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Effects of Splitter Blade Length on Disc Pump Performance

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Abstract: The disc pump operates using boundary layer principle and viscous drag with a relatively low efficiency. There are methods to increase head and efficiency, one of them is the placing of blades sectors or splitter blades in discs. This method has been applied only in the low viscosity fluids pumping ($v<0.1$ stokes). This study describe an experimental research in a hight viscocity fluid ($v = 2$ stokes) with exit angle $\beta_2 = 35°$ and different splitter blades Lengths (Ls) (75, 50, 25%). The purpose is to determinate the splitter blades length that achieves the most effective combination between the blade effect and boundary layer effect in order to increase the energy transmission efficiency from the impeller to the fluid. As result, it can be established that the use of spliter blades is an alternative to increase the performance of the disc pump. The highest efficiency and head were obtained for the gapsize between two discs (b) of 12 mm using a 50% spliter blades length of the main blade length.

Key words: Pump, disc pump, splitter blades, boundary layer, viscous drag, blades lenghts

INTRODUCTION

In sugar mill and other industries use pumps with low wear resistance, high initial cost and construction complexity. The disc pump can be the solution of these problems. These equipments are increasing their use in different flow processes, for example, as an element used in a chemical reactor in air purifier and in sugar mill. This pump model implies that in gapsize between discs, a steady-state fully developed laminar flow of a viscous incompressible fluid occurs.

Parallel discs that form the pumping mechanism of the disc pump rotate in a plane perpendicular to the pump inlet. A boundary layer forms on the disc surfaces it transfer energy from rotating discs to successive fluid layers which are parallel to the discs. The force created by this boundary layer combination and viscous drag propels the fluid through the pump in a smooth and pulsation-free flowing (Fig. 1) (Pacello and Hanas, 2000).

The fundamental difference between the disc pump and an estandar centrifugal pump impeller is that with the discpump the pumpage does not affect on the rotating pump mechanism, so that it generates a pulsation-free, laminar flow pattern through the pump. The disc pump lacks an impingement device with minimal contact between the pump and the product being pumped. This feature makes it to operate effectively in hard-to-pump applications (Pacello and Hanas, 2000). The macro scale disc pumps cannot compete in efficiency with centrifugal pumps therefore they were relegated to special applications (Oliveira and Pascoa, 2009).

In disc pumps, the volute diffuser must handle the flow with a very small inlet angle it causes that volute works inefficient. That is why viscous disc pumps have much lower efficience that the expected from considerations of the flow in the rotor (Dolgushev and Khaidarov, 2001). Other reason that have a negative effect on energy efficiency is that the disc pump has wide internal clearances. Also, in water-like applications the downside is that wider clearances reduce the pump's efficiency (PCI., 2001). One factor that hinders its implementation as new technology in some systems of viscous fluids pumping is limiting in terms of head and efficiency to meet the requirements of that systems (Martinez-Diaz, 2000).

Some research has been carried out in order to increase the disc pump efficiency. One of them is related to the placement of turbulizators elements at the discs outlet (Martinez-Diaz, 2000). Another research is based on the adding splitter blades in the pump disc. For the hight viscosity fluids pumping ($v>0.1$ stokes) with disc pump there is not information about the effective splitter blade lenght, the number of them (Zs) and the outlet angle (β_2). In the case of centrifugal pumps, if several researches have been carried out to determinate the effect of the splitter blades on pump perfomance.

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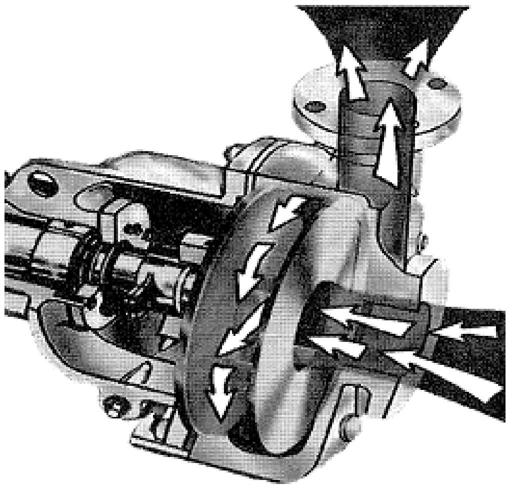

Fig. 1: Cross-section in a disc pump

Splitter blades in centrifugal pumps: Azuaje adopted numerical method to analysis the effect of splitter blade on the internal flow of centrifugal impeller and the whole flow field with specific speed of 117 which proved that adding splitter blades could improve pump performance by increasing the slip factor on the design point.

