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FLUIDIZATION XVI

Experimental Study on Separation Characteristics of a Gas-Liquid Cyclone Separator in WGS

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Outline

1. Research background
2. Experiments and analysis methods
3. Results and discussion
4. Conclusions

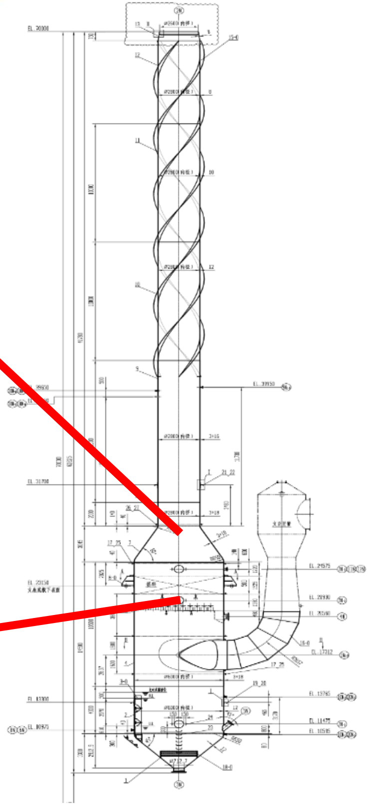
Research Background

1. Background

- Wet Gas Scrubbing (WGS) is a Flue Gas Desulfurization method to remove SO_X widely used in China, particularly, in China Fluid Catalytic Cracking (FCC) units.
- A gas-liquid cyclone separator is a crucial equipment which separate the cleaned flue gas and alkaline in a WGS system.

Research Background

1. Background



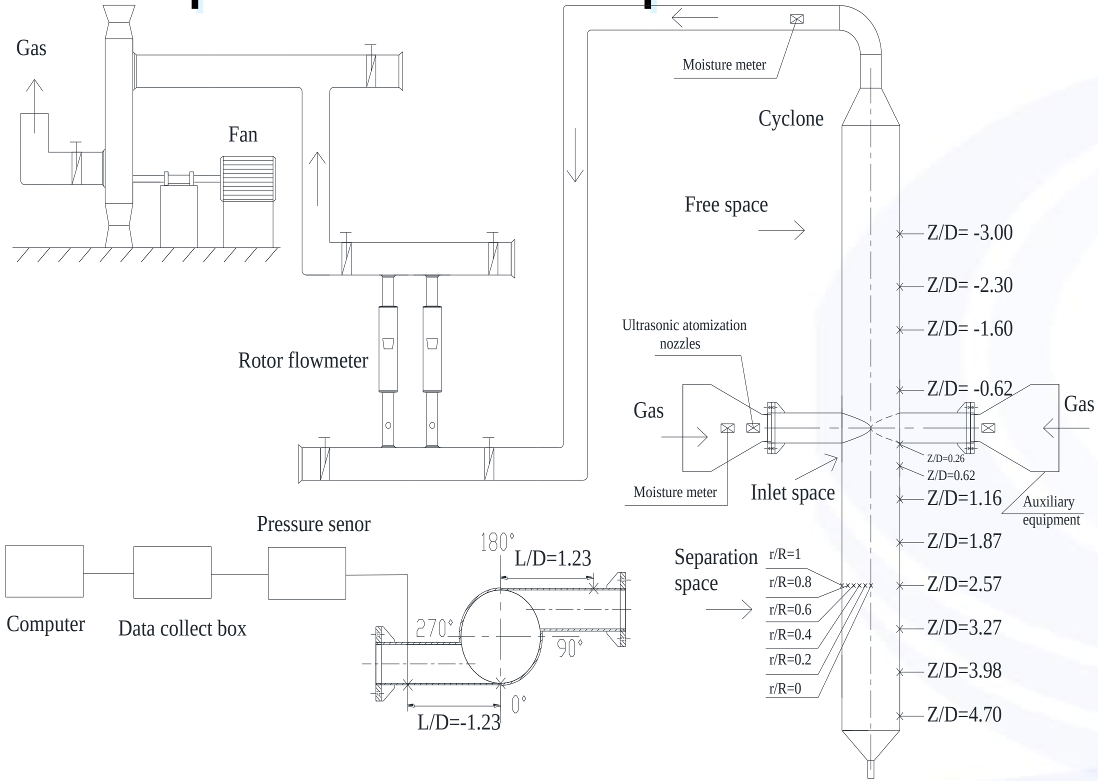
In order to improve the separation efficiency of the separator, it is necessary to analyze the flow features therein.

