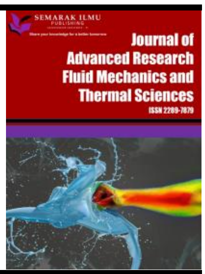
Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 100, Issue 1 (2022) 89-97

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879



Vortex Control Using Plate Type Floor Splitter in Pump Intake

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ARTICLE INFO

Article history:
Received 8 April 2022
Received in revised form 1 September 2022
Accepted 15 September 2022
Available online 5 October 2022

Keywords:
Anti-vortex device; single plate floor splitter; twin plate floor splitter

ABSTRACT

Pump sump design is very crucial in ensuring a minimum requirement for its operation. Improper pump sump design will influence the development of vortices and swirls that can adversely affect the pump efficiency which subsequently could damage the pump. This can be mitigated by installing an anti-vortex device (AVD) beneath the intake pipe in the pump sump. The AVD works by suppressing the development of vortices and swirls in the flow of water into the intake pipe. ANSI/HI 9.8-2012 standard has outlined various AVD shapes and concepts that can be used. This experimental study was conducted to determine the appropriate parameters and configurations of twin plate floor splitter (TPFS) to suppress the development of vortex in the intake pipe. Geometries and other outlines in experiments were based on the guidelines by ANSI/HI 9.8-2012. The AVD model variations used were models with no floor splitter, single plate floor splitter (SPFS), and TPFS with 25 mm, 45 mm and 65 mm gap variations. The results showed that the distance between the two sides of twin plate affects the number of vortex generation and the swirl angle reduction. The number of vortices increased with the distance between the plates but with lower localized vortex intensity. However, the TPFS models that were used produced a swirl angle of less than 5° with the 25 mm variation producing the lowest swirl angle of 2.41°. The use of TPFS shows significantly improved performance in swirl angle reduction and vortex suppression as compared to no AVD case.

1. Introduction

The usage of pump systems has been used widely, especially for purpose of transferring fluid from one place to another. Various pipeline junctions of water interconnecting hundreds of kilometers are used to distribute clean water from the water treatment plant to each building [1,2]. Another important example is the pump station used in the urban area to prevent the backwater effect. Even though the drainage system is designed using the concept of design flood frequency, floodings due to extreme rainfall are still difficult to overcome [3]. Thus, a pump system is required in managing flood disasters. However, the effectiveness of pump operation may be disrupted by numerous problems such as cavitation, vibration and abnormality of flow [4,5]. This study

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https://doi.org/10.37934/arfmts.100.1.8997

emphasizes in suppression of vortex formation to improve the performance of pump intake. Vortices give more significant effects to wet pit installation compared to dry pit installation because most of the pump inlet is submerged in water which can directly get in contact with the pump impeller and cause damage to the pump [6,7].

Multiple factors have contributed to determining the performance of pump stations [8]. Based on the ANSI/HI 9.8-2012 [9], there are a few types of anti-vortex devices (AVD) that have been introduced and one of them is the floor splitter. Employing an AVD is one of the options used to suppress vortex formation because of its effectiveness [10–13]. However, the design of the floor splitter is in its conceptual stage, and there is no specific dimension proposed in the standard, although studies have proved that the floor splitter dimension impacts the result of vorticity reduction in pump intake sumps. The floor splitter concept is similar to surface treatment such as riblets application to wings to alter vortex formation therefore certain parameters can cause drag to be reduced [14,15] and drag penalties in large tankers as the latter is often substantially increased due to hull roughness [16,17]. In this study, five experimental settings namely with no floor splitter, single plate floor splitter and twin plate floor splitter with variable distance are used to analyze the vortex formation and measure the swirl angle reduction will be discussed.

2. Methodology

Figure 1 shows a single pump sump channel that was fabricated at the Coastal and Water Resources Engineering Laboratory, Universiti Kebangsaan Malaysia. The rig comprises a closed-loop piping system and an end suction pump which at as a flow feeder into the channel. To enable the observation of any vortex created at the suction entrance, the test section is built from acrylic. An acrylic pipe with a bell-shaped intake that resembles a real submersible pump serves as the suction end. This experimental rig is a continuous study from the previous setup [18,19], in which the researchers measured the reduction in swirl angle using a single plate type floor splitter. In contrast, in this article, the procedure includes employing a twin plate floor splitter and a non-intrusive method using particle image velocimetry (PIV) to analyze the characteristics of the fluid flow beneath the suction pipe.

