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WELL DESIGN AND INFLUENCE OF GROUND WATER LEVEL ON PUMP PERFORMANCE

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تصميم بئر وتأثير منسوب الماء الارضى على أداء الطلمبة

خلاصة :

تم تصميم وحفر بئر بمزرعة كلية الزراعة بالقصيم بعمق ٦٠٠ متر وقد أختيرت الطلمبة التوربينية المناسبة لها ، ذات أربعة عشرة مرحلة ، لتتمشى مع متطلبات الرى من حيث التصرف والضاغط الديناميكى الكلى .

أوضح البحث الذى أجرى على هذه الطلمبة أن الأنخفاض الحاد فى منسوب الماء الأرضى يجعل الطلمبة لاتعطى التصرف المطلوب وكذلك الضاغط حتى عند أعلى سرعة لها مما يترتب علية أعطال أو تلف الطلمبة . لذا يجب زيادة طول عمود التصرف لها بالقدر الذى يتمشى مع الانخفاض فى منسوب الماء الأرضى .

يقدم البحث معادلات تربط بين سرعة الطلمبة وكل من التصرف والضاغط الديناميكى لها من واقع قراءات عملية تم تحليلها احصائيا وقد أتضح أختلافها عن القوانين النظرية المعطاه لها . كذلك أوضح البحث العلاقة بين مستوى الماء الاستاتيكى وتصرف الطلمبة .

ABSTRACT

A deep water well of 600 m depth was designed and drilled in the farm, college of agriculture Al-Qassim, A fourteen stages turbine pump was selected, to be installed on this well, according to the total head and water discharge required for irrigation.

A severe decline of ground water level will not provide the required water discharge and total head even if the pump works under its maximum speed. This could make a trouble shooting or damage to the pump unless its column pipe length will be increased to deal with the existing water level.

Relationships between pump speed and both the water discharge and total head, based on field measurements and statistical analysis are given. It was found deviations of these equations from the corresponding theoretical ones. Relationship between the static water level and pump discharge is also presented.

INTRODUCTION

Since 1950, Al-Qassim region in the Kingdom of Saudi Arabia has been dependent largely on the Saq aquifer and the withdrawl rates have been increased gradually with the increasing population and agriculture in the area. Recharge is approximately 80.0 M m^3/year and the pumping rate was estimated to be 232 M m^3 in the year 1982 (2). Consequently, the static water level has steadily declined causing a rate of depletion of about 4.0 m/year. A seasonable severe decline of water level or piezometric head also occurs during April and May each year due to the excessive pumping of irrigation water requirements at that period.

Saq sandstone is an extensive confined aquifer. It is one of the largest water reservoir in the central Arabia. The surface on the Saq sandstone can be followed along the Arabian Shield, from the south of Jordan in the north to the central Saudia Arabia for a distance more than 1200 km and thickness varying between 600 m and 800 m. Ground water reserves of Saq aquifer were estimated to be 49900 M m^3 (11).

Transmissivity values are in the range between 0 to 2450 m^2/day. Storage coefficient values vary between 1.3×10^{-3} in the unconfined parts and 2.5×10^{-5} and 6.3×10^{-5} in the confined ones (10).

Improperly designed and constructed irrigation wells are a major cause of many pumping problems and a contributing factor to high pumping costs. Adverse effects are, sand pumping, air entrainment and encrustation and all becoming more severe with continuing pumping and water table decline. (8).

Well design and well operation are independent, with a given well design, one should optimally operate the well. Different views for optimal drawdown are given in literature (4). One of which is 67 % of the saturated thickness. However the design discharge should not provide the drawdown the aquifer can not provide. On the other hand, the design discharge should not provide high entrance screen velocity which causes sand migration around the screen, thus decreasing the hydraulic conductivity.

Well depths and distances between wells are subjected to the Ministry of Agriculture and Water regulations. In the study area the permissible well depth is 600 m and the minimum distance between any two wells is 500 m. Hydraulic conducivity is 2.2 m/day(2).

It was required to construct a well and to install a suitable turbine pump on it in the college farm, with required discharge 2000 gpm (454.3 m^3/hr) and total dynamic head of 900 ft.

PUMPING WELL

A deep well of 600 metres for agricultural use was designed and drilled in the college farm Fig.(1). The Saq aquifer is used as a source of water in the Al-Qassim region of centeral Arbia and it was found at about 230 metres from the ground surface. The well site was selected after inquiring and reviewing the existing geological informations in the area and drilling local regulations.

A hydraulic drilling equipment, using a roller bit and drilling mud was used. The well was drilled down to a depth of 600 metres with a casing of 300 metres, 10 metres of which has 20 inches inside diameter. The inside diameter of the well was designed to be 12.25 inches along the 300 metres. Water level was found at a depth of about 85 m from the ground surface, Fig.(2)

PUMP SELECTION

The selection of a pump depends mainly on the water discharge and the total dynamic head or the system head curve. The type of pump should be chosen to operate at or near its maximum efficiency. The pump manufacturer's catalogs with the characteristic curves or tables are used to select the pump models and number of stages.

Column Discharge Pipe

The column pipe transmits the water from to bowls to the pump discharge head. The column diameter should be selected to suit the diameter of well casing and large enough to permit the passage of the design discharge with acceptable friction loss. not to be exceeded 5 m/100 m or 5 ft/100 ft (6). The column pipe should be long enough to keep the bowls of pump submerged under different pumping conditions. Table (1), Appendix gives the column pipe diameter according to the water discharge (1).

