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The Effects of Stage Number on Pump Operation Characteristics in Vertical Line Shaft Deep Well Irrigation Pumps[1]

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Abstract: In this study, the effect of stage number on operation characteristics of three different diameter deep well pumps used in irrigation pumping plants was researched. The pumps were tested with 6 stages number that manufacturer offered at three different RPM. The RPM where maximum efficiency obtained assumed as optimum RPM. The working characteristics of pumps at (1 – 6) stages number were determined. The tests were performed according to ISO 2548 regulations and as three repetitions.
According to the result of the test, statistical analysis were applied on the function of the stage number, power and pressure in full closed valve (FCV) and flow and best efficiency in full opened valve (FOV).
According to the results of the research, on condition that the shaft diameter and impeller dimension are stable, the effect of stage number variation on power pressure and efficiency was significant whereas insignificant on flow.
Key word: Turbine deep well pumps, pump performance, stage number, pump efficiency

Derin Kuyu Pompalarında Kademe Sayısının Pompa İşletme Karakteristiklerine Etkisi

Özet: Bu çalışmada; pompaj tesislerinde kullanılan üç farklı çaptaki derin kuyu pompalarının kademe sayısının işletme karakteristiği üzerine etkisi araştırılmıştır. Pompalar, önce 6 kademe sayısında firmanın önerdiği üç değişik devirde denenmiştir. Sonra, her pompa için en yüksek verimin sağlandığı devir sayısı, o pompa için optimum devir sayısı olarak kabul edilmiştir. Daha sonra, her üç pompa kendi optimum devir sayısında olmak üzere altı ayrı (1-6) kademe sayısındaki işletme karakteristikleri belirlenmiştir. Denemeler ISO 2548'e göre gerçekleştirilmiş ve üç tekerrürlü olarak yürütülmüştür.
Denemelerin sonucuna göre, kademe sayısının fonksiyonu olarak, tam kapalı vanadaki (TKV) güç ve basınç, tam açık vanadaki (TAV) debi ve en yüksek verim değerleri üzerine istatistiksel analizler yapılmıştır.
Çalışmanın sonucuna göre, mil çapı ve çark ölçüleri sabit kalması koşuluyla kademe sayısının değişiminin güç, basınç ve verim üzerine etkisi önemli, debi üzerine etkisi ise önemsiz bulunmuştur.
Anahtar kelimeler: Türbin derin kuyu pompaları, pompa performansı, kademe sayısı, pompa verimi

INTRODUCTION

Nowadays that aridity threatens lives; the efficiency of the pumps in irrigation plants bears importance in terms of reservoir and energy.

Nearly 30% of the 28 billion hectare agricultural land can be irrigated economically. According to 2006 data, only 50% of the mentioned area was irrigated. Based on the same year's data, 65% of the potential water, total 112 billion m^3 water 12 billion cubic m of which is subterranean water, was used. It has been reported that 75% of the consumed water is used in agricultural irrigation. Referencing this data it can be said that approximately 12.850 cubic m/ hectare year (1.285 mm/year) irrigation water is used for agricultural irrigation. Approximately 10% of the irrigated fields underwent pressure irrigation (Kara,

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2005; Dumlu et al., 2006; Anonymous, 2007a; Anonymous, 2007b).

It is a known fact that pressure irrigation systems (irrigation pumping plants) are needed to increase the efficiency and usage of irrigation water. The biggest restrictive factor in the extension of the pressured system, the cost of energy supply needed for this is to be very high.

Deep well pumps were designed for water supply from subterranean water sources in the areas where there aren't aboveground water sources or where water transmission is very expensive. The pressure need of the deep well pumps increases so long as the level of underground water is decreased and the pumping technologies developed. The pressure of the pumps is supplied by increasing RPM and impeller diameter. Some factors such as motor technology pump impeller size and mechanical features of the material used restrict the enhancement of the RPM and well diameter restricts the impeller diameter. Therefore, another pressure increasing method is the manufacturing of the pumps in multistage (series). Shaft diameter and hub diameter of the impeller of the deep well pump determine the maximum stage number. The diameter is a function of shaft power and mechanical resistance of the material and shaft power is the function of momentum and RPM. Except some theoretical approaches, practical tips and catalogue information, we could not encounter any scientific study on the effects of stage numbers on pump operation characteristics (Baysal, 1975; Shulz, 1977; Serven, 1979; Anderson, 1986; Karassik et al., 1986; Saqib and Khan, 1993; Stepanoff, 1993; Nelik, 1999; Anonymous, 2000; Hanson, 2000; Rishel, 2002; Çalışır et al., 2004; Çalışır et al., 2005; Çalışır , 2007).