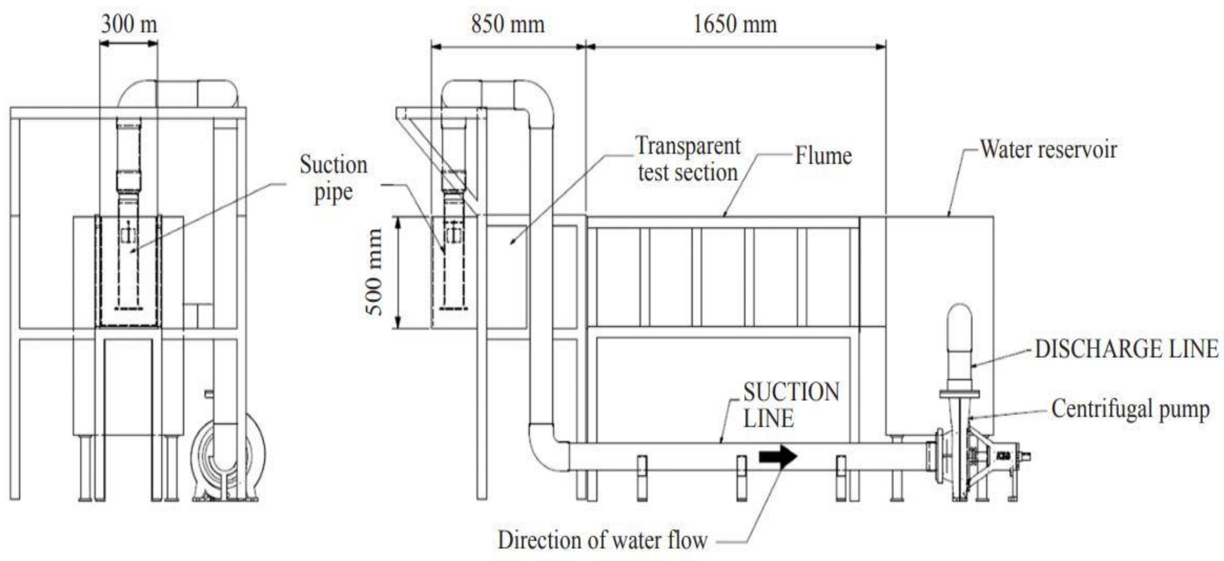

Fig. 1. Experimental pump sump model at the Coastal and Water Resources Engineering Laboratory, Universiti Kebangsaan Malaysia (UKM)

In this study, to maintain a consistent velocity at the pump input throughout the experiment, the flow rate of the pump Q was adjusted to a maximum capability of $0.0103\ \mathrm{m^3s^{-1}}$ using variable speed drive (VSD). The pump submergence S was determined in accordance with the minimum inlet submergence S_{min} to prevent the formation of free-surface vortices using the following equation

$$S_{min} = D(1.0 + 2.3Fr_{in}) \tag{1}$$

where Fr_{in} the inlet Froude number, was set to be constant at 0.48. The swirl angle was measured using a device called a swirl meter installed in the pipe with the specification according to the ANSI/HI 9.8 (2012) standard. The following equation is used to compute the swirl angle θ

$$\theta = tan^{-1}\frac{\pi dn}{u} \tag{2}$$

d is the inner diameter of the suction pipe with a value of 0.094 mm, u is the axial velocity with a value set at 1.48 m/s and n is the number of swirl meter rotations. The number of revolutions of the swirl meter blades was measured using a tachometer at 10-second intervals throughout a 10-minute period. The location of the Tachometer is shown in Figure 2.

