2006-264: LOW COST VARIABLE SPEED PUMP EXPERIMENTAL SETUP

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Abstract
Educating students to *practice* engineering is the main goal of engineering education, which demands a curriculum that indulges students in thought provoking hands-on experiences. Creation of such environments invariably involves consumption of considerable financial resources, which are often limited and meager. In these circumstances, it is very difficult and burdensome to replace the outdated laboratory equipment with the expensive experimental setups. Even if these canned experimental systems are installed, they seldom offer operational and design variations. And by and large, these systems permit only limited and a cookbook approach to experiments. They are not only dreary but the implementation costs of these canned systems are ever more increasing. This is a dilemma, which are difficult to resolve. To assist in alleviating these difficulties, this study reports the design and fabrication of a low cost pump setup for the fluid mechanics laboratory. This effort engages *design, build, and test* concepts to create an economical and effective experimental setup. The system is constructed using off-the-rack and in-house components readily available in most laboratories. The system is flexible, which can be operated at a wide range of variable conditions such as speed, power, flow rate, and head. So that at a time different student groups are assigned different operating conditions for which associated manufacturer's characteristics curves can be obtained and specific design limitations can be identified. The students are able to verify the affinity laws and show how well they hold true. The system is also modular so that it can be altered to fit other design needs. This system does not only help instructors avoid the cookbook approach, but also provides students valuable experiences in the design of experiments, encourages team work, and offers learning in a problem-based environment. Designing and employing this setup helps to satisfy an important and not easily achievable outcome requirement namely *design of experiments* -the Accreditation Board of Engineering Technology (ABET) Outcome B.

Introduction
The knowledge of the design and selection of pumps are critically important for mechanical, civil, and environmental engineers. Conventionally, many engineering lab experiences revolve around the demonstration of physical phenomena, which often employ expensive canned experimental setup. Unfortunately they normally permit only limited and cookbook approach to experiments and rarely offer any design experiences with the exception of some sophisticated equipment. For many engineering programs acquiring such expensive and precision equipment are often unattainable. The experimental pump setup described here has been designed and installed entirely by students under faculty guidance and supervision using almost no capital resources. The setup has been created using standard, off-the-shelf components, which are readily available. The experimental setup is easily adaptable to the existing curriculum, which can help satisfy an important objective, yet not easily achievable, "the design of experiments" component of ABET outcome B[1]. In addition it will help engineering students learn the pump concepts, measure various pump performance parameters over a wide range of conditions, and develop pump characteristic curves[2]. It will facilitate learning pump affinity laws[3,4] and help in demonstrating how well these laws hold true. This experience can provide small engineering programs an opportunity to expose their students to designing and building a low cost experimental pump setup and on the same time achieve the "experiment design" objectives.

The experimental pump setup described here was developed by the combined efforts of several student teams in fluid mechanics laboratory class. The main objectives of the project were clearly articulated to all participating students. The process began with the assignment of distinct and different tasks to each team in the beginning of the semester. As a group they were required to design and build a modular pump experimental setup from scratch, and test the system to validate the engineering principles, determine the pump performance parameters and plot its characteristics. The collaboration and time management among all teams were overseen by the instructor and a teaching assistant. Finally, the requirements of submission of a project report on the designed system and its presentation by each team at the end of the semester provided an increased opportunity to enhance the oral and written communication skills of the students.

In order to design, build, and test an experimental pump setup, which can be used in future experiments required a comprehensive planning on part of the student groups and the instructor in implementing these phases together. In the first phase, the system design including the selection of specific equipment and associated costs (capital and operating costs) were completed. Once the best design was approved, each team then acquired and assembled the desired components as specified in their design. In the last phase all student teams joined hands and installed and tested the system together as a group. The students were also mandated to follow the safe operating practices during the testing phase.

To successfully accomplish the task all students were introduced to the salient features of the pump experimental system and the associated components. The energy equation was employed to explain the dependency of the flow rate Q upon the pressure head (H) added by the pump. In ideal conditions this imbalance is the pressure difference (ΔP) between the system inlet and outlet. So that the pressure head obtained by a pump is directly dependent upon the power (P) supplied to the pump. Students were then explained how various combinations of the appropriate pump parameters such as flow rate (Q), head (H), Power (P), Speed (N - rpm), and the impeller diameter (D) yield affinity laws[3, 4]. It was further shown how these laws are used to predict the performance of a pump by changing one or more pump parameters before conducting the actual tests and how to verify them after the test. For example, the change of flow rates in a pump system is directly proportional to the cube of the impeller diameter the rotational speed while the change in pump head varies with the square of both the impeller diameter and the rotational speed (rpm)[3,4]. During the testing phase, the teams used these relations to find an ideal match between the system requirements and the pump's performance. The various pump operating parameters were used to generate the pump performance curves[5]. These curves are vital tools in analyzing the pump's operational characteristics. Changing the pump rotational speed N, pump operational efficiency also changes, which directly affects the operational costs. As depicted in the Figure 1 the efficiency of variable speed pumps varies with the changes in flow. It is also evident that the variable speed pump is more efficient than the constant speed pump at lower and mid-level flow rates. However, as the flow rate approaches towards the maximum, the difference between the efficiencies reduces until they are the same. It is therefore, important to employ as efficient pump as possible for any system. The students were encouraged to consider these parameters before planning the system. Involving and challenging the students in designing, building and testing the experimental setup placed the responsibility for the outcome on themselves.

