

CHAPTER 3

EXPERIMENTAL RESULTS

Chapter (3)

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3.1. Introduction

In this chapter, the experimental results of the pump in direct (pump mode) and reverse (turbine mode) modes are discussed. Complete characteristic curves; head vs. flow rate, power vs. flow rate and efficiency vs. flow rate for both modes are plotted and the results are analyzed. Then, the relation between the two groups of curves are discussed. The effect of changing the speed of rotation for both modes is studied for 2000 RPM and 1700 RPM. In addition, the validity of the results comparing with the mentioned correlations in the last paragraph of chapter (1) are studied.

3.2. Pump Mode

Operating conventional centrifugal pumps as turbines took place widely unlike the inline centrifugal pumps which weren't used before as a turbine. The experiments tested the ability of an inline centrifugal pump to be used as a turbine for two sets of rotational speeds.

For pump operation, the pump was stable during the experiments along the two rotational speeds of the test. Experimental results show that as the flow rate increases, the head will decrease as shown in Figure (3-1) which is a consistent to the reality. The test was performed for two different speeds 1700 RPM and 2000 RPM. The results, for each speed of rotation, show a reasonable trend. The maximum head was 5.5 m for the 2000 RPM curve and 4m for the 1700 RPM curve. It is well observed from the curves that the 2000 RPM curve is shifted up from the 1700 RPM one which means that for the same flow rate the head given by the pump at the higher speed is increased. The measurement of the flowrate, head and power were made for about ten times for different delivery valve openings. A curve fitting from the second degree was plotted for all the graphs in order to draw the complete curve from the scattered points.

In addition, the power input to the pump was measured for the same two speeds. The mechanical power entering the pump was not measured because of the small size of the pump shaft which did not allow a disk friction dynamometer to be fitted between the pump and the motor working as a generator. If a dynamometer was fitted it couldn't allow to take many readings as the power of the motor is very low (about 70 watts maximum). Instead of measuring the mechanical power, the electrical power input to the motor was measured. Hence, the input power was measured for the whole unit (i.e. pump and motor) using AVO meters. It is observed that at both speeds of rotation, as the flow rate increases the input power increases as shown in Figure (3-2). The maximum power obtained was 72 watts for 2000 RPM curve and 40 watts for the 1700 RPM curve. In addition, the curve shifts up as observed from Figure (3-2) when the speed of rotation of the motor is increased the flow rate is increased.

Ultimately, the efficiency at small flow rates starts to increase till reaching its maximum value at the Best Efficiency Point (BEP) and then starts to decrease as shown in Figure (3-3). The maximum efficiency was 26% for the 2000 RPM curve and 22% for the 1700 RPM curve. Moreover, the efficiency curve is shifted up as the speed of rotation is increased due to the reduction in friction

at higher speeds. The maximum efficiency. Concerning the 2000 RPM curve, the flowrate at the BEP was 1.62 m³/hr, the head was 3.8 m and the power was 68 watts. Additionally, the flowrate was 1.5 m³/hr, the head was 2.2 m and the power was 40 watts at the BEP of the 1700 RPM curve. The pump specific speed for 2000 RPM and at the BEP is 15.535 (m, m³/s) and 20.08 (m, m³/s) for 1700 RPM.

3.3. Turbine Mode

The turbine mode characteristic curves were plotted for two different speeds of rotation of the motor as a generator. For turbine operation, the experimental results show that when the flow rate increases the head also increases as well as shown in Figure (3-4) as expected. The test was performed for the same speeds as the pump mode. The (H-Q) curve should be started from zero flow rate but due to friction occurred. It started from a value of 2.7 m³/hr for the 2000 RPM curve and 2.6 m³/hr for the 1700 RPM curve as the friction increases while increasing the RPM. The minimum head was 4.2 and 3.3 m for 2000 RPM curve and 1700 RPM respectively. It can be noticed that while increasing the RPM the curve is shifted up which means that for the same flow rate the head at the higher speed is increased as illustrated in Figure (3-4). Moreover, while increasing the flow rate for a certain RPM the head is increased as mentioned before.

On the other hand, as the flowrate increases the power increases as shown in Figure (3-5) which corresponds to 1700 RPM and 2000 RPM. The minimum power was 32 watts and 24 watts for 2000 RPM curve and 1700 RPM respectively. In addition, increasing the RPM shifts up the power curve as happened in pump mode as illustrated in Figure (3-5).

At small flow rates, the efficiency first increases till reaching a maximum at its Best Efficiency Point (BEP) and then decreases like pump mode. The efficiency curves for 1700 RPM and 2000 RPM are illustrated in Figure (3-6). The efficiency curve starts from a flow rate value other than zero because of friction. The maximum efficiency is 25% for the 2000 RPM curve and 23% for the 1700 RPM curve. The efficiency curve is shifted from zero to the right as the speed of rotation is increased due to the expected increase in friction as shown in Figure (3-6). Concerning the 2000 RPM curve, the flowrate at the BEP was 3.3 m³/hr, the head was 6.2 m and the power was 55 watts. Additionally, the flowrate was 3.4 m³/hr, the head was 5 m and the power was 42 watts at the BEP of the 1700 RPM curve.

The turbine operation was stable except at high flow rates because of the vibration. In addition, high flow rates and high pressures affected the electrical circuit components specially the controller and the rectifier badly as they were heated up which may affect some readings.

In case of pump operating in reverse mode (PAT), when the rotational speed is increased the head is increased for the same flow rate. On the other hand, the head is increased while increasing the flow rate unlike the direct mode.

