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Investigation of Oil Droplet Distribution in a Vane-Type Pipe Separator

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Abstract. The droplet size distribution (DSD) in a swirl flow field formed by guiding vanes in a vane-type pipe separator (VTPS) was experimentally studied. The cumulative volume fraction and maximum droplet diameter of the dispersed phase were determined using a laser particle size analyzer. The results show how the characteristics of droplets in a swirl flow field changes with the dispersed phase content, flow rate and water velocity at the inlet. A quasi-power law function is shown to fit the DSD cumulative volume fraction results better than the Rosin-Rammler Function.

Introduction

As exploitation of an oil field enters the mid-late life-cycle period, the proportion of water in production fluids continuously increases. The growing water content reduces the efficiency and economic outlook of oil fields. One method to solve this problem is to adopt downhole oil/water separation (DOWS) technology, which separates oil and water phases and re-injects the water into the formation [1]. In this context, use of a Vane-Type Pipe Separator (VTPS, shown in Fig. 1a) has recently been proposed for DOWS. This methods creates vortical motion in the fluid through rotation of guiding vanes in the pipe center, whereas conventional cyclones for oil-water separation form the vortical motion at the tangential entry structure [2]. The authors have previously demonstrated that this new method can produce improved oil-water separation performance in preliminary experimental study [3]. The feasibility of this method has also been shown at the Caofeidian oil field in West Bohai Bay, China.

Since cyclones are based on the principle of centrifugal mechanics, many factors affect its separation efficiency [4,5]. Of these factors, the size distribution of the dispersal droplets has the greatest impact on separation efficiency and is pivotal to the structural arrangement optimization of cyclones [6,7]. The droplet size distribution (DSD) provides the basic information for establishing a mechanistic model to evaluate the cyclones separation performance [8,7], and it can also be used for droplet breakage and coalescence mechanism research [9,10]. Accordingly, the investigation of the DSD characteristics in cyclones under different conditions becomes meaningful and essential [11].

Literature Review

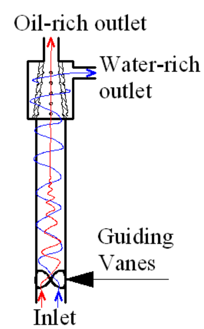
A reliable method of measuring droplet size is required to investigate the efficiency of cyclones; however, existing droplet testing methods have previously shown significant difficulty in realizing online real-time measurement of the DSD in a swirl flow field. Zhou [12] used a non-intrusive particle dynamics analyzer to investigate the size of the oil droplets in an oil-water separation cyclone. Their method basically performs point by point analysis, which means the DSD of a large area cannot be acquired simultaneously. Angeli and Hewitt [13] employed a photographic technique to get water DSD in oil phase of pipe flow. Simmons and Azzopardi [14] used a Lasentec TM Par-Tec 300C instrument for situations with high concentrations of dispersed phase and a Malvern 2600 particle size analyzer, which is based on light diffraction, for situations with low concentrations of dispersed phase to get a DSD in pipe flow. Angeli [15,16] tested the DSD of oil droplets point-by-point in the dual continuous horizontal pipe flow using a dual conductivity probe.

By comparison, with the VTPS system the oil phase is concentrated in the central area of the pipe [3]; and both the photographic and the laser image processing techniques are not applicable for DSD measurements because of the graphic overlay problem [2]. Thus, a particle size analyser, Malvern Insitec SX, which is based on light diffraction, was chosen in this study to examine the DSD characteristics in the VTPS. This method is non-intrusive, online and in real-time. Hence, this method was chosen to investigate the characteristics of the DSD in a swirl flow field formed by the guiding vanes in the VTPS.

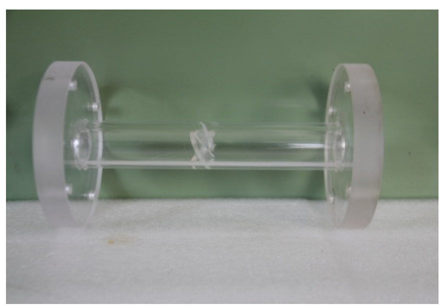
Experimental Method

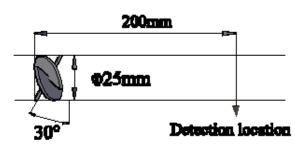
Guiding Vanes

To test the characteristics of the DSD in swirl flow, a 0.025m ID concentric tube was used. This tube contained semi-elliptical plates, which represent the guiding vanes, made of transparent plexiglass (Fig.1b). Three semi-elliptical plates where used with an angle of 30° adopted between the plates and the tube wall. The distance from the guiding vanes to the detection location is 0.2 m.



