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A Computational and Experimental Evaluation of the Performance of a Conical Hollow Shaped Impeller for Pump

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Abstract

An experimental study of the performance of a conical hollow shaped impeller for pump has been carried out at King Mongkut's University of Technology Thonburi. The conical hollow shaped impeller is an innovative design for pump. The pump is for agricultural use. The impeller is formed from a single sheet metal. The pump impeller diameter is 139 mm with 4 blades, truncated cone height (h) of 97.71 mm. The pump mid-span blade inlet and outlet angles are 2.73 and 12.74 degree, respectively. In this study, the flow patterns throughout the pump are visualized by numerical flow simulations (a commercial code: CFX). The comparison between CFD predictions and experiments are highlighted. The results showed that CFD can predict the flow patterns with accuracy for the model. The pump best efficiency point (BEP) gives efficiency of 39.54% at volume flow rate of 0.03 m3/s, head of 2.26 m and break power of 1.73 kW. The specific speed (Ns) of the pump is 2.48. The predicted performance by numerical was in good agreement with experimental results. The numerical simulation of pump can give a good significant to understand the pump flow phenomena, when the fluid enters into the impeller and receives the energy transfer by means of rotating blades. This revealed that the flow in the impeller was reversed and recirculated especially in base height (H) and impeller hub. These help significantly to understand the flow and to improve the design of a conical hollow shaped impeller for pump.

***Keywords**:* conical hollow shaped impeller, pump performance, CFD, flow patterns, JIS-pump test

1. Introduction

Computational Fluid Dynamics (CFD) has been widely used for designed and predicted characteristic of various turbomachines. This is because it can be implemented of complex geometry with accurately and fast outcome. The predicted flow fields help significantly to understand the flow and to improve the design of turbomachines. To correctly predict flow fields, it is absolutely necessary to model the correct geometry of the entire pump including the inlet and outlet pipes [1].

The Thai-made irrigation pumps (Tor Payanak) have been well known among Thai farmers since developed for over 50 years [2]. A summary of design and operation of the pumps was described excellently by Fraenkel [3]. The applications to determine the flow characteristics of pump have studied by many authors. Kaewprakaisaengkul [4], Kasantikul and Laksitanonta [5,6] investigated on the Thai-made irrigation pump (Tor Payanak) efficiency by CFD method.

In this study, a conical hollow shaped impeller is designed for farm pump that is appropriate in paddy-field working environment. The original design was performed by using CFD code [7]. The results from CFD reveal that the performance of the pump was dependent on flow rate which was affected as impeller height was changed. The influence of height causes the pump to develop pressure in a given flow rate. But the change in height of each design to the pressure development along the impeller was not greatly affected. This means that the flow rate of the pumps vary with height value. The variation of pressure development, on the other hand, was not greatly affected. The present work continues to improve the pump performance by CFD. The predicted flow fields by the CFD in the previous design pump were investigated. Focusing the pump impeller, suppression of separation and exit flow uniformity, these are leading to the modification with high-performance impeller and pump inlet cover plate. To confirm the new design, the pump performance has also been compared with the experiment measurements.

2. Numerical Flow Simulations

The computational domain is included 3 sub-domains (the inlet pipe, the impeller and the outlet pipe) as shown in Fig. 1. The impeller diameter is 139 mm with 4 blades. Its truncated cone height (h) is 97.71 mm. Each sub-domain is connected by domain interfaces to complete the entire domains. The flow in the impeller is computed in the rotating frame of reference, while the flow in the rests is calculated in the stationary frame of reference. Steady state calculations were performed for relative positions between the impeller and the outlet pipe in a frozen position. By this method together with correct geometry are necessary to correctly predict the flow fields [8, 9].

