Investigations on the Performance of Centrifugal Pumps In Conjunction With Inducers

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Abstract

An inducer is an axial flow impeller with blades that wrap in a central hub. An inducer serves as a small booster pump for the main impeller [1]. Usually inducers have between (2) and (4) vanes, although they may be more [2]. Although the inducer usually has a lower NPSH requirement than the main impeller it can, and often does, cavitate during normal operation [3], The key is that there is so little horsepower involved with an inducer that there is virtually no noise, vibration, or resulting mechanical problems. Meanwhile, the higher horsepower main impeller sees sufficient head to operate without cavitations [4]. An inducer invariably has higher suction specific speed (S) than an adjacent impeller. (S) is a dimensionless term that describes the inlet characteristics of a pump [5]. A pump equipped with an inducer may operate at ½ to 1/3 the NPSHR levels of a non-inducer version of the same pump, at the same conditions. [6] Inducers have been developed to improve the required net positive suction head requirements (NPSHR) [7]. The inducer mounts on the threaded area of the rotor assembly (taking the place of the impeller nut) Fig. (1), and operates as a low (NPSHR) axial flow impeller in series with the main pump impeller. The inducer can be added to any of the standard models by removing the impeller nut and replacing it with the inducer. This feature will achieve field reduction of the (NPSHR).The inducer has a built-in locknut to prevent loosening or spinning-off during rotation check. Total dynamic head and capacity are not affected by the inducer and all standard modification and accessories can be specified on the pump with inducers. [8]

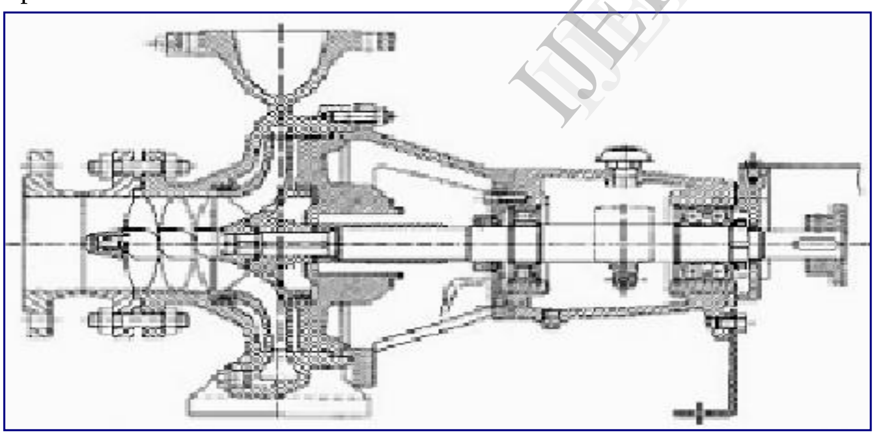

Fig 1 Centrifugal pump-with helical inducer.

1. INTRODUCTION

Generally, there are two types of inducers.

(a) Axial inducer: (Fig. 2)

This type of inducer, reduces the (NPSHR) of the pump throughout the entire operating range. [9]

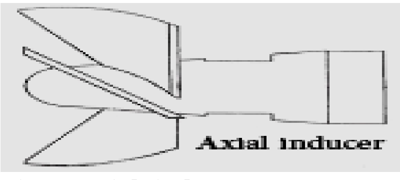

Fig. 2 Axial- inducer

(b) Helical Inducer: (Fig. 3)

A helical inducer, will lower the (NPSHR) more than an axial inducer for a specific flowrate, but care must be taken that the flow remains within the operating range of the inducer [10].

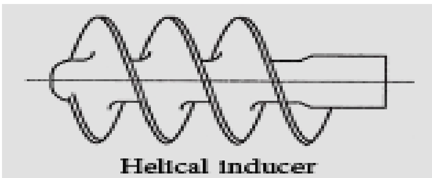

Fig. 3 Helical Inducer

Inducers are single stage axial flow helixes installed in the suction eye of centrifugal pump impellers to lower the (NPSHR) of the pump. This allows use of increased rotating speed for a given NPSHA or a lower NPSHR for a given speed. Shallow blade inlet angles are used to draw liquid into the inducer channels, which are shaped to impart enough energy to provide sufficient NPSH for the main impellers to avoid detrimental cavitation [11].

2-EXPERIMENTAL SETUP & PROGEDURE

(2-1) PLAN OF STUDY (RESEARCH SCHEME)

Investigation on the performance of centrifugal pump in conjunction with inducers are studied, for this purpose, a test rig, (Fig. 4).

