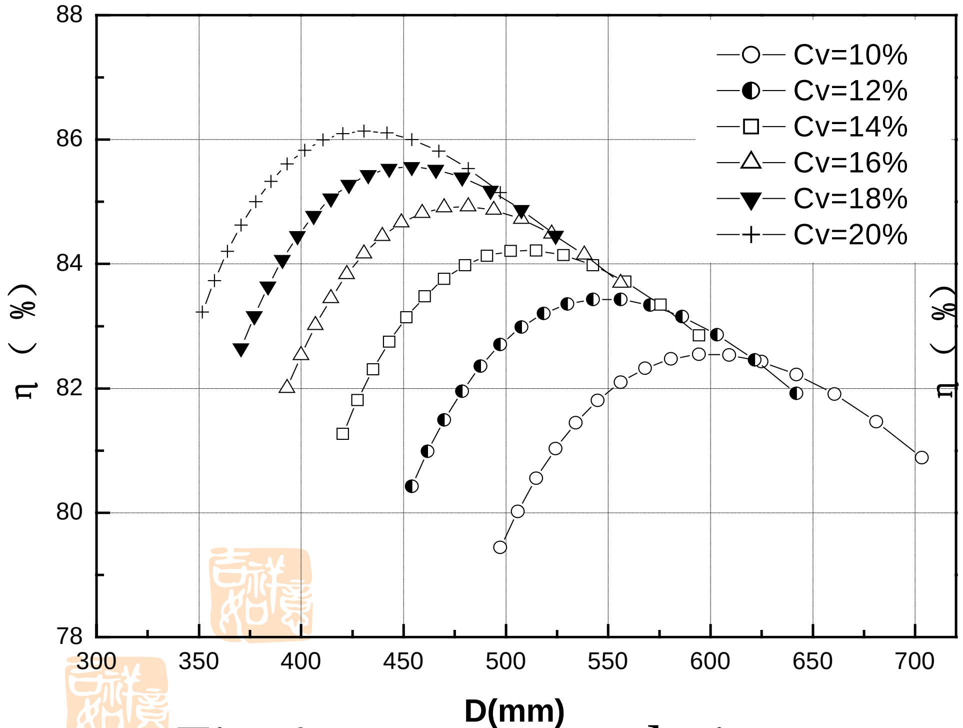
- After unification of the unit, we get,

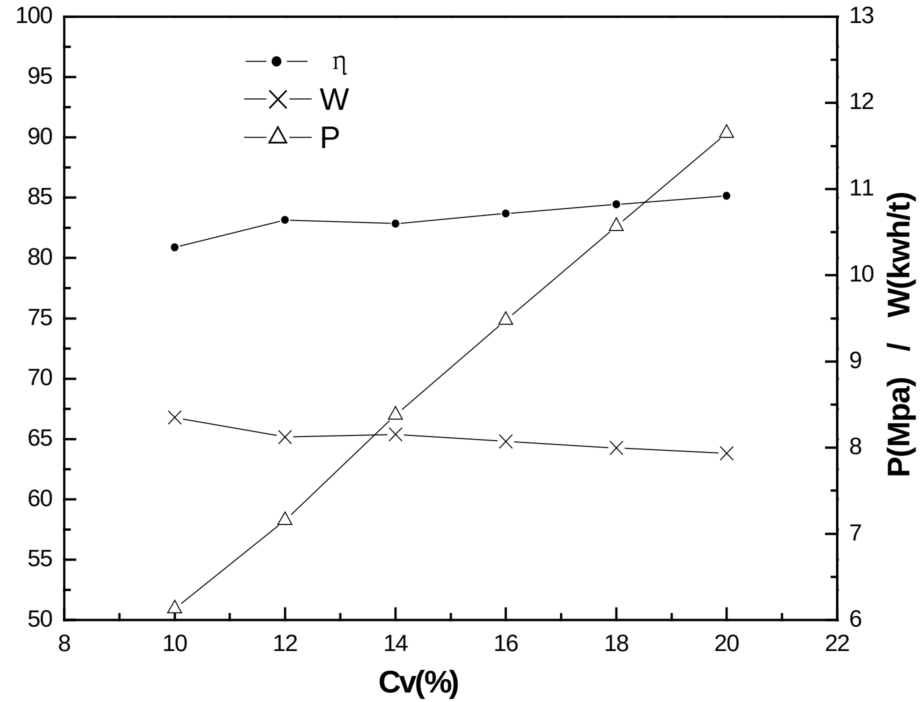
$$D = \frac{1}{30}\sqrt{\frac{Q_m}{V_m \cdot \pi}}$$

- For lifting pressure P that is $P = \rho \cdot g \cdot l \cdot i_t$

Its unit is mH_2O or Mpa.