3.4. Pump Mode versus Turbine Mode

The experimental results of the pump at direct and reverse modes assures that operating inline centrifugal pumps as turbines gives reasonable results and are applicable for low power systems specially.

Concerning (H-Q) curves, the pump as a turbine curve is obtained when extending the flow axis into its negative values which represents the reverse operation of the pump as illustrated in Figure (3-7). In addition, the power increases with increasing the flow rate in direct and reverse modes. The increase of the turbine mode is steeper than pump mode as shown in Figure (3-8).

The efficiency curves of both modes have the same behavior. The maximum efficiency in both modes for a single speed of rotation is approximately the same as shown in Figure (3-8).

For the 2000 RPM curve and at the BEP; the flowrate of the turbine mode is about twice the flowrate of the pump mode. Moreover, the head of the turbine is about 1.65 the head of the pump mode. Additionally, the power of the turbine is about 0.81 the power of the pump mode at the BEP.

On the other hand, for the 1700 RPM curve at the BEP; the flowrate of the turbine mode is about 2.26 the flowrate of the pump mode. Moreover, the head of the turbine is about 2.27 the head of the pump mode. Additionally, the power of the turbine is about 1.05 the power of the pump mode at the BEP.

From the previous results, it is well observed that using pumps as turbines is applicable for this special type of centrifugal pump (Inline pump). The Inline pump efficiency is low but this did not affect the conversion from a pump to a turbine.

The experimental results of the pump at direct and reverse mode resemble S. Derakhshan et. al. curves [17] as shown in Figures (3-10 to 3-12).

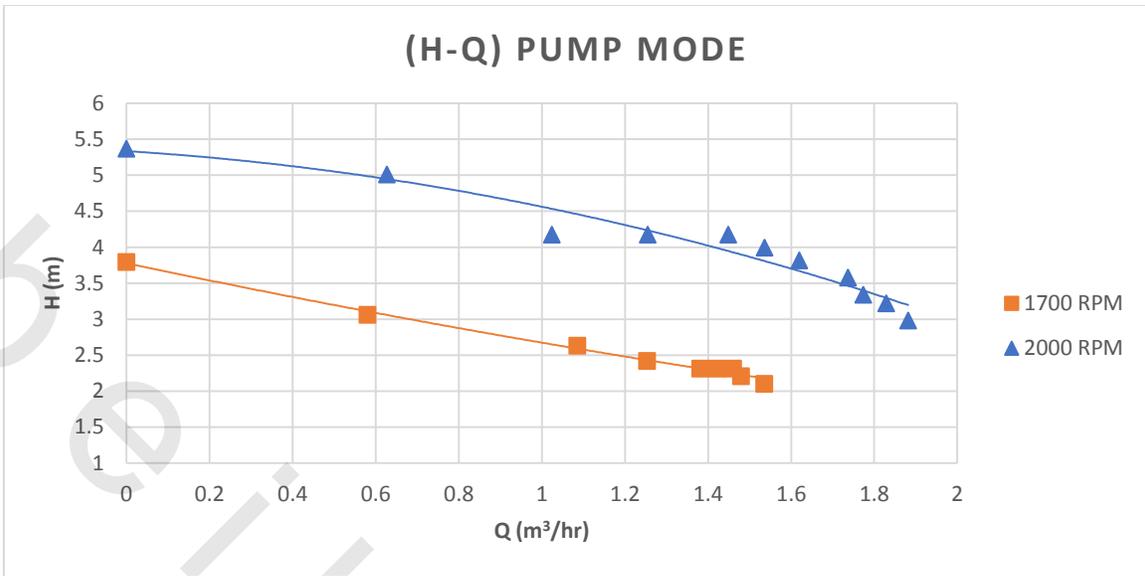


Figure (3-1) Head versus flow rate for pump mode at 1700 and 2000 RPM

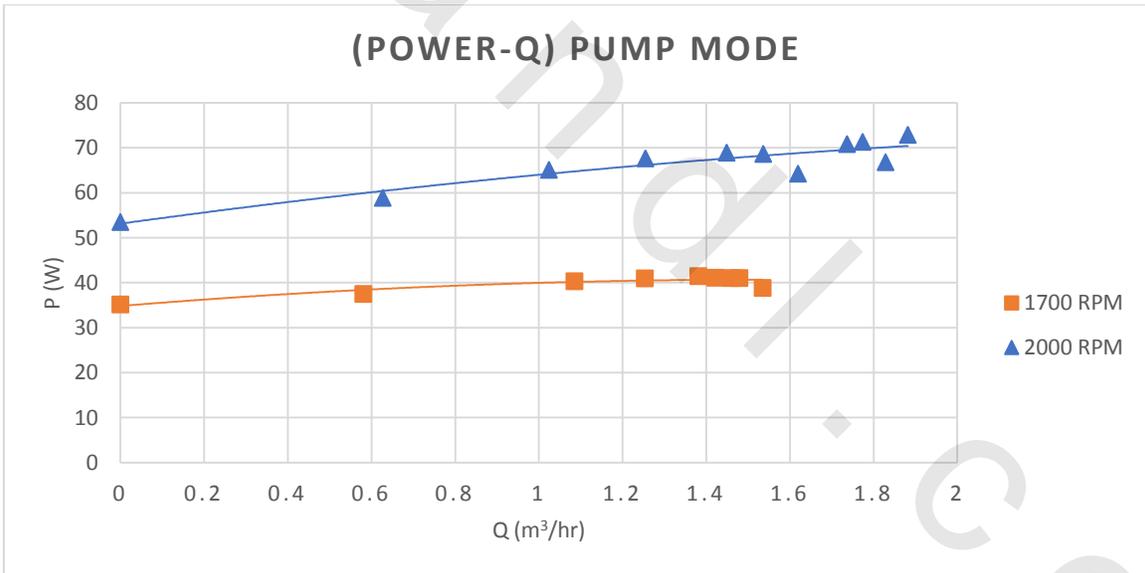


Figure (3-2) I/P power to the motor versus flow rate for pump mode at 1700 and 2000 RPM

