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Numerical and Simulation Study of Cavitation in Centrifugal Pump at Low Flow Rate

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Abstract: Cavitation is the compressible and unsteady turbulent flow caused by the mass transfer between gas and liquid phase which has significant influence on the operating stability and service life of a centrifugal pump. Cavitation can form in a fluid because of localised decreases in dynamic pressure. The collapse of vapour cavities created extremely high pressures, which usually damage neighbouring surfaces and lead to reduce performance. This study aims to simulate a computational model of the cavitation flow using ANSYS Fluid Flow (Fluent). Next, to determine the cavity volume fraction in a centrifugal pump at low flow rate. In this study, the design point of the centrifugal pump used a rotational speed of pump motor at 1450 rpm and initial inlet pressure at 2500 kPa. The simulation of the cavity volume fraction was conducted with four different H_{NPSHa} value, which are 2.09, 1.43, 1.32 and 1.21 m at 25°C of water temperature. The result shows that the values of H_{NPSHa} did affect the cavity volume fraction of pump impeller. Its shows that the decreasing in H_{NPSHa} value, the cavity volume fraction is increased. This study came out with the simulation analysis that predicts a cavitation of the centrifugal pump at different H_{NPSHa} values. The outcomes of this study may help the future researcher to understand how cavitation occurs at low flow rate and its relationship between H_{NPSHa} values

Keywords: Centrifugal pump, cavitation, simulation analysis

1. Introduction

Cavitation is the compressible and unsteady turbulent flow caused by the mass transfer between gas and liquid phase. It has a significant influence on the operating stability and service life of a centrifugal pump. It induces pressure fluctuation and uneven load distribution and then reduces the pump's efficiency and affects their stable operation range [1]. When exposed to increase pressure, the air bubble collapses, resulting in powerful shockwaves. Cavitation is a primary source of internal component wear [2]. The repetitive implosion of collapsing bubbles on a metal surface causes tension. This will cause metal surface fatigue and leads to a kind of wear known as "cavitation". The most common examples of this kind of wear are to pump impellers and bends where a sudden change in the direction of liquid occurs in a closed cavity [3].

The extent of cavitation depends on how low the pressure is in the pump. Cavitation generally lowers the head and causes noise and vibration [4]. Besides, cavitation first occurs at the point in the pump where the pressure is lowest, which is most often at the blade edge at the impeller inlet [5]. In the other case, the different flow rates show different kinds of cavitating flow structures. At lower flow rates asymmetric blade cavitation develops where the intensity of cavitation peaks in one of the blade channels, whereas obtained a uniform distribution of cavities on each blade at higher flow rates [6]. With the decrease in NPSHa, the cavity expends to the impeller channel and block the flow [7]. The pump head was drop and the cavitation bubbles become larger resulting in a sudden fall in the pump head. Bubbles occupy the whole impeller channels, and the pump head reduces by 30% as stated by Tan Lei et al., [8].

In this study, the effect of different values of the H_{NPSHa} used was investigated. The location of the cavitation occurs was at pump impeller. Meanwhile the HNPSHa values were chosen at 2.09 m, 1.43 m, 1.32 m, and 1.21 m. The

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simulation analysis of the cavity volume fraction was obtained from the fluid flow analysis. The specific centrifugal pump model located at biodiesel pilot plant was used as it gives a real geometry and has been used for a long period [9]. The experiment of flow visualization of internal flow pattern by Yun L. et al., [10] are helpful for accurate analysis at the impeller. This study would show the cavity volume fraction occurs when different H_{NPSHa} values were applied. The value of H_{NPSHa} were expected to give a significant impact to the cavitation occurred in centrifugal pump.

2. Methodology

The centrifugal pump used is Ebara pump model 80 x 65 FSHA end suction volute pump. The models of pump impeller were constructed in Solidworks to develop full solid models for both design and analysis in a simulation.