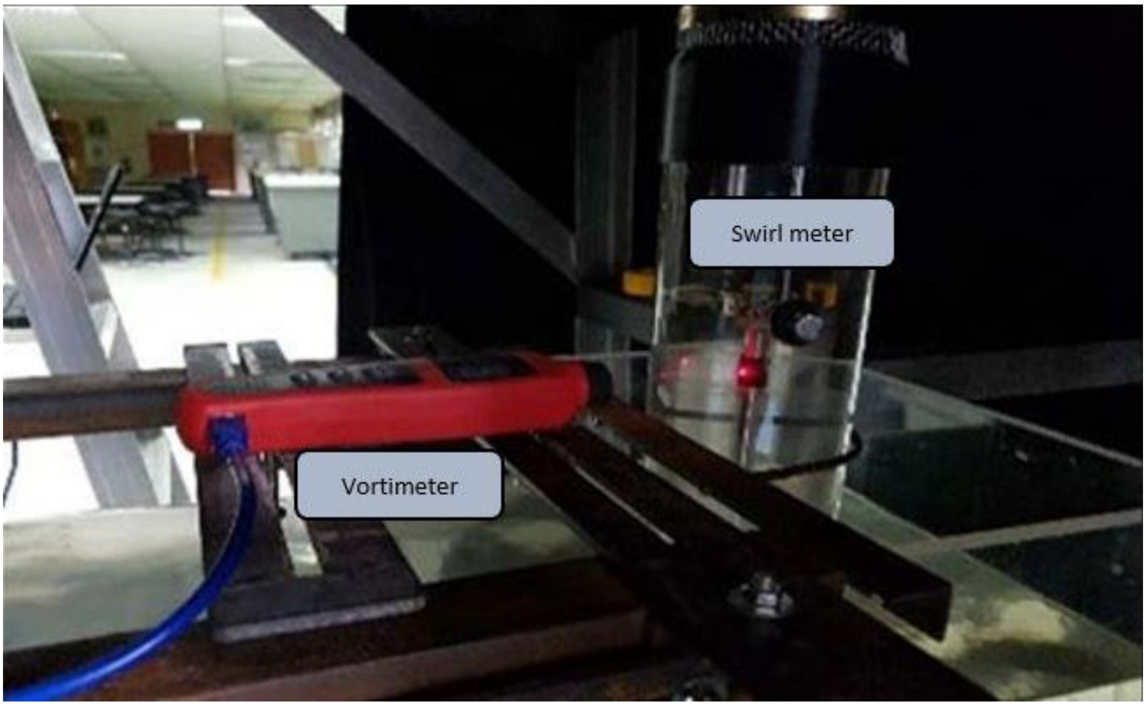

Fig. 2. Placement of tachometer to measure the rotation of swirl meter blade

The variable in this study is the installation of AVD because the implementation of AVD has been proven to help in eliminating the vortices and reducing the swirl angle. The type of AVD used is a plate-type floor splitter that conforms with ANSI/HI 9.8-2012 standard. There are six different conditions consisting of cases: installation of floor splitter, single plate floor splitter (SPFS), and twin plate floor splitter (TPFS) with 4 different positions. The floor splitter is situated on the floor of the pump sump beneath the pump inlet and the configuration of the floor splitter is illustrated in Figure 3.

Experiment	H (mm)	L (mm)	l (mm)	C (mm)	a (mm)
No FS	-	-	-	45	-
SPFS	33	187	210	45	0
TPFS 25 mm	33	187	210	45	25
TPFS 45 mm	33	187	210	45	45
TPFS 45 mm	33	187	210	45	65
TPFS 85 mm	33	187	210	45	85

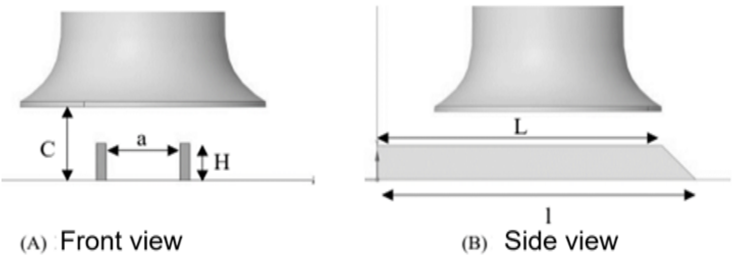

Fig. 3. Design and dimension of the floor splitter

Non-intrusive measurement technique using particle image velocimetry (PIV) was used to visualize the formation of vortex and subsequently measure the vortices strength. The PIV measurement system consists of a double-pulsed Nd Yag laser, a high-resolution CCD camera, a synchronizer and analysis software called PIVLab [20]. A laser sheet was emitted to the measuring section with a level of 33 mm parallel to the channel floor beneath the suction pipe and the CCD camera was positioned beneath the intake channel to capture the vortex's particle images. The PIV system's diagram is shown in Figure 4.