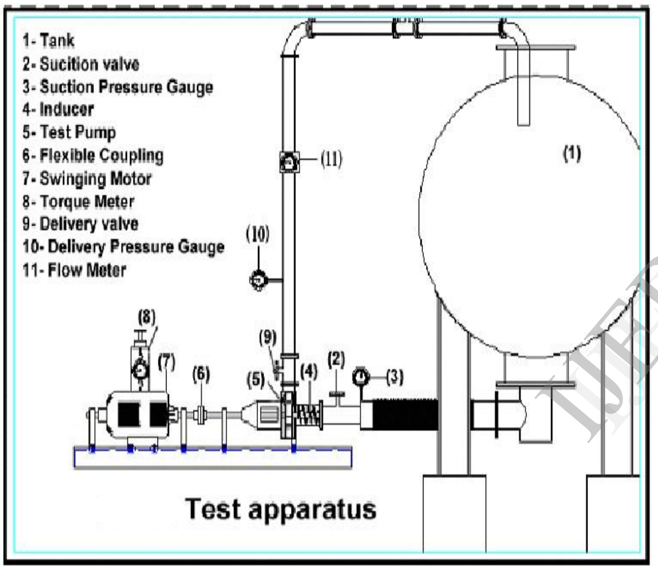

Fig. 4 Test Apparatus

The test rig, is specially designed to suit the investigation of the parameters under consideration for case studies of helical and Axial inducers shown in (Fig. 5 and Fig. 6).

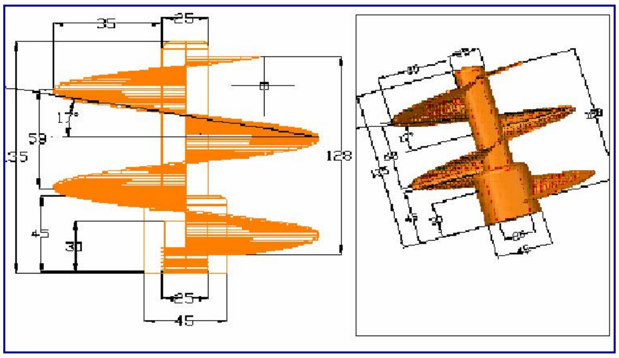

Fig. 5 Helical Inducer (2) turns (17º) Length (28mm), Depth (35mm) - pitch (58mm).

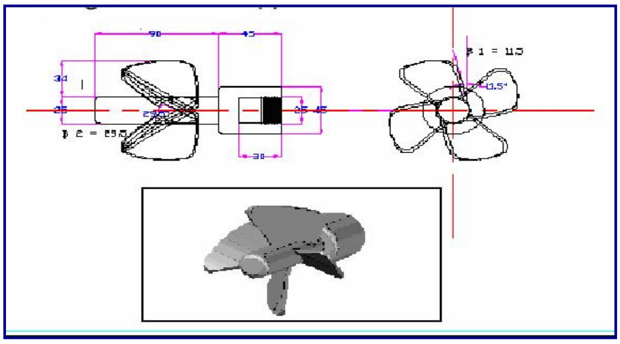

Fig. 6 Axial Inducer (4) Bladed (β1=11.5º, β2=29.5 º).

A series of experiments is carried out to investigate the effect of having helical and axial inducers with changing the following parameters:

a) For Helical Inducers, Table (1):

(1) Pitch
(2) Angle
(3) Length
(4) Depth

Table (1) Cases studies of Helical Inducers

	Without-with inducer	Number of turns	Angle (°)	Length (mm)	Depth (mm)	Pitch (mm)
1	Pump without Inducer	×	×	×	×	×
2	With helical inducer (2-turns,(17°))	2	17°	128	35	58
3	With helical inducer (2-turns,(12°))	2	12°	85	35	30
4	With helical inducer (2-turns,(15°))	2	15°	110	25	55
5	With helical inducer (2-turns,(8°))	3	8°	85	35	30
6	With helical inducer (2-turns,(9.5°))	3	9.5°	110	25	37
7	With helical inducer (2-turns,(12°))	3	12°	128	35	30
8	With helical inducer (2-turns,(9°))	4	9°	128	35	35

b) For Axial Inducers, Table (2):

(1) In-line Axial Inducers:
(2) Cascade Axial Inducers
(3) pitch of stages
(4) Angle of blades

Experiments were carried out with eight different operating speeds.

Table (2): Cases studies of Axial Inducers

	Without-with inducer	Number of blades	Inlet blade angle (β1)	Outlet blade angle (β2)	Pitch (mm)	Shaft length (mm)	Shaft Diameter (mm)
1	Pump without Inducer	×	×	×	×	×	×
2	With Axial inducer 3- Bladed	3	11.5°	29.5°	×	90	25
3	With Axial inducer 3- Bladed	3	18.5°	34.5°	×	90	25
4	With Axial inducer 4- Bladed	4	11.5°	29.5°	×	90	25
5	With Axial inducer 4- Bladed	4	18.5°	34.5°	×	90	25
6	With Axial inducer 5- Bladed	5	11.5°	34.5°	×	90	25
7	With Axial inducer 5- Bladed	5	18.5°	34.5°	×	90	25
8	With Axial inducer (cascade) 3- Bladed	3	11.5°	29.5°	35	90	25
9	With Axial inducer (cascade) 3- Bladed	3	18.5°	34.5°	30	90	25

(2-2) TEST PROCEDURE:

Tests for every inducer (helical – axial) a complete set of readings are taken at different discharges from shut- off to fully open delivery valve: Suction head, delivery head, discharge, speed and torque of motor are measured at different selected points.