Table 1 - Pump specification

Model No.	Rotational Speed (rpm)	Motor Power (kW)	Impeller Diameter (mm)	Head (m)	Volumetric Flow Rate (m^3/h)	Impeller Material
80 x 65 FSHA	1450	1.5	207	40	25	Bronze

2.1 Model Preparation

In this study, the impeller and casing used were based on manufacturer's catalogue. In this model, the impeller used is closed-type impeller with 207 mm of diameter and six blades. The model represent the Ebara pump model used at biodiesel pilot plant.

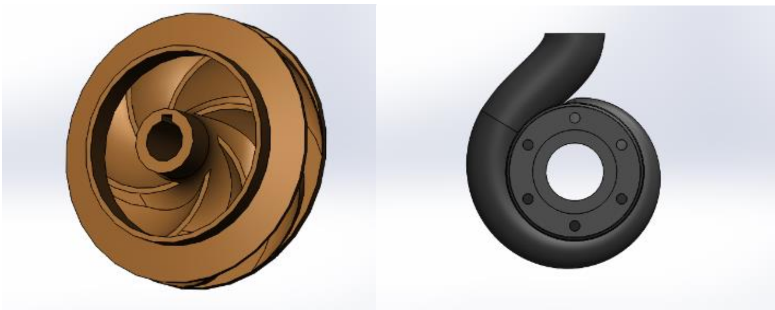

Fig.1 - 3D modelling of Closed Impeller and Casing

2.2 Material and Mechanical Properties

The material of the impeller is bronze and cast iron for the casing. The mechanical property of a material according to national codes and standards published by the American National Standards Institute (ANSI) and ASTM.

Table 2- Mechanical property of material (Impeller)

Property	Value	Units
Elastic Modulus	1.1×10^{11}	N/m²
Poisson's Ratio	0.3	N/A
Shear Modulus	4.3×10^{10}	N/m²
Mass Density	7400	Kg/m³
Tensile Strength	551485000	N/m²
Yield Strength	275742000	N/m²

Table 3 - Mechanical property of material (Casing)

Property	Value	Units
Elastic Modulus	6.61781×10^{10}	N/m²
Poisson's Ratio	0.27	N/A
Shear Modulus	5×10^{10}	N/m²
Mass Density	7200	Kg/m³
Tensile Strength	151658000	N/m²
Yield Strength	-	N/m²

2.3 Mesh Generation

The impeller mesh used the fine types or standard type mesh. This type of meshing represents small feature and curve geometries. It is ideal because of their better degrees of freedom hence a greater number of elements and the results obtained had been closed to analytical results. The smaller the element size and tolerance, the better the quality of the mesh.

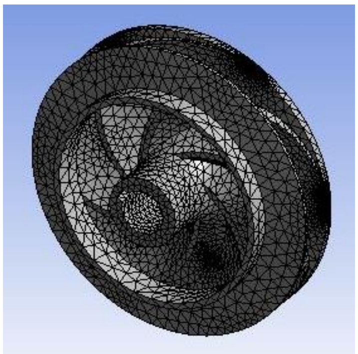

Fig. 2 - Meshing Part of the solid domain

Table 4 - Characteristic of the meshing part

Mesh Type	Solid Mesh
Mesh Used	Standard Mesh
Elements Size	0.001 m
Mesh Quality	High
Total Nodes	27756
Total Elements	125907

3. Results and Discussion

In this section, all result was discussed. The simulation analysis was carried out to determine the effect of different H_{NPSHa} values effect on cavity volume fraction. When the H_{NPSHa} applied and increase, the cavity volume fraction at the pump impeller was recorded.