Pump Shaft Diameter

The diameter of the line shaft should be chosen to transmit the required power to the impellers at the design pump speed. Other important factor in the selection of the shaft diameter is the shear stress of the shaft material. The pump shaft is also subjected to vertical forces that stretch the shaft; weight of the impellers, weight of line shaft assembly; and the hydraulic thrust. Manufacturer`s curves or tables are used to select the shaft diameter. Table (2) Appendix (1).

Suction Pipe

In order to make the water entering the bottom stage of a turbine pump in a vertical direction. a suction pipe should be fitted. It is recommended that the length of this pipe should be less one metre (6 ,14).

Pump Head

The friction loss through the pump head should be less than one metre(5). The size of pump head should be compatible with the column pipe and dimension of the gear head. The pump has been driven by internal combustion engine.

Procedure

It is required to install a suitable turbine pump for the given well, which deliver a design discharge of 2000 gpm (454.3 m^3/hr) with total head 900 ft (274.3 m)

From Table (1), Appendix, the column pipe diameter for the flow rate 2000 gpm is 8 inches. The choice of 10 inches could also be suitable for the well casing. Brake horse power of the pump (B.H.P.) is given by the following equation:

$$B.H.P. = \frac{Q \times H_t}{3960 \times E} \qquad (1)$$

in which:

- E = pump efficiency;
- Q = water discharge in gpm; and
- H_t = total head in feet.

Assuming pump efficiency = 80 %. The estimated brake horse power = 568.2 H.P.,according to the value of this power and from Table (2), Appendix the recommended shaft diameter is 1.9375 inches.

From the pump characteristic curves, Fig.(3), at 2000 gpm, for 9.6875 inch impeller diameter and line shaft 1.9375 inch, the head per stage is 66.5 ft, brake horse power = 42.5 H.P., and pump efficiency = 79 %.

The column pipe diameter is usually associated with the pump shaft diameter . The suitable column assembly is 10" × 1.9375". from Fig.(4), the friction loss per 100 ft at 2000 gpm is 4.1 ft.

The pump setting is 600 ft, consequently, the total friction head loss in the column pipe assembly is $(4.1/100) \times 600 = 24.6$ ft.

Total dynamic head = 900 + 24.6 = 924.6 ft.(281.8 m)
Number of stages = 924.6/66.5 = 13.9 = 14 stages.
power absorbed by the pump line shaft is $14 \times 42.5 = 595$ H.P.

RESULTS AND ANALYSES

Severe decline in water level usually occurs in this region during April and the beginning of May due to the increasing water requirements for Wheat and Alfalfa at that period. This decrease in water level makes a great trouble in the pump performance. It does not provide the required flow rate even at high value of speed. Fig.(5) gives the relationship between pump discharge and speed. The figure demonstrates the difference in discharge values at the same speed within one week. For example at 1500 rpm, Q = 500 gpm ($113.6\ m^3/hr$) with 30 psi in 22/4/1992 and Q = 390 gpm ($88.6\ m^3/hr$)with 20 psi in 29/4/1992. At normal pumping at 1500 rpm, pump discharge is usually 1200 gpm ($272.5\ m^3/hr$) with inlet pressure of about 70 psi. Based on statistical analyses (SAS) program, (12) it was found a polynomial from the second degree could be suitable to fit these relationships, Tables(1,3).

Equations are given by:

$$Q = -10718 + 12.75\ N - 0.0035\ N^2 \ldots 1400 \leq N \geq 1700 \ldots 22/4/1992.(2)$$

$$Q = -11825 + 13.59\ N - 0.0036\ N^2 \ldots 1400 \leq N \leq 1700 \ldots 29/4/1992.(3)$$

in which ; Q is the pump discharge in gpm and N is the pump speed in rpm.

Relationships between pressure at inlet of the discharge pipe and pump speed during that period are given in Fig (6). The equations between the pressure head and pump speed are given as follows:

$$P = 137.85-0.36\ N+1.91 \times 10^{-4} N^2 \ldots 1400 \leq N \leq 1700 \ldots 22/4/1992.(4)$$

$$P = -92.34-0.0375\ N+7.5 \times 10^{-5} N^2 \ldots 1400 \geq N \leq 1700 \ldots 29/4/1992.(5)$$

in which; P is the pressure in psi and N is the pump speed in rpm.

Theoretically, the relationship between the pump discharge and its speed is given by straight line passes through the origin. Based on selected records of about one year, the linear relationship between pump discharge and speed is given in Fig.(7) having straight line. The same relationship in a second degree polynomial is given in equation (7). It could be more accurate to be represented by a power relationship equation (8) and Fig.(8).

$$Q = -2190.52 + 2.25\ N \quad \text{.......(6)}$$

$$Q = -16087.1 + 23.25\ N - 0.00791\ N^2 \quad \text{.......(7)}$$

$$Q = 1.14 \times 10^{-11}\ N^{4.427} \quad \text{.......(8)}$$

in which; Q is the water discharge in gpm and N is the pump speed in rpm .

Fig.(9) exhibits a second degree polynomial relationship between the total head and the pump speed in the form:

$$H_t = 2896.05 - 4.076\ N + 0.00175\ N^2 \quad \text{.......(9)}$$

in which; H_t is the total head in feet and N is the pump speed in rpm.

A better fitting of this relationship is given in Fig. (10) as a third degree polynomial by the following equation :

$$H_t = -1174.5 + 29.28\ N - 0.0235\ N^2 + 6.34 \times 10^{-3}\ N^3 \quad \text{.......(10)}$$

Equations (6) through (10) for pump speed (N) varied between 1100 rpm and 1500 rpm.