Tests for every inducer are repeated for different motor speeds (500 -750 - 1000 - 1250- 1500 – 1750 – 2000 - 2150) rpm. The previous steps are repeated for the centrifugal pump without inducer for various setting of the delivery valve to cover the entire range of operation of the pump with and without inducers. Plots (Q-H) curves, (Q-B.P.) curvese and (Q-η) curves are used to show the effect of pump performance with and without inducers for different number of motor speeds for different parameters of helical and axial inducers are shown in (Fig. 7a,b,c and Fig. 8a,b,c).

Fig. 7a

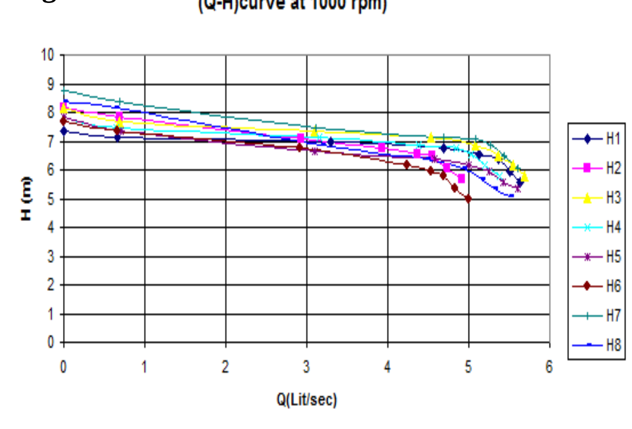

Fig. 7b

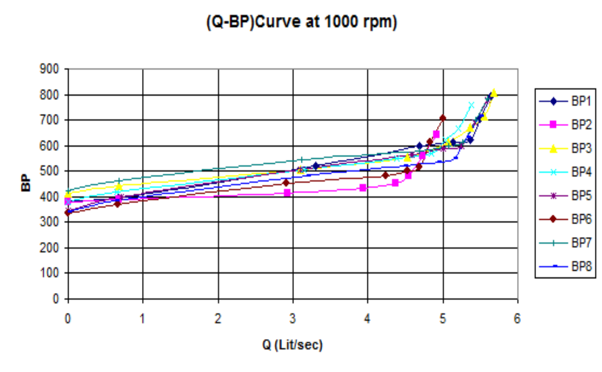

Fig. 7c

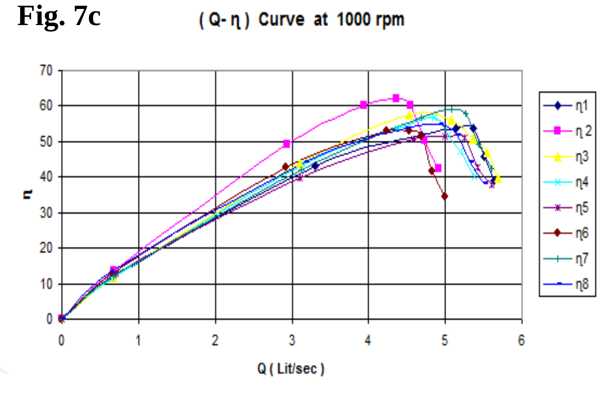

Fig. 7 (a, b and c) Effect of helical inducers on pump performance at 1000 rpm .

