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DETERMINATION OF THE TYPICAL PERFORMANCE CURVES OF THE CENTRIFUGAL PUMPS IN AN UNIT OPERATIONS LABORATORY

Antonio Valiente Barderas[1]
[1]Facultad de Química,
UNAM, México

Genovevo Silva Pichardo[2]
[2]Facultad de Química,
UNAM, México

Stephanía Gómez Rodea[3]
[3]Facultad de Química,
UNAM, México

ABSTRACT

In the laboratory of Unit Operations of the Faculty of Chemistry at the Universidad Nacional Autónoma de México (UNAM) the chemical engineering students perform a series of practices to improve their aptitudes, attitudes and knowledge. Among those practices is the one related with the performance curves of the centrifugal pumps. In this paper we present the experiments and calculations that the students must do to get the results.

KEY WORDS: *Pumps, efficiency, performance curves, competences, chemical engineering.*

I.- INTRODUCTION

The trend in education is the training in skills. Competence is the skill acquired from adequately carrying out a task, duty or role. It is made up of two distinct components in that it is associated with specific work in a particular context and it incorporates different types of knowledge, skills and attitudes. In a wider sense, skills are the general and subject specific knowledge, skills and motivation that make up the prerequisites for effective action in a wide variety of contexts that higher degree holders must deal with, and formulated in such a way that they are equivalent in terms of significance in all such contexts. The majority of skills that refer to higher education distinguish between subject specific skills and cross or generic skills. Several generic competences are repeated insistently: critical thinking, problem solving (cognitive skills), team work, communication (interpersonal skills), initiative, responsibility, ethics, life-long learning (personal skills) and "things that are very useful " such as languages, computer skills, skills in searching for documentation, etc. [1], [2]

Much more emphasis is put on active ways of learning, such as problem-solving, case analysis, behavior, simulation, experiments in real-life situations, etc. It requires an important change in the evaluation paradigm: the student is asked to construct the answers and that requires projects, algorithms, protocols, reports, judgments, etc. to be prepared. In the Faculty of Chemistry at the Universidad Nacional Autónoma de México (UNAM) the students must carry out a series of practices to put at work the different kind of skills. Among this experiences in the laboratory of Unit Operations is to get experimentally the pump curves.

II.- THEORY

Pumps are equipment that are widely use in the Chemical and petro-chemical industry. They are used to pump or move Newtonian or non-Newtonian fluids from one place to another through pipes or hoses. The most useful pumps are the centrifugal one. These pumps have a characteristic behavior that is usually present in form of charts or graphics. The characteristics curves are; head versus flow, the flow versus efficiency and the power versus flow, among others. Those graphs are usually provided by the manufacturer and take the form showed in Fig. 1.