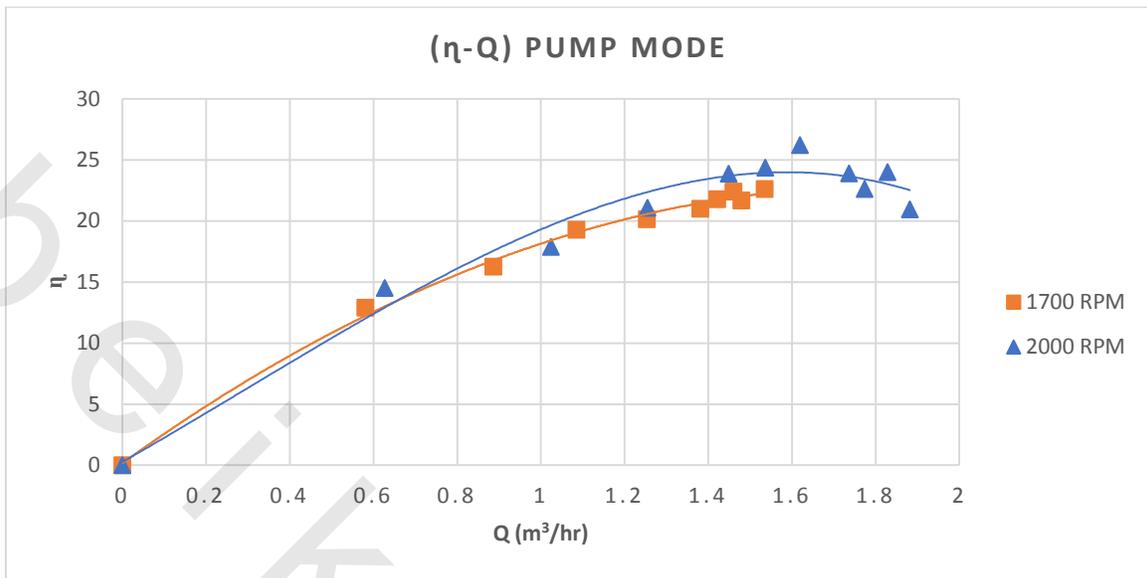


Figure (3-3) efficiency versus flow rate for pump mode at 1700 and 2000 RPM

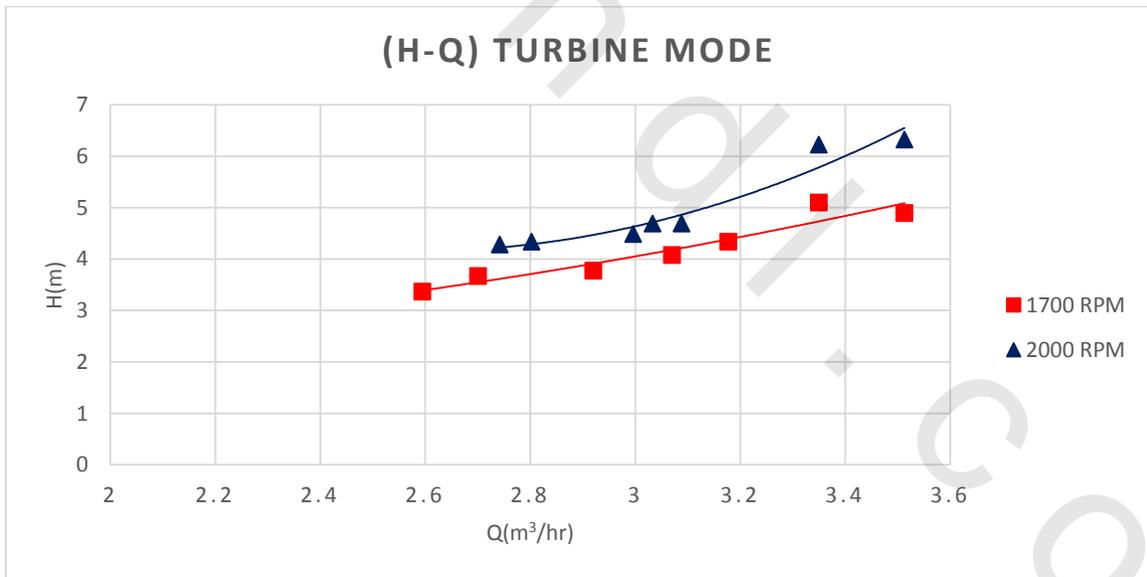


Figure (3-4) Head versus flow rate for turbine mode at 1700 and 2000 RPM

