Experimental Thermal and Fluid Science 60 (2015) 208–212

Contents lists available at ScienceDirect

Experimental Thermal and Fluid Science

journal homepage: www.elsevier.com/locate/etfs

Flow field of continuous phase in a vane-type pipe oil–water separator

Shi-ying Shi [a,b], Jing-yu Xu [a,*]

[a] LMFS, Institute of Mechanics, Chinese Academy of Sciences, Beijing 100190, China
[b] Institute of Chemistry, Chinese Academy of Sciences, Beijing 100190, China

ARTICLE INFO

Article history:
Received 24 April 2014
Received in revised form 15 September 2014
Accepted 18 September 2014
Available online 26 September 2014

Keywords:
Flow field
Pipe separator
Particle Image Velocimetry

ABSTRACT

In this work, the measurements of the swirling field of continuous phase in a new vane-type pipe separator have been carried out to validate the separation characteristics by the Particle Image Velocimetry. The radial, tangential and axial velocities were obtained. The results show that the new separator can successfully form a symmetrical swirling field. The transition region of the tangential velocity between the free vortex and the forced vortex shows a wider range than that in the traditional hydrocyclone. The axial velocity is always positive from the pipe wall to the central area and appears three-peak distribution. The tangential and axial velocities are dependent to the inlet flow rate, and yet show a low sensitivity to the ratio of flow split when the ratio of flow split is less than 13.1%. These results are helpful to the optimal design of the downhole oil/water separator.

1. Introduction

With the large-scale development of deep-sea petroleum resources, the water content of output fluids is ever-increasing so that most of water treatment systems on platforms have reached its maximum capacity [1]. To solve this problem, the center for frontier engineering research (C-FER) proposed the technology of downhole oil/water separation (DOWS) which could separate the output fluids and re-injected water into the producing well [2]. This new technique has been proved to be feasible in the wells with a very high water cut. However, for the wells with high flow rate and low water cut, the processing result of the new technology is not satisfactory [3]. The reason may be due to the fact that the tangential inlet of DOWS restricts the size of hydrocyclones used in downhole. When flow rate increasing and water cut decreasing, the shear stress of fluid exerting on the oil droplet increases quickly so that the oil droplet is broken into smaller ones. To solve these problems, the technology, which the guide vane is installed in the straight pipe to generate the swirling field, attracts the attention of researchers. Gupta et al. [4] found that the straight vane could generate the swirling flow with the low level of turbulence. The following studies [5–7] showed that the guide vane with same radius in a central body could establish a symmetric flow field, and thus the droplets could be removed from gas [8–10]. In addition, Dirkzwager [11] first introduced this kind of swirl element into an oil–water separator, and successfully carried out the separation of oil and water base on the strong swirling field generated by the guide vane. However, most of studies only present qualitative information and quantitative research needs to be further investigated in detail.

In our previous work [12], a new vane-type pipe separator (VTTS) was designed as the downhole oil–water separation. Fig. 1 shows the schematic diagram of the device. The original intention of this design is to force the continuous phase to form the swirling field by the axial guide vanes installed in VTPS, which can cause the lighter dispersed phase to move toward the central area of the pipe. In this case, the water phase (continuous phase) is separated through the tangentially holes while oil phase (dispersed phase) continues to move upward. The main difference between this new separator and the traditional hydrocyclone is the inlet structure. It is well-known that the traditional hydrocyclone forms the swirling flow by a tangential slot on the side, which the VTPS is created by the axial guide vanes installed. In the present study, the swirling field of continuous phase in the VTPS was measured by the Particle Image Velocimetry (PIV), and the quantitative results were presented.

2. Experimental

2.1. Flow-loop

A VTPS with 72-mm inside diameter was constructed of plexiglass for the PIV measurements. The guide vane is composed of three semicircular plates. Each plate has a fixed angle 30° with the cross section of the pipe, and occupies a half of the tangential

* Corresponding author. Tel.: +86 10 8254 4179; fax: +86 10 6256 1284.
E-mail address: xujingyu@imech.ac.cn (J.-y. Xu).

http://dx.doi.org/10.1016/j.expthermflusci.2014.09.011
0894-1777/

Nomenclature

Q_w	flow rate at the water-rich outlet	Δt	time interval
F	ratio of flow split	Q_i	flow rate at the inlet
t	time	v_θ	tangential velocity
v_r	radial velocity	v_z	axial velocity
L	vertical height from the guide vane		

sectional area. The thickness of the plate is 2 mm. A schematic diagram for the installation is shown in Fig. 1. The tangential holes are distributed evenly at the cross section in the conical pipe with the same tangential velocity direction of the fluids flow. In this experiment, if the velocity vector was measured directly through the circular pipe wall, the errors from the light distortion could be caused by the pipe wall. Thus, the test section was wrapped with water in a rectangular box to reduce the errors of the distortion. This approach can make the measurement errors less than 1.6%, and the same method is also adopted by other researchers to measure the swirling flow [13,14].