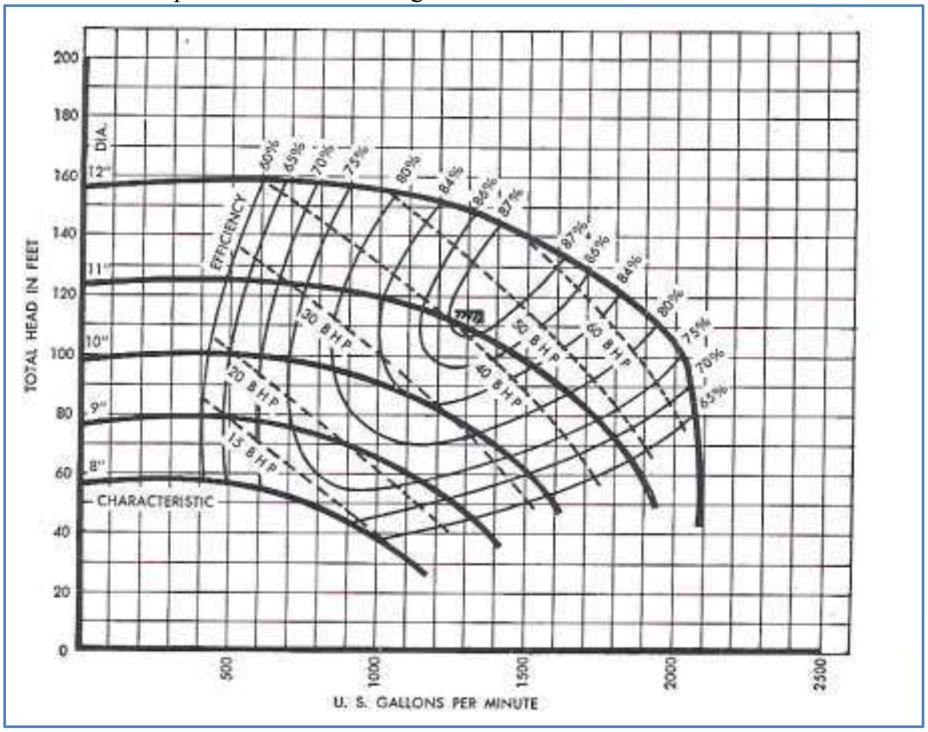


Fig. 1.- Typical performance curve of a centrifugal pump at 1750 rpm with varying impeller diameter.

Where the head is given by:

$$H = \frac{P_d - P_s}{\rho}$$

Pd is the discharge pressure, Ps is the suction pressure, and ρ is the density of the fluid.

Power hydraulics is the work required to change for a fluid of a position, pressure and speed to another position, pressure and speed at a given time.

Ph = W L ; where, W is the work of pumping and L is the liquid flow .

Power hydraulics can be also calculated as the head by spending between the density.

$$P_h = \frac{H \times L}{\rho}$$

The efficiency of a centrifugal pump is the ratio between the power absorbed by the fluid and power to the brake is supplied by the pump shaft.

Therefore the efficiency is: $\mu = \frac{Hydraulic\ power}{Brake\ power}$

Series and parallel operations

With frequency centrifugal pumps are usually coupled in series or in parallel so to increase the flow or the discharge pressure. With several pumps at hand it may be more desirable to install several small pumps in parallel instead of a single larger. When the demand decreases one can stop any pump, making the others to operate near peak efficiency. When you have a single pump in the case that the demand decreases the demand output should close and will operate at reduced efficiency. In addition, when using several pumps, one can give maintenance to any of them without closing the production, which would be essential if you have one. Similarly, several small pumps in series can be used when you want to increase the head.

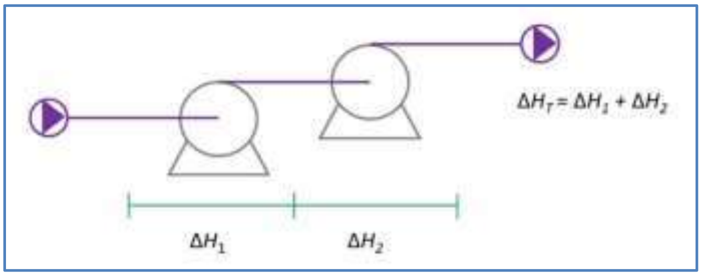


Fig.2.- Pumps operating in series.

In order to plan those facilities, one must before anything draw a curve of head against capacity. The head required by the system is the sum of the static heads (difference in heights or its equivalent in pressure) plus the variable head (friction losses). The first is usually constant for a given system, while the latter increases approximately with the square of the speed, the resulting curves are represented as the line AB in Figure 3. [3]

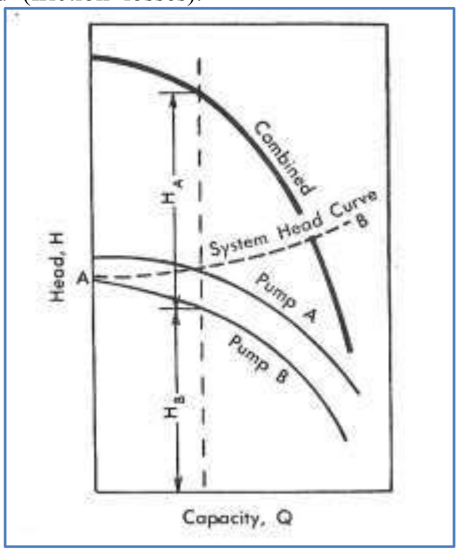


Fig.3.- Head capacity curves of pumps operating in series.