- Pressure fields
- Velocity fields
- Separation efficiency vs. the inlet gas velocity and the inlet liquid concentration

Outline

1. Research background
2. Experiment apparatus and analysis methods
3. Results and discussion
4. Conclusions

1. Experiment setup



Size of separator：

cyclone: Φ 0.284 m

feed tubes: Φ 0.12 m

total height: 3.535 m

- Pressure field and velocity field : 9.83 m/s
- operating inlet gas velocity： 5-12 m/s
- inlet liquid concentration： 30-85 g/m^3

2. Material

- Air - tap water system
- Pressure field : Pressure sensors—500 Hz / 60 s
- Velocity field : Five-Hole probe
- Separation efficiency measuring method:

$$m_1 = Q \times (RH_{out} \times W_{out} - RH_{in} \times W_{in})$$

$$E = \frac{m_o}{m_i - m_1} \times 100\%$$

m_1 : the water loss mass
m_o : collected water mass
m_i : the feed water mass
Q : the gas flow rate
RH_{in} : the relative humidity at the entrance
RH_{out} : the relative humidity at the exit
W_{in}/W_{out} : the saturated air moisture at the T_{in}/T_{out}

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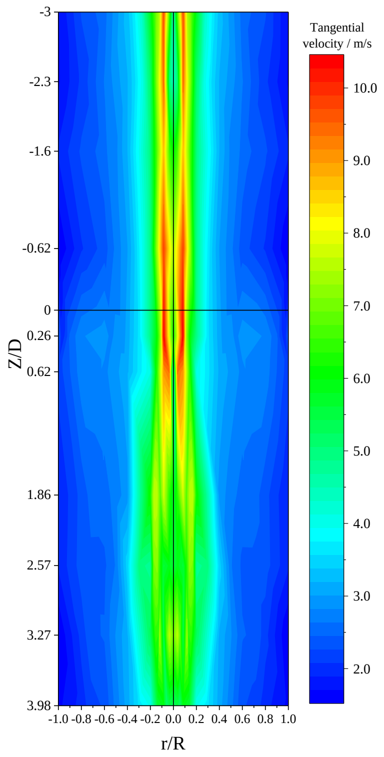
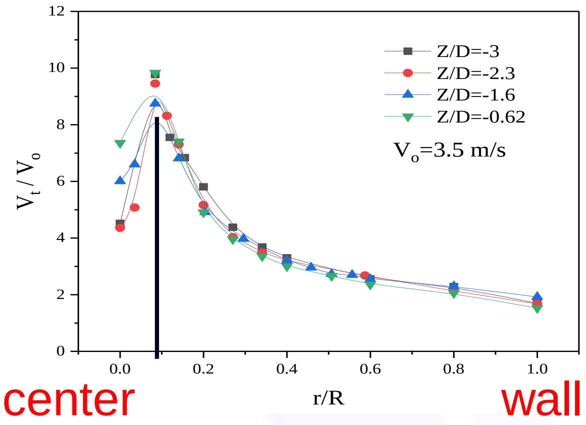
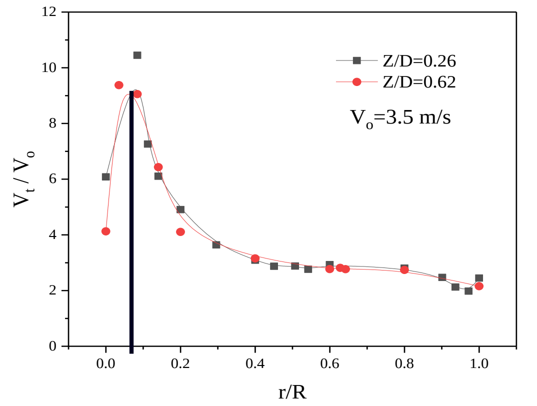
1. Velocity field--tangential velocity