Influence of ground water fluctuations on the pump discharge, based on records of about one year. Power, linear, exponential and logarithmic fittings between the pump discharge and static water level provided the same curve Fig (11)

The power relationship is given by :

$$Q = 1057030\ H_s^{1.14125} \quad \text{.......(11)}$$

Third degree polynomial could be more accurate representation, Fig.(12), which is given by the equation :

$$Q = 142826 - 889.57\ H_s + 1.86\ H_s - 0.013\ H_s^3 \quad \text{.......(12)}$$

CONCLUSIONS

An irrigation water well was designed and constructed in the college farm, suitable turbine pump was selected. to deal with the water discharge and head.

In the design procedure, the column pipe diameter could be selected first, according to the required water discharge. This selection will help in choosing the suitable well casing size and from which the corresponding well diameter could be chosen.

Troubles could occur due to the severe decline of water table or piezometric head. These difficulties can be tackled by increasing the column pipe assembly of the pump. Increasing the number of bowls will increase the total head without any noticeable increase in the discharge.

The rate of depletion of the ground water depends on the consumptive use of water due to irrigation water requirements and the hydrological characteristics of the aquifer. Bowls of pump should be submerged under any condition of the water table. This should be considered in the well design and pump selection.

Fluctuations of ground water level have an effect on the pump characteristic curves. The theoretical relationships are no longer valid. Relationship between discharge and pump speed could be fitted by second degree polynomial or power function, and between total head and speed is a polynomial from the third degree.

Static water level has a great influence on pump performance. The relationship between pump discharge and static water level could be fitted by third degree polynomial.

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NOTATION

The following symbols are used in this paper :

E = pump efficiency ;
F = statistical parameter, F-test ;
H_s = static water level ;
H_t = total dynamic head ;
N = pump speed ;
P = pressure at inlet of the discharge pipe;
R^2 = multiple correlation coefficient of determination ; and
T = statistical parameter, T-test.

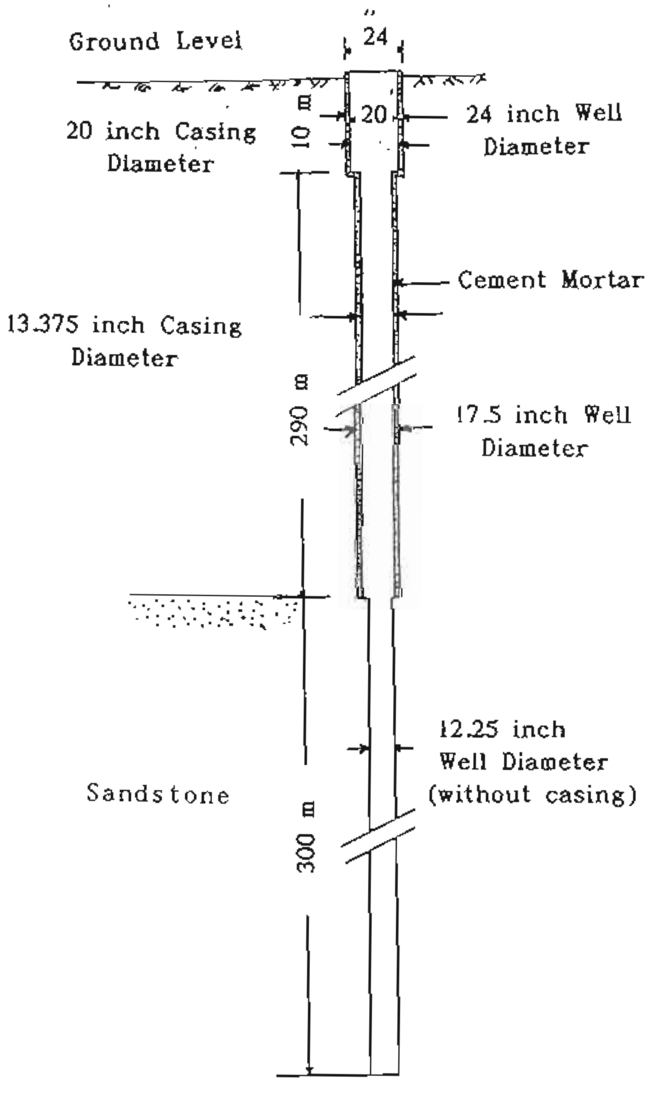


Fig (1) Longitudinal Section in The Designed Well

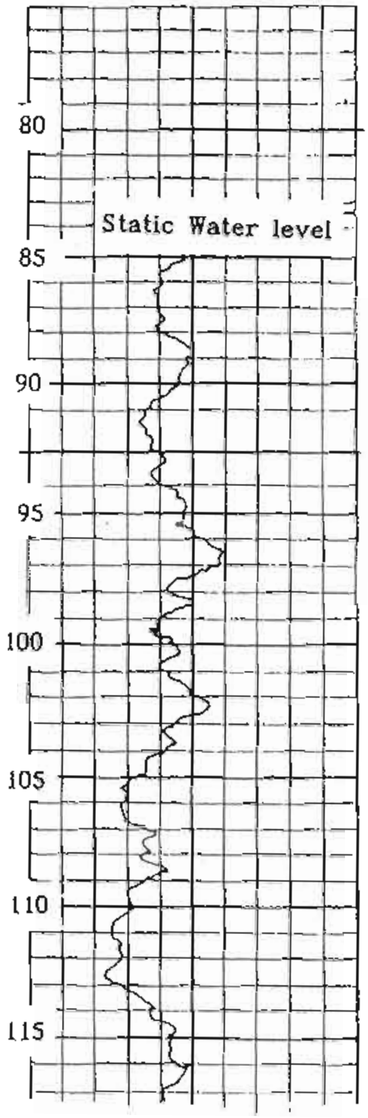


Fig (2) Electrical Logging (Gamma Ray)