If two pumps are operating in series, the combined head for any flow is equal to the sum of the individual heads as shown in the figure 3. Combined horsepower curve can be obtained by adding the HP given by the curves for individual pumps.

The combined efficiency can be found using the following equation:

$$Eff = \frac{Q(H_A + H_B)}{3960(BHP\ a\ H_A + BHP\ a\ H_B)}$$

III.- EQUIPMENT USED

The experimental part of the obtaining of the typical curves of the centrifugal pumps was developed in the "Pump module" of the hydraulic system in the Laboratory of Chemical Engineering (Fig 4), integrated for the following part shown in the figures 5, 6, 7 and 8.

Fig. 4.- Pump Module.

Fig. 5.- ¾,1, 1.5 Hp pumps.

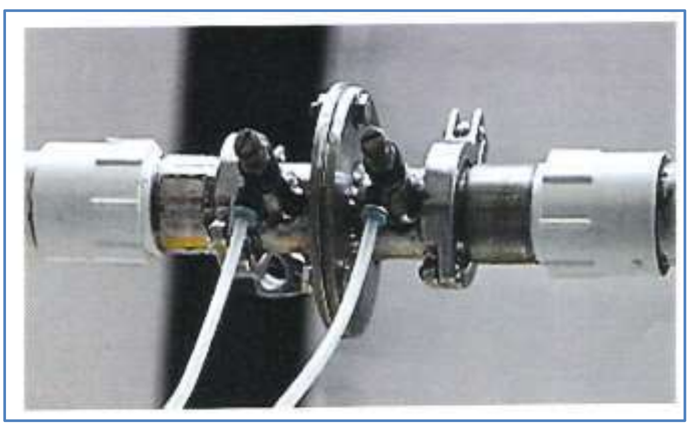


Fig. 6.- Orifice meter.

Fig.7.- Manometric pressure meters.

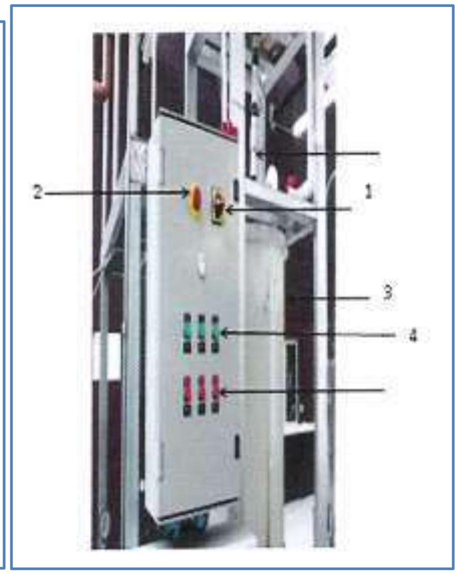


Fig. 8.- Control panel.

Table 1. Pump module technical data.

Component	Specifications
Centrifugal pump	Brand Weg. Model MSL MJ Monophasic motor ¾ H.P., 110 Volts, 3370 RPM. Suction diameter: 1 ¼ inch. Discharge diameter: 1 inch.
Centrifugal pump	Brand Weg. Model MSL MJ Monophasic electrical motor 1 H.P., 110 Volts, 3490 RPM. Suction diameter: 1 ¼ inch. Discharge diameter: 1 inch.
Centrifugal pump	Brand WEG Model MSL MJ 3910 Monophasic electrical motor 1 ½ H.P., 110 Volts, 3410 RPM. Suction diameter: 1 ¼ inch. Discharge diameter: 1 inch.
Tank	Capacity: 120 liters. Polyethylene.
Manometers	6 manometers with connections to pumps suction and discharge.
Rotameter	Range 0 to 250 liters / minute.
Tubes	Suction NPS 1 ¼, discharge NPS 1 inch.