In this research, the effects of stage number on vertical line shaft deep well shaft diameter, on condition that the body and turbine geometry and RPM are stabled, pump efficiency and efficiency components was researched.

MATERIAL AND METHOD

Material

In this study, three different diameter vertical shaft deep well pumps (4",5"and 6") that are commonly used for agricultural irrigation were selected. In 2007, the pump was tested at SU Agriculture Faculty according to ISO 2548 standard in the pump test stand of agricultural machinery department (Hansen, 1974; Anonymous, 1997). The environment temperature at the stand was 9~10 C° and 45~50 % relative humidity was measured. During the test, clean water with a temperature of 13–14°C was used.

First of all, each of the pumps was mounted as 6 stages. Considering the advice of the manufacturer, each of the pumps was tested for three different RPM. The highest detected RPM was accepted as optimum RPM. In opt. RPM with stable clearance and stable shaft diameter, all stages of the pumps were tested from stage 1 until stage 6. The decrease in the RPM of the pumps was realized by eliminating the sub levels of the pumps.

In the test stand, variable frequency driver (VFD) with a 45 kW (50HP) AC electric motor was used. The RPM was measured by the tachometer. The flow rate was measured by the DN 150 electromagnetic flow meter. Pressure was measured by the manometer. The shaft power was measured by the dynamometer. Output of the measurement, in the 11 different valve opening, running at least 10 minutes in each of the opening, was saved as tree repetitions.

When the test results were evaluated, as the function of the stage number for each pump separately, a variance analysis was applied to maximum efficiency (%), pressure (bar) and power (kW) at full closed valve, flow rate at full opened valve (l/s). LSD test was applied to the parameters that were found significant in the variance analysis. Also for the three pumps, graphics of the relationships between stage number with efficiency and components of the efficiency were drawn; regression equation and correlation coefficient were detected at the linear model (Anonymous, 1980; Anonymous, 1991).

RESULTS AND DISCUSSION

The variance analysis applied as a function of stage number to the values of pressure (p-bar) and shaft power (P-kW) of the pumps in closed valve obtained in opt. RPM, flow rate in full open valve (Q-l/s) and maximum efficiency (η- %) and LSD test results were given in Table 1.

When Table-1 is examined, for all of the three different deep well pumps, with the increase of the stage number, pressure, power and efficiency increased as well. These increases were found statistically meaningful ($p<0.01$). Stage number was not effective on pump flow rate ($p>0.05$). The diameter and flow rate of the pumps were proportional.

According to average specific speed values, it can be said that these three pumps are mixed flow types. The reason for this increase can be attributed to the decrease of the RPM against increasing flow rate.

At the full closed valve, differences between powers of the 1st stage with power per one stage of the 6th stage were found significant. The power per one stage of the high stage number is smaller than power of the 1st stage. These decrease rates for (4″,5″,6″) pumps were calculated successively ; 35.05%, 32.75% and 24.48%.

At each of the pumps, the pressure obtained at closed valve has increased significantly depending on the stage number. However, for each of the three pumps there has been no significant change among the pressure per stage produced at 1st stage and 6th stage.

For all stage number (1…6) of each of the pumps the same flow rate was obtained.

As stage number increased, the maximum pump efficiency obtained at optimum stage numbers increased. The increase rates between efficiency of the 1st stage with efficiency of the 6th stage were calculated as 19.47%, 10.32% and 18.54% for 4″, 5″ and 6″ pumps successively.

Also at the opt. RPM of the pumps, pictographic changes of the operation characteristics which are functional of the stage numbers are shown in Figure 1-4.