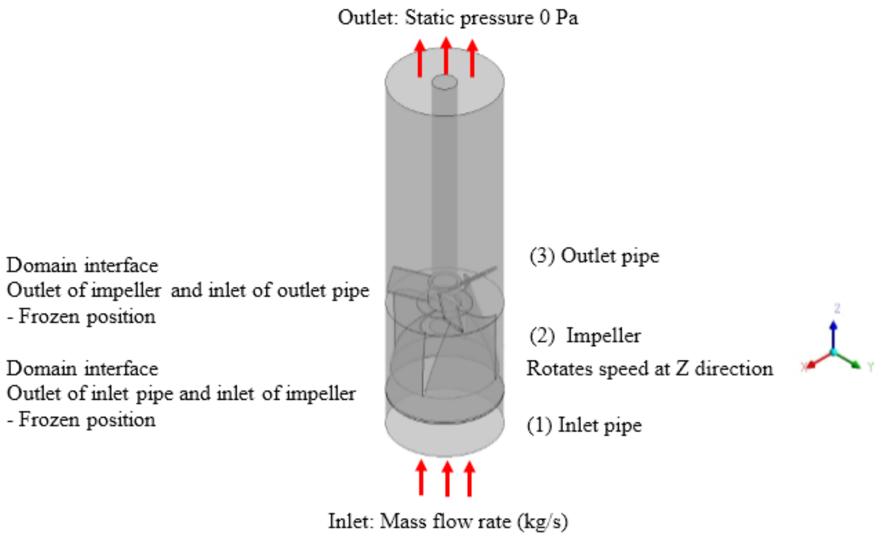


Fig 1. Solid model assembly of the conical hollow shaped impeller for pump

Asvapoositkul and Sanghirun [7] investigated on impeller height to the pressure development by CFD method. Their results showed that the change in height of each design to the pressure development along the impeller is not greatly affected.

3. Concepts of Developing Efficiency Pump Components

The flow physics within a conical hollow shaped impeller has been investigated in the previous study [7]. The impeller diameter is 139 mm with 4 blades. Fig 2 (a) illustrates a G2 impeller which resulted from the previous investigation.

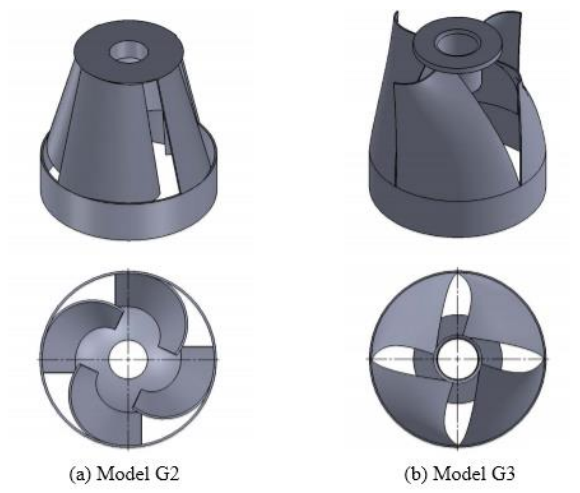


Fig. 2 The shape of impeller (a) original design (b) modified design.

In this study the improvement of pump performance particularly focused on impeller with blades inclined to the axis of rotation and the inlet cover plate. This is because the previous study revealed that the flow in the impeller showed strong three-dimensionality and non-uniform especially around the inlet and the leading edge of the impeller (see Fig. 3-4). In those regions the flow separation was also observed. The velocity vectors directed toward to the tip of the blade. This is due to the effect of secondary flows and high pressure generated near the pipe wall.

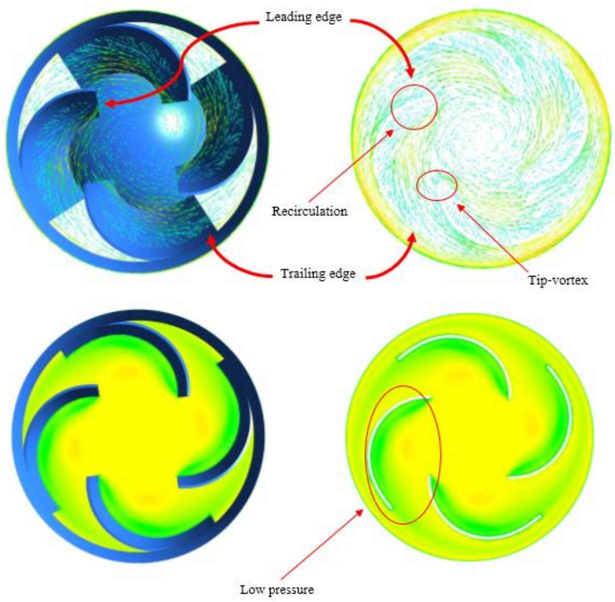


Fig. 3. Velocity vectors and pressure contour at BEP of model G2 in mid-height, Z = 0.102 m