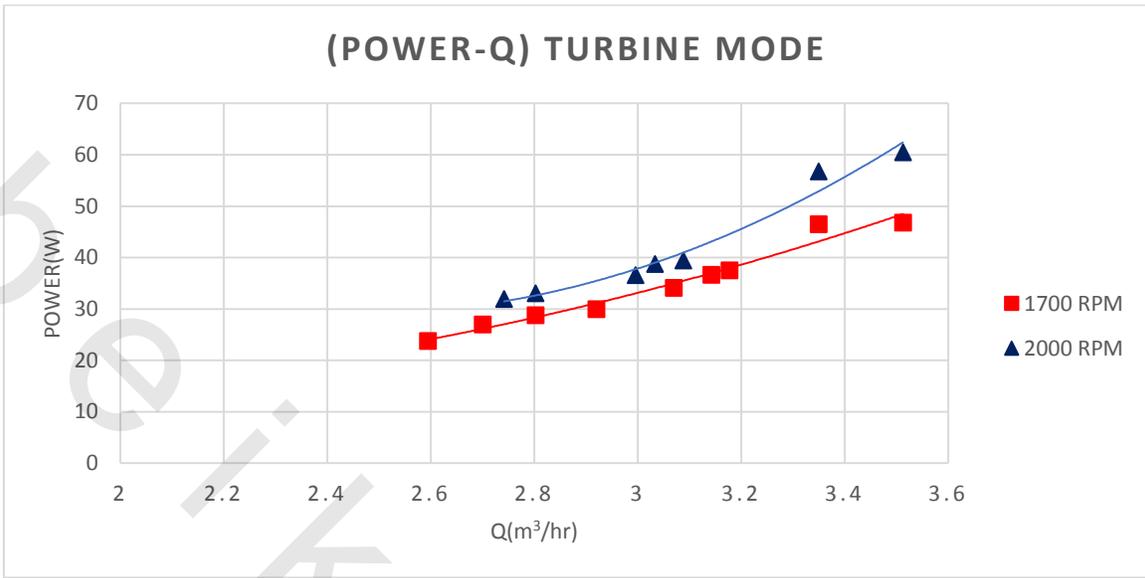


Figure (3-5) I/P power versus flow rate for turbine mode at 1700 and 2000 RPM

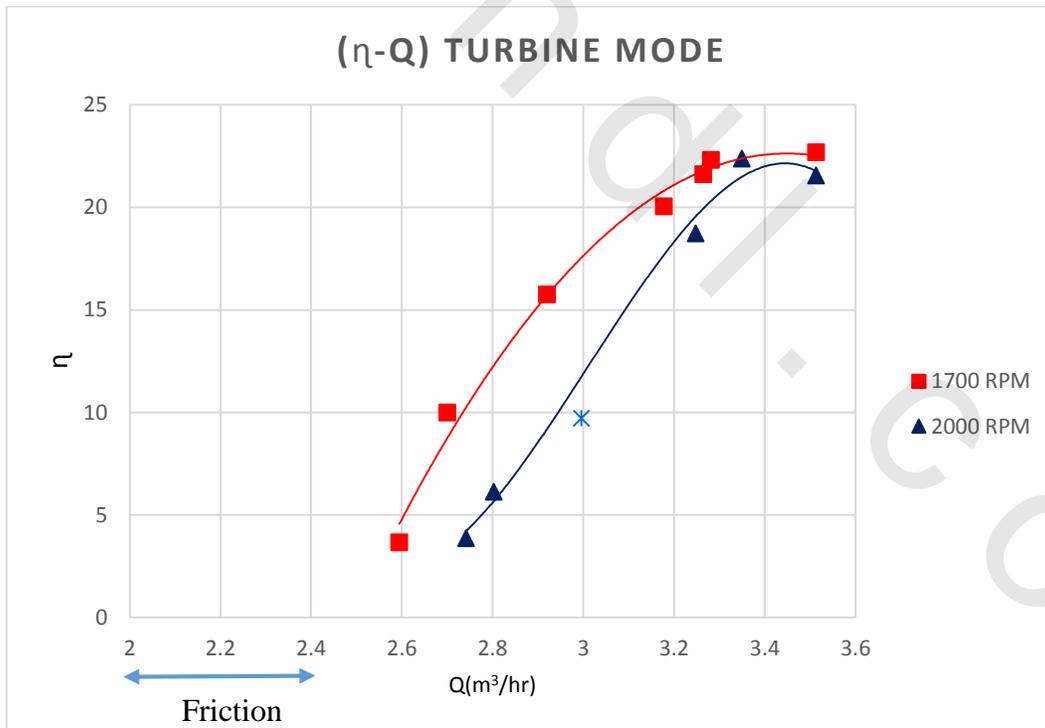


Figure (3-6) Efficiency versus flow rate for turbine mode at 1700 and 2000 RPM