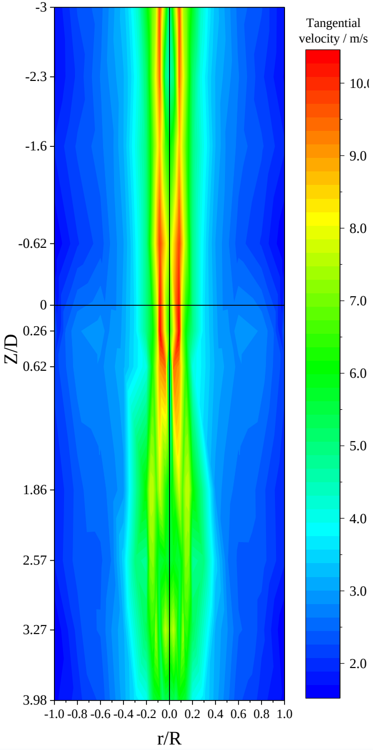
1. The free space

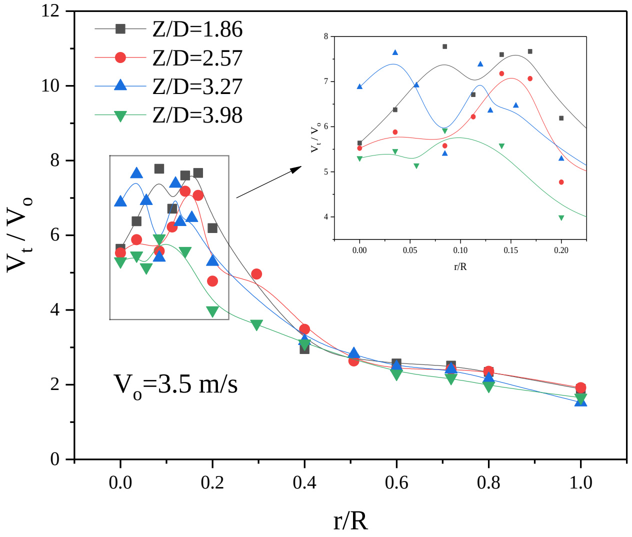


2. The inlet space

At the free space and inlet space, the radial position of the boundary point between internal and external vortex is r/R=0.1.

1. Velocity field--tangential velocity



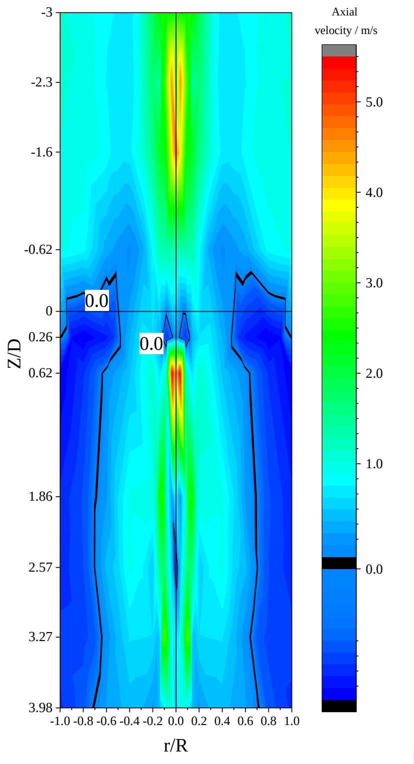


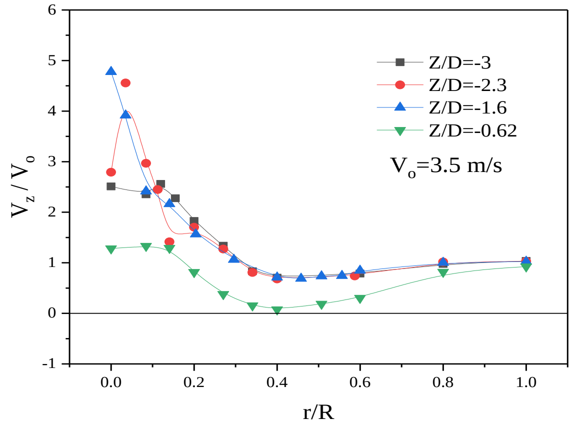
3. The separation space

All the velocity curves have two peaks in different measured cross-sections.

