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Configuration of Pumps in Series or Parallel installations: Delivery Capacity Enhancement

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ABSTRACT

The challenge of today's engineers is to find the most efficient way to operate a pump by increasing its delivery head and its discharge flow in every given condition. Configurations of pumps in series, parallel and single installations were compared and studied for eventual developments in pumping systems, technologically and economically beneficial for future pumping applications in domestic, industrial, agricultural and re-creational use. The study evaluated the effect and delivery of the single pump and the configuration in series and parallel arrangement of the units of equal geometric characteristics. The performance of the delivery discharge and head and the best arrangement or configuration of the pumping units for an optimum capacity enhancement was determined.

Results of the study show that the pumps configured in series and parallel statistically increased their respective capacities in terms of static delivery head and discharge volume flow, respectively.

Keywords: Pump, discharge flow, water, pumping system, Total Dynamic Head

INTRODUCTION

Pumps are defined as the device that draws a fluid or water from one point, raises its pressure then discharges it to another point or location. The challenge of today's engineers is to find the most efficient way to operate a pump by increasing its delivery head and its discharge flow in every given condition. Configurations of pumps in series, parallel and single installations was compared and studied for eventual developments in pumping systems. This should be technologically and economically beneficial for future pumping applications in domestic, industrial, agricultural and re-creational use.

One of the world's largest pumping installations that experienced a shortage of delivery height was the Edmonston Pumping Plant of the State of California water project (White, 2011). This plant lift water over Tehachapi mountain. At this plant there are 14 four-stage vertical-shaft centrifugal pumps. Each is capable of delivering 8.9 m^3/sec against a head of 600 m when rotating at 600 rpm. The pumps were configured to attain maximum heads of delivery (Fischer, 2008). Miller Brewing Company in the 1970's experienced a shortage of continuous supply of water resulting from capacity insufficiency of their pumping units. The maintenance team opted to increase the capacity of the units but to no avail, until an intensive study of their pumping system

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and eventual configure the pump set-up, the company have able to remedy the lingering production set-back (Heilmann et al.,2010).

Similarity laws permit the prediction of the performance of a prototype pump from the best of the scaled model. These laws also permit prediction of the performance of a given pump under different conditions of operation from those under which it may have been tested. Similarity laws are based on the concept that two geometrically similar machines with similar velocity diagrams at entrance to and exit from the rotating element are *homologous*. This means that their streamline patterns will be geometrically similar, i.e., that their behaviors will bear a resemblance to one another (Daugherty, et al, 1989:472).

When the pumps are installed in series or parallel it is very important that they have reasonably similar head-capacity characteristics throughout their range of operation; otherwise, one pump will carry most of the load, and under certain conditions, all of the load, with the other pump acting as a hindrance rather a help. Whether pumps are used in series or in parallel, the arrangement will be uneconomical unless both pumps are operating near their best efficiency.

Thus, this study aimed to determine the performance capacities of the pumps configured in series or parallel pumping arrangement compared against the single pump installation to determine an enhance capacity of delivery.

Conceptual Framework

The study is all about the comparative performance of the pumping units of geometrically similar capacities configured units in series and parallel installations against single pump installation. When the pumps are installed in series or parallel it is very important that they have reasonably similar head-capacity characteristics throughout their range of operation; otherwise, one pump will carry most of the load, and under certain conditions, all of the load, with the other pump acting as a hindrance rather a help. The configuration of pumping units of the same size will result to an eventual increase of delivery capacities in terms of discharge volume flows and its static height. White, (2011) averred that two pumps need not to be identical at all, since they merely handle the same discharge; they may even have different speeds, although normally both are driven by the same shaft. The combined operating-point head or resulting head will be more than either pump *A* or pump *B* separately but not as great as their sum.

MATERIALS AND METHODS

Research Design and Methods

This study uses an experimental method. The desired data on this study includes the output capacity of the pump in unit power, in unit volume flow, the speed in revolutions per time, the frequency in cycle per second, etc.

The direction and the flow of the research study follows the Input-Process-Output scheme, as shown in **Figure 1**. The Input contains the corresponding specific data of centrifugal pumps essential for the performance capacity evaluations. The Process shall include the validations of the experimental performance results of configured model from single installation, series and parallel connections in contrast with the numerical performance. The Output of the study determines the enhanced delivery capacity of the pumps in configurations and the eventual economical pumping set-up.