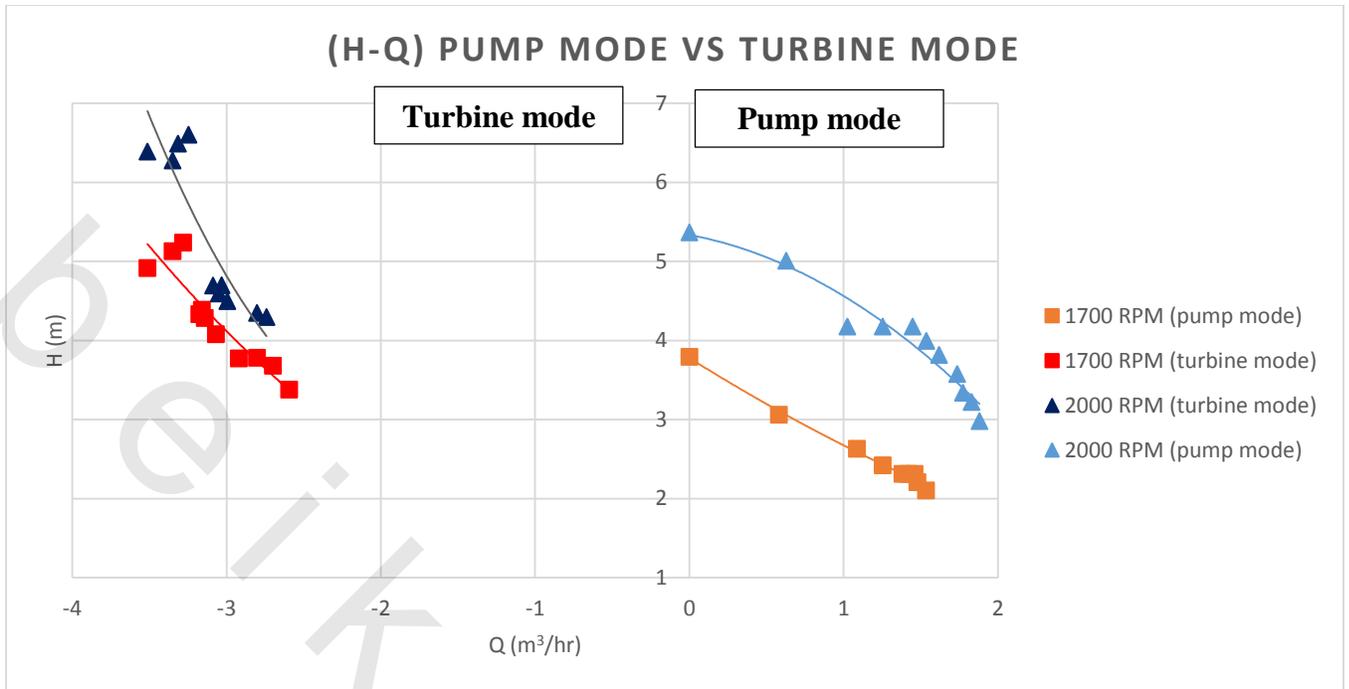


Figure (3-7) Head versus flow rate for pump and turbine modes at 1700 and 2000 RPM

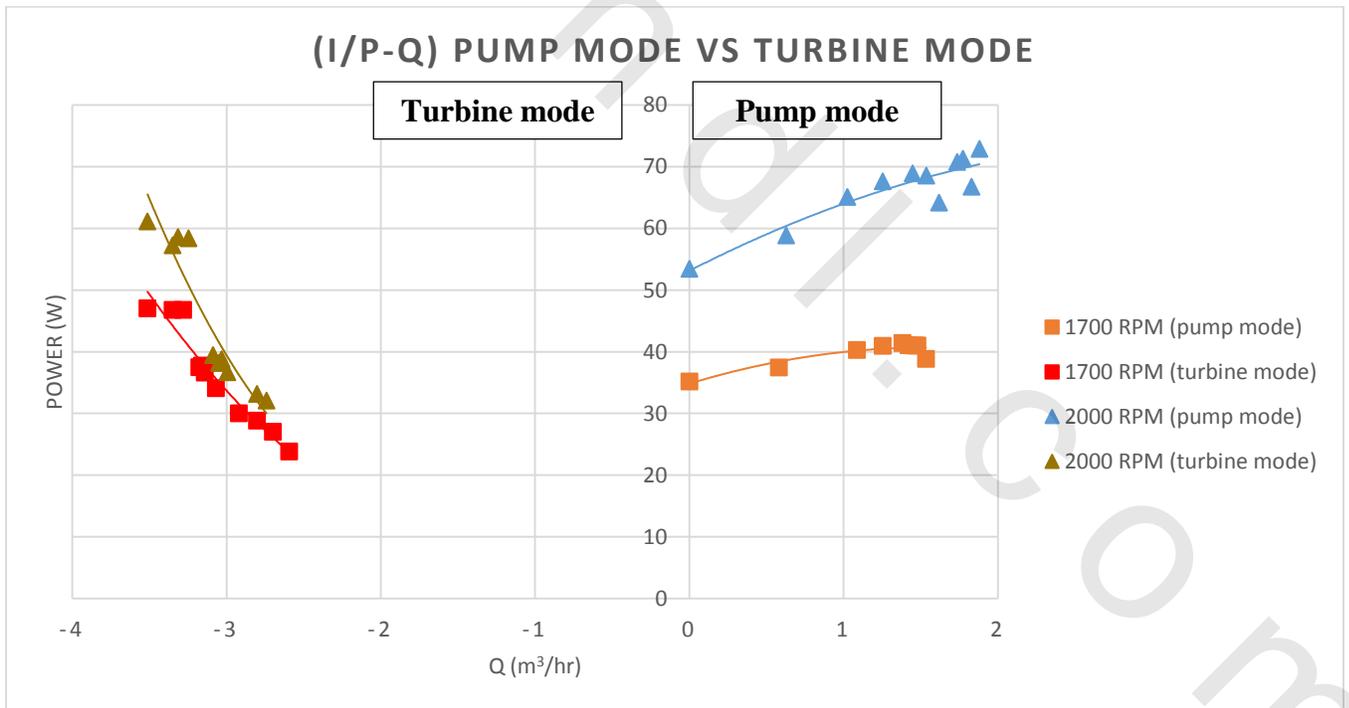


Figure (3-8) I/P power versus flow rate for pump and turbine modes at 1700 and 2000 RPM