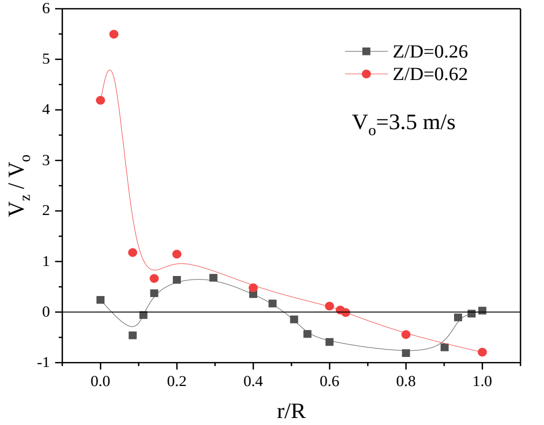
Firstly, it may be due to that the motion friction made the velocity fall gradually.
Secondly, it is because that the gas from outer vortex to the inner vortex made the turbulence dramatically increase with rising axial height.

2. Velocity field--axial velocity





1. The free space

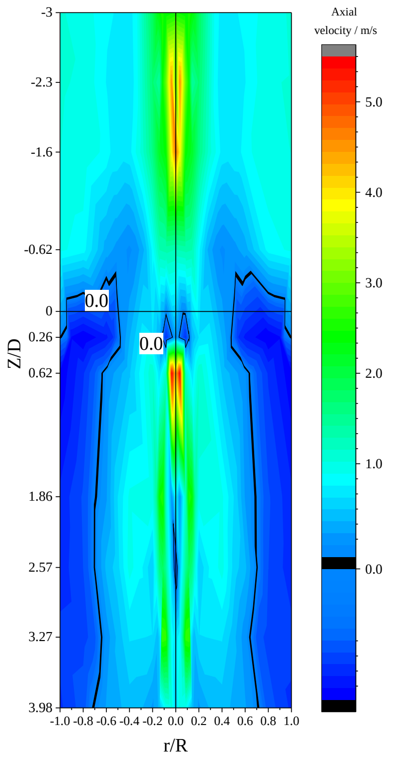


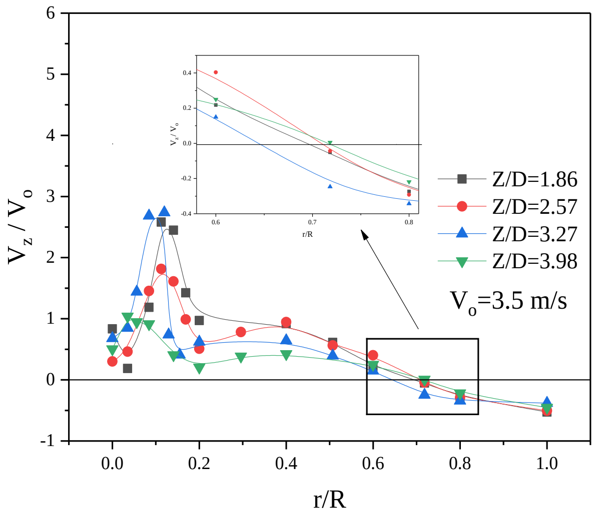
2. The inlet space

All axial velocities in free space is positive, it means gas moves upward in the free space.