IV.- EXPERIMENTAL PROCEDURE

For the development of the practice the students before the experiment should [4]:

4.1.-Make sure that there is power at the control panel, for which (refer to Fig. 8), check that the knob marked with the number 1 is in the off position.

4.2.- Verify that tank feeding the pumps marked with no. 1 in Fig.4, is at the same time the receiver tank, water level indicated.

4.3.- For the operation of a single pump like the one shown in Fig. 5. The student should open and close the corresponding valves so that the suction is connected to the feeding tank and the discharge is connected to the recirculation line at the feed tank. Once the above is done, press the pump start.

4.4.- With the system in operation, by manipulating the valve of the pump Fig. 8 the student should record the pressure drop in the orifice meter for five conditions of flow and record the pressure drops between the suction and discharge manometers. Fig. 7.

4.5.- For each flow, it should be recorded, through the digital wattmeter, the value of the power in watts consumed by the pump.

4.6.- For the operation of two pumps in series, the students must interconnect pumps. Before that they must decide what will be the first bomb and what the will be second so that the discharge of the first feed to the second. Subsequently the pumps must be aligned to connect them with the tank and the orifice meter.

4.7. Once the pumps are aligned the system is booted and the pressure drops, flows and power consumption corresponding to five readings are taken.

4.8.-When the measurements have been completed close the system.

V.- EXPERIMENTAL RESULTS

The students of the courses of fluid flow following the instructions obtained the information of each one of the pumps shown in the following tables. The students took the data for five conditions of volumetric flow (Q), pressure of suction and discharge of the pump (Ps, Pd) and the electric power consumed (Pe). Then the students performed the calculations of head (H), (Ph) the hydraulic power, and efficiency (µ). We also show the data that students obtained when they interconnected the pumps in series.

5.1. Calculation example for ¾ HP pump.

Volumetric flow (Q) = $65.856\,\frac{L}{min} \times \frac{1m^3}{100\,L} \times \frac{1\,min}{60\,s} = 0.001093\;m3/s$

Suction pressure (Ps) = -1766.97 kgf/m²

Discharge pressure (Pd) = 15000 kgf/m²

Head (H) = $\frac{(15000+1766.97)}{1000} = 16.766\;m$

Electrical power (Pe) = $579\;W \times \frac{0.101\frac{kgm}{s}}{W} = 59.101\,\frac{kgf\;m}{s}$

Hydraulic power:

(Ph)=$16.766\,\frac{kgf\;m}{kg} \times 0.001093\,\frac{m^3}{s} \times 1000\,\frac{kg}{m^3} = 18.32\,\frac{kgf\;m}{s}$

Efficiency (µ) =$\frac{18.32\frac{kgf\;m}{kg}}{59.101\frac{kgf\;m}{kg}} \times 100 = 30\;\%$

Table 2. Experimental data of the pumps single operating.