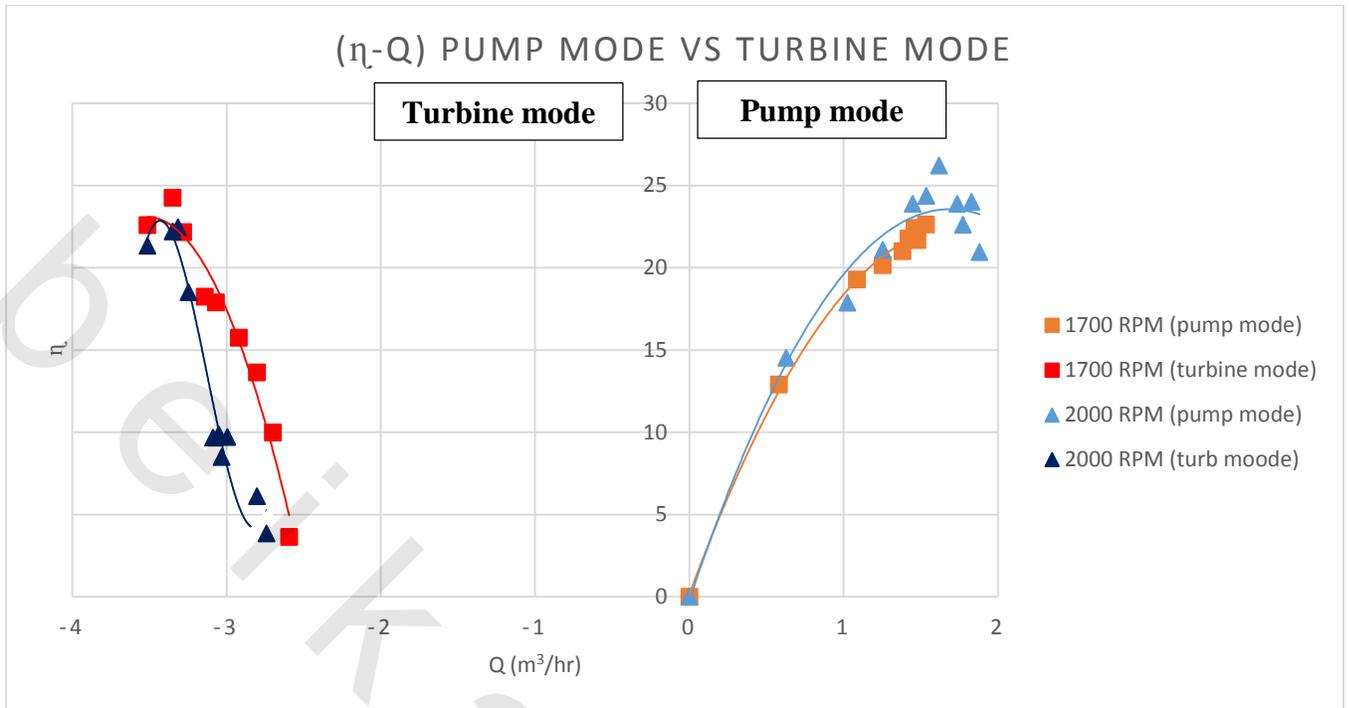


Figure (3-9) Efficiency versus flow rate for pump and turbine modes at 1700 and 2000 RPM

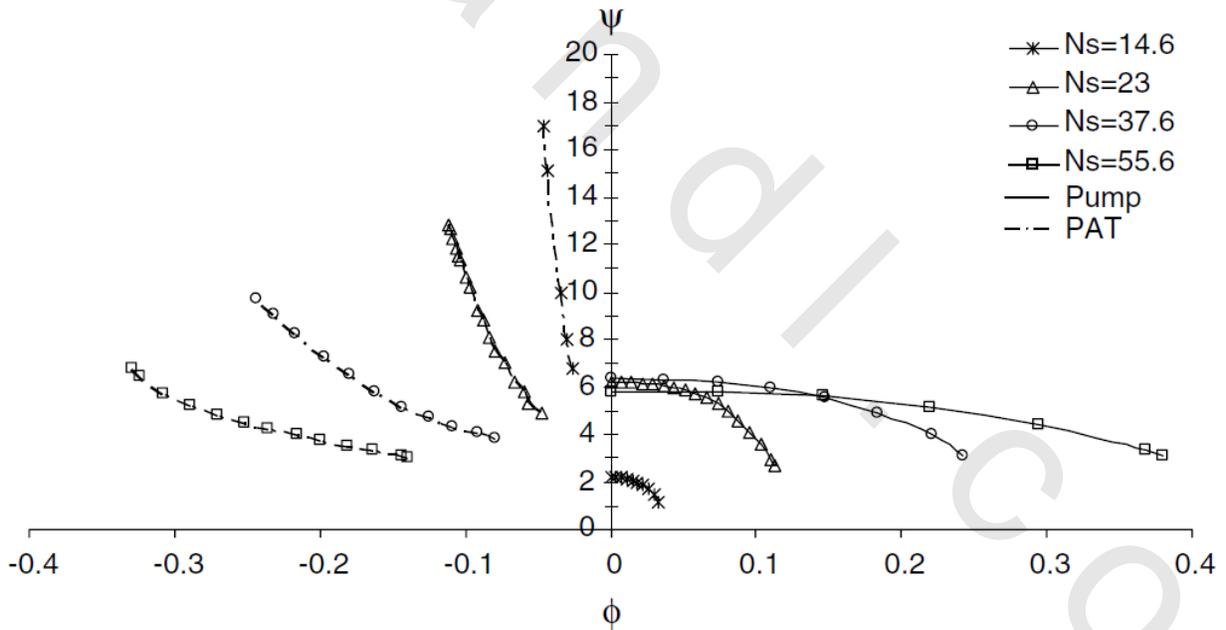


Figure (3-10) Dimensionless head versus Dimensionless flow rate of PATs in pump and turbine modes for different specific speeds [17]