Calculation analysis in industrial mining





- Fig.4 $\eta \sim D$ relation

Fig.5 η、W、$P \sim C_v$ relation

In all, the proposed industrial exploitation lifting system should use the optimize parameters as:

D=497mm, C_V=15%，V_m=2.0m/s，i_t=0.174，W=7.98kwh/t， η =84.58%，P=8.79Mpa

2.2 Emergent Discharge Analysis

In this section, we mainly

- Analysis the force beard by the slurry in the lifting pipeline
- Establish the hydraulic motion equations
- Discuss the relationship between the velocity of discharge slurry and the lifting concentration, pipeline diameter
- Compared four different supposed rapid discharge programs and find out the best and effective one

2.2.1 Analysis the Slurry Discharge Process in the Lifting Pipeline

- In the process of long distance transport process, the friction loss i_f is the main part of the pressure loss. Here, we adopt Fanning Formula to calculate the friction loss i_f

$$i_f = \lambda_f \frac{v^2}{2gD}$$

- and the slurry density is: $\rho_m = c_v \rho_s + (1 - c_v)\rho_w$
- the slurry discharge height is: $H = H_0 - \int_0^t v dt$
- Weight of the slurry left is: $m = \rho_m H_0 A - c_v \rho_s (H_0 - H) A$
- Finally, we got

$$(\rho_m - \rho_w) gHA - i_f \rho_w g H_0 A = m \frac{dv}{dt}$$

Results

- **According to the calculate results, we draw the following Figures on the condition of different concentration and different diameters.**