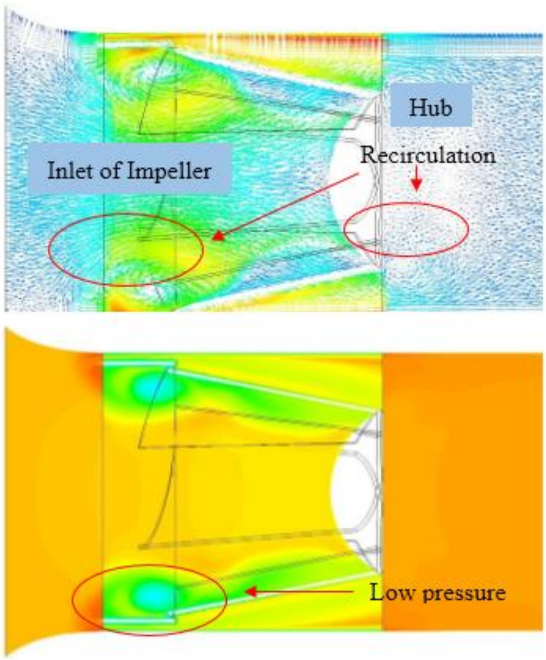
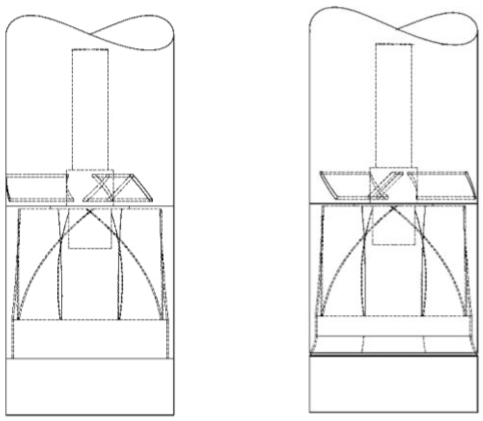


Fig. 4. Velocity vectors and pressure contour at BEP of model G2 in along center-line, Y=0

3.1 Impeller

Comparisons and reviews dealing with on the designs of pump impeller can be seen in Stepanoff [10]. It indicates that high-performance impeller can be designed with blades slightly brought towards hub. The manufacturing of the blade is also simple with this impeller since there is no protruding blade surface into the suction chamber at the truncated cone height. In this study the impeller blades incline at mid-span blade inlet angle of 2.73 degree and outlet angle of 12.74 degree. The outlet area is also slightly increased. The impeller blades before (Model G2) and after modifications (Model G3) are shown in Fig 2.



(a) Model G3 (b) Model G3I

Fig. 5 The shape of inlet pipe (a) without cover plate (b) with cover plate

3.2 Cover plate

The cover plate is the part of the inlet pipe at the suction which is closest to the blade inlet pipe. In the previous study the inlet pipe has brought a curve to a straight parallel to the blade inlet pipe, while the improved design the cover plate is extended a curve to the blade inlet pipe. The difference design is shown in Fig. 5.

4. Pump Performance Curve

The efficiency of the pumps Model G1 (original design), G2, G3 and G3I from computation is shown in Fig. 6. By visual comparative, one can see that overall pump performance is improved with Model G3I. The results indicate that Model G3I operates with high efficiency at high flow rate compare to other Models. It is interesting to observe from this study that the performance of the pump is dependent on flow rate which is affected as designs are changed. In order to visualize the results of change in inlet guide, Models G3 and G3I results at BEP were analyzed in the followings.