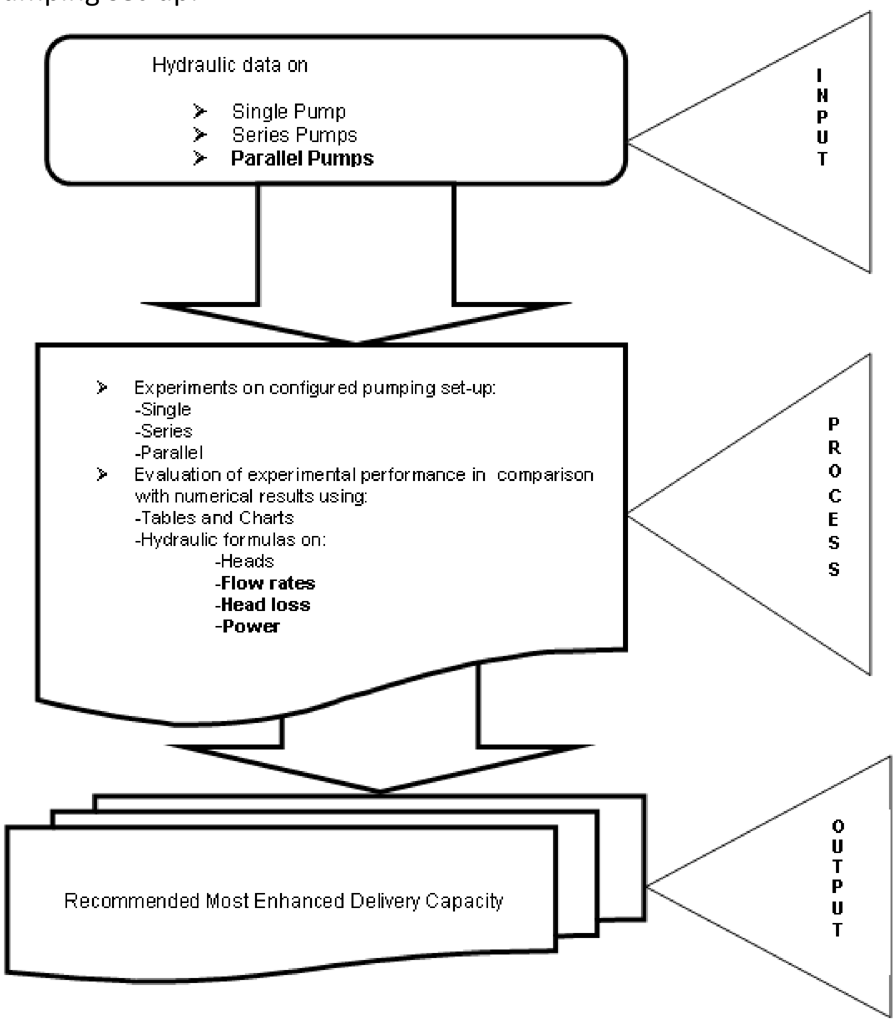

Figure 1.The direction and the flow of the research study

Process

Fabrication of a Configured Model of Pumps

A fabricated model consists of two pumping units installed at equal geometric capacities. The fabricated pumping set-up of the model includes the installations of the pressure gauges from inlet section of the pump (or at the suction side), to the outlet section (or at the discharge side) of the pump, the flow meter, the valve fittings, and the specified size of piping systems.

Pumping operation

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A single pumping operation is done individually either in Pump A or Pump B by shutting off the other unit so as to acquire only the single pump performance capacity between the two pumping units. Pumping operations of the two pumps from the fabricated model are configured either in series or parallel arrangements by closing down the respective gate valves of piping lines leading to the desired flow of fluids. The changes of fluid flow particularly in series or parallel is altered through a control of flow in the gate valves, or by closing or opening the certain flow line as desired. In the series installation, fluids of respective pumping units are collectively discharged to a single pipeline. While in parallel installation, the flow of fluid of two pumping units is separately discharged in the respective piping system.

This study analyzed the effect and delivery of the single pump installation and the configuration in series and parallel arrangement of the units of the same geometric characteristics. The performance of the pumps was compared particularly the discharge delivery in volume flow rate and static head or the transfer of fluid at a vertical elevation in order to determine the best arrangement or configuration of the pumping units for an optimum capacity enhancement.

Data Gathering Procedure

Actual experimentations and acquisition of data on pump performances were actually obtained rather than relying on computer simulations. The data obtained were taken from the various parameters such as: the pumping capacities, the size of motor, size of pipes, the fittings installed, etc. These were considered in the series of experiments for these affect the performance of the pumping system particularly in friction losses. A corresponding specific characteristics of the pump as to the driving power capacity, its speed and its discharge capacity were initially established prior to an experimental performance.