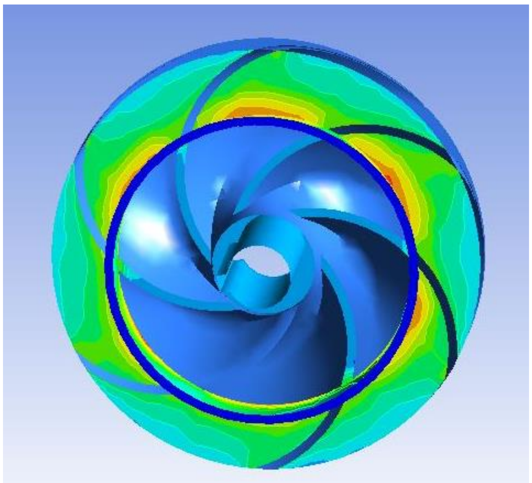

Fig. 3 - Distribution of Pressure at Impeller Inlet

Fig. 3 shows the contour of the pressure distribution at impeller inlet. The initial inlet pressure applied is 2500 kPa with 25°C of water temperature and rotational speed at 1450 rpm. The contours become reddish around the impeller inlet as the maximum pressure occurred in that area.

3.1 Fluent Analysis of Impeller

The results were obtained by using different values of the NPSH margin. The NPSH margin describes the safety factor by which NPSHa must exceed NPSHr to avoid cavitation. NPSH margin ratio indicates NPSHa must be 10% greater than NPSHr. The value of NPSHr is quoted by pump manufacturers as a result of extensive testing under controlled conditions. The NPSHr of Ebara pump is 1.1 m. The table below shows the NPSH margin used in this study.

Table 5 - NPSH Margin

NPSHr (m)	NPSH Margin	NPSHa (m)
1.1	10%	1.21
	20%	1.32
	30%	1.43
	90%	2.09

The design point of the centrifugal pump is as follows: the volume flow rate Q=25 m^3/h, the rotational speed n=1450 rpm, the head H=40 m and the impeller blade Z= 6. Fig.4 shows the computational domain of the centrifugal pump.