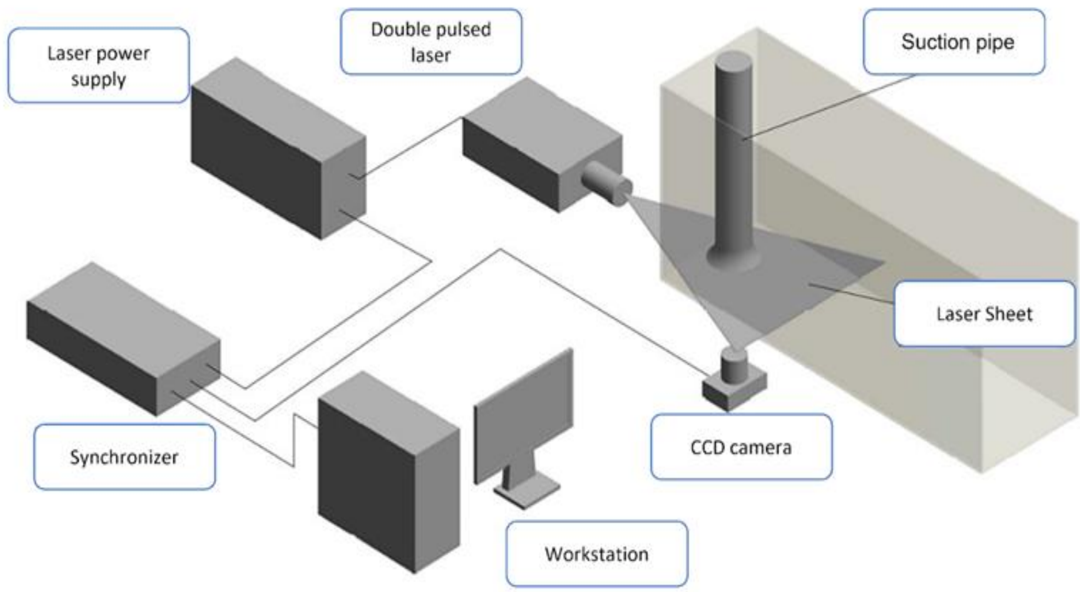

Fig. 4. Schematic diagram of PIV measurement system

3. Results

3.1 Vortex Formation in a Flow Channel

This section discusses the results obtained from the image captured by PIV system. The image captured has been processed in Tecplot 360 to visualize the streamlines as shown in Figure 5. Figure 6 shows comparison of vorticity contour plot between no installation of floor splitter with twin plate floor splitter and Table 1 summarises the value of vorticity strength from the contour plot. The boundary with red dashed-line represents the diameter of the suction pipe. The results show the six significant differences in vortex formation concerning their condition. The first condition with no floor splitter shows one vortex core formed with a large diameter located toward the back wall of the sump while the vortex rotates in counter-clockwise direction. This is because fluid moving toward the intake pipe is being pushed by fluid travelling in a high-velocity direction from the back wall. The vorticity strength is 260 1/s which corresponds with the studies performed when the larger the vortex form, the higher the whirling motion, which influences the pump's performance [21]. The installation of SPFS beneath the intake pipe has obstructed the swirling motion which causes the vortex to split into two cores with smaller diameters that rotate in a clockwise direction. The strength of the vorticity was reduced to 220 1/s with a reduction of 15.58%. Further observation using TPFS 25 mm shows no vortex being formed. The collision between flow from the inlet entrance with the back wall has been suppressed by the floor splitter.