Reliability tests were performed to determine the consistency of findings. The tests include the performance verification of the delivery capacity of the pumping unit particularly in the discharge rate and static head against the information provided in the technical specifications of the equipment. Consistency or uniformity of the results should be obtained so that error caused due to the failure of device shall be avoided. Result of the reliability tests is compared to the numerical manufacturers rated values as reference standard.

The pump design was also considered to further evaluate and determine the pumping performances of the single pump operations, pumps configured in series, and in parallel arrangement. In this aspect, hydraulic empirical formulas and tables were utilized in the evaluation of the most enhanced delivery capacity and the most economical pumping set-up resulting from this study.

RESULTS AND DISCUSSION

Performance Capacities of Pumps

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The performance capacity of pumping units is measured in terms of their delivery efficiency. The efficiency of the unit is measured in terms of the ratio of its output capacity to its input capacity based specifically to the delivery performance of the pumping units in head and in the volume of fluid discharged measured per unit time.

As shown in **Figures 2** and **3,** the individual performance capacities of the single pump installations in **Pump A** and **Pump B,** could hardly develop beyond the maximum delivery height of **41.554m.**while motor pump at this point, could no longer drive further to discharge a fluid. However, the tail end of the graph in **Fig. 3** indicates a maximum discharge of **40.958 liters/min.** and a corresponding delivery head of**2.480 m.** This only shows that numerous fittings in the piping installation further retard the flow of fluid in the pipe causing some losses within the piping lines such as the friction loss in the fluid.

With pumps configured in series and parallel arrangements, the set-up eventually developed a maximum head of **78.22 m.** in series connection**,** and a maximum discharge of **79.78 liters/min,** for parallel connection, an indication of an enhanced capacity against the controlled single pump installations. The configuration of pumps either in series or parallel installation delivers an optimum performance of almost twice the desired output in static head and discharge flow, respectively.

Single Installation: ***Discharge Flow and Total Dynamic Head***

Accordingly, the discharge flow rate of water is inversely proportional with the develop head from **Fig.2**, at a maximum develop head of **41.554 m.**, the discharge fluid of ***Pump A*** could hardly flow anymore. The column of fluid could be raise to as much as that height but the pump could no longer drive to discharge a fluid. However, the tail end of the graph measures a *minimum head* of **2.534 m.** with a corresponding flow rate of **39.331 liters/min** of discharge water using water meter at a specified period of time. The pumping installation of ***Pump A*** is directly located a few meters from the source so that, at a minimum height of delivery, the pumping unit yields a maximum discharge capacity at this much. Also, numerous fittings in the piping installation further retard the flow of fluid in the pipe causing some losses within the piping lines due to friction loss in the fluid.

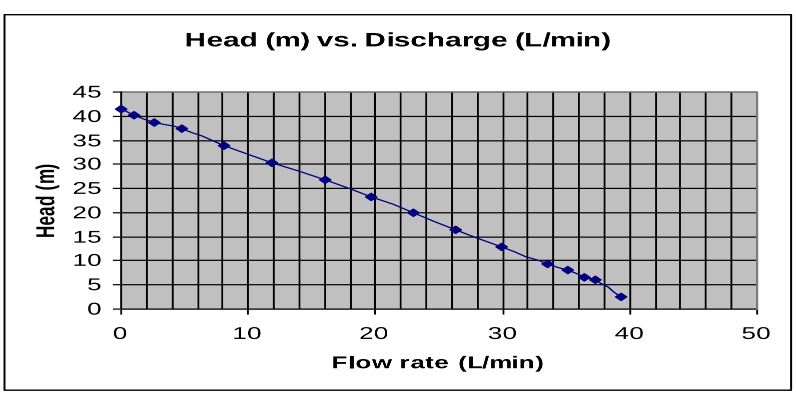

Fig. 2. Flow rate at Any Given Head for Single Pump (Pump A)

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In the graphical presentation of *Pump B* in **Fig. 3** illustrates a flow rate at a varying delivery head. Since the flow rate is inversely proportional to the head developed by the pump installed, it explains how the volume flow rate decreases while the head developed increases and vice versa. ***Pump B*** stops delivering fluid at a peak head of **38.714 m.** In contrast with *Pump A*, the ***Pump B***is installed at **247 m.** pipelines but is distracted with several fittings before it reached the reservoir. The source of supply water is located at a sufficient distance away from ***Pump B*** causing a suction difficulty in the pumping. These aggravated more in the delivery performance of the pumping unit with some appreciable losses in the piping lines.