The inlet gas moves upwards will cause the short circuit flow

2. Velocity field--axial velocity





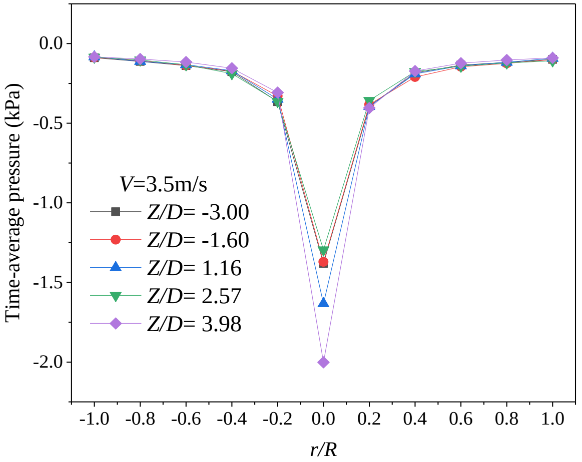
3. The separation space

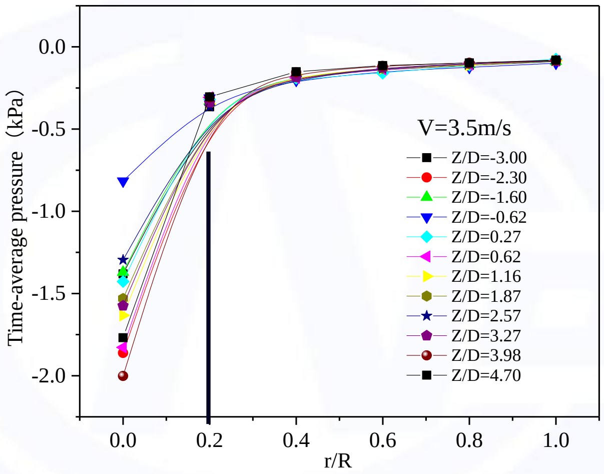
There are two distinct regions formed in this axial height, which are the downward region of the negative velocity and the upward region of the positive velocity.

The boundary of two different axial regions is *r/R*=0.65.

Results and discussion

3. Pressure field--the time-averaged pressure

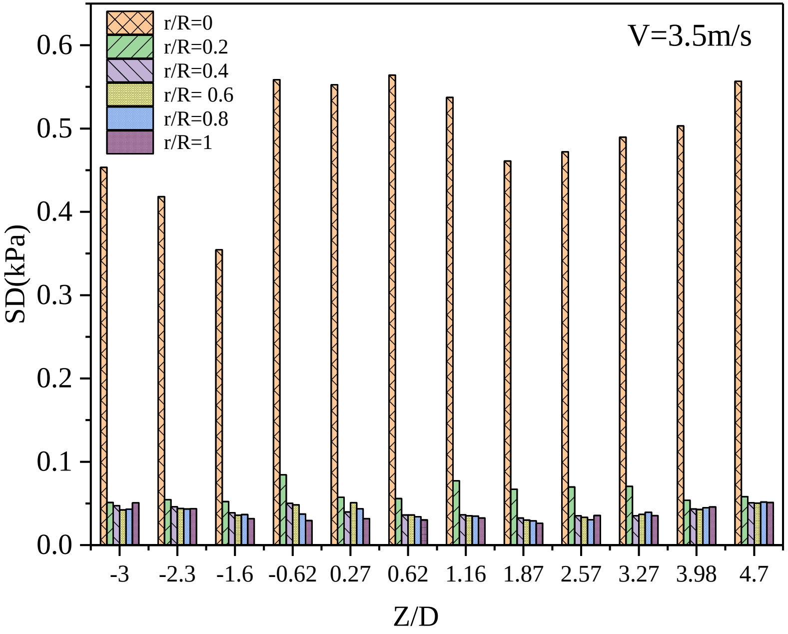




The time-average pressure shows good symmetry in the random selected radial direction.

The inner (*r/R*=0-0.2) and outer (*r/R*=0.2-1) regions are easily distinguishable.