At the full closed valve, regression equation and determination coefficient of the pressure change which functions of stage number were detected as $y = 1{,}4.X$ ($R^2=1$); $y = 0{,}1067 + 1{,}5029.X$ ($R^2=0{,}9993$)

Table1. Deep well pumps, effect of the stage number on the efficiency and component of the efficiency

Pump diameter; Opt. RPM and Ns average specific speed number	Stage number (i) (unit)	Power (at the full closed valve) (P) (kW)	Pressure (at the full closed valve) (p) (bar)	Flow rate (at the full opened valve) (Q) (l/s)	Best efficiency (η) (%)
4″ Opt.RPM 3050 1/min Aver. Ns 277 1/min	1	2.48 ^{f}	1.4 ^{f}	28.37	49.78 ^{c}
	2	4.20 ^{e}	2.8 ^{e}	27.43	57.50 ^{ab}
	3	5.81 ^{d}	4.2 ^{d}	28.37	55.03 ^{b}
	4	7.65 ^{c}	5.6 ^{c}	27.32	56.90 ^{ab}
	5	9.48 ^{b}	7.0 ^{b}	25.38	58.47 ^{a}
	6	11.08 ^{a}	8.4 ^{a}	27.26	59.47 ^{a}
	LSD (%1)	0.4732	0.2087	-	2.597
5″ Opt.RPM 2400 1/min Aver. Ns 253 1/min	1	3.81 ^{f}	1.6 ^{f}	43.61	60.67 ^{d}
	2	6.86 ^{e}	3.2 ^{e}	43.60	62.87 ^{cd}
	3	9.79 ^{d}	4.6 ^{d}	43.27	63.57 ^{bc}
	4	13.29 ^{c}	6.0 ^{c}	43.28	64.33 ^{bc}
	5	16.09 ^{b}	7.6 ^{b}	43.29	65.43 ^{ab}
	6	17.19 ^{a}	9.2 ^{a}	42.86	66.93 ^{a}
	LSD (%1)	0.4925	0.2231	-	2.228
6″ Opt.RPM 1600 1/min Aver. Ns 237 1/min	1	2.39 ^{f}	1.0 ^{f}	51.72	53.57 ^{c}
	2	3.90 ^{e}	2.0 ^{e}	51.87	61.90 ^{ab}
	3	6.08 ^{d}	3.1 ^{d}	51.09	60.63 ^{b}
	4	7.73 ^{c}	4.2 ^{c}	51.08	62.78 ^{ab}
	5	9.63 ^{b}	5.2 ^{b}	51.51	64.67 ^{a}
	6	11.54 ^{a}	6.2 ^{a}	51.42	63.50 ^{ab}
	LSD (%1)	0.7185	0.2087	-	2.597

and y = - 0,0533 + 1,0486.X (R^2=0,9996) for 4”, 5” and 6” pumps successively at the linear model. Relationship between stage numbers with pressure was found significant (Figure 1).

At the full closed valve, regression equation and determination coefficient of the power change which functions of stage number were detected as y = 0,6887 + 1,7505.X (R^2=0,9986); y = 1,3641 + 2,8025.X (R^2=0,9846) and y = 0,4175 + 1,8457.X (R^2=0,9986) for 4”, 5” and 6” pumps successively at the linear model. Relationship between stage numbers and shaft power were found significant for all three stages. The shaft power needs of the 4 and 6 pumps were measured equal this can be explained with the efficiency power of the shaft power to the flow, pressure and productivity (Figure2).