Miyamoto *et al*. (1992) examined the influence of splitter blades on flow and performance, measuring velocity and pressure in unshrouded and shrouded impeller passages. The length of the splitter blades used was approximately 60% of the length of the main blades. Yuan (1997) showed that, the use of splitter blades is one of the techniques to solve three hydraulic problems of low specific speed centrifugal pumps (relatively lower efficiency, drooping head-flow curve and easily overloaded brake horsepower characteristics). The radial length of the splitter blade was fixed at 70% of the main blade length or 50-75% of the impeller outlet diameter. He pointed out that the effects of splitter blades on pump performance depend primarily on the circumferential position and then on the stagger angle. Other contributory parameters include the inlet diameter and the fixing situation. Also, Yuan (1997) suggest that the use of splitter blades with larger discharge angles may be preferred to get better results, especially for impellers with a large number of blades. Jeon (2005) revealed that the splitter blades impeller influences the acoustic characteristics, reduce the slip phenomena and raise the performance of the centrifugal fan.

Kergourlay *et al*. (2007) obtained as most important result that with the adding of splitter blades where the pressure fluctuations decrease and the vibrating acceleration level and radiated noise is minimized.

Based on a great amount of experiments and theoretical research, splitter blades are often adopted in order to increase efficiency or decrease energy consumption in centrifugal pump. Adding splitters can reduce the span of low-speed zone; increase the slip factor which mean to increase the head. To obtain better pump performance with splitter blades at design point it is necessary a reasonable splitters length and inlet deviation. While, the design criteria for deviation still need further research it is clear that adding splitters can reduce the span of low-speed zone, increase the slip factor which mean to increase the head (Jianping *et al*., 2007).

Djebedjian (2009) revealed that the improvement in rapid drop of the head was achieved with the 50% splitter blades lenght of de main blades lenght. The power consumption increases with the increase of the length of the splitter blade. For the efficiency, the splitter blades Ls = 0.8 Lb result in an increase in the efficiency at the best efficiency point from 49.71-56.08%.

Yuan *et al*. (2009) carried out Computational Fluid Dynamics (CFD) simulations with different splitter blade length. Results showed that for an impeller with splitter blades the "jet-wake" flow at the impeller outlet is improved and the velocity distribution inside the impeller is more uniform. This explains why impeller with splitter blades shows higher head and efficiency.

Golcu *et al*. (2010) investigated the effects of the splitter blade length on the pump performance in a semi-open impeller with splitter blades using an Artificial Neural Network (ANN). The data in this study have been obtained from a previous study where the performance values for lengths of splitter blades in ratio of 1/3, 2/3 and 3/3 of the main blade length, since, the experimental studies to determine head, efficiency and effective power in applications with splitter blades are complex, time consuming and expensive. The effects of lengths of splitter blades in ratio of 3/6 and 5/6 of the main blade length, on the pump performance have been estimated by using the best ANN Model (Goral, 2000).

Li (2011) demostrated that in low viscosity, the optimal blade exit angle for best efficiency occurs near 30° but while it increase viscosity it prefers to be large one. For the experimental pump maximum efficiency is obtained at $\beta_2 = 25°$ for $v = 180$ mm^2/sec and for $v = 255$ mm^2/sec the peak efficiency is achieved at $\beta_2 = 60°$.

Babayigit *et al*. (2012a, b) studied periodic analysis of the 4 and 5 bladed configurations with adding splitter blades using CFD. It was found from the overall analysis results that the 4 bladed configuration with Ls/Lb = 0.7 splitter blade and the 5 bladed configuration with Ls/Lb = 0.6 splitter blade yield the most suitable efficiency values, respectively.

Xu studied 5 and 6 bladed impeller configurations. They found that the 5 bladed configuration has improved the efficiency by 1.1~2.9%. Zhou *et al.* (2012) investigated the length of the splitter blades on the 6 bladed impeller configuration. They found that the head has improved slightly while there was almost no change in hydraulic efficiency.

Gjernes (2014) revelated that splitter blades can definitely improve significantly the wear characteristics in a slurry pump. Furthermore, they do not affect the performance of the pump with respect to efficiency. The recommendation is that splitter blades are beneficial to slurry pump impeller designs, especially, when the vanes are very wide. Using optimization, it can be determined an optimal location for the splitter blades to reduce the wear keepling performance efficence.

Jingchun (2012) patented blood pump with splitter impeller blades, splitter stator vanes and manufacturing methods. The mixed flow impeller includes both principle blades and splitter blades, the splitter blades exhibiting a shorter axial length than the principle blades. For a long term implantable blood pump is required high efficiency, low blood damage and smooth operation at design and off-design conditions. High efficiency is achieved with the inclusion of splitter blades for impeller and stator.