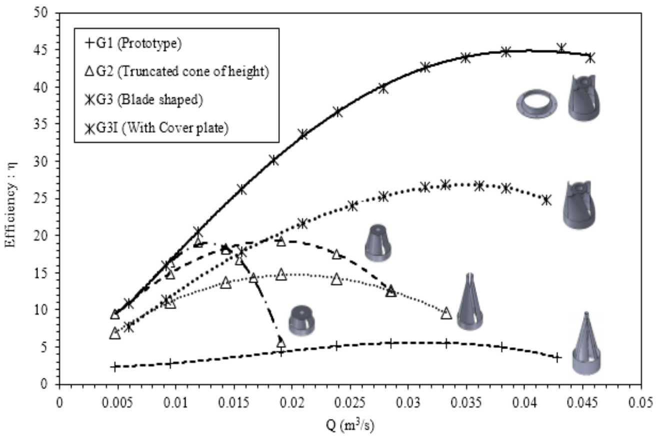


Fig. 6. The Efficiency of model G1, G2, G3 and G3I from computation

5. Flow Fields Analysis

The numerical results were obtained for the design point. Fig. 7-8 presents the velocity vectors and pressure contour predicted by CFD, which shows the flow pattern inside impeller before (Model G3) and after installation with cover plate (Model G3I). Details of flow fields analysis and pressure development of Model G1 and G2 can be seen in [7] and [11]. The quality of flow is judged from the plots through the impeller. Although the flow rate was that for the design point, a large separation vortex was observed in Model G3 especially at blade near the inlet pipe. Those intensities were reduced in Model G3I. On visual inspection, it was found that cover plate (Model G3I) reduces the strong cross flow at suction region near the blade pipe (as shown in Fig. 7) with more uniform flow (as shown in Fig. 8). Fig. 9 presents the pressure development along the flow path of each Model at BEP. The variation of pressure development of Model G3I at the suction side is smoothly changed compare to that of Model G3. As the consequence the variation of pressure development of Model G3I at the discharge is slightly higher than that of Model G3.

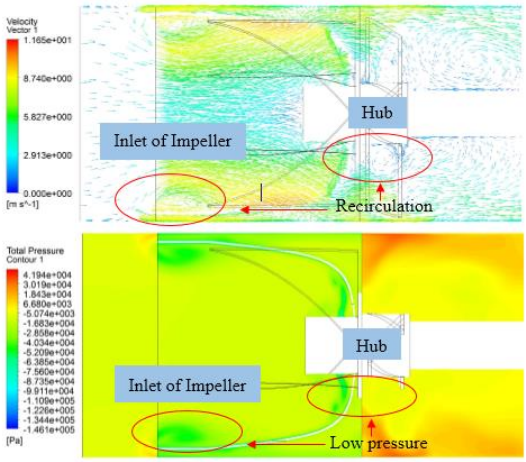


Fig. 7. Velocity vectors and pressure contour at BEP of model G3 in along center-line, Y=0

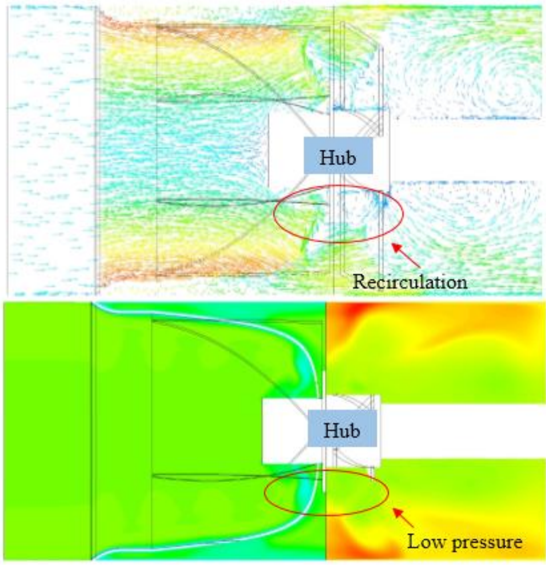


Fig. 8. Velocity vectors and pressure contour at BEP of model G3I in along center-line, Y=0