3. Pressure field--the standard deviations of pressure

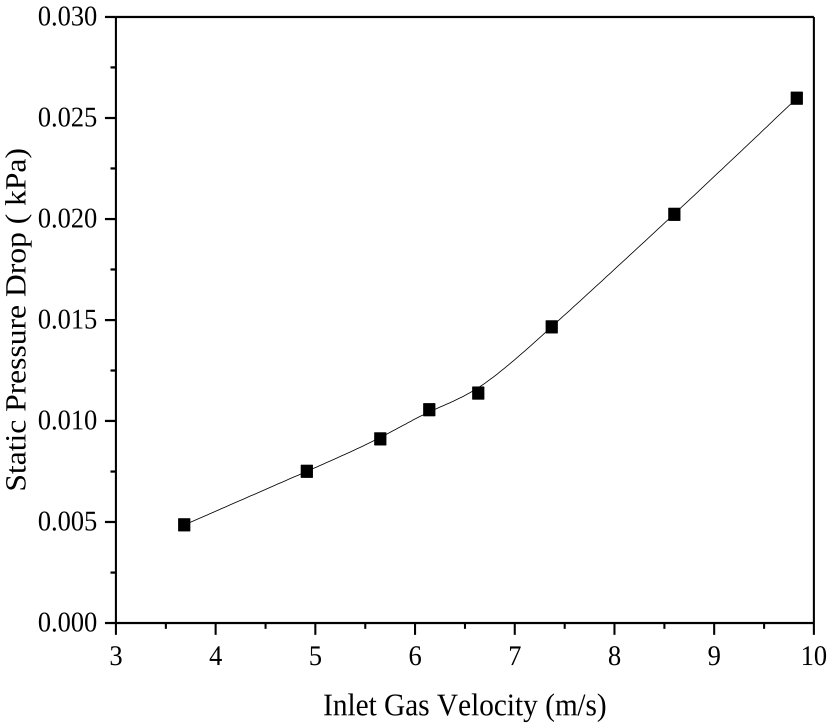


The flow field in the inner vortex is more turbulent and complicated than that in the outer vortex.

A little outer swirling gas will enter the inner swirling flow in the separation space. The amount of gas will grow up with the increase of axial altitude

Most of the outer swirling flow reverses to the inner swirling, and it occurs in the region of *Z/D* = 3.27-4.70.

3. Pressure field--static pressure drop

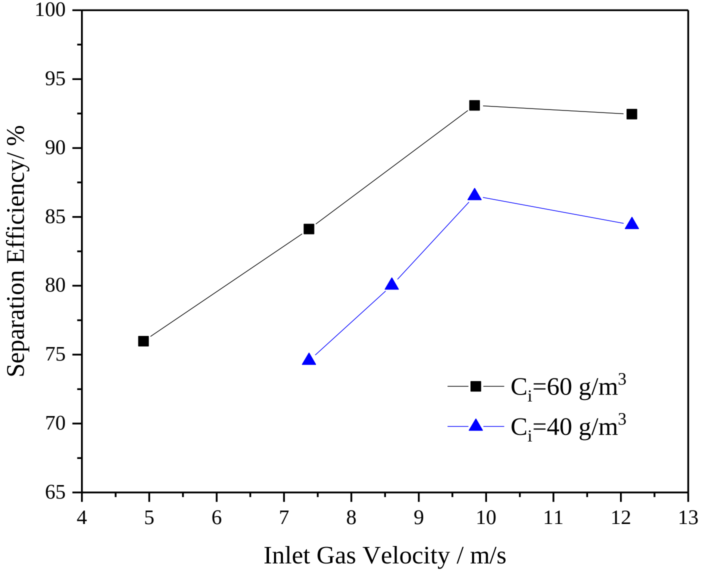


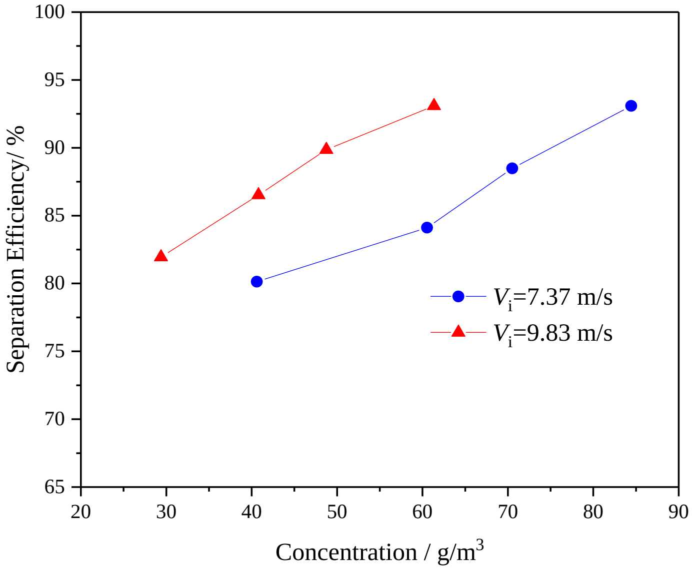
$$Eu = \frac{2\Delta P}{\rho u^2}$$

The experimental results indicated that the total pressure drop was less than 30 Pa, while the *Eu* number keeps 4.7×10^{-4} under the inlet gas velocity ranging from 3.7 to 9.8 m/s.