Pump ¾ (HP)								
PS (man.)	PD (man.)	H	Q	Q	Pe.	Pe	Ph	µ
KgF/m^2	KgF/m^2	m.	L/m	m^3/s	Watts	Kgm/s	Kgfm/s	%
0	20500	20.5	0	0	372	37.933584	0	0
-1766.973684	15000	16.76697368	65.85651468	0.001093218	579	59.041788	18.32995985	31.04573975
-4213.552632	10000	14.21355263	99.69861584	0.001654997	709	72.298148	23.52338729	32.53663882
-5572.763158	7500	13.07276316	113.6024873	0.001885801	749	76.377028	24.65263361	32.27755028
-6116.447368	5000	11.11644737	125	0.002075	760	77.49872	23.06662829	29.76388293
Pump 1 (HP)								
PS (man.)	PD (man.)	H	Q	Q	Pe.	Pe	Ph	µ
KgF/m^2	KgF/m^2	m.	L/m	m^3/s	Watts	Kgm/s	Kgfm/s	%
0	21000	21	0	0	343	34.976396	0	0
951.4473684	17500	16.54855263	59.98267926	0.000995712	517	52.719524	16.47760031	31.2552145
2038.815789	15000	12.96118421	77.32893357	0.00128366	575	58.6339	16.63775758	28.3756625
4349.473684	10000	5.650526316	110.0319321	0.00182653	676	68.933072	10.32085624	14.97228536
6116.447368	7000	0.883552632	128.6235637	0.002135151	734	74.847448	1.886518425	2.520484632
Pump 1.5 (HP)								
PS (man.)	PD (man.)	H	Q	Q	Pe.	Pe	Ph	µ
KgF/m^2	KgF/m^2	m.	L/m	m^3/s	Watts	Kgm/s	Kgfm/s	%
0	26000	26	0	0	461	47.009092	0	0
1359.210526	20000	18.64078947	65.76651505	0.001091724	694	70.768568	20.35060004	28.75655198
2990.263158	17500	14.50973684	84.96795143	0.001410468	771	78.620412	20.46551941	26.03079645
4621.315789	15000	10.37868421	106.7561884	0.001772153	850	86.6762	18.39261354	21.2199122
5980.526316	12000	6.019473684	124.4081683	0.002065176	903	92.080716	12.43127014	13.5004056

5.2.- The calculations for the pumps operating in series are done with the corresponding data Q, H, and Ph in the same way that in the former example of calculus.

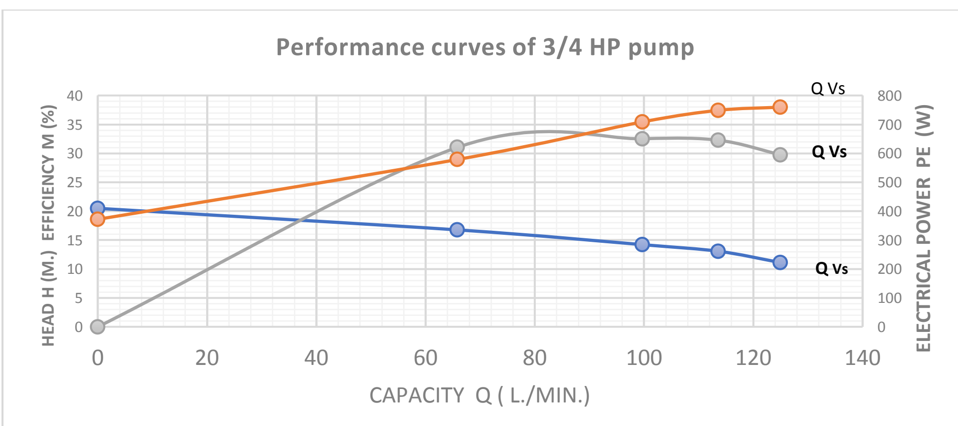
Table 3
Experimental data of the pumps operating in series.