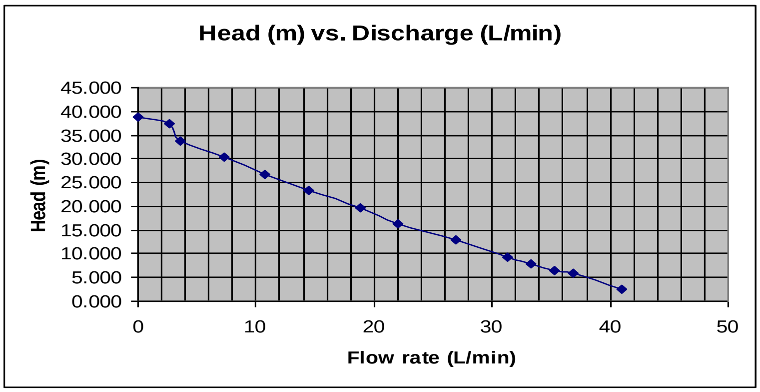

Fig. 3. Flow rate at Any Given Head for Single Pump (Pump B)

Series Connection: *Discharge Flow and Total Dynamic Head*

As shown in F**ig. 4 and Table 1,** the pumps connected in series developed a maximum head of **78.22 m.**, and at this capacity head, the fluid will no longer flow. The column of water could rise at this maximum height but no further flow rate is discharging. The tail end of the curve, (Figure 4) showed that the minimum head is measured only at **3.157 m.** and at a corresponding discharge flow rate of **43.053 liters/min.** Precisely, the developed head in the series pumping set-up is twice or more than the capacity of the single pump. However the discharge flow in the configured units remains constant. The pumping capacity of two units in series coordinated the suction effect of the first pump where pressure eventually increases with suction in the second pumping unit. The increment of delivery head in series is due to the pumping effect of the first unit which eventually raises the pressure of the fluid after it discharges and suction to the second pump, adding pressure to it, thereby translates it to an added head and finally delivered to a desired destination conveyed through the pipelines.

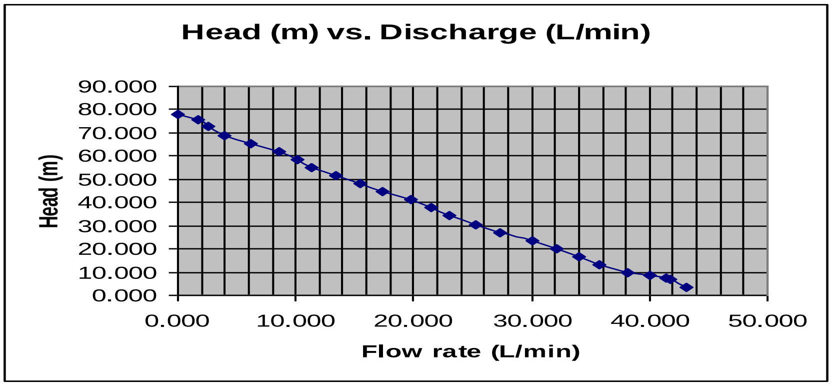

Fig. 4. Flow rate at Any Given Head for Pumps in Series

Table 1. Experimental Performance Capacity of Series Pump

Total Dynamic Head (m)	Flow rate (L/min)	Flow rate (L/sec)	Total Head loss (m)	Power Developed (Kw)	Power Consumed (Kw-hr/m3)
3.157	43.053	0.718	0.975	0.600	0.232
6.615	41.667	0.694	0.914	0.624	0.250
7.305	41.360	0.689	0.901	0.638	0.257
8.654	40.080	0.668	0.846	0.642	0.267
9.977	38.171	0.636	0.768	0.656	0.286
13.401	35.816	0.597	0.677	0.669	0.312
16.856	34.076	0.568	0.614	0.691	0.338
20.308	32.187	0.536	0.548	0.712	0.369
23.754	30.006	0.500	0.477	0.741	0.412
27.188	27.283	0.455	0.396	0.775	0.474
30.652	25.276	0.421	0.340	0.808	0.533
34.116	23.091	0.385	0.285	0.844	0.609
37.597	21.417	0.357	0.245	0.873	0.680
41.083	19.781	0.330	0.210	0.908	0.765
44.554	17.301	0.288	0.161	0.939	0.905
48.043	15.415	0.257	0.129	0.961	1.039
51.534	13.360	0.223	0.097	0.994	1.240
55.029	11.260	0.188	0.070	1.029	1.522
58.539	10.074	0.168	0.056	1.062	1.757
62.048	8.554	0.143	0.041	1.110	2.162
65.551	6.110	0.102	0.021	1.141	3.112
69.064	3.980	0.066	0.009	1.182	4.952
72.583	2.567	0.043	0.003	1.223	7.937
75.401	1.713	0.029	0.002	1.218	11.849
78.220	0.000	0.000	0.000	1.246	0.000