Fig. 8a

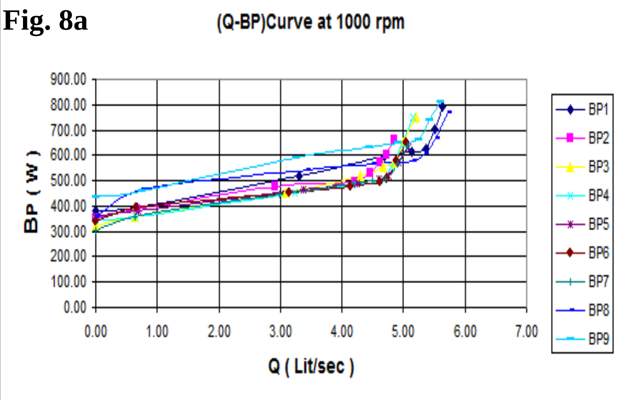

Fig. 8b

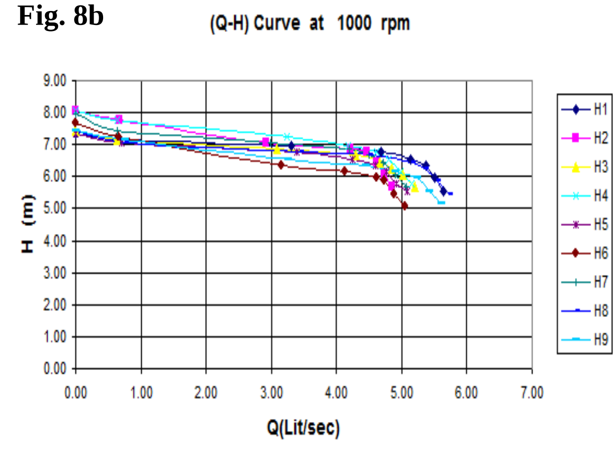

Fig. 8c

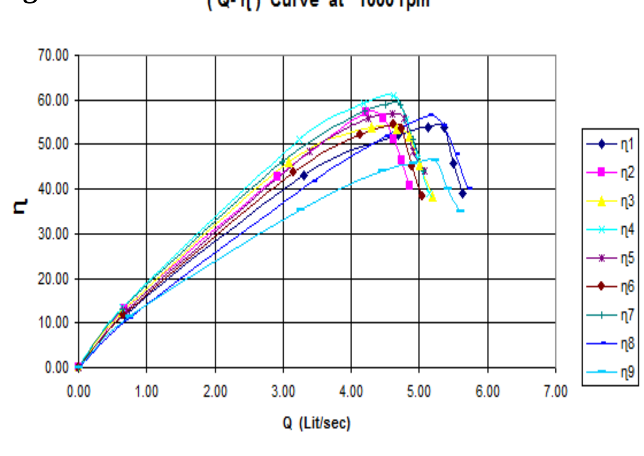

Fig. 8 (a, b and c) Effect of axial inducers on pump performance at 1000 rpm .

(2-3) CALCULATIONS:

The pump manometric head (H_m)

$$= H_{md} - H_{ms} + I$$

The brake power (B.P) = $T * 2\pi\, n / 60$

Pump overall efficiency (η) = $\rho\, g\, QH$ / B.P.

Pump head coefficient (ψ) = $g\, H / n^2 D^2$

Pump discharge coefficient (Φ) = $Q / n\, D^3$

Pump power coefficient (Π) = B.P. $/\rho\, n^3\, D^5$

(2-4) TEST APPARATUS:

Figure 2 shows the test rig to measure the performance of centrifugal pump in conjunction with inducers (helical- axial) with water. The helical inducers were manufactured with turns (2-3-4) with different angles (12° - 15° - 17°) for 2- turns helical inducer. Also (8° - 9.5° - 12°) for 3-turns helical inducer and (9°) for 4-turns helical inducer. The axial inducers were manufactured with number of blades (3-4&5) with inlet and outlet blade angles (β_1- β_2) of (11.5°- 29.5°) and (18.5°- 34.5°) respectively Also the cascade inducers were manufactured with 3- blades with the same inlet and outlet blade angles and with different pitch of stages. The dimensions of inducers (helical-axial) were selected randomly as case studies.

The apparatus is a closed circuit, where the pump, sucks from and delivers it to a big tank ($4m^3$). Two manometers with an error reading of (±) 1% are mounted on the suction and delivery pipes to measure the pump head, while the calibrated flow-meter, with an error reading of (±) 2% is mounted on the delivery pipe to measure the pump discharge. The discharge is controlled by means of a sluice valve. The pump is directly coupled to a variable speed (5 hp), D.C, swinging motor. Its speed is measured by means of a tachometer, with an error reading of (±) 2%, while the torque applied to the pump is measured by means of a calibrated torque meter with an error reading of (±) 2%.

3- RESULTS AND DISCUSSION

(3-1) Effect of Variation of Parameters for Helical Inducers:

To study the effect of design parameters (pitch , angle, length, depth) for the helical inducers on centrifugal pump performance, inducers having different numbers of turns (2- 3- 4) with different angles (12° - 15° -17°) for 2-turns helical inducers, also (8° - 9.5° -12°) For 3-turns helical inducers and (9°) for 4-turns helical inducer for different pitch, length and depth were tested.

The tests shows that the case of (3-turns, (12°)) helical inducer give the best performance for the centrifugal pump at 750 rpm, also, the case of (3-turns, (8°)) helical inducer give the best performance for the centrifugal pump at 1250 rpm, also, the case of (2-turns, (12°)) helical inducer give the best performance for the centrifugal pump at (1500 - 1750 and 2000 rpm), because of having maximum efficiency maximum head and minimum brake power.