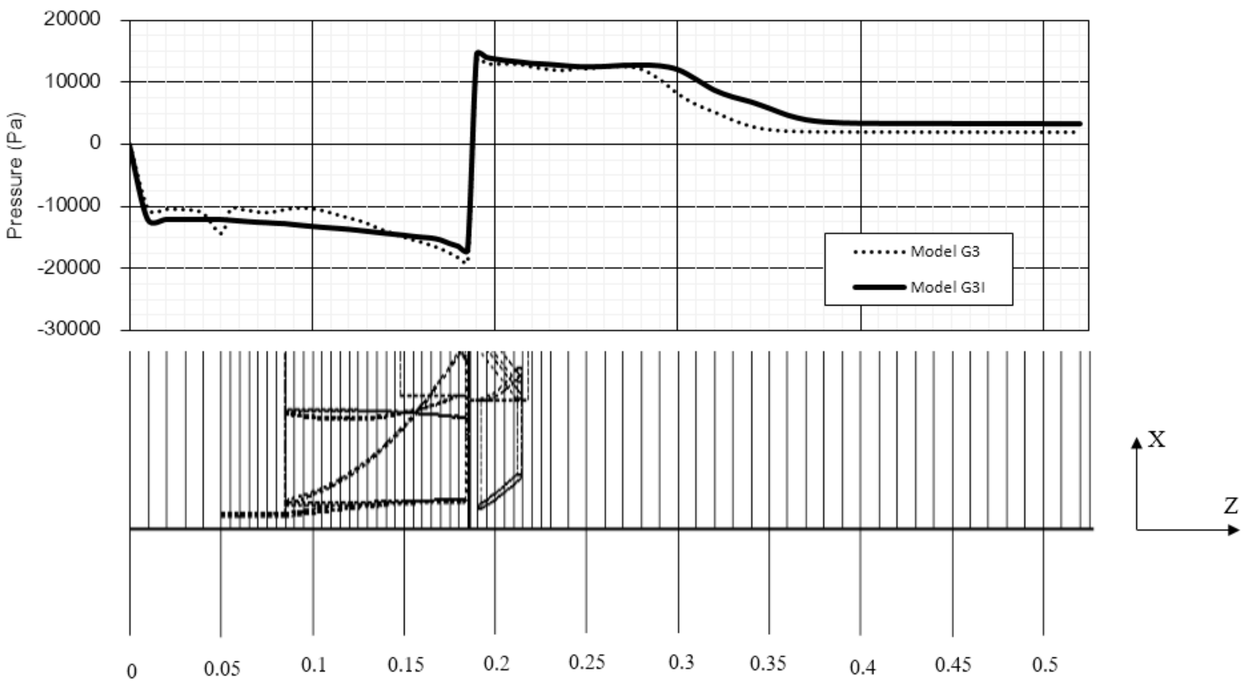


Fig. 9. Pressure development along the flow path of model G1 and G3I at BEP

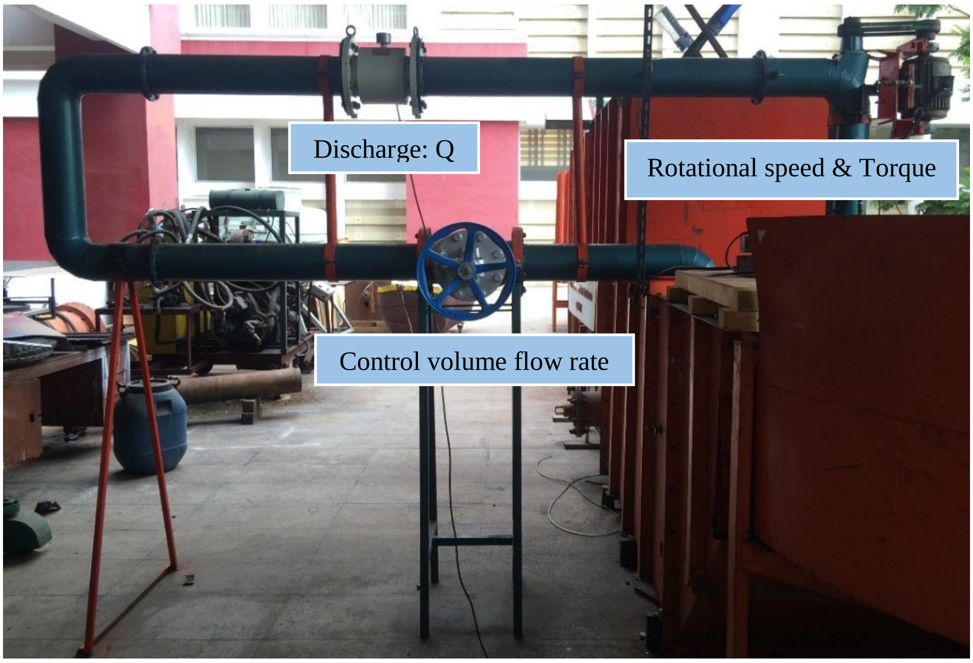


Fig. 10. Experimental setup of a conical hollow shaped impeller for pump

6. Experimental Validation

The conical hollow shaped impeller Model G3I was built for the test rig as shown in Fig.10. The experiments was performed according to JIS B 8301 2000 standard [12]. The comparison of the pump performance rating base on experiment and that from computation is shown in Fig. 11. The plots are in term of head coefficient [H* $= \dfrac{gH}{N^2D^2}$], power coefficient [P* $= \dfrac{P}{\rho N^3 D^5}$], flow coefficient [Q* $= \dfrac{Q}{ND^3}$], and efficiency. The results from CFD are slightly lower predicted by 11.44% for head coefficient, and by 16.38% for power coefficient at BEP. But the results form CFD are slightly higher predicted by 7.5% for efficiency at BEP.

The results show that when the flow coefficient increases, the head coefficient decreases but the power coefficient slightly changes. The maximum efficiency is at high flow coefficient. This is the main feature of an axial flow pump that the blades are designed to operate efficiency at high flow rate.