Parallel Connection: Discharge Flow and Total Dynamic Head

The graph in **Fig. 5 and Table 2** illustrate a corresponding increase in the discharge flow more than double in the single pump performance. A minimum delivery head of **2.547 m.**, the configured pumps in parallel yielded a tremendous flow rate of **79.78 liters/min.**, as shown in **Table 2**in the *Experimental Performance Capacities of Parallel Pumps* compared to a maximum delivery flow rate or discharge flow of about **39.331 liters/min.** only at a head of more or less

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2.534 m., (as presented in **Fig.19**),almost equal with the minimum delivery head in the parallel configuration. The pumping capacity of two geometric units in parallel installations is evidently showing an increase in the flow rate or its discharge flow combined. Pumps configured in parallel, their flow rates doubled and add up together thereby increasing the discharge capacity but with the heads remain constant. Normally pumps in parallel arrangement are operated side by side, with respective discharge lines yield to a common path whose flow rates doubled its individual capacity.

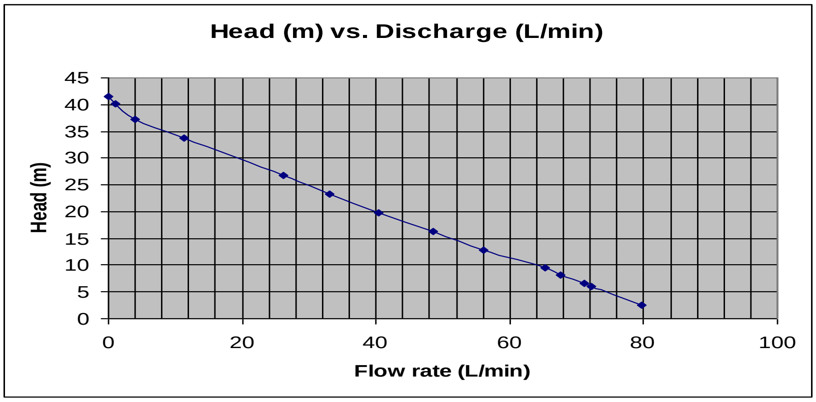

Fig. 5. Flow rate at Any Given Head for Pumps in Parallel

Table 2. Experimental Performance Capacity of Parallel Pumps

Total Dynamic Head (m)	Flow rate (L/min)	Flow rate (L/sec)	Total Head loss (m)	Power Developed (Kw)	Power Consumed (Kw-hr/m3)
2.547	79.780	1.330	0.430	0.612	0.128
5.988	72.247	1.204	0.353	0.655	0.151
6.68	71.028	1.184	0.342	0.667	0.156
8.055	67.605	1.127	0.310	0.691	0.170
9.441	65.247	1.087	0.289	0.704	0.180
12.884	56.112	0.935	0.215	0.741	0.220
16.35	48.512	0.809	0.162	0.790	0.271
19.822	40.465	0.674	0.113	0.853	0.351
23.307	33.137	0.552	0.077	0.920	0.463
26.801	26.058	0.434	0.048	0.973	0.622
30.3	18.397	0.307	0.025	1.049	0.950
33.809	11.193	0.187	0.009	1.113	1.658
37.325	4.073	0.068	0.001	1.196	4.892
38.735	2.512	0.042	0.001	1.200	7.961
40.144	1.014	0.017	0.000	1.276	20.965
41.554	0.000	0.000	0.000	1.256	0.000

Friction Loss in the Piping and Valve Fittings Resulting from Pumping System Configurations

The friction losses after system modifications both in series and parallel configurations approaches to zero at their maximum delivery head and showing both at their significant values when at their maximum discharge flow, as presented in **Tables1** and **2**. In a series connection (**Table 1)**, the total friction loss of **0.975 m.** occurs at a minimum delivery head of **3.157 m.**, but

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at a developed maximum delivery head of **78.220 m.**, friction losses in the piping and in the fittings become zero.