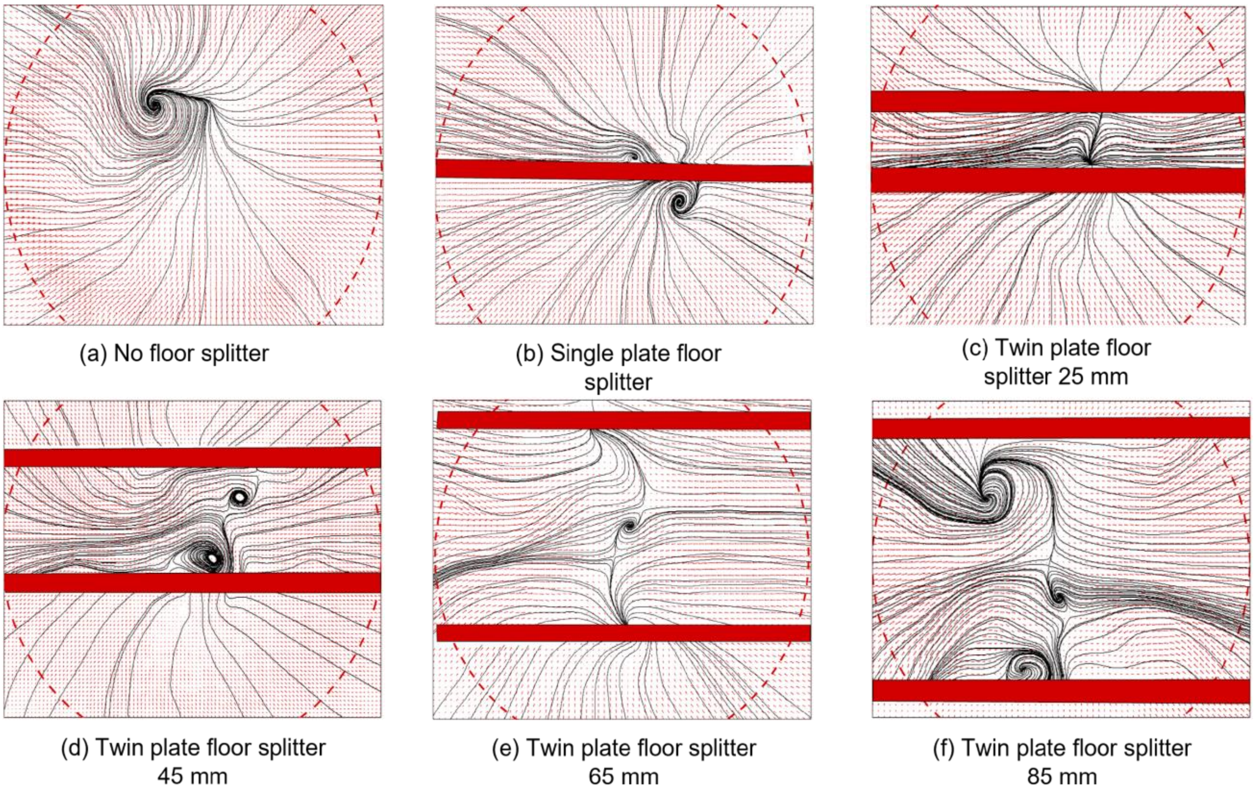

Fig. 5. Streamline plot showing vortex formation for different conditions

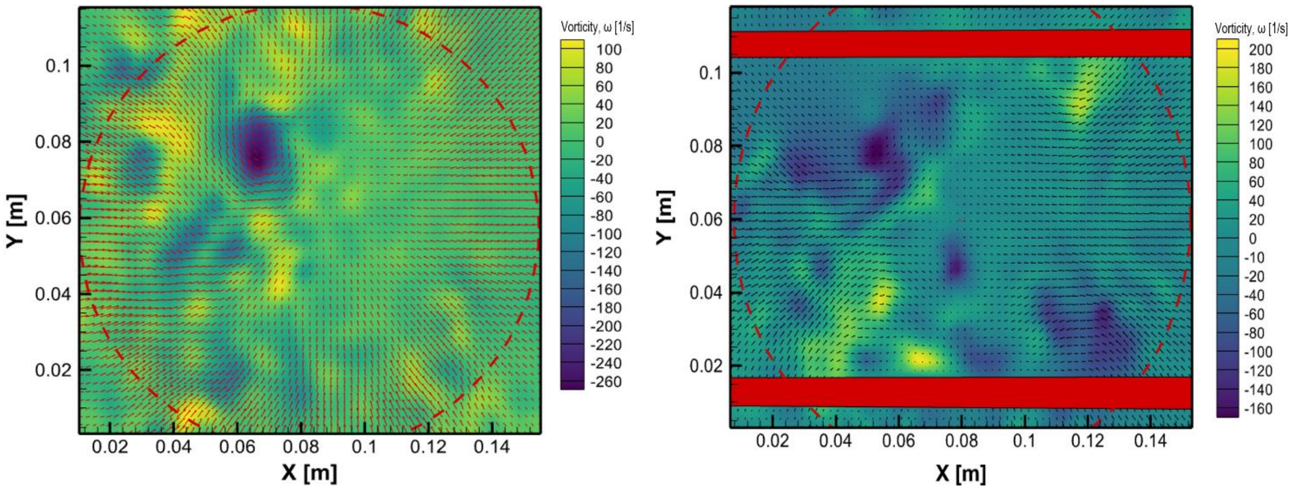

Fig. 6. Vorticity contour plot for 2 different conditions

Table 1
Vorticity strength with and without floor splitter

Experiment	Vorticity [1/s]	Reduction [%]
No FS	260	-
SPFS	220	15.58
TPFS 25 mm	140	46.15
TPFS 45 mm	180	30.77
TPFS 65 mm	190	26.92
TPFS 85 mm	200	23.07

The pump's suction through the bell mouth inlet, which drove the fluid upward, was the primary factor in the tendency of the circular motion, which is at 140 1/s. The TPFS 25 mm showed the largest reduction which was 46.15%. As the distance between the TPFS increases to 45 mm, the presence of two vortices with different diameter sizes rotating in a clockwise direction has been captured and the vorticity strength increases to 180 1/s. At 65 mm, the trend of the vortex initially shows the formation of three distinct but instantaneously suppressed by the floor splitter due to the gap within the plate. This is due to the other vortices merging to form one vortex in a smaller diameter that forms at the centre of the pump intake. The vorticity strength intensified to 190 1/s and the percentage of reduction reduced to 26.92%. Finally, an increase in the distance from 20 mm to 85 mm has caused the formation of three vortices, which shows the TPFS did not successfully disrupt the formation of vortex. The vortex can still develop because the TPFS has allowed the vortex to complete its swirling motion. The gap of TPFS is too large and did not cause a split in the flow formation but rather has become the primary driver for the vortex formation and has a vorticity strength of 200 1/s. The conclusion that can be made from these results is, the installation of floor splitter