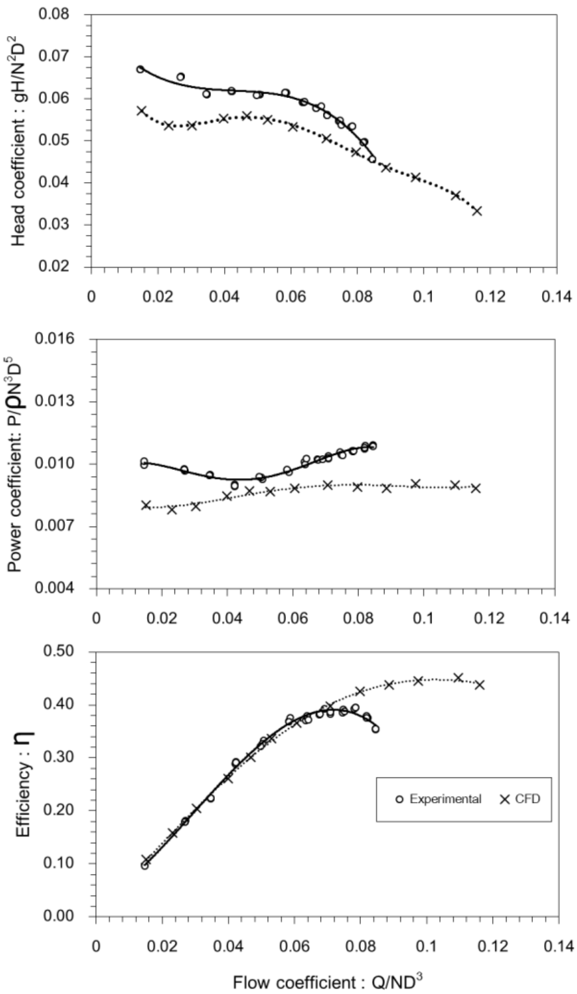


Fig. 11. Comparison pump characteristics of experimental and numerical results

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7. Concluding Remarks

A conical hollow shaped impeller for pump was analyzed using CFX software. The predicted flow fields by CFD gives a lot of potentially very useful information for improving the pump. The improvement efficiency can be obtained by the reduction of the flow losses. The intensity of secondary flows has an important effect on the flow filed at the exit of the impeller. The improving of the pump with the modification of blade shape and pump cover plate. It shows that the efficiency of Model G3I (modification of blade shaped with cover plate) is higher than those in Model G3 (modification of blade shaped). Moreover the secondary flow level of Model G3I is decreased. The experiments measured the flow and performance of the pump under a variety of operating conditions. Comparison of the pump test results with those of a computer simulation has demonstrated the validity of that simulation and its use as a design tool.

8. Acknowledgement

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