(3-2) EFFECT OF VARIATION OF PARAMETERS FOR AXIAL INDUCERS

To study the effect of parameters (angle of blades), (pitch of stages) for in- line axial inducers and cascade axial inducers upon centrifugal pump performance, inducers having different number of blades (3,4,5) with different angles($\beta1$=11.5°, $\beta2$ = 29.5°) and ($\beta1$= 18.5°, $\beta2$= 34.5°) also ,for cascade inducers (3-bladed) with the same angles and with different pitch (30mm,35mm) are tested. The tests show that the 3-bladed ($\beta1$= 11.5°, $\beta2$= 29.5 °)axial inducer gives the best performance for the centrifugal pump at 750 rpm, also the 5-bladed ($\beta1$= 18.5°, $\beta2$= 34.5 °) axial inducer gives the best performance for the centrifugal pump at 1000 rpm because of having maximum efficiency, maximum head and minimum brake power.

(4) COMPARISON BETWEEN EXPERIMENTAL RESULTS AND SOME PUBLISHED WORKS

(4-1) Comparison of best performance of a Centrifugal pump in conjunction with inducers (helical – axial):

Figure 9 shows the comparison of best performance of the centrifugal pump in conjunction with inducers (helical – axial) for three different speeds (500- 1000 - 1750 rpm). The best performance means (maximum efficiency, maximum head and minimum brake power).

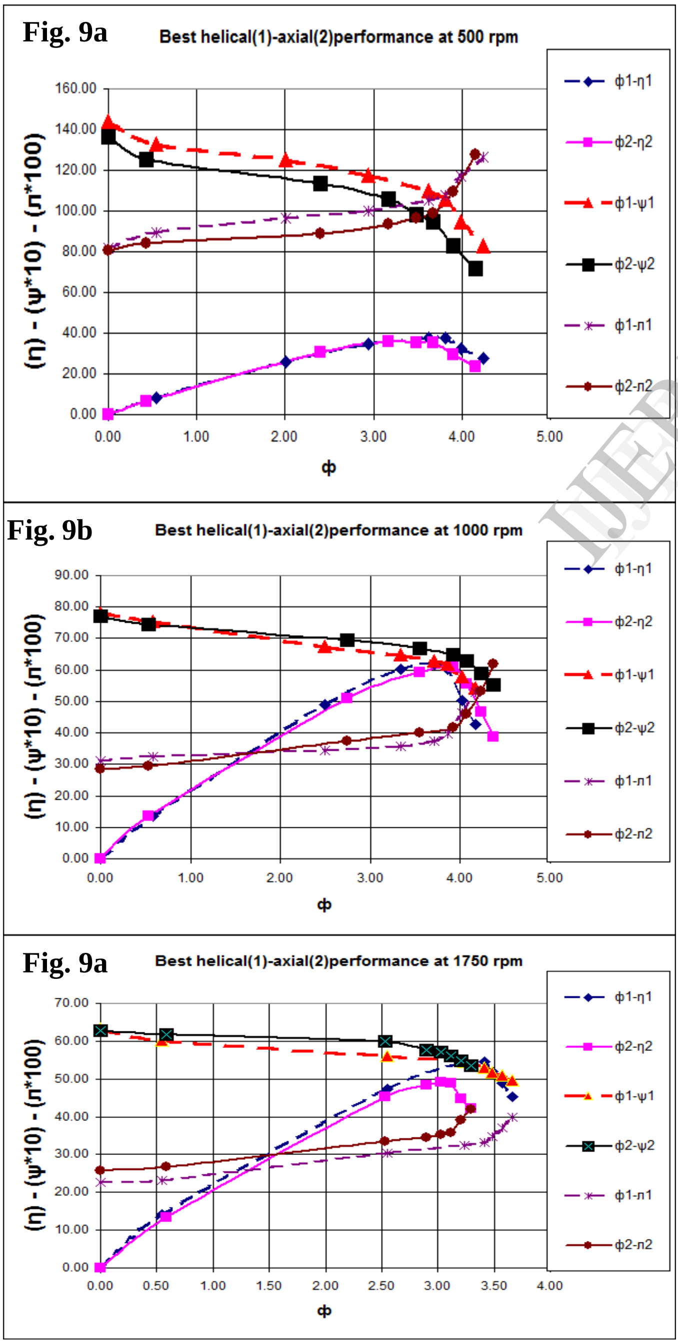

Fig. 9(a, b and c) Best helical (1)-axial (2) Performance at 500, 1000, 1750 rpm.

