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Full Length Research Article

Comparative study of various centrifugal pumps for energy saving opportunities

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Abstract

Centrifugal pumps are the most common types of the pumps used in the agriculture fields. If they are of proper size, design and of good material then they may lead to high efficiencies. In Pakistan most of farmers use pumps which are less energy efficient. The issue of less energy efficiency in tube wells is mainly due to mismatch of motor power with the size of impeller. Due to high energy requirements the most commonly used centrifugal pumps are working far away from their best efficiency point (BEP) and impart extra economic burden on the farmers. Now it is the time to study the pumps properly and adopt potential energy saving opportunities like "Impeller trimming". Whereas trimming of impellers is common practice that is used to adjust pump characteristics like flow rate and head to actual requirements. In this study it was tried to compare the "Energy Efficiency" of local made centrifugal pumps. Pump characteristics curves of different sized centrifugal pumps and same pump with different impeller diameters were drawn to compare them. A centrifugal Pump having size (100 mm× 125 mm) was tested with impeller diameters (222, 212, 195 and 180 mm). Pump showed discharges (42.64 ℓps, 8.81 ℓps, 36.79 ℓps and 31.19 ℓps) and power requirements (16.6 Amp, 14.6Amp, 10.8 Amp and 8.5 Amp) respectively. From above it was found that the reduction in discharge was 11.45 lps (27 %) which was less as compare to reduction in power requirement 8.1 Amp (49 %) as we reduced the impeller diameter from 222mm to 180 mm. Similarly it was observed that large sized pump (125 mm×150 mm having efficiency 76.48 %) were more efficient as compared to small pump (63 mm×75 mm having efficiency 63.18 %).

Keywords: Impeller trimming, Pump efficiency, Pump curves, Energy efficiency
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Introduction

In Pakistan irrigation requirements for agriculture sector are mainly fulfilled by both canal water and tubewells whereas tubewells are diesel or electrically operated. Tube wells were introduced in 1953-54 in country and by using tube wells only 0.24% area was covered. Numbers of tube wells were 86611 in 1960 and with the increase of 11 times became 921229 in 2010 (GOP, 2010). Pakistan has best irrigation system but as it is not available to all parts of the country. So, it was suggested to use ground water in those parts by using tubewells (Aurangzeb, 2007).

In Pakistan mainly tubewells are mounted with 1.5 kW to 18.7 kW motors or 9 kW to 18.7 kW diesel engines. Annual operating hours are about 1600 for electric tube wells while 700 in case of diesel tube wells. Mostly farmers use the pump set that are less efficient due to incompatibility of impeller diameter with motor power (Qureshi *et al.* 2003).

European Commission (2003) published a report on the topic "Study on Improving the Energy Efficiency of Pumps". They selected centrifugal pumps which were newly manufactured and old ones and then analyzed them. Main purpose of this study was to know the reasons why pump efficiency decreases over the time. After their research they found the following important points:

1. Efficiency of a pump decreases when a pump is operated away from its BEP (best efficiency point).
2. Same pump with small impeller (not away from recommendation) can give good performance at lower duty.
3. Better pump selection could give 3% energy saving.

Evans (2012) found a Centrifugal pump having BEP efficiency with 13.21 ℓps was 70 % which dropped to 63 % when flow was above 12.58 ℓps or blew 11.95 ℓps showing very narrow range of BEP. To determine the breadth or range of high efficiency on both sides is an important factor.

Vogelesang (2008) reported that the design of a centrifugal pump mainly based upon the impeller design which allows pump manufacturers to produce pumps those can work efficiently under local conditions. Before selection of a centrifugal pump its performance curves are examined. These curves show the pumps capacity, efficiency input power requirement, head and discharge required.

Chunxi *et al.* (2011) studied the performance of a centrifugal pump with enlarged impeller size and unchanged casing type of G4-73. Comparison was done by taking original impeller and other two impellers with decrease in diameter 5% and 10% respectively. Results showed that efficiency was decreased with decrease in diameter and other factors like flow rate, total pressure, shaft power and sound pressure all decreased but considerable reduction in power requirement.