has successfully separated the vortex into smaller sizes while increasing distance between floor splitter provides a space for formations of smaller vortices. If the distance of the floor splitter is placed within the diameter of the bell mouth shaped 150 mm, the vortex formed is similar to the condition with no floor splitter. The use of TPFS with a distance of 25 mm gives the best performance in suppressing vortex with the greatest reduction in vorticity strength.

3.2 Swirl Angle Reduction

Figure 7 shows the distribution curve of the swirl angle for all cases. Each swirl angle was determined using equation (2), which indicates the average swirl angle for every 10 s interval for a measurement period of 10 minutes. Generally, the usage of a floor splitter has successfully reduced the swirl angle in all conditions with different reduction ratios. However, the requirements outlined by ANSI/HI 9.8-2012 standard must not exceed 5°. This is set to be the benchmark for the effectiveness of the floor splitter. The condition with no floor splitter did not achieve the requirements which were measured at 16.86°, far beyond the allowable standard. The application of floor splitter shows a decreasing swirl angle value. When SPFS was used, the swirl angle obtained was 6.83°. This swirl angle nearly met the requirement with a reduction of 60% compared to not employing any floor splitter. The use of TPFS on the other hand, achieved the standard requirements. TPFS with splitter plates set 25 mm apart shows the lowest swirl angle with the value of 2.41°. The gradual increase of TPFS distance *i.e.,* 45, 65 and 85 mm produced proportional increase of 2.81°, 3.02°, 4.13° swirl angle respectively. The result shows that the application of TPFS with the smallest distance produces the lowest swirl angle.