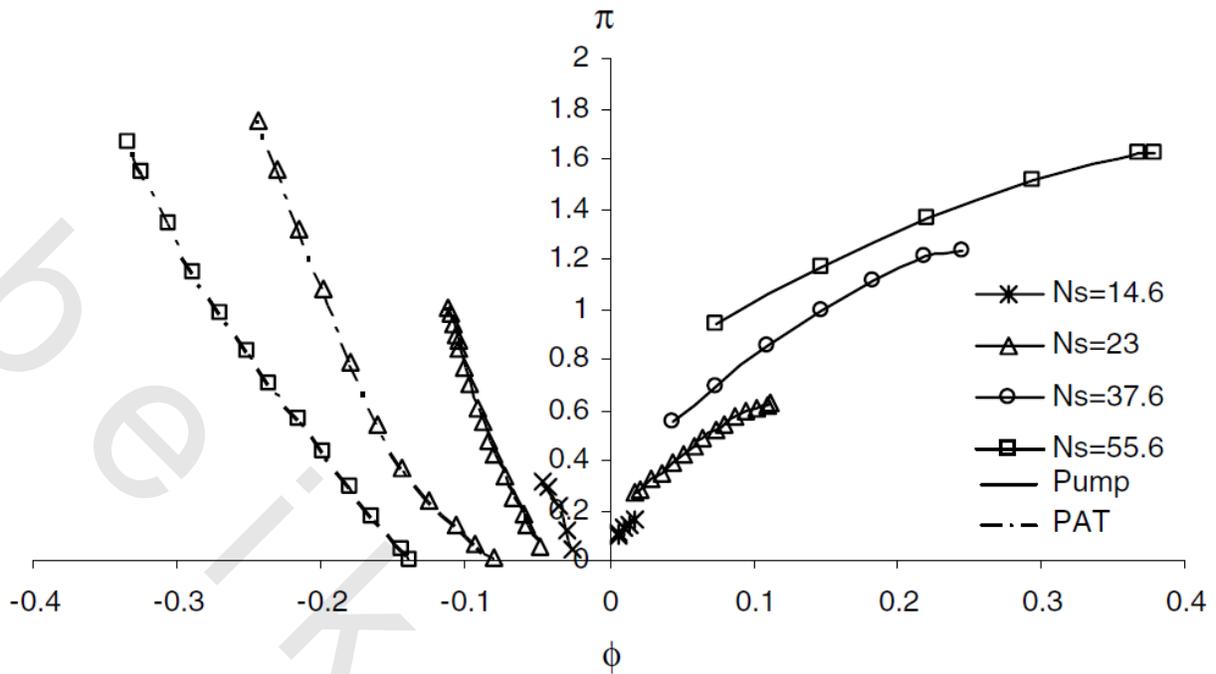


Figure (3-11) Dimensionless power versus Dimensionless flow rate of PATs in pump and turbine modes for different specific speeds [17]