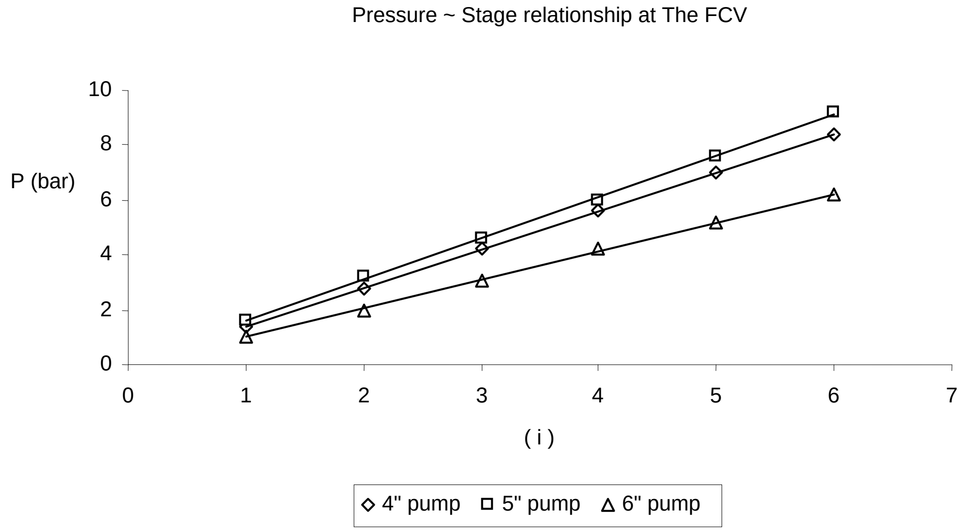

Figure 1. The effect of stage number on pressure at the multistage deep well pumps

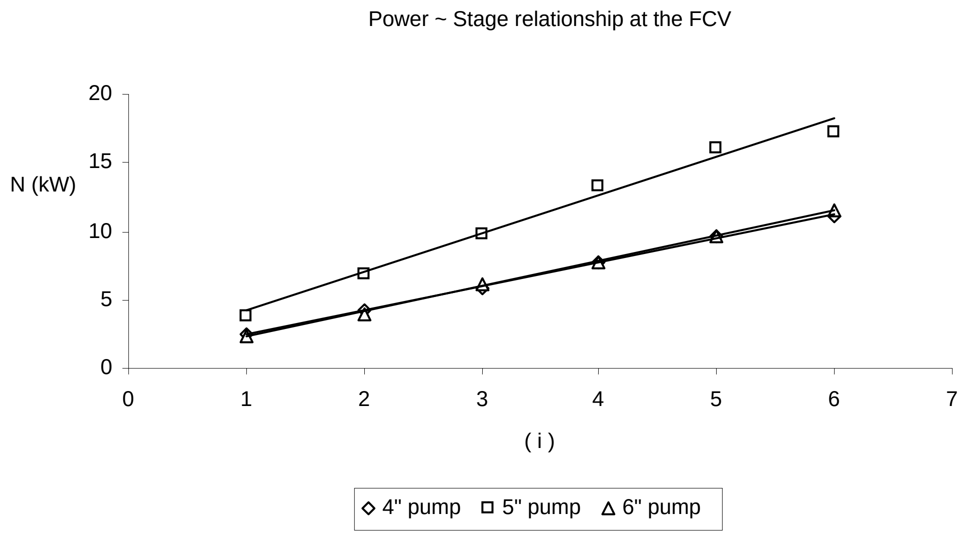

Figure 2. The effect of stage number on power at the multistage deep well pumps

At the full opened valve, regression equation and determination coefficient of the flow change functions of stage number were detected as y = 28,548 – 0,3688.X (R^2=0,4671); y = 45,116 - 0,4186.X (R^2=0,6301) and y = 49,907 + 0,2981.X (R^2=0,7412) for 4″, 5″ and 6″ pumps successively at the linear model. Relationship between stage numbers with flow for all pumps was found insignificant. At increased stage numbers, pump flows keeping their levels followed a linear flow (Figure3).

Regression equation and determination coefficient of the best efficiency change functions of stage number were detected as y = 0,5058 + 0,0153.X (R^2=0,7264); y = 0,5734 + 0,0106.X (R^2=0,9711) and y = 0,5469 + 0,0174.X (R^2=0,6743) alternate for 4″, 5″ and 6″ pumps at the linear model. The relationship between stage numbers and efficiency was found to be significant. However, it can be said that this relation in pump number 6 was weak. The reason is that the increase in the pressure is lower than the power increase. The most significant relationship was observed in pump 5 (Figure 4).