(a) VTPS


(b) guiding vanes



(c) detection location

Figure 1. Photograph and schematic diagram for guiding vanes.

Experimental Setup

Experiments were conducted at the Laboratory of Applied Fluid Dynamics in Institute of Mechanics, Chinese Academy of Science. A schematic representation of the experimental system is shown on Fig.2. During the experiments, oil was pumped by a metering pump and mixed with water by a T-junction. The mixture was then pumped through the tube with the guiding vanes, after which the oil phase was broken into small droplets and flowed through the detection location. Finally, the liquid entered a mixture tank and the phases are separated. The oil phase was then pumped back to oil tank and the water was discharged.

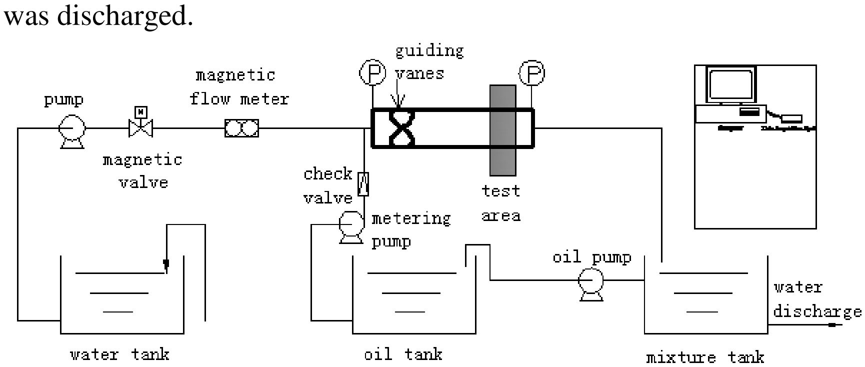


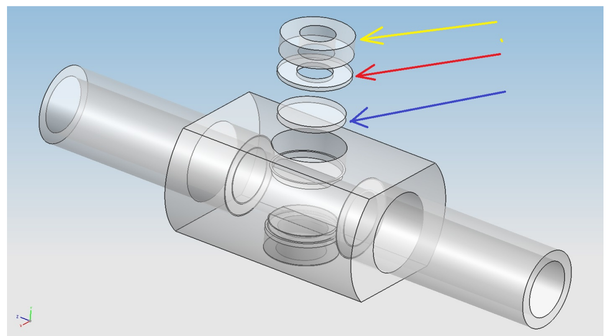
Figure 2. Experimental system for measuring DSD after guiding vanes.

In the experiments, LP-14 white oil and deionized water were used. Their physical properties under test conditions were as follows: $\rho_o = 836.0kg/m^3$, $\mu_o \approx 0.215Pa \cdot s$, $\rho_w = 998.2kg/m^3$, $\mu_w \approx 0.001Pa \cdot s$. The temperature of oil-containing water was 16-18℃.

Measurement System

The Malvern Insitec SX was employed to measure the DSD in the VTPS. The device illuminates the droplets with a collimated low-power He-Ne laser beam, and the scattered light was passed through a Fourier transform lens. The far field diffraction pattern was focused onto a series of concentric photoelectric detectors. The DSD was then acquired from the scattered light intensity using the controlling computer. The size measurement range of the instrument is dependent upon the focal length of the Fourier lens used and hence varies with application. In the present study, a 500 mm lens was chosen, which gives a size measuring range of 0.5-2000 μm. Fig.3 shows the Malvern Insitec SX and schematic assembly of the online sample pool.

(a) Malvern Insitec SX in experiments



(b) The online sample pool

Figure 3. Diagram of the detection location of measurement system in the pipe.

Results and Discussion

The Effect of Dispersed Phase Content on DSD

Fig.4 shows the effect of oil content on DSD at a total inlet flow rate of 3.30 m3/h. The results suggest that as the oil content increases, the volume fraction of the droplets also increases. This occurs because at a constant flow rate increasing the oil content reduces the breakage rate since the dispersed phase takes up more volume and reduces the local turbulent energy [17].