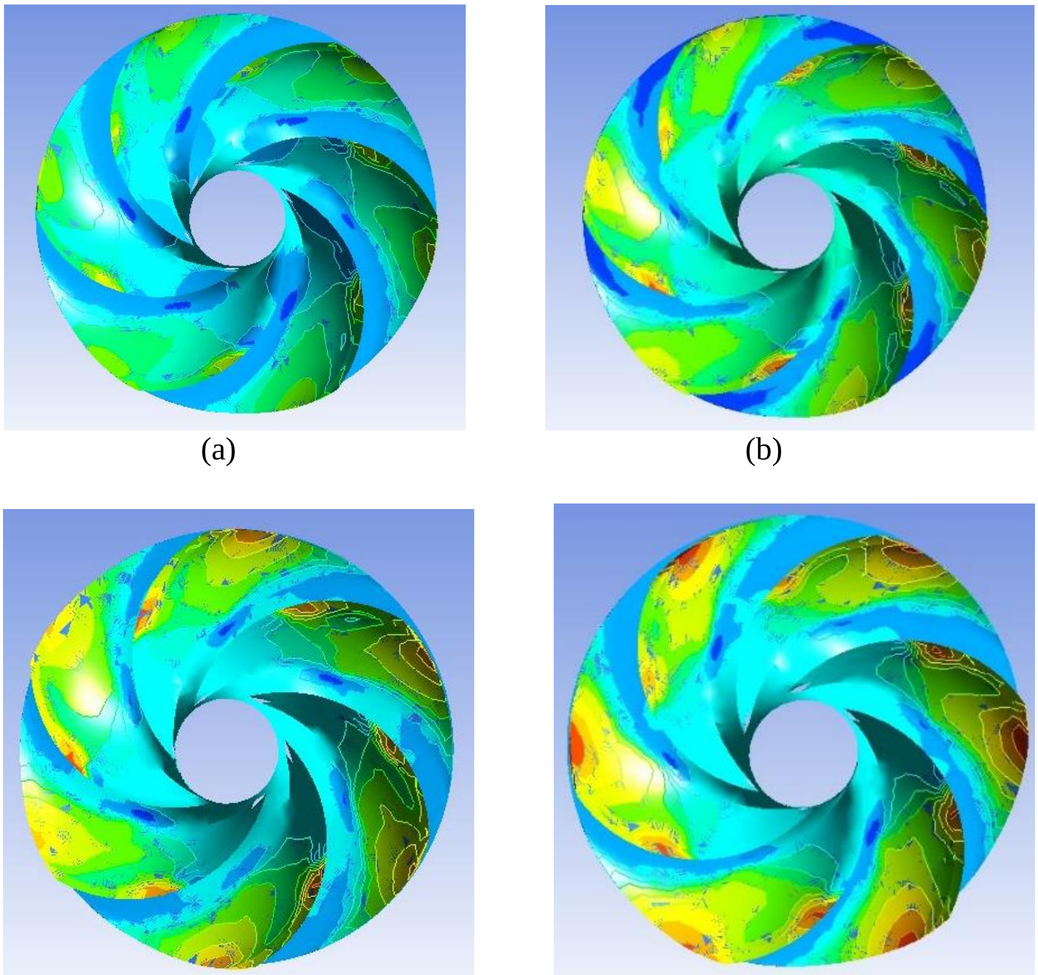

Fig. 4 - Distribution of Cavity Volume Fraction in Impeller. (a) H_{NPSHa} = 2.09 m, (b) H_{NPSHa} = 1.43 m, (c) H_{NPSHa} = 1.32 m, (d) H_{NPSHa} = 1.21 m

Fig.4 reveals the distribution of cavity volume fraction in the centrifugal pump at low flow rate. The positive incidence is formed at the impeller inlet when the pump works under low flow rate condition. There will be a local area of low pressure at the impeller inlet on the back of blade due to flow separation. Thus, the decrease of NPSHa, a cavity first appears on the side of the blades and gradually grows upward. As shown in Fig. 4 (a) and (b), at which time there is no significant drop of the pump head. When the NPSHa decrease to 1.32 m and 1.21 m, a large area of cavity emerges on the impeller.

Furthermore, the cavity begins to expend from the side of the blades to the middle of the channel as shown in Fig. 4 (c) and (d). With further decrease of the NPSHa, the cavitation inside the impeller is aggravated and a cavity begins to occur on the pressure surface of the blades. The cavity area expends sharply, thus the impeller channels become seriously blocked, which result in the drastic falling of the pump head.

4. Conclusion

This computational fluid domain (CFD) method acquired the cavity volume and pressure behaviour of the pump impeller. The effect of the cavitation occurs was then analysed. The values of H_{NPSHa} were made decreased from 2.09 m to 1.21 m. The higher the magnitude of the H_{NPSHa}, the less cavitating flow was going to occur. The results showed a cavity first appears on the suction side of the blades and gradually grows to the centre channel of impeller blades. The results shows that impeller with 2.09 m of NPSHa has the smallest of distribution of cavity volume fraction. The cavitation inside the impeller is worsened when the H_{NPSHa} decreases more. The cavitation bubbles get larger as a result of this situation and the impeller channel become severely blocked. Due to this analysis, the lowest the H_{NPSHa} values, the bigger the vapour volume fraction occurred. To improve the pump performance, the H_{NPSHa} must be increased to increase the pressure at the suction of the pump. Cavitation occurs because there is not enough pressure at the suction end of the pump and will lead to fluctuating pressure, mechanical damage, vibration, noise and pump failure. However, several improvements can be made through this study to achieve a better result. As for recommendation, further research can attempt or perform an experiment to investigate the cavity volume that occurred in the pump impeller with different values of H_{NPSHa} and also can make a comparison between experimental and simulation analysis to obtain the result whether it agrees with each other. Because the different values of NPSHa will affect the result differently, all of this can help researchers to come out with better and reliable research.

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