Results and discussion

4. Separation efficiency

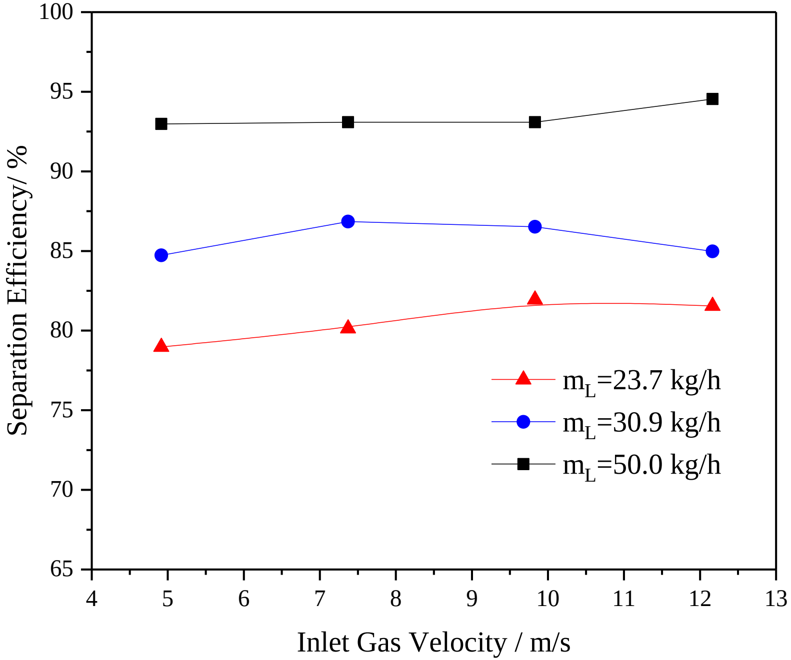




A high tangential velocity is beneficial to the centrifugal force field to improve the efficiency. However, a strengthen centrifugal force can also breakup the droplets easily. The optimal inlet velocity of this rig is 9.83 m/s.

Results and discussion

4. Separation efficiency



The separation efficiency does not substantially increase or decrease with changes in inlet gas velocities at the same inlet droplet mass.

At the identical mass rate, the inlet droplet concentration drops with increasing the gas velocity, the coalescent is diminishing, so the droplets gradually fall in size.
However, as the inlet velocity grows, the centrifugal force makes the efficiency rise up gradually, even though the gas velocity exceeds the optimal velocity.

5. Separation efficiency model

Parameters related to the property of gas and liquid:
the gas phase density ρ_g, the liquid phase density ρ_l, and the gas; viscosity V_i ;

Parameters related to the operating:
the inlet velocity V_i, the droplet diameter d_p and the inlet concentration C_i;

Parameters related to the structure:
the cyclone separator cross-section diameter D and the inlet tube diameter D_{in}.

5. Separation efficiency model

$$E(d_p) = f(\rho_g, \rho_l, \mu_g, V_i, d_p, C_i, D, D_{in})$$

$$E(d_p) = f(Re, stk, \langle C_i \rangle)$$

$$Re = \frac{D V_i \rho_g}{\mu_g} \qquad stk = \frac{(\rho_l - \rho_g) d_p^{\,2} V_i}{18 \mu_g D} \qquad \langle C_i \rangle = \frac{C_i}{40.8}$$