Yang *et al*. (2012) conducted an experimental and numerical investigation on impeller trimming technique to know the effect on a single stage centrifugal pump. The results showed that pump used as turbine shifts the flow rate at BEP (best efficiency point) from 26.45 ℓps to 24.06 ℓps and then back to 26 ℓps with efficiency dropped by 4.11% as impeller is trimmed from 225 to 215 mm.

Houlin *et al.* (2010) took four different impellers having 4, 5, 6 and 7 numbers of blades and other design factors kept constant. It was found that with increase in the number of blades, head always increased but change in efficiency of pump was complex. When 7 and 5 blades were used Optimum efficiency founded while on other hand good cavitation characteristics were found with 5 and 4 blades.

Materials and methods

Eight number of pumps were divided in two groups. In first group there were four pumps with same casing size but four different sized impellers while in second group there were four different casing sized pumps with full impeller diameters.

Pressure head measurement

A digital pressure gauge was fixed on the delivery side and pressure reading was converted in to head.

Suction depth and Gauge height

Suction depth and gauge height were measured with the help of a measuring rod.

Pipe friction losses

Pipe friction losses were directly measured by using different pump losses graphs. Pipe friction losses depend upon the;

i. Pipe inner diameter
ii. Flow rate through pipe
iii. Age of pipe
iv. Material of pipe

Check valve losses

Swing Check valve was used and its head loss was measured by using following equation

$$H_l = V^2 \times \zeta_{nrv} \times \frac{1}{2g}$$

$$V = \frac{4Q}{\pi D^2}$$

Here,
H_l = Head loss due to non return valve in (m)
V = velocity in $(m\,S^{-1})$
ζ_{nrv} = non return valve coefficient
Q = discharge in $(m^3 S^{-1})$
g = gravitational acceleration = 9.81$(m\,S^{-2})$
D = inner diameter in (m)

Reducer losses

Here during testing procedure two reducers, one on suction side and one on delivery side were used. Head loss due to reducer was directly proportional to the velocity head and depends on;

(a) Ratio of the pipe diameters e.g. diameter of pipes before and after the reducer.
(b) Angle of enlargement

It can be determine by using formula

$$H_l = K\left[\frac{V^2}{2g}\right]$$

Where,
K = Resistance coefficient

Note: Resistance coefficient can be determining using diameters ratio (D_2/D_1) verses angle of enlargement in degrees table.

Bend losses

When flow direction of water is changed, due to loss in energy, fluid pressure is dropped. In pump testing procedure, a bend was used. Head loss due to that bend was measured in similar way as that of loss due to reducer. Head loss in bend was inversely proportional to the angle of bending and directly proportional to velocity head loss.

Pump testing procedure

First of all, the pump to be tested was taken to the test bench. Pump suction and delivery sides firmly bolted with suction and delivery pipe lines. A gas kit was placed on both sides to avoid leakage. Pump was connected to the power supply and then pump was allowed to run at its full capacity by opening the valve cock fully at delivery side. Different parameters (pressure, discharge, rpm, volt and current) were measured. The same procedure was repeated by gradually closing the valve cock and 7-10 readings were noted. The last reading was noted when the valve cock was fully closed. Suction depth and gauge height were also measured for further calculations. Total head was measured by using the formula.

Total dynamic head (TDH)

It was calculated as

$$\text{Total dynamic head (TDH) in (m)} = \text{Head lose due to all types of losses in (m)} + \text{Pressure head in (m)} + \text{Suction depth in (m)} + \text{Gauge height (m)}$$

Water Horse Power

The power added to water as it moves through a pump can be calculated with the following formula

$$WHP = \frac{(Q \times TDH \times 9.81)}{1000}$$

Where,
Q = Flow rate in (ℓps)
TDH = total dynamic head in (m)
WHP = water horse power in (kW)

Break Horse Power

The horsepower required at the pump shaft to pump a specified flow rate against a specified TDH is the Brake Horsepower (BHP) which is calculated with the following formula

$$BHP = \frac{WHP}{Pump\ Eff. \times Drive\ Eff.}$$

BHP = mechanical energy in hp supplied to pump shaft from motor.

Motor Efficiency

Efficiency of the drive unit between the power source and the pump. For direct connection this value is 1, for right angle drives the value is 0.95 and for belt drives it can vary from 0.7 to 0.85. In this study, the efficiency of motor is assumed 0.8.