The above phenomenon illustrates that characteristics of the DSD in the VTPS for dilute and dense dispersions are markedly different. Figure 4 also shows that if the oil content is increased too high the measuring range of the Malvern Insitec SX can be exceeded by the larger droplets. Therefore, this paper is limited to investigating the characteristics of more dilute dispersions to ensure the majority of the droplets remain within the measurable range of the testing device.

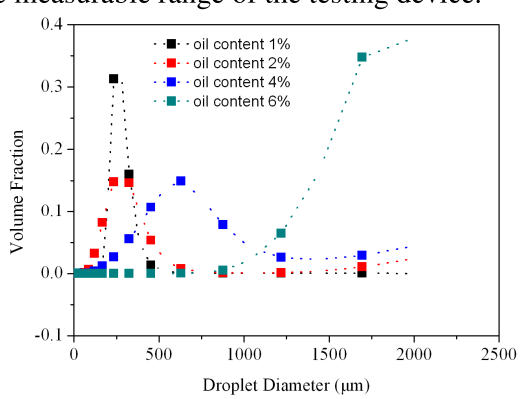


Figure 4. DSD of different oil contents under same inlet flow rate.

The Effect of Surficial Water Velocity at the Inlet on Maximum Droplet Size

The size of the largest drop is a primary driver for the droplet breakup through guiding vanes. So the maximum droplet size in dilute dispersions (⩽1%) under different surficial water velocities at the inlet of the VTPS has been investigated. The results on Fig.5 show that as the inlet water velocity increases, the maximum droplet diameter decreases. This may be explained by the increasing shear stress that the continuous phase imposes on droplets as the velocity becomes larger. As a result, the droplets become increasingly likely to break into smaller ones.

The Effect of Inlet Water Velocity on Cumulative Volume Fraction

Figure 6 shows the variation of the cumulative volume fraction for dilute dispersions when the inlet water velocity changes. The results show that as the superficial water velocity increases the droplet diameter decreases (as shown previously) but the overall shape of the cumulative volume fraction distribution remains relatively constant.

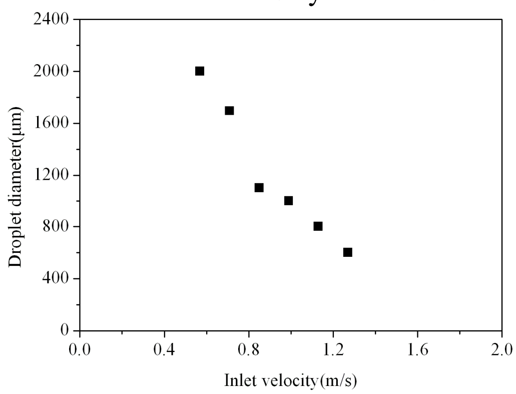


Figure 5. Maximum droplet size at different inlet water velocities.

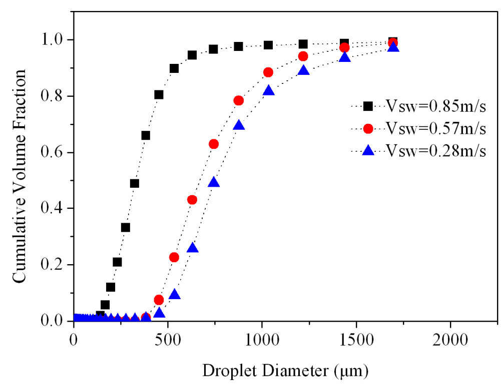


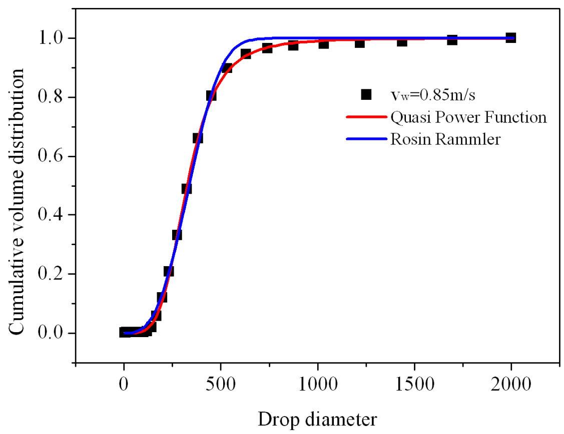
Figure 6. The influence of inlet water velocity on cumulative volume fraction.