For Helical Inducers, the best performance of the pump is obtained by using ((2) turns,17°)), shaft diameter 25mm helical inducer; For Axial inducers, the best performance of the pump is obtained by using (4)- Bladed, β1 = 11.5°, β2 = 29.5° axial inducer. The trend exhibited Figure 9 are the relation between flow coefficient (Φ) with overall efficiency (η), head coefficient (Ψ) and power coefficient (п) As shown from Figure 9 at (500 rpm) that maximum efficiency and higher value of head are obtained by using helical inducer, also the minimum brake power is obtained by using axial inducer. The obtained performance curves at (1000 rpm) showing that the maximum efficiency and higher value of head are obtained by using helical inducer; also the minimum brake power is obtained by using axial inducer. Similar trend of performance curves at (1750 rpm), showing that the maximum efficiency and lower value of brake power are obtained by using helical inducer, also the higher value of head is obtained by using axial inducer.

(4-2) Net Positive Suction Head (NBSH) for centrifugal pumps:

One of the most important considerations in selecting and applying a centrifugal pump in the conditions existing is the pump's suction system. These conditions are best expressed as “Net positive suction head” (NPSH). This term is officially defined in accordance with the standards of the Hydraulic Institute as “The total suction head in feet of liquid absolute, determined at the suction nozzle and corrected to datum, less the vapor pressure of the liquid in feet absolute. [12]” In simple terms, NPSH is the absolute pressure in feet of liquid at pumping temperature available at the pump suction flange above vapor pressure. Since centrifugal pumps are incapable of handling large quantities of vapor the pump's external suction system must provide sufficient absolute pressure to prevent vaporization or flashing in the impeller. This pressure is normally referred to the centerline of the pump suction nozzle, When this pressure is not sufficient to prevent vaporization.

This phenomenon known as (cavitations), occurs causing damage to the impeller, reduction in pump developed head and capacity, noise and This is referred to as NPSHR (net positive suction head required). Conversely, the NPSH available in the system is referred to as NPSHA(net positive suction head available). For cavitation free operation the NPSHA must equal or exceed the NPSHR at the vibration. Pump manufacturers determine by test the NPSH, required various capacities for a particular pump and plot it as a function of capacity. desired capacity. [13]. It must be realized that suction conditions and NPSHA are very important than the pumps capacity and total head. More attention to suction conditions and NPSHA will result in more trouble, free pump operation.

(4-2-1) Comparison between (NPSH) for centrifugal pump with helical, axial and without inducers

In order to compare the present work with other investigators regarding the pump NPSH, the best obtained configuration of the inducers section was selected and the NPSH was calculated at this selected types at the maximum efficiency point which is:

1- For Helical inducer, maximum efficiency (62%) at (1000 rpm) is obtained by using ((2 turns-17º) helical inducer.

2- For Axial inducer, maximum efficiency (60.9%) at (1000 rpm) is obtained by using (4) Bladed- (β1=11.5º, β2 =29.5º) axial inducer.

3- For the case without inducer, maximum efficiency (53.7 %) at (1000 rpm). *Figure 10(a&b), shows the comparison between (NPSH) For Centrifugal pump with helical, axial and without inducer.*