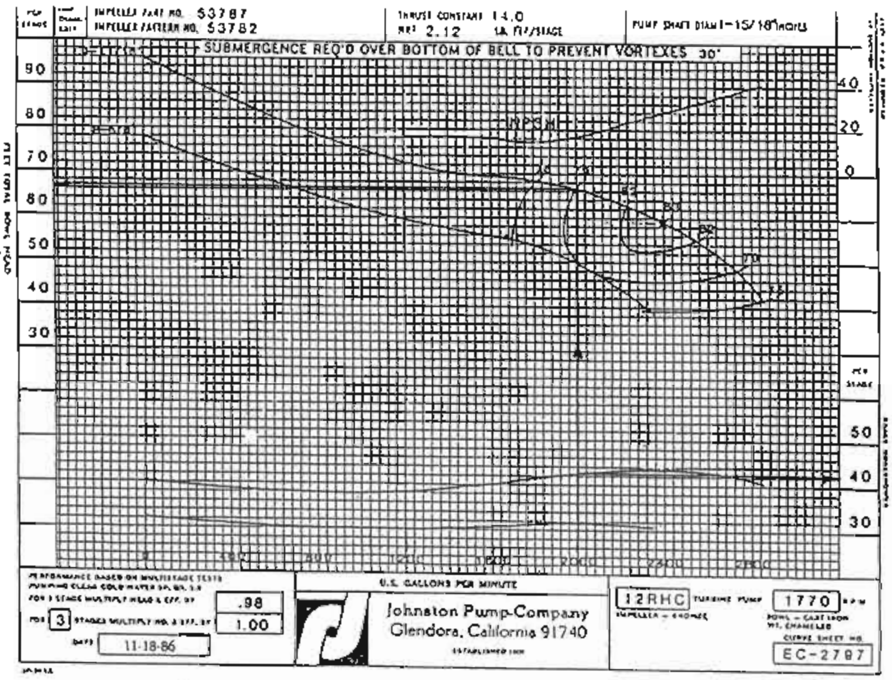


Fig. (3) Pump Characteristic Curves

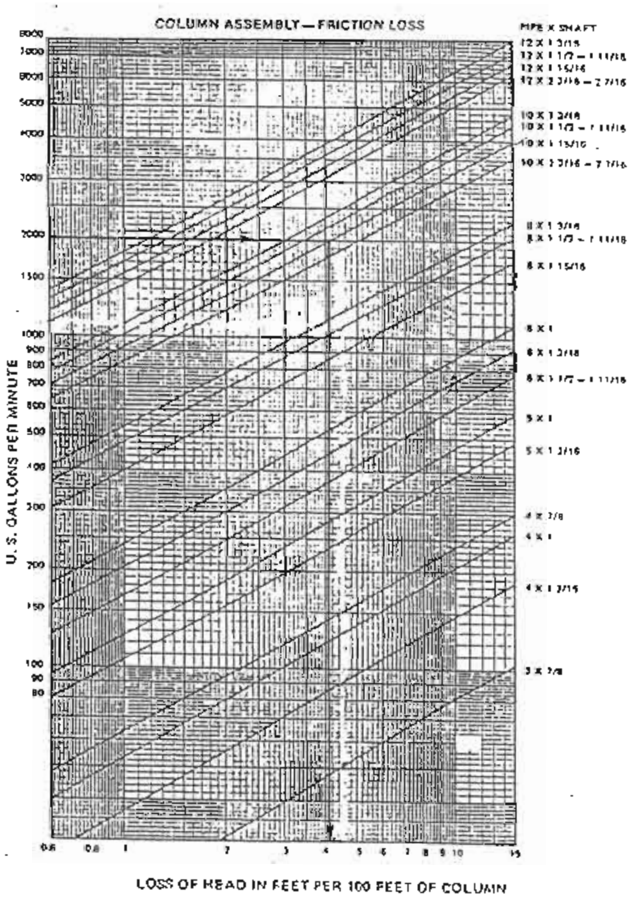


Fig. (4) Column Selection Chart

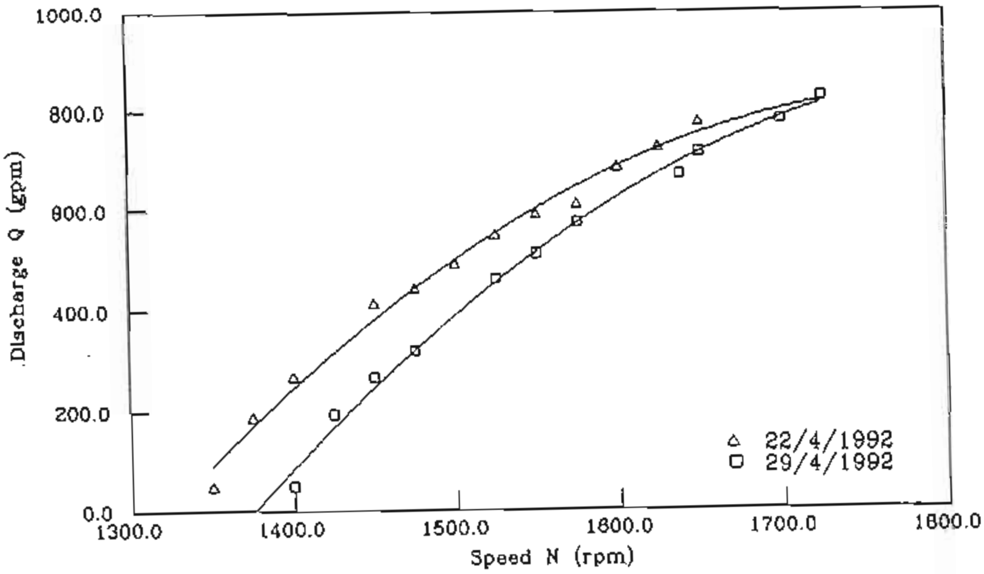


Fig.(5) Second Degree Polynomial Relationship between Pump Discharge and Speed.(Severe Decline of Ground Water Level)