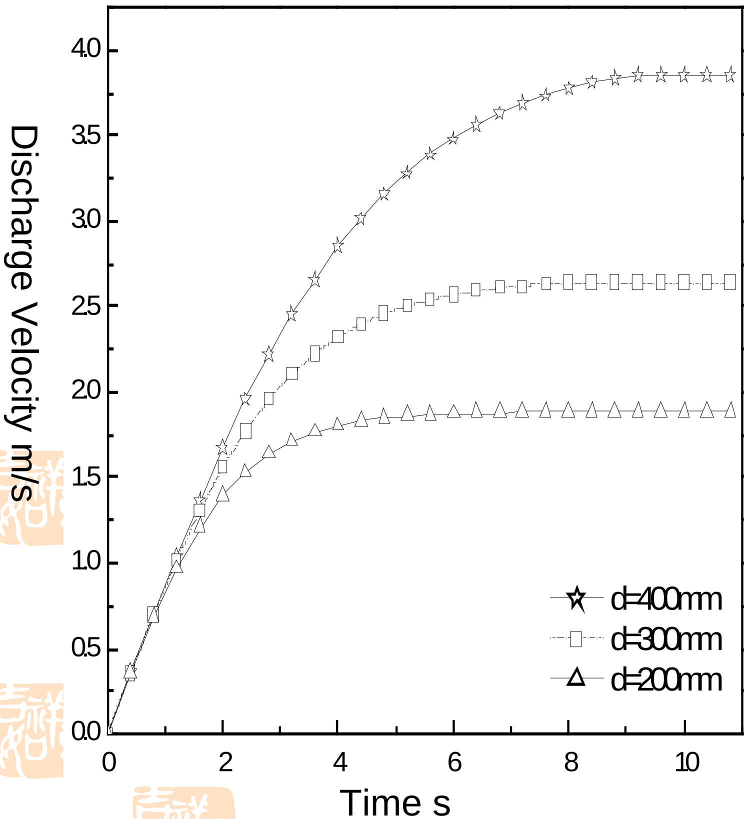


Fig 6 the relation between v~ t when c_v=10%

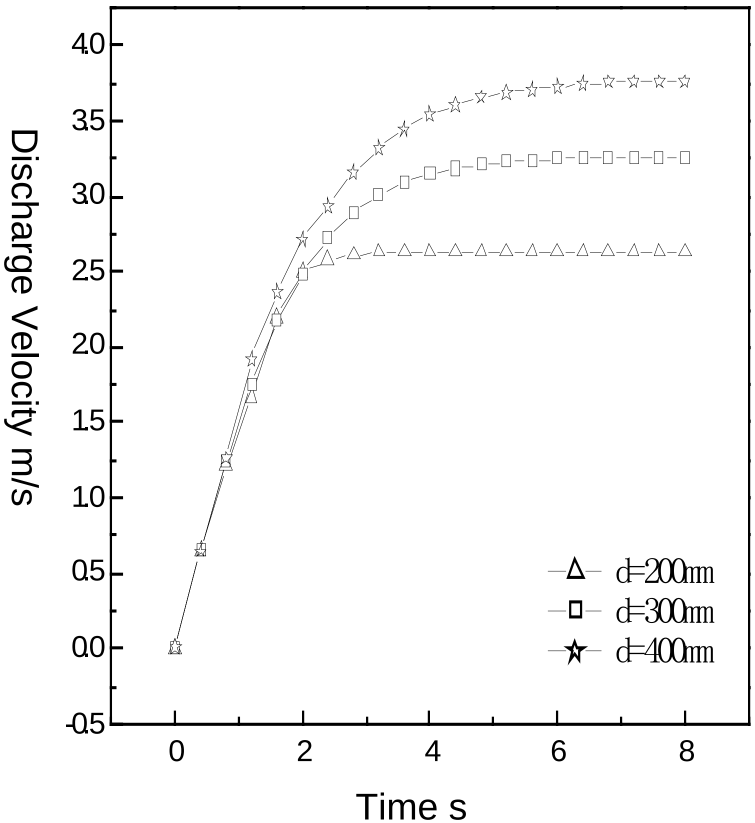


Fig 7 the relation between v~ t when c_v=20%

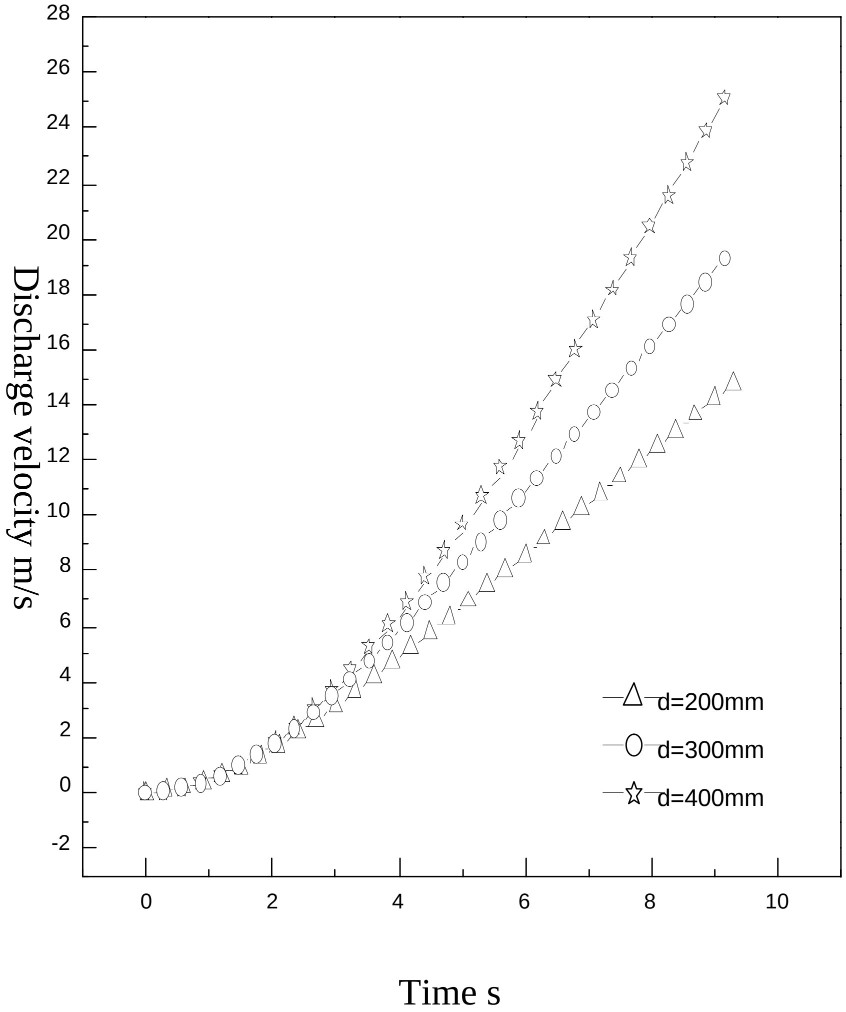


Fig.8 H~t relation when slurry concentration is 10%

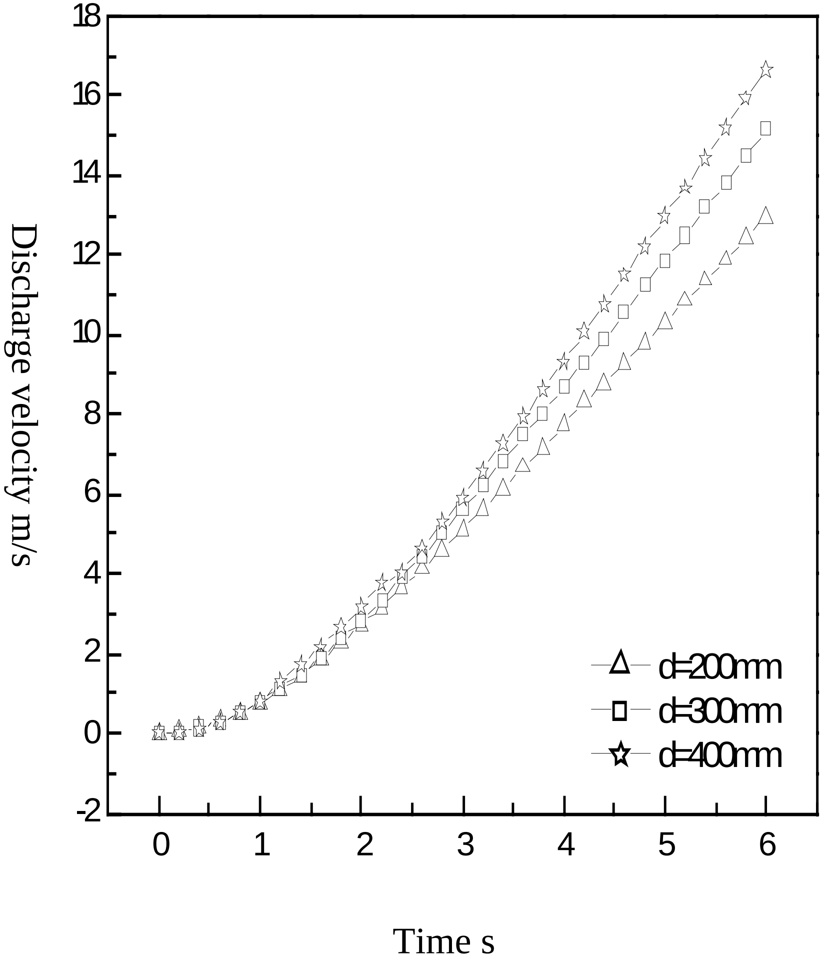


Fig9 H~t relation when the slurry concentration is 20%

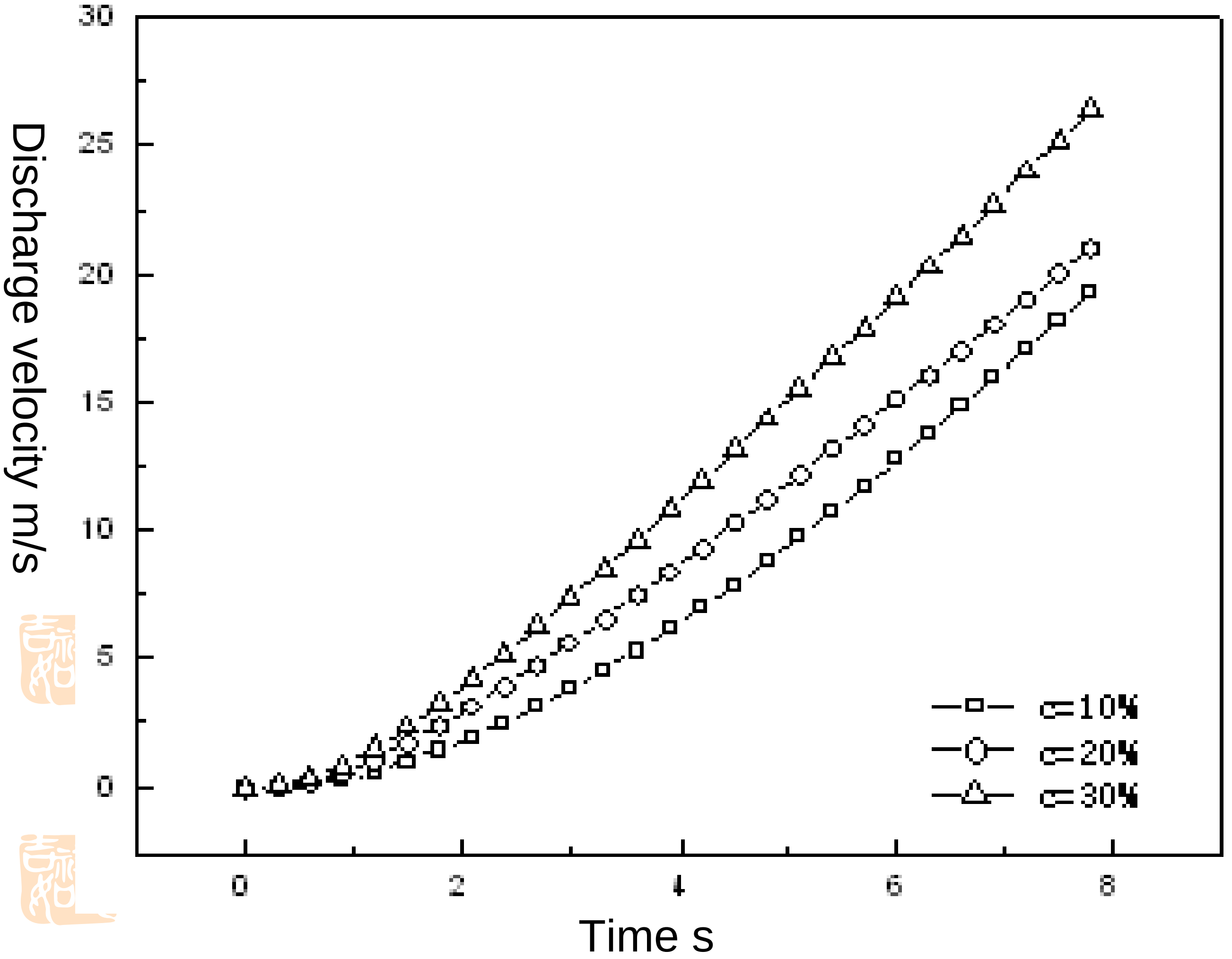


Fig.10 the H~ t relation when the pipeline diameter is 300mm

- **Increased slurry outfall, that is, in the appropriate place of the lifting pipeline set outfalls, so that under the circumstance of pipeline default we can open more then one outfalls to limit time. Assuming raise pump installed in the 1,200 meters underwater, we considered four emissions programs, the calculation results show in the following tables:**

- **Table 2 Total time needed to discharge all the slurry in the pipeline when the concentration is 10%** (min)

	Pipeline Diameter (mm)		
Programs	200	300	400
1	44.4	27.8	23.0
2	33.7	21.1	17.1
3	16.8	10.6	8.6
4	10.5	6.7	5.4

- **Table 3 Total time needed to discharge all the slurry in the pipeline when the concentration is 20%（min）**

	Pipeline Diameters (mm)		
Programs	200	300	400
1	31.8	23.4	21.4
2	24.2	17.8	16.2
3	12.1	9.0	8.1
4	7.6	5.6	5.1

THE END !

THANK YOU!