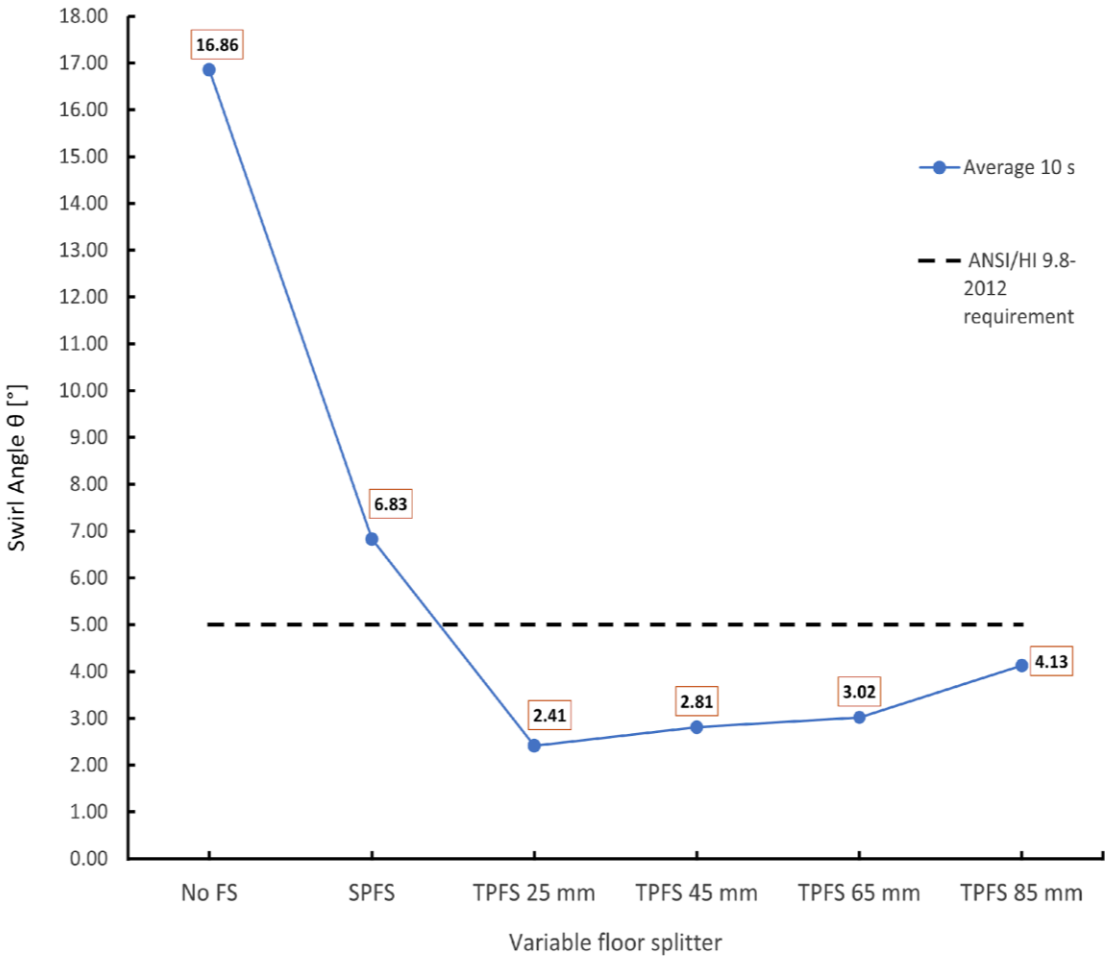

Fig. 7. Swirl angle values with and without floor splitter

4. Conclusions

An experimental study on the behavior of the flow field beneath the suction pipe and the swirl angle characteristics was performed. The behavior of vortex formation was measured using a non-intrusive method called PIV while the swirl angle was measured using a swirl meter concerning the specification. The results show that the installation of a floor splitter has successfully obstructed a large size of vortex into vortices with a smaller size, and weaker vorticity strength compared to no installation of a floor splitter. Swirl angle, on the other hand, shows significant reduction, especially with the application of TPFS where the swirl angle is reduced to the allowable value below 5° based on the requirement of ANSI/HI 9.8-2012. The use of TPFS with 25 mm distance has resulted in the best approach to consider which achieves the lowest swirl angle and no vortex form.

Acknowledgement
This research was funded by a grant from Universiti Kebangsaan Malaysia grant GUP-2020-015.

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