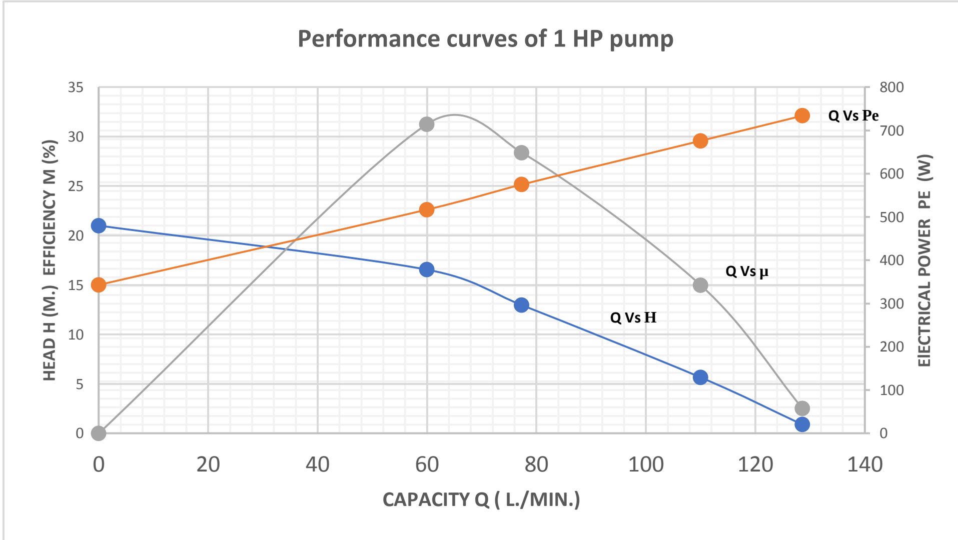
Arrangement 1HP+0.75HP								
Ps	Pd	Q	Q	H	Ph	Pe	Pe	µ
(KgF/m^2)	(KgF/m^2)	(L/min)	(m^3/s)	m	Kgf.m./s	(W)	(Kgfm/s)	%
345.000	40000.0	0.0	0.000	39.655	0.000	860.000	87.696	0
172.500	35000.0	57.0	0.001	34.828	32.959	1210.000	123.386	26.71169092
690.000	30000.0	89.6	0.001	29.310	43.571	1410.000	143.781	30.30398552
1380.000	26000.0	105.4	0.002	24.620	43.083	1410.000	143.781	29.96437582
1725.000	22000.0	119.9	0.002	20.275	40.355	1590.000	162.135	24.8898122
Arrangement 0.75HP+1.5HP								
Ps	Pd	Q	Q	H	Ph	Pe	Ps	µ
(KgF/m^2)	(KgF/m^2)	(L/min)	(m^3/s)	m	Kgf.m./s	(W)	(KgF/m^2)	%
34.500	44000.0	0.0	0.000	43.966	0.000	990.000	100.952	0
345.000	38000.0	63.4	0.001	37.655	39.626	1430.000	145.820	27.17467753
1035.000	32000.0	94.4	0.002	30.965	48.548	1640.000	167.234	29.02999424
1725.000	26000.0	120.7	0.002	24.275	48.641	1800.000	183.550	26.50017295
2415.000	20000.0	138.8	0.002	17.585	40.517	1910.000	194.767	20.80306735
Arrangement 1HP+1.5HP								
Ps	Pd	Q	Q	H	Ph	Pe	Ps	µ
(KgF/m^2)	(KgF/m^2)	(L/min)	(m^3/s)	m	Kgf.m./s	(W)	(KgF/m^2)	%
34.500	44000.0	0.0	0.000	43.966	0.000	970.000	98.913	0
690.000	35000.0	89.6	0.001	34.310	51.004	1580.000	161.116	31.65677542
2760.000	30000.0	108.1	0.002	27.240	48.892	1700.000	173.352	28.20403034
3105.000	26000.0	126.0	0.002	22.895	47.890	1800.000	183.550	26.09109769
3450.000	21000.0	143.8	0.002	17.550	41.881	1920.000	195.786	21.39098111

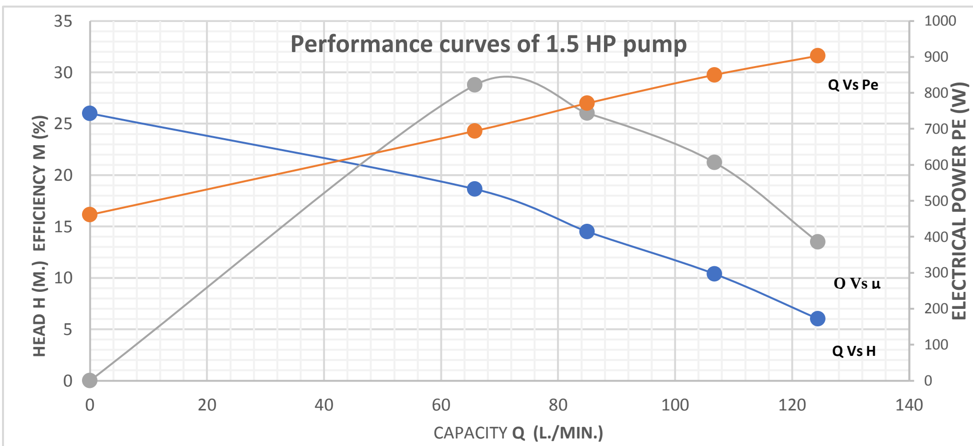
5.3.- Performance curves of the single operating. centrifugal pumps.