Pump Efficiency

Efficiency of the pump is usually read from a pump curve and having a value between 0 and 1. It can be measured by using following formula

$$Pump\ Efficiency(\eta) = \left(\frac{WHP}{BHP}\right) \times 100$$

Where
BHP (break horse power) = Power input to pump by motor in (kW)
WHP = water horse power in (kW)

Overall pumping system efficiency

It is the combination of both pump and motor efficiencies and can be determined by using following formula

$$Total\ Efficiency = Pump\ Efficiency \times Motor\ efficiency$$

Pump performance curves

Pump performance curves especially Q-H Curves were drawn for each pump and then overlaid those to compare variation with pump size and variation in impeller size with same pump size using excel software. In this way variations in efficiencies of newly manufactured centrifugal pumps were observed, analyzed and compared.

Results and discussion

The comparison of group one pumps is given below:

Comparison of characteristics of pump size 100 mm × 125 mm with four different Impeller sizes

Four impellers having different diameters i.e. 222 mm, 212 mm, 195 mm and 180 mm were installed in same sized pump casing of 100 mm× 125 mm. The performance of centrifugal pump with these trimmed impellers was compared by drawing characteristic curves in Fig.1.

It is clear from Figure 1 that head and discharge are different for different impeller diameters. The largest impeller of 222 mm diameter showed highest head at all points of discharge as compare to other impellers. Lowest results of head and discharge showed by impeller of 180 mm because of lower diameter as compared to other three impellers.

Figure 2 shows that how electrical power is affected by different impeller sizes. Figure 2 shows that pump with impeller size 222 mm takes maximum current at maximum and minimum discharge e.g. 16.6 and 11.1, respectively as compared to the other impellers. As the diameter of impeller reduces, the load on pump also decreases continuously. Load on pump having impeller diameter 180 mm is minimum e.g. 8.5 amp at maximum discharge and 5.5 ℓps at shut off point where discharge is minimum. Pumps with impeller diameters 212 mm and 195 mm showed intermediate results.

Figure 3 shows that maximum efficiency achieved by pump with impeller diameter 222 mm was 78.53 %. As impeller diameter trimmed continuously, reduction in efficiency was observed. Best efficiencies by pumps with impeller diameter 212 mm, 195 mm, 180 mm were 71.83 %, 68.89 % and 67.11 %, respectively.

Comparison of Characteristics of different sized centrifugal pumps

In second group four centrifugal pumps with different sizes of their casing i.e. 125 mm× 150 mm, 100 mm× 125 mm, 75 mm× 100 mm, 63 mm× 75 mm were selected for their testing on test bench. After testing the performance of these centrifugal pumps compared by drawing following characteristic curves and charts.

Fig 4 shows that pump casing size and discharge are directly proportional to each other and similarly casing size is directly proportional to head.

As results are showing in figure 5 that maximum efficiency was achieved by pump with body size 125 mm × 150 mm was 76.48 %. As pump size decreased efficiency was also decreased continuously. Best efficiencies showed by pumps with pumps 125 mm× 150 mm, 100 mm× 125 mm, 75 mm× 100 mm,63 mm× 75 mm were 76.48 %, 72.59 % and 63.55 % respectively.

Conclusion

1. With the decrease in impeller diameter from 222 mm to 180 mm discharge was decreased from 42.64 ℓps to 31.19 ℓps and power requirement also decreased from 16.6 Amp to 8.5 Amp respectively.
2. It was found that the reduction in discharge was 11.45 ℓps (27 %) which was less as compare to reduction in power requirement 8.1 amp (49 %) as we reduced the impeller diameter from 222mm to 180 mm.
3. Large sized pumps were more efficient as compare to small sized pumps e.g. pump having size 125 mm × 150 mm achieved maximum efficiency 76.48 % in second group and similarly other pumps with sizes 100 mm× 125 mm, 75 mm× 100 mm,63 mm× 75 mm gained maximum efficiency as 72.59 %, 63.55 % and 63.18 % respectively.
4. It was also noted that pump with impeller diameter 222 mm diameter achieved maximum efficiency 78.53 %.
5. At shut off point all pumps showed maximum head.