Sensel and Kowalak (2012) patented a vortex pump impeller using primary blades in combination with splitter blades. An increase in total head is observed through exemplary impellers in a vortex pump, compared to an impeller lacking the splitter blades. The splitter blade length is 45-50% of the main blades.

Jinfeng *et al.* (2013) studied the influence of adding splitter blades on the performance of low-specific-speed centrifugal pump model IS 50-32-160, using a numerical method. For the splitter solution, the impeller outlet velocity is increased with splitter blades and converted into pressure energy through volute, the resulting pumping head, discharge ability through volute throat and operating range are improved. This is because-flow velocity at impeller outlet is higher when it is compared with that without splitter blades. The influence of splitter blades can be interpreted as follows: average pump head has been increased 4~15%, the pumping head increases with the increase of discharge and the H-Q curve turns flatter. The efficiency at large discharge are improved and keeps higher at a wider range.

Pranit and Todkar (2013) contributed giving an idea about the previous researches and their finding about study of effect of splitter blades on the centrifugal pump performance. The impeller slip factor increase with the head grow, however, that reduce efficiency. This also leads to reduce the pressure fluctuation, hence, decreases the vibration acceleration. The effects of lengths of splitter blades in ratio of 3/6 and 5/6 of the main blade length on head, efficiency and effective power is as shown in Table 1.

Table 1: Performances of splitter blades

B.E.P.	Hm (m)	η (%)	Pe (kW)
Without splitter blade	33.86	39.80	5.56
K = 3/6	34.48	38.90	5.80
K = 5/6	34.69	38.47	5.90

Where Q = 400 Lpm.K = Ls/Lb

Shigemitsu investigated pumps with simple structure and splitter blades to improve the performance and the internal flow condition in a mini centrifugal pump. It was found from the experimental results that the half of the main blade length was the best blade length of the splitter blade in 3 types of rotors having splitter blades lengths from 1/2-1/4 of the main blade chord length.

Three impeller schemes were proposed based on a model pump IS50-32-160, one without splitter blades and the others with different inlet diameters splitter blades (Zhang *et al.*, 2014). The characteristics of internal flow and the pump cavitation performances at different NPSHA with the CFD technique were carried out using numerical simulations. Results showed that the additional splitter blades had positive effect on the pump cavitation performance if the inlet diameter of the splitter blade is properly selected. The head of the pump model is not only increased by 2-12% with the splitter blade, however, its H-Q curve became flatter.

Cavazzini *et al.* (2015) carry out an experimental and numerical comparison between centrifugal impeller pumps with and without splitter blades in terms of suction performance. Results showed that the incidence flow angle of relative velocity in the impeller pump was related with the trend of the NPSH exhibited.

Vasava and Mital (2015) showed that, splitter blades addition is an easy alternative to increase centrifugal perfomance and having length about half of main blade, the pressure fluctuation decrease, total pressure losses are reduced and increase pump efficiency at high flow rate.

Golcu and Pancar (2005) perfomed several impeller with different splitter blades length, i.e., 25, 35, 50, 60 and 80% of the main blade. They found that splitter blade is seen to be useful when discharge blade angle is low also, they found that power consumption decrease and overall efficciency increase in the best efficiency point.

Korkmaz *et al.* (2017) studied the effect of the number of blades (z = 5-7), blade discharge angles ($\beta_2 b = 25°$ and $\beta_2 b = 35°$) and splitter blade lengths 40, 55, 70 and 85% of the main blade length on deep well pump. As a result the highest efficiency was obtained on the impeller with the number of blades z = 6, blade discharge angle $\beta_2 b$ = 250 and 85% splitter blade.

MATERIALS AND METHODS

Influence of the splitter blades on the pumping effect: When a fluid flows through betwen blades channels (Cherkasski, 1986), three currents are created as shown in Fig. 2. The translation current I is directed from the center to the periphery, the velocities are radial and correspond to the continuity equation. The rotational movement II that is conditioned by the inertia of the liquid and circulation current III that is related to Zhukovski's theorem with the difference of pressures between the working surfaces and the back of the blades:

- I: Radial movement
- II: Rotational movement within impeller passageway
- III: Circulation around the blades related to Zhukovski's theorem

The action of the circulation (Γ) causes a decrease in relative speed in the face of work of the blades and increase in the back face, against the direction of rotation. This creates a pressure drop that becomes a force. Pfleiderer (1960) also define the pump theorical head as:

$$H = \mu\eta_h.\frac{\omega}{2.\pi.g}.(\Gamma_2 + \Gamma_1) \quad (1)$$

Where:

- η_h = Hydraulic performance
- μ = Coefficient that takes into account the finite blades number
- ω = Angular velocity
- g = Gravity aceleration
- Γ_1 = Circulation at the impeller inlet
- Γ_2 = Circulation at impeller outlet

In Eq. 1, it is observed that the pump head depends of the difference between the circulation at the impeller outlet (Γ_2) and the circulation at the impeller inlet (Γ_1). The inclusion of splitter blades in the periphery of the discs, Fig. 3 contributes to the creation of circulation current III, Fig. 2 related to the Zhukovski's theorem and therefore the pump head and efficience is increased.