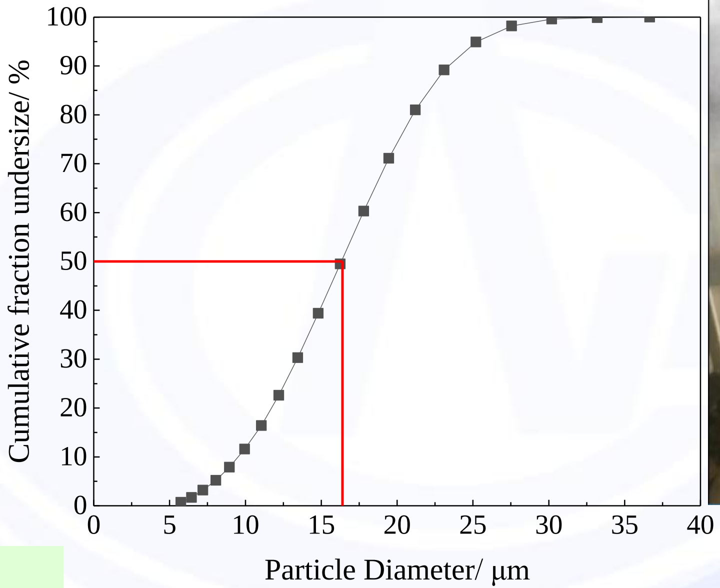
Results and discussion

5. Separation efficiency model

$$d_p = kV_iC_i + b$$

$$d_p = (0.0516V_iC_i - 4.9774)\times 10^{-6}$$

$$E(d_p) = (1 - me^{aRe^b stk^c C_i^d})\times 100\%$$



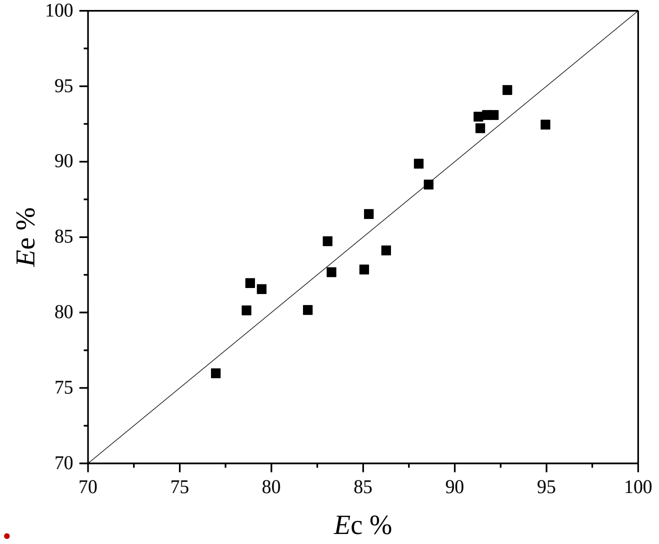
Results and discussion

5. Separation efficiency model

$$E(d_p) = (1 - 0.8652e^{-4.61\times10^{-6}\langle Re\rangle^{1.23182}\langle stk\rangle^{-0.12182}\langle C_i\rangle^{1.03528}})\times100\%$$

$$d_p = (0.0516V_iC_i - 4.9774)\times10^{-6}$$

$$\langle Re\rangle = \frac{D\dfrac{V_i}{9.83}\rho_g}{\mu_g} \qquad \langle stk\rangle = \frac{(\rho_l-\rho_g)d_p^{\,2}\dfrac{V_i}{9.83}}{18\mu_g D}$$



The average error of the model is approximately 1.84%.

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Conclusions

1. The velocity field and the pressure field indicate that the separator is divided into the inner vortex and the outer vortex, the boundary of the inner vortex and the outer vortex is about $r/R=0.1$.

2. In addition, two different axial regions are found in the separation space, the boundary of two different axial regions is $r/R=0.65$.

3. The inlet gas occurs short circuit flow when the gas enters the separator. A part of the gas and droplets directly move upward to escape. It makes the separation efficiency fall obviously.

Conclusions

4. The pressure drop of this cyclone separator is smaller than most separators, thus it can be used in the WGS process.

5. The optimal inlet velocity of this rig is 9.8 m/s. The separation efficiency was increased from 82% to 93% when increasing the inlet liquid concentration from 30 g/m^3 to 60 g/m^3 at a fixed gas velocity 9.8 m/s.

6. A separation efficiency model was given. The average error of the model is approximately 1.84%, it can be used for engineering design purpose.

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Thank you

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