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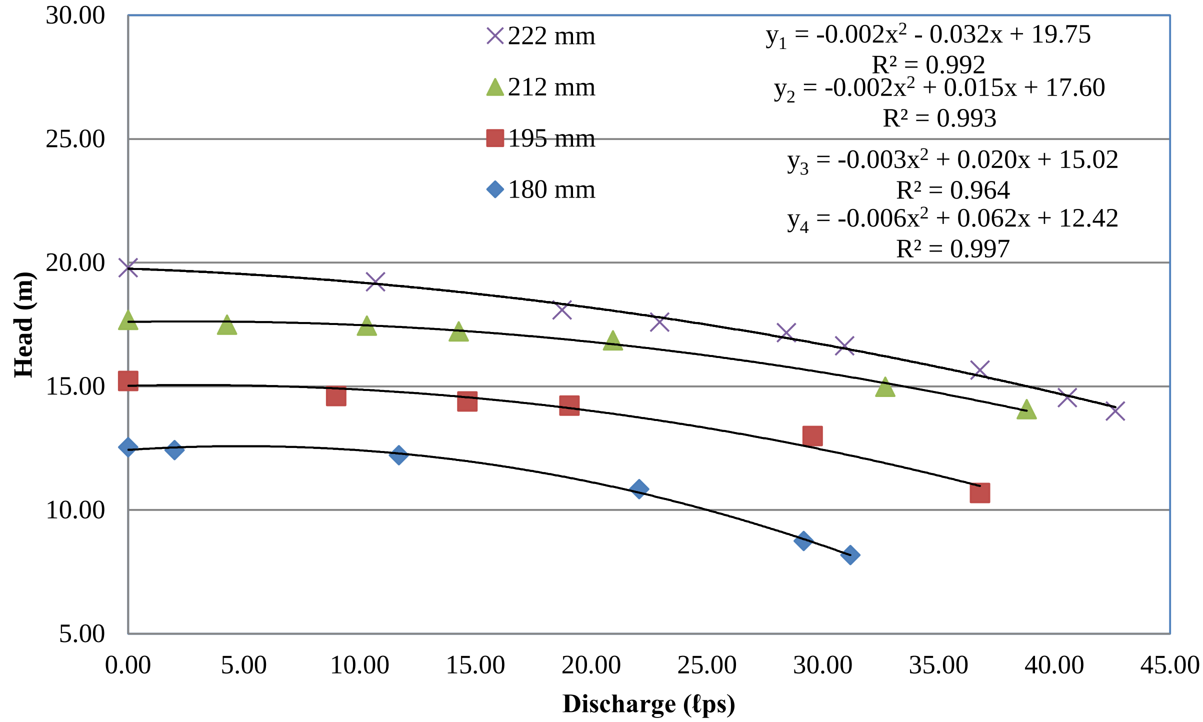