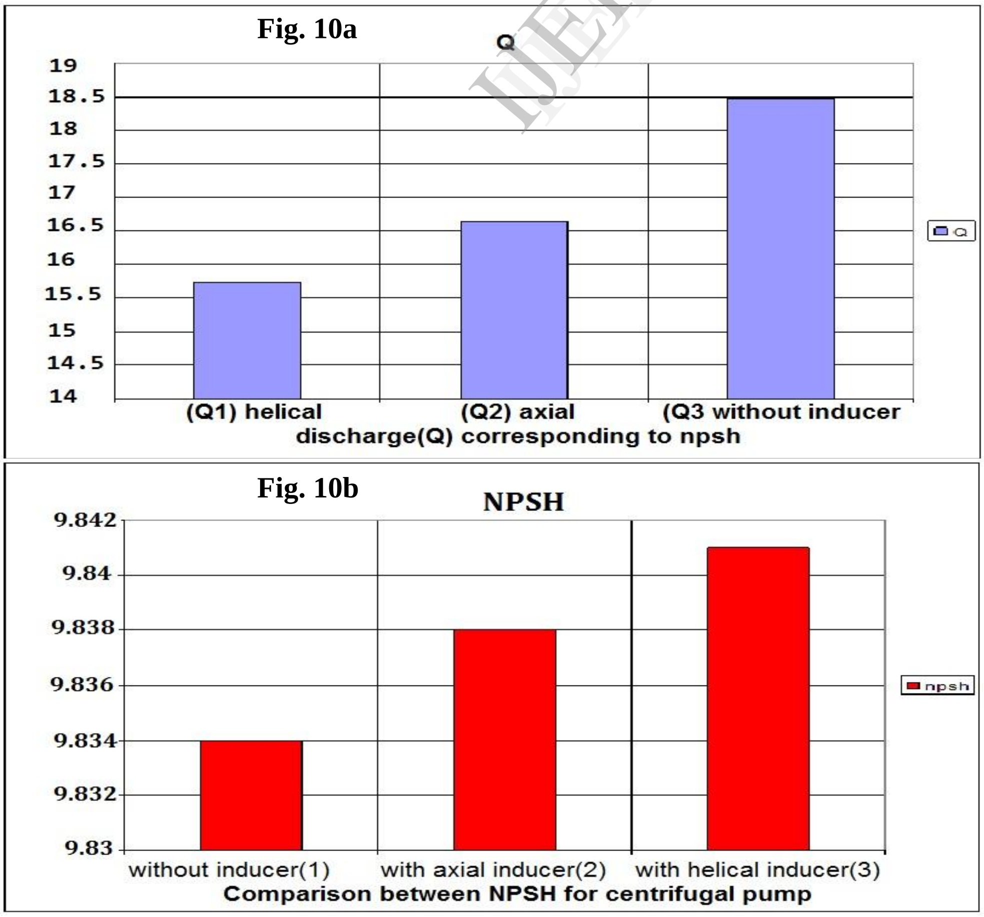

Fig. 10 (a and b) Comparison between (NPSH) For centrifugal pump with helical, axial, without inducer.

(4-3) Comparison with other Investigators, MASAO OSHIMA[14]:

In order to compare between experimental results, a sample of a test pump with the inducer [14] is introduced to specify the pump geometry related to such a comparison. As a matter of fact, no exact comparison could be achieved due to variations of pump geometry obtained from several references. However, the compared results were put in a dimensionless farm to show the general trend of performance curves obtained from the available present and previous work.

As shown from Figure 10, comparison is made with the present work and the previous investigation [14] in a dimensionless form. The maximum efficiency and higher value of head are obtained by using (2) turns, 17º shaft diameter 25mm helical inducer (η= 62%) , the max value of efficiency for the previous investigation[14] (η = 59%), also the previous investigation has a lower value of brake power than the present work.

For the design work condition, the static pressure increases gradually from inlet to outlet. The pressure difference between the outlet and inlet can be got by simulation heads can be computed by the pressure difference. The head of the high-speed centrifugal pump is the highest with the two turns, helical inducer than three or four turns helical inducer.