The typical performance curves of the centrifugal pumps operating individually or coupled in series were built with the data of the experimental results.

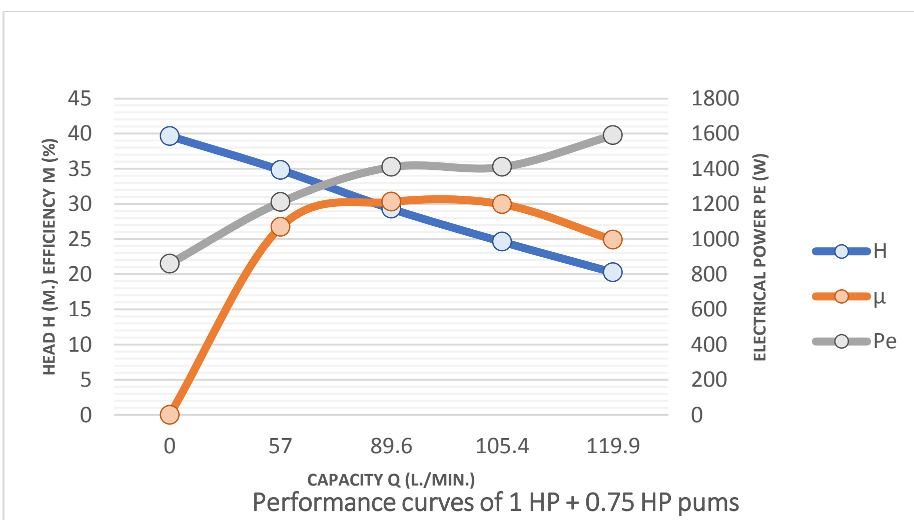
Performance curves of the single operating centrifugal pumps.