Fig. 1 H-Q Curves of pump size 100 mm× 125 mm with different impeller diameters

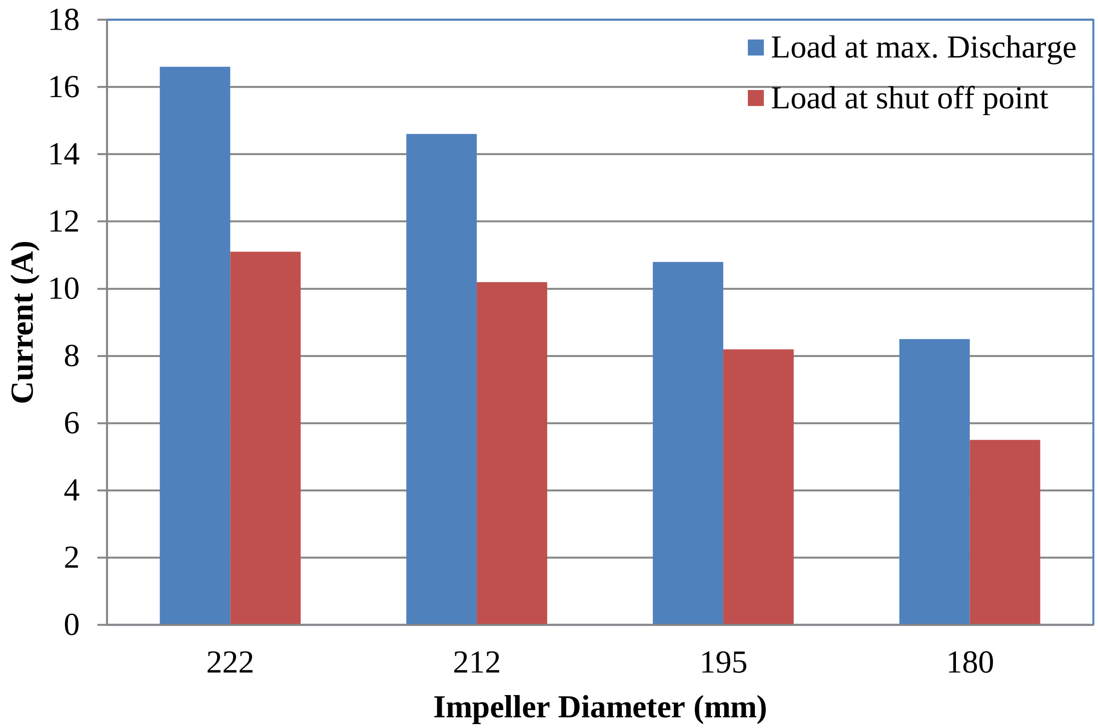

Fig.2 Current drawn at maximum and minimum discharge by pumps VS impellers diameter

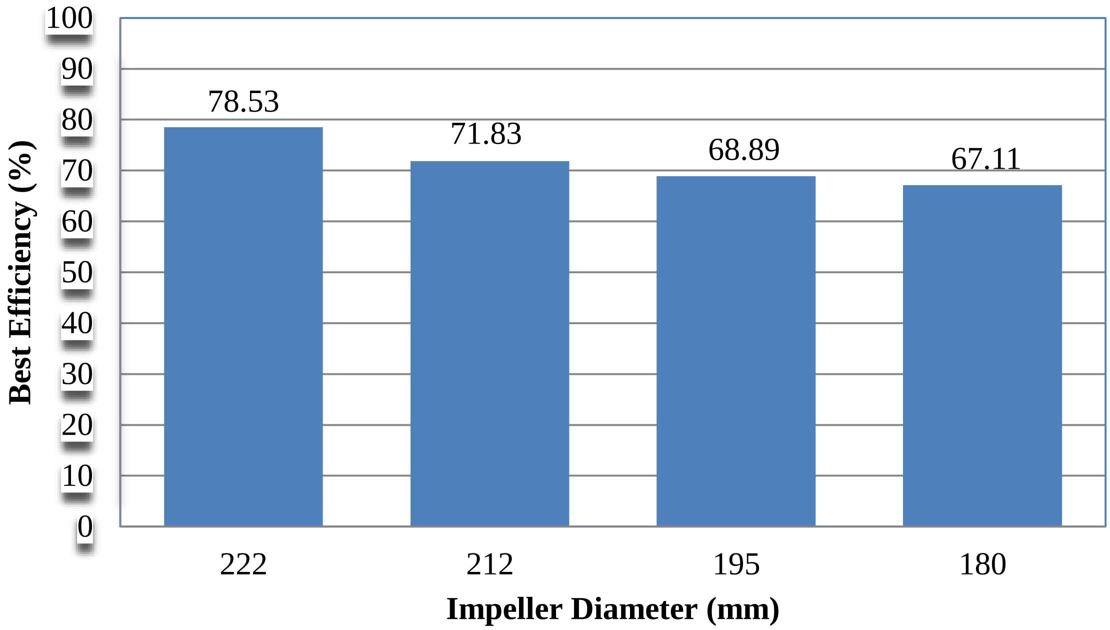

Figure- 3: Best efficiency attained by 100 mm× 125 mm pump with different sized impellers