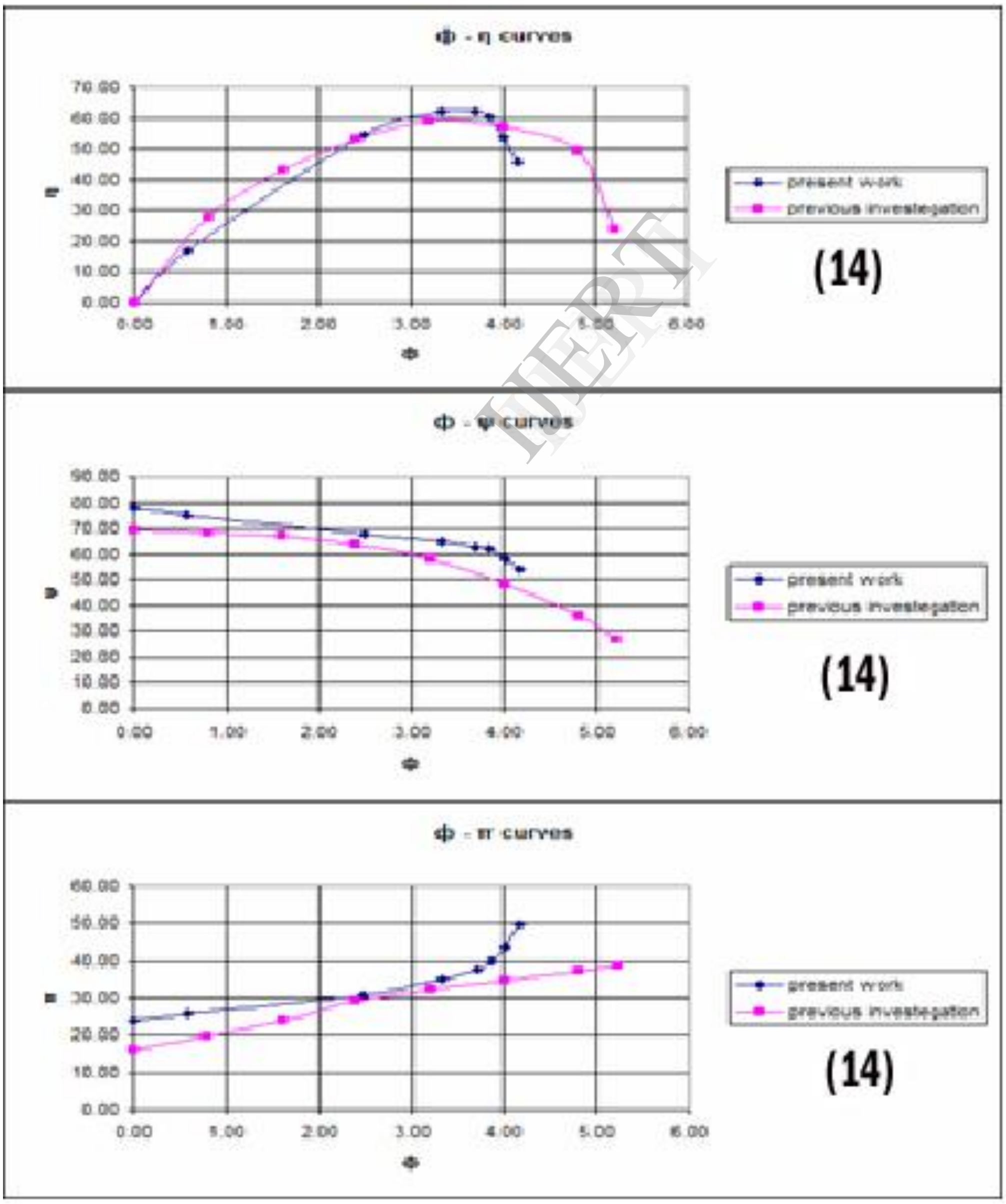

Fig 11 Comparison with other Investigators, MASAO OSHIMA.

(5) CONCLUSIONS

From the pervious experimental work and discussions, the following conclusions can be drawn:

1- When selecting the inducer (helical-axial), we must have the best performance (maximum efficiency, maximum head and minimum brake power) for having the best performance when operating with centrifugal pump.

2- Maximum efficiency and maximum value of NPSH of the Centrifugal pump are obtained by using helical inducer (2 turns (17º)), shaft diameter 25mm in all case studies of inducers (helical-axial) and it is preferable to be used for having the best performance of the centrifugal pump.

3- when operating the centrifugal pump with axial inducers, the best performance is obtained by using (3) bladed and (5) bladed axial inducers at low rpm with different angles.

4- comparison of best performance:

For Helical inducers, the best performance is obtained by using (2-turns,(17)), shaft diameter; For Axial inducers, the best performance is obtained by using (4)-Bladed (β_1 = 11.5 º, β_2 = 29.5º) Axial inducers.

5- comparison of (NPSH):

The maximum value of (NPSH) of the centrifugal pump is obtained by using (2-turns,(17)) helical inducer and the minimum value of NPSH is obtained when operating the centrifugal pump without inducer.

6- The experimental work show that it is preferable for the users of the inducers with centrifugal pump, that helical inducers give best performance of the centrifugal pump than axial inducers, also, the head of the high-speed centrifugal pump is the highest with the two turns helical inducer than three or four turns helical inducer.

NOMENCLATURE

A	Cross _ Sectional area of flow .	(m^2)
B	Impeller Width.	(m)
B.P.	Brake power	(w)
C	Absolute velocity of flow in the channel.	(m/s)
d	pipe diameter	(m)
D	Impeller diameter	(m)
F	Force .	(N)
g	Gravitational acceleration	(m/s^2)
H	Total head (effective head)	(m)
Hm	Manometric head.	(m)
Hms.	Manometric suction head	(m)
Hmd.	Manometric delivery head	(m)
Hn	Normal head (effective head)	(m)
I	Distance between Suction and delivery pressure gauges	(m)
M	Momentum to fluid by impeller per second	($kg.m/s^2$)
n	Shaft Speed	(rps)
N	Shaft Speed	(rpm)
P1	P2 Pressure on suction,discharge sides	(N/m^2)
Q	Volume flow rate or pump capacity.	(m^3 /s)
R	Radius.	(m)
t	Time.	(Sec)
T	Torque.	(N.m)
s	Suction	(-----)
S	Specific speed	(-----)
v	Velocity	(m/s)

V	Volume	(m^3)
X	Axial clearance.	(m)
Y	Radial Clearance ratio = Y/D	(Dimensionless)
Z	Number of impeller blades .	
β_1	Inducer inlet blade angle	(degree)
β_2	Inducer outlet angle	(degree)
λ	Specific weight	(N/m^3)
η	Pump overall efficiency	
W	Impeller angular velocity	(m/s)
ρ	Density	(kg/m^3)
Φ	Flow coefficient =	
Ψ	Head Coefficient = $\frac{g\,H}{n^2\,D^2}$	
π	Power Coefficient = $\frac{B.P.}{\rho n^3\,D^5}$	
η	Overall efficiency = $\frac{\rho\,g\,Q\,H}{B.P.}$	

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pump FAQS _ welcome to hydraulic instilnte "what is an inducer and how it work "

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Key Structure: Centrifugal pump, Inducer, NBSH, Pitch, Angle.