The schematic diagram of the flow loop is illustrated in Fig. 2. Deionized water was used as the fluid, which contained silver-coated glass particles with the density of 10^3 kg/m^3 and the mean diameter of 10 μm. Prior to the experiments, these silver-coated glass particles were evenly scattered in the water tank by stirring. And then, the water phase was fed into the VTPS under the different flow conditions. A butterfly valve was installed in the water-rich pipe to control the flow rate of the water-rich outlet. Based on an assumption that the impact of dispersed phase on the flow field of continuous phase could be ignored, the volumetric ratio of oil to water was controlled below 0.1 in this work.

The flow split of the VTPS is defined as the ratio of the flow rate of the water-rich outlet to that of the inlet:

$$F = \frac{Q_w}{Q_i} \tag{1}$$

here F is the ratio of flow split, Q_w and Q_i are the flow rates of the water-rich outlet and the inlet, respectively.

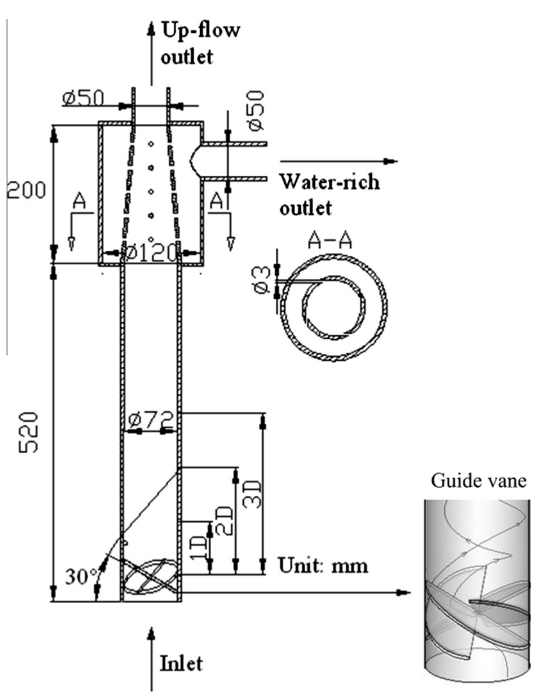

Fig. 1. The schematic diagrams of the VTPS and guide vane.

2.2. PIV system and signal processing

PIV system can obtain the velocity vector of the entire planes and is proved to be an effective test method. Lim et al. [15] adopted 2D PIV to study the velocity vector distribution in the hydrocyclone. Martins et al. [16] compared the typical behaviors of the tangential and axial mean velocity components got by LDA (Laser Doppler Velocimetry) with those by 2D PIV. The results showed a good agreement between two methods.

In this work, the PIV measurements were conducted with a Stereoscopic LaVision system. Short duration (4 ns) high energy (800 mJ) pulses of green light (532 nm) were ejected by a double pulsed Nd: YAG laser. The collimated laser beam transmitted through two cylindrical lens (10 mm and 20 mm) to generate a 1 mm thick light sheet. The reflected light of the reference target in the flow field was caught by a CCD camera with 1376 × 1040 pixels and 64-bit resolution. The cameras were furnished with Nikon 35 mm/50 mm and the numerical diameter 1.8 mm. For all the measurements, the velocity vectors were obtained by Davis 7.2 Software which processed the adaptive correlation on 64 × 64 pixel-size final interrogation spots with a 64 × 64 vectors grid. The pixel resolution was 6.45 × 6.45 μm. Through the adaptive correlations, the location $r(t)$, $\theta(t)$, $z(t)$ of the same tracer particle were functions of time t. Thus, the velocity of water point that the tracer particle locates can be expressed as follows:

$$v_r = \frac{dr(t)}{dt} \approx \frac{r(t+\Delta t) - r(t)}{\Delta t} = \overline{v_r} \tag{2}$$

$$v_\theta = \frac{d\theta(t)}{dt} \approx \frac{\theta(t+\Delta t) - \theta(t)}{\Delta t} = \overline{v_\theta} \tag{3}$$

$$v_z = \frac{dz(t)}{dt} \approx \frac{z(t+\Delta t) - z(t)}{\Delta t} = \overline{v_z} \tag{4}$$

here v_r, v_θ, v_z are the instantaneous velocity along the radial direction, tangential direction and axial direction, respectively. $\overline{v_r}, \overline{v_\theta}, \overline{v_z}$ are the mean velocity. Δt is the time interval between two continuous shooting. After the flow becomes stable, 200 samples within

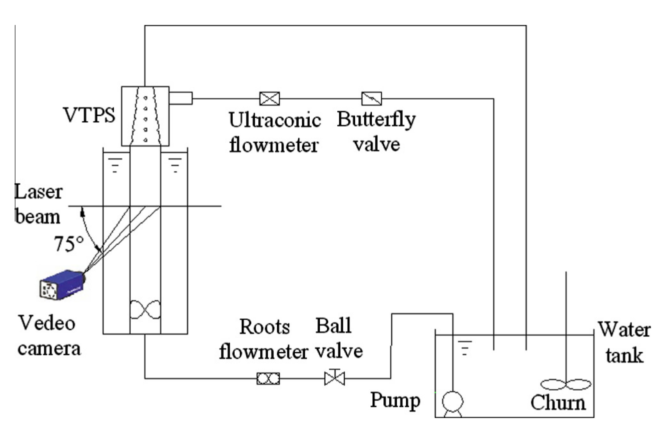

Fig. 2. Diagram of flow-loop.