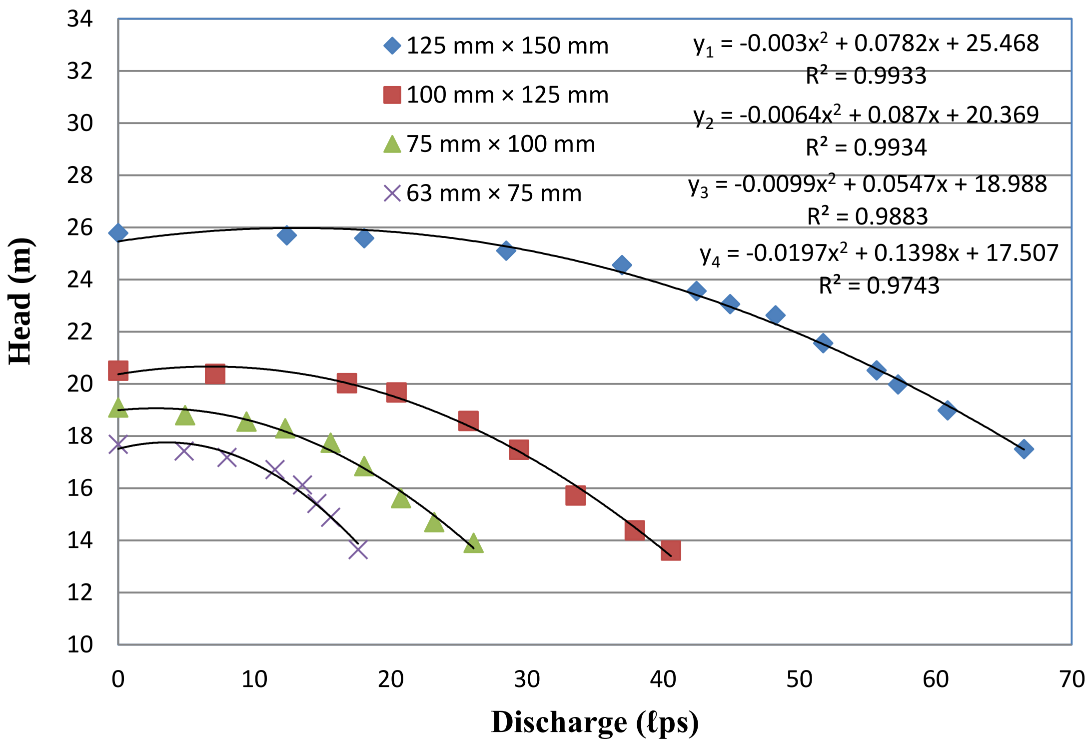

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Fig. 4 H-Q Curves of pumps with different body sizes

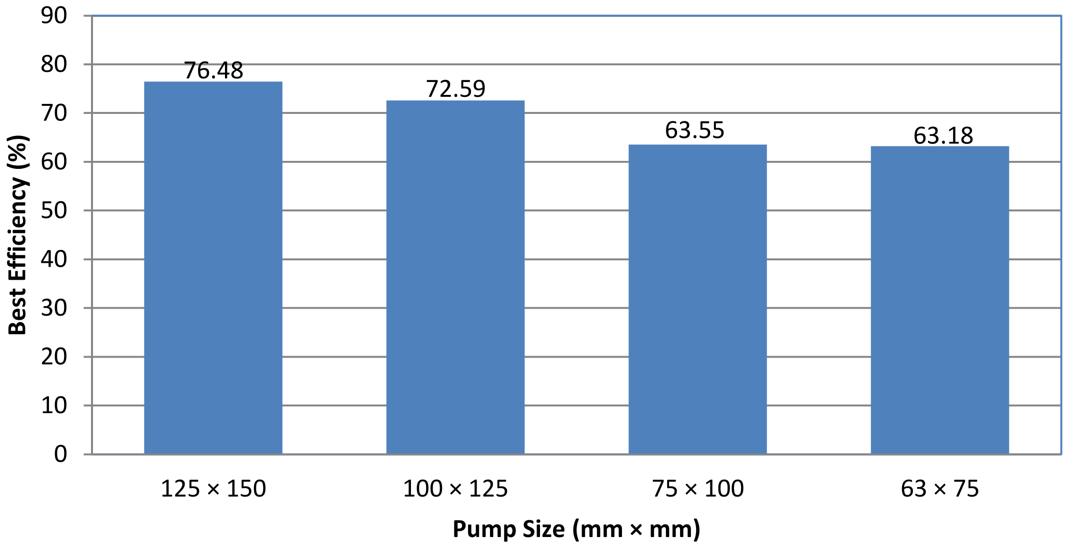

Fig. 5: Best efficiency attained by pumps with different sizes