Cumulative Volume Fraction Distribution of Droplets in Swirl Flow Field

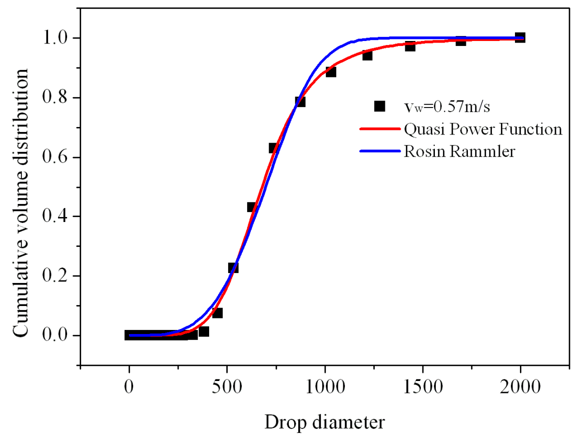
Rosin-Rammler Function is often used to describe cumulative volume fraction distribution for oil-water two phase pipe flows [18]. To investigate whether this function is applicable for the DSD in the VTPS, a comparison between Rosin-Rammler Function and a quasi-power law function proposed based on the current experiments is conducted. The results are shown on Fig.7 and Table 1. Using a linear least-squares optimization, the quasi-power law function is able to fit the data better than the Rosin-Rammler Function, which was originally adopted for pipe flows. This difference is consistent with the mechanism of droplets breaking in swirl flow field being different from pure pipe flow.

Table 1. Comparisons of the two functions.

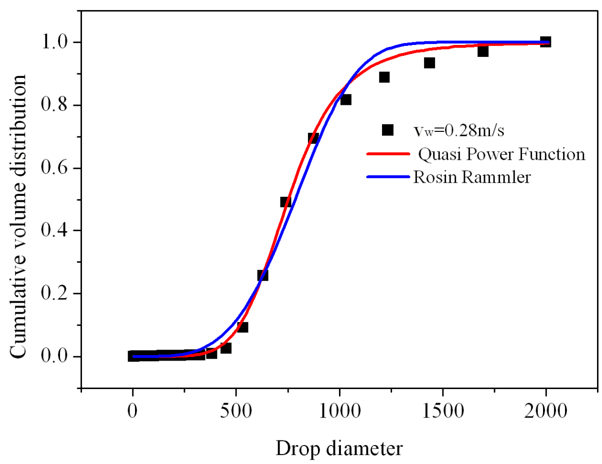
Inlet water velocity (m/s)		Rosin-Rammler Function	Quasi Power Function
		$F(d)=1-\exp[-ad^n]$	$F(d)=\frac{1}{1+(d/a)^b}$
0.85	Parameters	a=2.05E-8,b=2.98	a=326.13,b=-4.19
	R^2	0.98	0.999
0.57	Parameters	a=1.29E-11,b=3.78	a=677.44,b=-5.33
	R^2	0.971	0.999
0.28	Parameters	a=4.92E-12,b=3.85	a=751.92,b=-5.86
	R^2	0.978	0.999



(a) Inlet water velocity, 0.85 m/s



(b) Inlet water velocity, 0.57 m/s



(c) Inlet water velocity, 0.28 m/s

Figure 7. Cumulative volume distribution as a function of droplet size.

Conclusions

In this paper, the characteristics of the DSD, maximum droplet size and cumulative volume fraction in a swirl flow field induced by guiding vanes in a VTPS were experimentally studied using a Malvern particle size analyzer. This study focused on the behavior at relatively dilate oil concentrations. The following conclusions are attained from these results.

When the flow rate at the inlet remains constant, increasing the oil content generates larger droplets after the VTPS. At a constant oil content, the maximum droplet diameter decreases as the velocity at the inlet increases. As inlet water velocity increases, the droplet diameter decreases when the cumulative volume fraction. A quasi-power law function was applied to the cumulative volume fraction results, which shows a better fit to the data than the Rosin-Rammler Function. This approach may provide a more accurate method to predict the DSD for dilute dispersions in the swirl flow field of a VTPS. These results provide a solid foundation for further research on droplets breakup mechanism in the new downhole oil/water separator-VTPS.

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