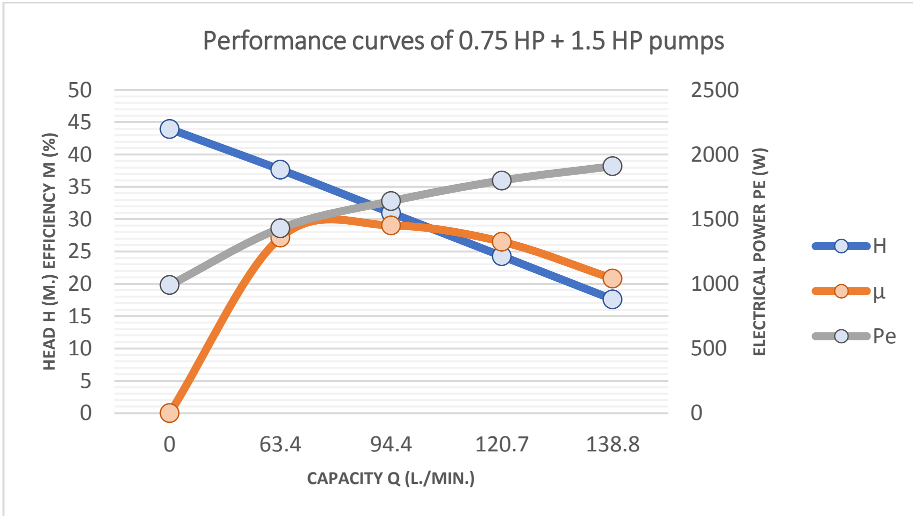


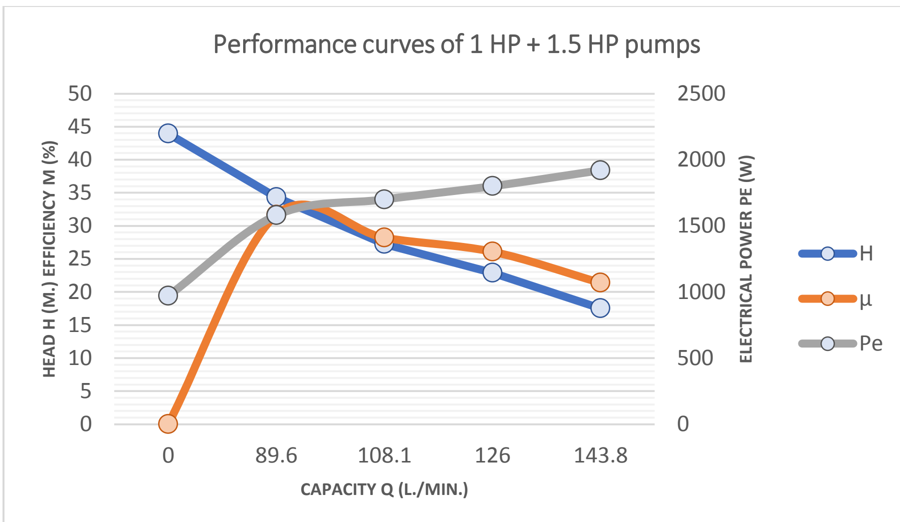




Performance curves of two pumps operating in series.







VI.- ANALYSIS OF RESULTS

6.1. It was observed that the experimental curves of pumps are similar to that provided by the "manufacturer's catalogs" and that with the information obtained, it is possible to specify the conditions of operation and the efficiently when these pumps are operating individually, or in arrangement, as shown in the following tables 4,5, 6.

Comparative Table 4.

Efficiency at Best Operating point for single pumps			
Pump (HP)	Capacity Q (L7min.)	Head H (m)	Maximum efficiency μ (%)
0.75	80	15	34
1	66	15	33
1.5	72	18	29
Efficiency at Best Operating point for two pumps arrangement in series			
Pumps	Capacity Q (L/min)	Head H (m)	Maximum efficiency (%) μ
¾ and 1 HP	96	28	31
¾ and 1.5 HP	80	34	29
1 and 1.5 HP	94	33	33

6.2.-The values of flow (Q) and (H) head of the resulting curves of two pumps operating in series are equal if they are determined experimentally or if they add directly the individual from each of the pumps data as shown in the table 5.

Comparative Table 5

Comparative results of the H - Q experimental and calculated values for the pumps operating in series.

	Experimental data for single pumps.			Calculated data for two pumps operating in series.			Experimental data of two pumps operating in series.		
	0.75 HP	**1 HP**	**1.5HP**	**(0.75 + 1) HP**	**(1 + 1.5) HP**	**(0.75 + 1.5) HP**	**(0.75 + 1) HP**	**(1 + 1.5) HP**	**(0.75 + 1.5) HP**
Q	H	H	H	H	H	H	H	H	H
(L/min)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)
0	20.5	21	26	41.5	**47**	46.5	41.5	47	**46.5**
20	19.5	19.8	23.8	39.3	**43.6**	**43.3**	39	43.6	**37.5**
40	18.3	18.5	21.5	36.8	**40**	**39.8**	37	40	**39.7**
60	16.1	17	19.3	33.1	**36.3**	**35.4**	34.2	36.3	**36.2**
80	15.8	15.5	17	31.3	**32.5**	**32.8**	31.3	32.5	**32.5**
100	14.2	13	14.3	27.2	**27.3**	**28.5**	27.2	27.3	**28.7**
120	12	3	6	15	**9**	**18**	15.8	9	**21**

VII.- CONCLUSIONS

With the results obtained experimentally, the students could check that the "pump module" allows then to build, understand and apply the information contained in the characteristic curves of centrifugal pumps and their arrangements in series. The achievement of these experiments allowed the students to understand the behavior of centrifugal pumps. The students that carried out this practice put to work their skills in the areas of knowledge, skills and attitudes

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