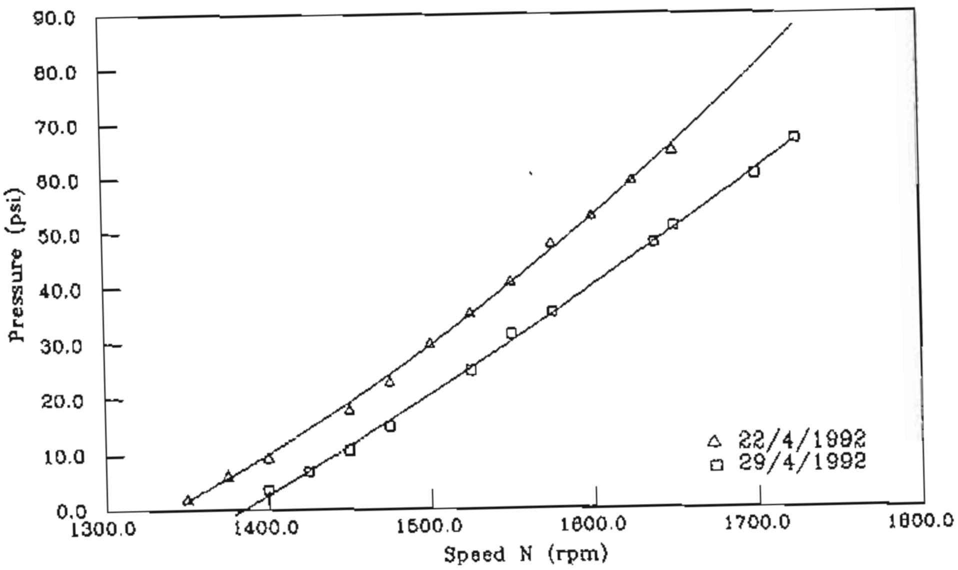


Fig.(6) Second Degree Polynomial Relationship between Inlet Pressure and Pump Speed.(Severe Decline of Ground Water level)