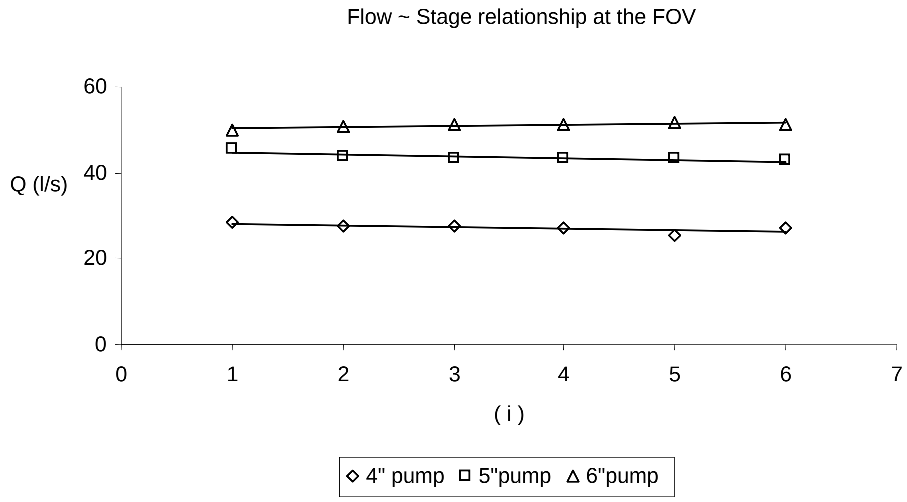

Figure 3. The effect of stage number on the flow at the multistage deep well pumps

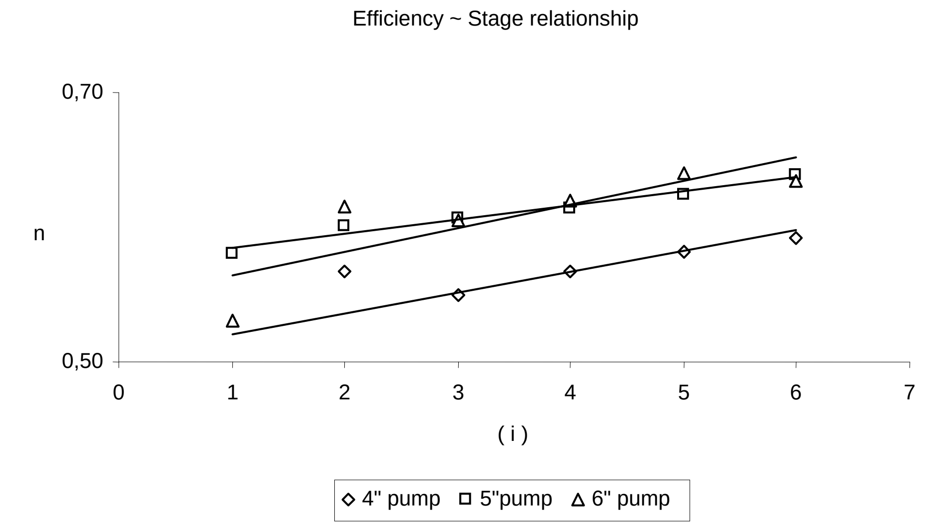

Figure 4. The effect of stage number on efficiency at the multistage deep well pumps

CONCLUSION

If shaft diameter, impeller dimension and RPM are stable, the following conclusions can be drawn with respect to tested vertical shaft deep well pumps that are multistage or serial mounted;

*As the stage number increased, the pumps shaft power increased proportionally. (R^2= 0, 9846…0, 9986). However, depending on the increasing stage number, the power consumption per each stage decreased at the rates of %24, 5…%35, 1.

*As the stage number increased for all pumps, pump output pressure had a linear increase (R^2= 0, 9996…1). But the pressures per one stage were stable.

*The flow rate was unaffected by the stage number (R^2= 0, 4671…0, 7412).

*For each of the pumps, maximum pump efficiency values increased depending on the stage number (R^2= 0, 6743…0, 9711). Increase rates of the efficiencies were 10, 32%-19, 50%.

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