In the present research is studied the effect of adding splitter blades to disc pump with a high viscosity fluids (Molasses B) to t = 52°C the temperature of molasses in the sugar industry. The variables analized was the splitter blade length (Ls and gapsize between two discs (b).

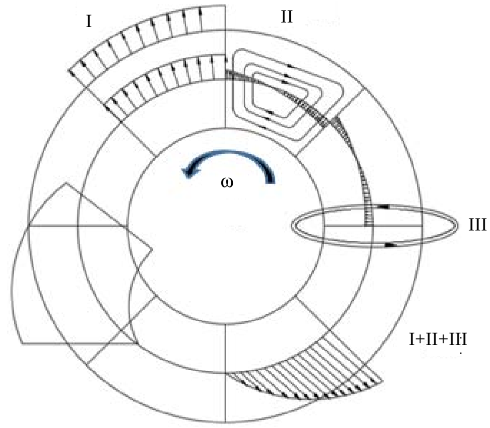

Fig. 2: Relative movements within impeller passageway

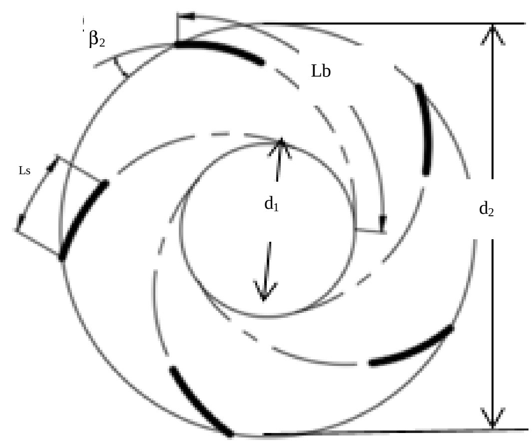

Fig. 3: Disc with splitter blades

Experimental procedure: The dimensions of the impellers are: Outside diamter (d_2) = 272 mm, Inside diameter (d_1) = 110 mm, Number of splitter blades (z) = 5, Outlate angle β_2 = 35° and the Angular velocity (w) = 183 sec^{-1}.

The values of gapsize between discs (b) were taken 4 and 12 mm. The value b = 4 mm is obtained from equation for the optimum gapsize between two discs (bop) (Misyura *et al*., 1986). This equation takes account the fluid kinematic viscosity value and the angular velocity value of the discs. The value b = 12 mm corresponds to a greater value than gapsize optimum betwen discs and smaller than the width of the volute. The splitter blades length where 75, 50 and 25% of the length of the main blade for centrifugal impeller of the same dimensions. The kinematic viscosity for Molasses B is v = 2.4 stokes. According to the before six experiences were planned as follows in Table 2. Six impellers with splitter blades were manufactured. The disc with splitters blades is showed in Fig. 3.

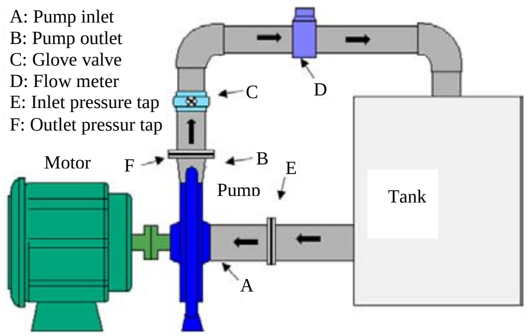

Fig. 4: Experimental setup

Table 2: Experimental plan

Experiment	Splitter blade lenght (Ls) (%)	Gapsize between discs (b) (mm)
1	75	12
2	50	12
3	25	12
4	75	4
5	50	4
6	25	4

Table 3: Measured variables

Variables	Descripcion
p_d	Discharge or oulet pressure (MPa)
p_s	Suction or inlet pressure (MPa)
Q	Pump flux (l/sec)
P_e	Electric Power (kW)
I_1, I_2, I_3	Phase current (A)
V	Line voltage (V)

Experimental setup: The experiments were performed in the experimental setup as seen in Fig. 4. Some interest variables measured during the experimentation are presented in Table 3.