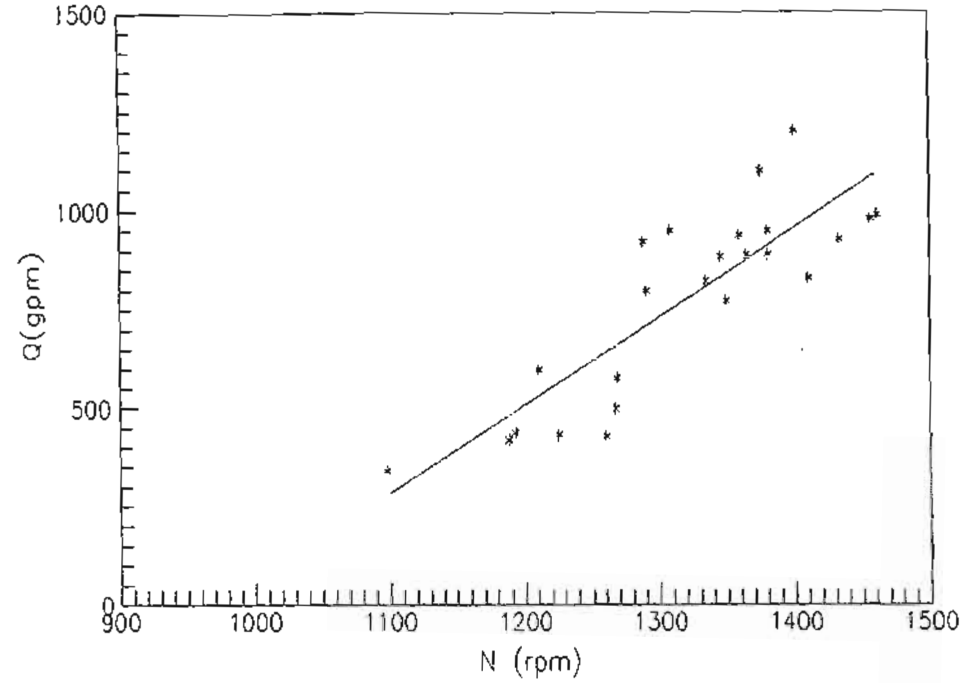


Fig.(7) Linear Relationship between Pump Discharge and Speed

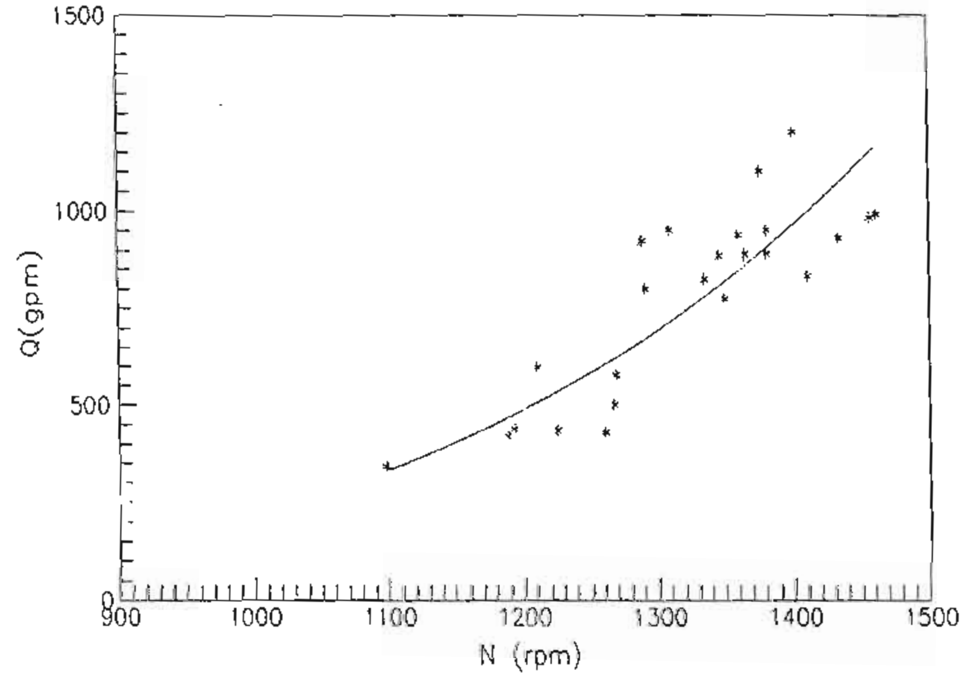


Fig.(8) Power Relationship between Pump Discharge and Speed

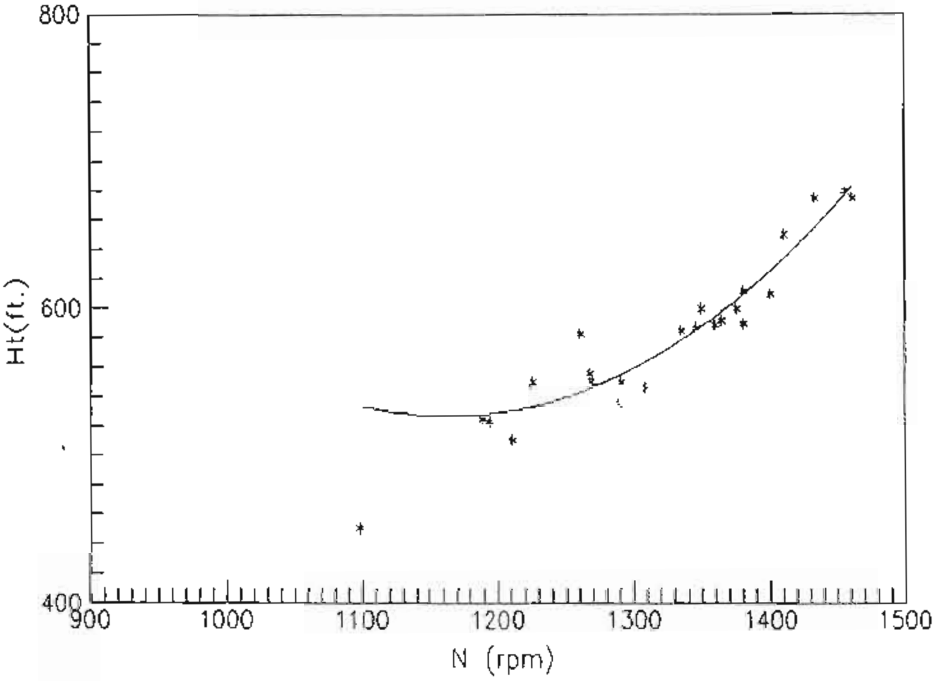


Fig.(9) Second Degree Polynomial Relationship between Total Head and Speed

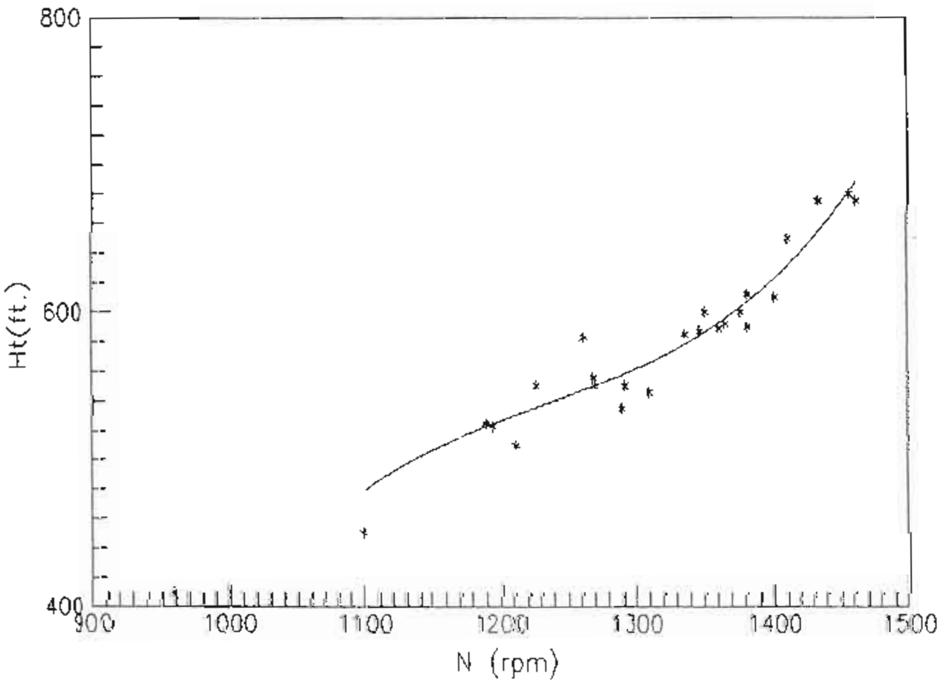


Fig.(10) Third Degree Polynomial Relationship between Total Head and Speed