This is also evident in the parallel installation after the two pumping units were configured in this system, where a significant value of **0.430 m** was considered a total friction loss at a head of **2.547 m (Table 2).**In series and in parallel connections, both have shown significant figures of total frictional losses when performing at their best discharge capacities.

Friction loss is prevalent in physical property of fluid and also inherent in the piping lines. The total length of pipelines traversed by the fluid is dominant in major friction loss which could be easily determined through Darcy Weisbach's formula. Other losses in pipelines were subjected to the presence of various fittings such as elbow, tee, reducer, couplings, valves and burrs inside the pipe wall. The flow of fluid in the pipes is retarded by those factors causing actual loss of energy in water delivered.

Performance Differences of the Three Connections

Head at any given Flow Rate

In single installation, *Pump A* performs slightly better than *Pump B*in most of the conditions set. However, at a lower delivery heads, *Pump B* illustrates a much higher discharge rate capacity.

The delivery head developed in series is imminently twice the head in the single pump operation and in the parallel pumps. Likewise the flow rate of pumps in parallel is also doubled compared to that of single and series pump operations. It would be practical to use pumps in series if the system delivery head is way above the pump datum line or as precisely shown in the intersection of *Point A*(**Fig. 6).** In a system where heads is significantly below *Point A,* but lines appreciably elongated and extended towards the right of the horizontal axis, then it would be optimum to choose the parallel connection. The heads located along intersection A, has no significant difference in the flow rate of pumps operated both in series and in parallel connections.

The result of the study shows that there is significant difference of fluid delivery in pumping operations among pumps in single installations, in series and parallel configurations in terms of total dynamic heads (F_c=6.90; F_α= 3.23) at 5% level of significance. Indicative of the performance of the pumps configured in series installation is the tremendous increase in delivery head at 78.22 m (**Fig. 6)** compared to single pumps and pumps configured in parallel installation. The increment of delivery head in series is due to the pumping effect of the first unit which eventually raises the pressure of the fluid after it discharges and suction to the second pump, adding pressure to it, thereby translating in with added head.

In terms of the volume flow rate or the discharge flow of the fluid delivery in pumping operations, result shows significant difference in single installations, series and parallel

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configurations, (F_c= 5.14; F_α= 3.23; at 5% level).

In terms of discharge flow rate, (**Figure 6)** result also suggests a significant volume of fluid discharging at 79.78 liters/min. The pumping capacity of two geometric units in parallel installations is evidently showing an increase in the flow rate or its discharge flow combined. Pumps configured in parallel had their flow rates doubled and add up together thereby increasing the discharge capacity but the heads remain constant. Normally pumps in parallel arrangement are operated side by side, with respective discharge lines yield to a common path whose flow rates doubled its individual capacity.

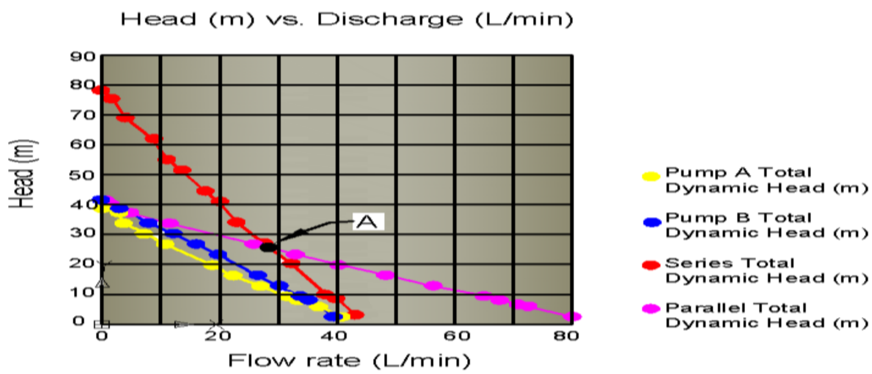

Fig. 6. Head at any given Flow rate for all Configurations

CONCLUSION

The pumps configured in series and parallel statistically increased their respective capacities in terms of static delivery head and discharge volume flow, respectively.

RECOMMENDATION

Installing two half-sized pumps is recommended for systems having variable flow or delivery head requirements to attain the optimum efficiency of the combined units. Thus, it is economically viable for the consumption of power and saving power cost.

It is further recommended to use larger diameter pipe because the larger the diameter, the slower the fluid flow which implies a smaller loss of head.

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