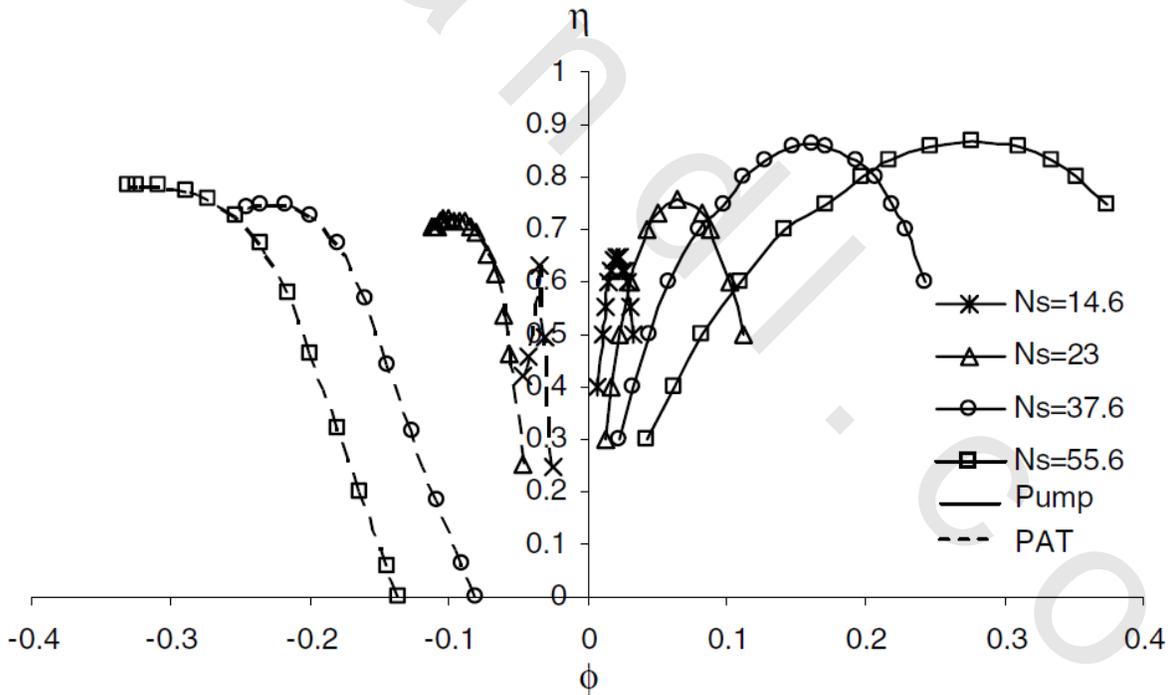


Figure (3-12) Dimensionless efficiency versus Dimensionless flow rate of PATs in pump and turbine modes for different specific speeds [17]

As a conclusion, Experiments showed that a centrifugal pump can operate as a turbine without mechanical problems for different rotational speeds, heads and flow rates. The characteristic curves for both modes showed a reasonable trend compared to the theoretical curves.

According to the before-mentioned correlations in chapter one the relation between the experimental results and the curves obtained from these correlations are illustrated in Table (3-1). The inputs to these correlation are the BEP head and flow rate of the pump mode to obtain the BEP of the turbine mode which are 3.8 m and 1.62 m³/hr respectively.

Table (3-1) flow rate and pressure of turbine mode for different correlations at 2000 RPM

Method	Q_{Turbine} (m³/hr)	H_{Turbine} (m)
Present experimental	3.3	6.4
S. Derakhshan et. al.	2.365	7.532
Sharma	4.728	19.039
Naber and Hausch	2.105	5.1516
Palgrave	2.382	5.613
Sanchez	2.186	4.961
Steppanoff	3.163	14.565
Child	6.180	14.565
McClaskey and Lundqvist	6.180	–
Williams	5.200	20.943
Alatorre-Frenk	3.049	9.884

Using these relations, the flow rate and head at the best efficiency point for turbine mode were obtained. The (H-Q) characteristic curve was drawn using correlation which is applicable for low specific speeds [14] (mentioned at chapter (1)). There is an observed deviation from the experimental results as shown in Figure (3-13). This deviation is due to the fact that although two pumps have the same specific speed, the geometry of the pumps is not the same which affects the performance as shown in Figure (3-13).

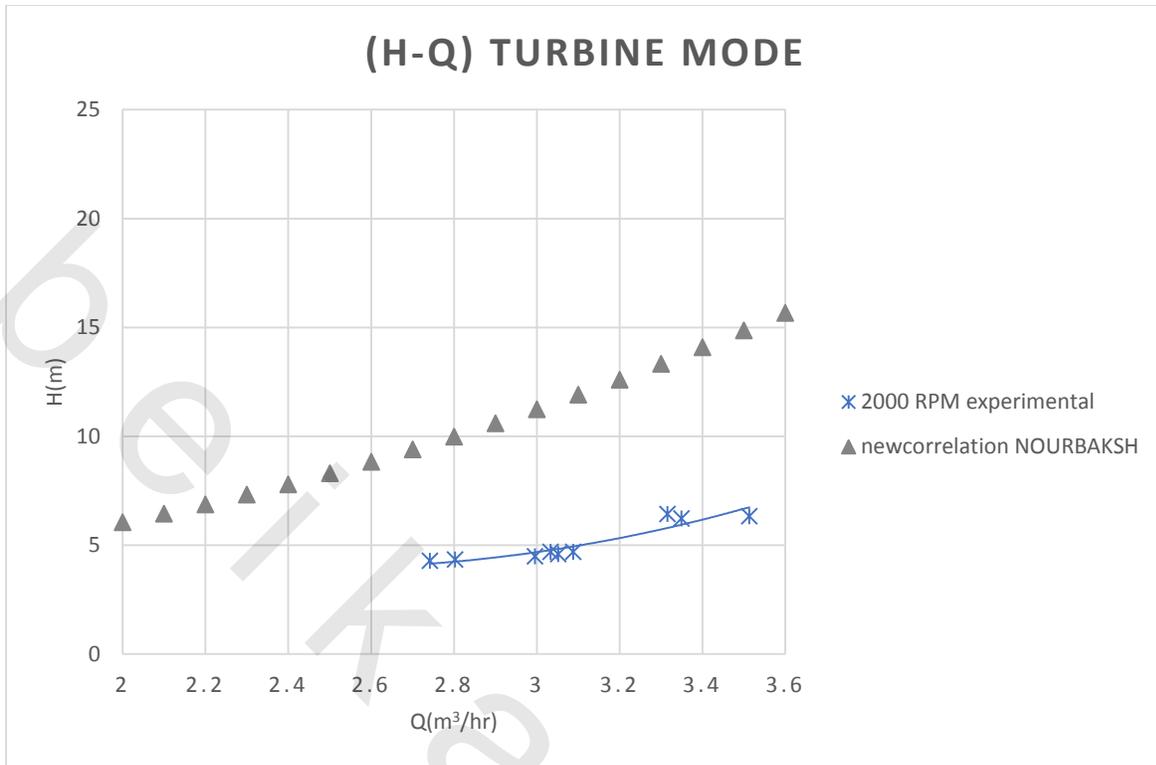


Figure (3-13) difference between (H-Q) characteristic curve obtained from experimental results and from Nourbaksh correlation