The uncertainty of the flow and head measurements were estimated to be 0.65 and 0.53%, respectively and the uncertainties in power consumption and efficiency were calculated as 0.44 and 0.13%, respectively.

RESULTS AND DISCUSSION

The experimental information using a conventional algorithm according to hydraulic performance acceptance tests, grades 1-3 for pumps assessment were processed (ISO, 2012).

It was not possible to evaluate the combinations of different gapsizes between discs with splitters blades with a lenght of 75% due to the very unstable work of the pump and its power high consumption under those conditions. The Head (H) and efficiency (η) versus flow (Q) curves for other experiments are shown in Fig. 5 and 6.

Figure 5 shows the Head (H) versus flow (Q) curves for different evaluated variants. It can be observed that

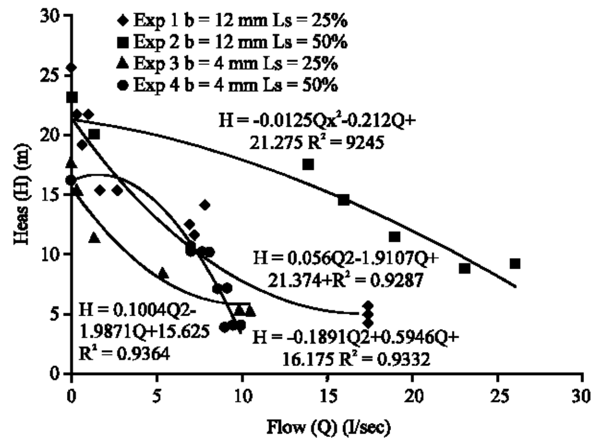

Fig. 5: The effect splitter blades lenght on the disc pump head

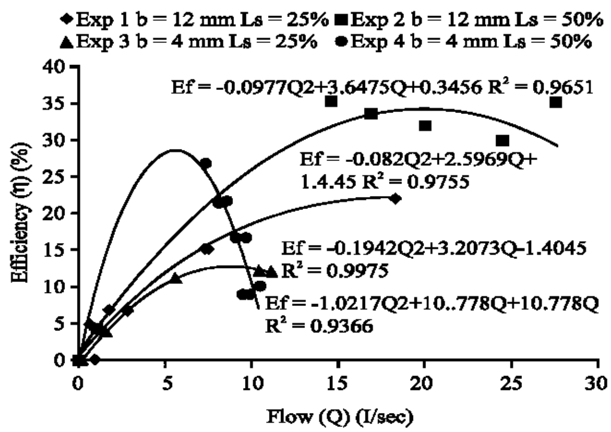

Fig. 6: The effect splitter blades lenght on the disc pump efficiency

the best result in terms of head was the experience 2 corresponding to lenght of splitters blades of 50%. In this case, the blade effect with the boundary layer effect is effectively combined.

A splitter blade length reduction from 50-25% of the main blades length produces a change in the head versus flow curve from exponentially to parabolic funtion. This change in Fig. 5 between the curves of the experiences 1 and 2 and between curves 3 and 4 is observed. In the first case, for splitter blades length 50%, the shape of head versus flow curve is similiar that shape head-flow curve of centrifugal pump. In the case splitter blades lenght 25% a marked disc pump behavior is observed according to (Misyura *et al.*, 1986).

When splitter blades are added to a disc pump, the optimum gapsize between discs (bopt) cannot be calculated by the expression given by Misyura *et al.* (1986). In this case, a better result is obtained with gapsize between discs greater (b = 12 mm) than the optimum gapsize between discs (b = 4 mm). The above by comparing the head versus flow curves of experiments 1-3 and 2-4 in Fig. 5 is observed.

In Fig. 6, describe the splitter blades length increase from 25-50% for gapsize betwen disc b = 12 mm an increase efficiency in 12% at the Best Efficiency Point (BEP).

CONCLUSION

The addition of blade sectors in the discs of the disc pump is a way to increase the head and efficiency. The efficiency was observed to increase with increasing splitter blade length up to 50% for all gapsize betwen discs perfomed.

Splitter blades lenght greatter than 50% of the main blades lenght decrease the disc pump efficiency. The case of gapsize betwen discs b = 12 mm and splitter blades length 50% results in the best performance for all flow value obtained.

The disc pump can operate with at least a 50% splitter blades length and space between discs b = 12 mm in B- molasses systems in sugar industry for head of 15 m and flow of 12 l/sec. These head and flow value are the required value in that system (Martinez-Diaz, 2000).

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