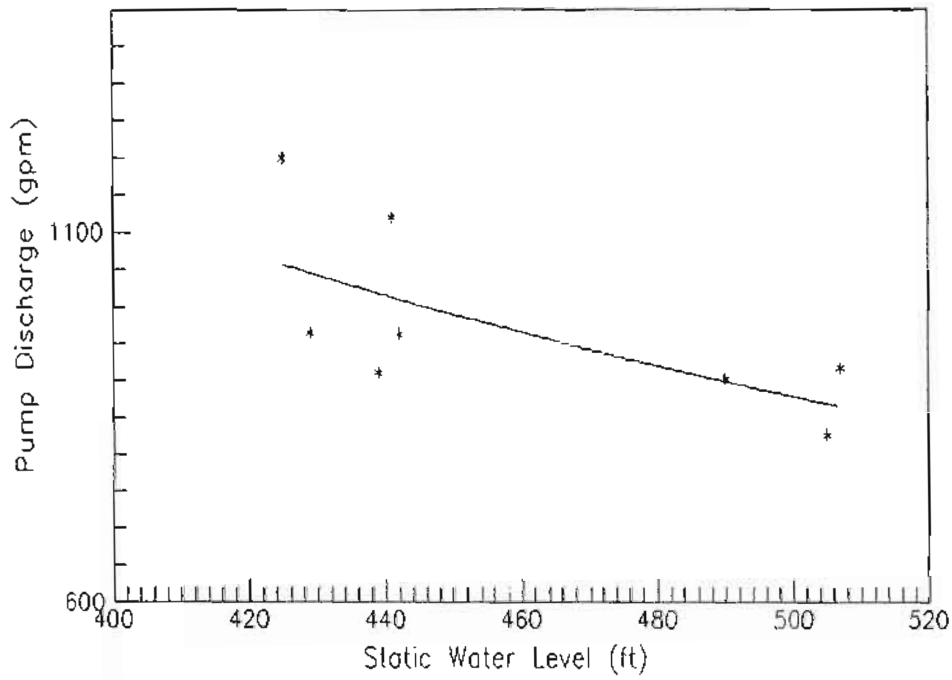
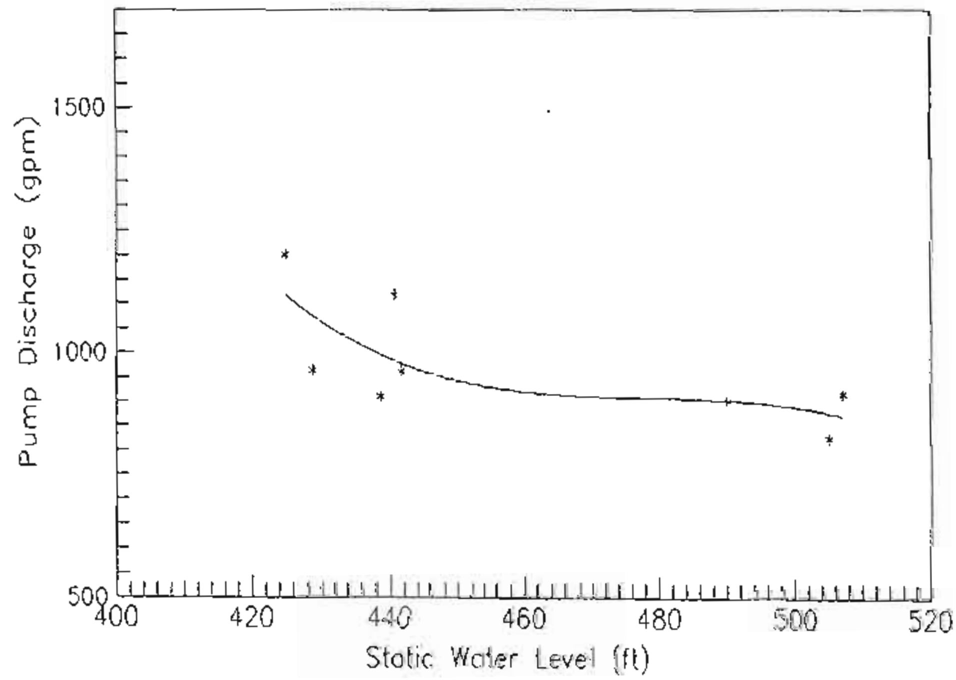


Fig.(11) Power Relationship between Pump Discharge and Static Water Level at Speed 1400 rpm



Fig(12) Third Degree Polynomial Relationship between Pump Discharge and Static Water Level at Speed 1400 rpm.

Table (1) Statistical Analysis, "SAS" Program,
Relationship between Q and N (22/4/1992).

Function	Analysis of Variance: F	prob>F	R^2	R^2 adj	Parameter Estimate	T	prob>T	Durbin Watson coefficient	1 st. order auto correlation
Polynomial 1st degree (Y)	347.02	0.0001	0.9720	0.9692	Intercept	-15.89	0.0001	0.76	0.350
					X	18.628	0.0001		
Polynomial 2nd degree (Y)	426.083	0.0001	0.9895	0.9872	Intercept	-5.29	0.0005	1.234	0.191
					X	4.704	0.0011		
					X^2	-3.889	0.0037		
Polynomial 3rd degree (Y)	1066.27	0.0001	0.9975	0.9966	Intercept	-5.557	0.0005	2.424	-0.283
					X	5.352	0.0007		
					X^2	-5 176	0.0008		
					X^3	5.051	0.0010		
Power LN(Y)	31.993	0.0002	0.7619	0.7381	Intercept	-5.203	0.0004	0.889	0.221
					LN(X)	5.656	0.0002		
Exponential LN(Y)	28.894	0.0003	0.7429	0.7172	Intercept	-2.204	0.0521	0.858	0.232
					X	5.375	0.0003		

Table (2) Statistical Analysis, "SAS" Program
Relationship between H and N (22/4/1992).

Function	Analysis of Variance: F	prob>F	R^2	R^2 adj	Parameter Estimate	T	prob>T	Durbin Watson coefficient	1 st. order auto correlation
Polynomial 1st degree (Y)	1395.0	0.0001	0.9929	0.9922	Intercept	-33.51	0.0001	0.496	0.594
					X	37.35	0.0001		
Polynomial 2nd degree (Y)	3095.96	0.0001	0.9955	0.9982	Intercept	1.905	0.089	1.22	0.306
					X	-3.711	0.0048		
					X^2	5.927	0.0002		
Polynomial 3rd degree (Y)	4856.21	0.0001	0.9995	0.9992	Intercept	3.769	0.0055	2.548	-0.324
					X	-3.816	0.0051		
					X^2	3.779	0.0054		
					X^3	-3.627	0.0067		
Power LN(Y)	90.329	0.0001	0.9003	0.8904	Intercept	-9.236	0.0001	0.695	0.330
					LN(X)	0.8904	0.0001		
Exponential LN(Y)	76.745	0.0001	0.8847	0.8732	Intercept	-6.936	0.0001	0.655	0.350
					X	8.760	0.0001		

Table (3) Statistical Analysis, "SAS" Program.
Relationship between O and H (29/4/1992).

Function	Analysis of Variance				Parameter Estimate			Durbin Watson coefficient	1 st. order auto correlation
	F	prob>F	R^2	R^2 adj		T	prob>T		
Polynomial 1st degree (Y)	357.08	0.0001	0.9754	0.9727	Intercept	-16.23	0.0001	0.833	0.288
					X	18.908	0.0001		
Polynomial 2nd degree (Y)	843.71	0.0001	0.9941	0.9943	Intercept	-7.766	0.0001	1.884	-0.172
					X	6.946	0.0001		
					X^2	-5.799	0.0004		
Polynomial 3rd degree (Y)	903.03	0.0001	0.9974	0.9963	Intercept	-2.938	0.0218	2.434	-0.311
					X	2.726	0.0295		
					X^2	-2.543	0.0385		
					X^3	2.412	0.0467		
Power LN(Y)	28.34	0.0005	0.7590	0.7322	Intercept	-4.891	0.0009	0.92	0.190
					LN(X)	5.323	0.0005		
Exponential LN(Y)	25.57	0.0007	0.7397	0.7107	Intercept	-1.997	0.0770	0.887	0.203
					X	5.057	0.0007		

Table (4) Statistical Analysis, "SAS" Program.
Relationship between K and H (29/4/1992).

Function	Analysis of Variance				Parameter Estimate			Durbin Watson coefficient	1 st. order auto correlation
	F	prob>F	R^2	R^2 adj		T	prob>T		
Polynomial 1st degree (Y)	3979.27	0.0001	0.9977	0.9975	Intercept	-56.33	0.0001	0.976	0.245
					X	63.08	0.0001		
Polynomial 2nd degree (Y)	3538.71	0.0001	0.9989	0.9986	Intercept	1.428	0.1913	1.587	0.128
					X	-0.451	0.6642		
					X^2	2.826	0.0223		
Polynomial 3rd degree (Y)	2691.04	0.0001	0.9991	0.9988	Intercept	1.373	0.2122	1.915	-0.033
					X	-1.473	0.1841		
					X^2	1.511	0.1745		
					X^3	-1.457	0.1884		
Power LN(Y)	99.87	0.0001	0.9173	0.9081	Intercept	-9.659	0.0001	0.496	0.482
					LN(X)	9.994	0.0001		
Exponential LN(Y)	82.823	0.0001	0.9020	0.8911	Intercept	-6.831	0.0001	0.481	0.489
					X	9.101	0.0001		

APPENDIX

Table (1) Selection of Column Pipe Diameter

Diameter (inch)	Discharge	
	m^3 / hr	gpm
2.0	0 - 14	0.0 - 61.6
2.5	14 - 20	61.6 - 88.0
3.0	20 - 45	88.0 - 198
4.0	45 - 80	198 - 352
5.0	80 - 140	352 - 616
6.0	140 - 250	616 - 1100
8.0	250 - 500	1100 - 2200

Table (2) Selection of Pump Shaft Diameter

Diameter (inch)	Speed (rpm)		
	1450 H. Power	1800 H. Power	2200 H. Power
1.0000	54	65	78
1.1250	92	110	132
1.5000	205	250	290
1.6875	305	370	450
1.9375	475	575	700

N. B.

The pump shaft diameter is usually associated with the column pipe diameter as follows :

4" × 1" , 5" × 1.1875" , 6" × 1" , 6" × 1" , 6" × 1.25" , 6" × 1.5"

8" × 1.5" , 8" × 1.875" and 10" × 1.9375" .