Although formal student evaluations were not conducted in particular reference to this experience, some anecdotal student comments regarding the assignment were for the most part positive and encouraging. Some negative comments ranged from complaints of too much work to problems of cooperation among the team members and the inter-group communication.

Materials and Methods

The pumping system is construed of a water reservoir, 1″ PVC piping, several pressure gauges, valves, and a rotameter. Although the project received a gratis Grundfros (model CHIE-2-10) 0.5 HP, 230 Volt, 60 Hz, 15-A, single-phase variable speed pump and a wattmeter, the combined educational cost of these items is approximately $950. The pump is rated for a nominal flow of 10 gallons/min. and for a nominal head of 20 ft. As shown in the Table 1, the total installation cost of the setup is approximately $1033. It is evident that a packaged system capable of achieving the above mentioned objectives is not possible to acquire in less than $15,000.

Table 1 - Materials Cost

Part	Price/Piece	Quantity	Total Price
1" T" PVC Adapter	$0.49	4	$ 1.96
1" PVC 90 Elbow	$0.39	5	$ 1.95
1" PVC 90 Plug	$0.49	3	$ 1.47
1" PVC Adapter	$0.34	2	$ 0.68
1” PVC Ball Valve	$4.92	4	$19.68
1”x ½” Reducer	$0.46	2	$ 0.92
½” Brass Nipple	$1.21	2	$ 2.42
Rotameter	$27.00	1	$27.00
Pressure Gage	$7.00	2	$14.00
Drain Valve and plug	$5.00	1	$ 5.00
Reservoir	$10.00	1	$10.00
Grundfros, 0.5 hp Pump	Approx $ 900.00	1	$ 900.00
Wattmeter	$ 50.00	1	$ 50.00
		Total	**$1033.12**

After procurement of all components, the system was assembled and electrical connections were completed according to the electrical specifications of the motor and wattmeter. A block diagram of the installed system is shown in the Figure 2 and the actual experimental setup is depicted in the Figure 3. In this system the fluid (water) flows from a 35-gallon tank (reservoir) through 1″ PVC pipe and a pressure gauge to the pump. The water is then pumped back to the reservoir as it passes through a pressure gauge, a rotameter, a check valve and a ball valve. The ball valve is placed in the discharge line to control the flow through the system. The rotameter is used to measure the flow rate. The rotameter may be replaced by a digital flow meter if desired. The fan cover from the pump housing was removed exposing the motor fan to allow the strobe light to measure the pump RPM, while the wattmeter measured the power draw. For a very small flow rate, the ball valve (above rotameter) is closed and the check valve is opened such that the fluid drops into a graduated cylinder. A stopwatch is used to determine the small flow rate. The system tests were conducted and various pump parameters were measured from which a series of pump performance curves were developed. The experimental setup provides many variations in the operational parameters.

Results and Discussion

After the system installation, test data were taken on pump head, speed, and power required at various pump speeds. The pressures were measured at two locations as shown in Figure 3. The power draw was measured using the wattmeter. The pump efficiency was calculated using the water horsepower (WHP) and the electric horsepower (EHP). Using several experimental data sets several pump parameters were calculated. For instance, when the pump was running at 2263 rpm producing the volume flow rate of 12 gpm, and a head of 4 ft at amperage of 0.8 amps, the water horsepower, the electric horsepower and the efficiency(e) were calculated as shown below.

$$\mathrm{WHP} = \mathrm{Q}(\mathrm{gpm}) \times \mathrm{h}(\mathrm{ft}) \times \gamma\left(\frac{\mathrm{lb}}{\mathrm{ft}^3}\right) \times 4.1 \times 10^{-6} = 12 \times 4 \times 62.4 \times 4.1 \times 10^{-6} = 0.0121 \text{ hp}$$

$$\mathrm{EHP} = \text{watts} \times 0.00134 \ \frac{\mathrm{hp}}{\mathrm{watt}} = 20.8 \times 0.00134 = 0.0278 \text{ hp}$$

$$\text{and} \quad e = \frac{\mathrm{WHP}}{\mathrm{EHP}} = \frac{0.0121}{0.0278} = 43.52\ \%$$

The results were then analyzed and compared with the theoretical values obtained from the standard pump curves supplied by the manufacturer. Subsequently, the affinity laws were used to predict the head and efficiency at various speeds (before testing) and verified through tests. The tests were repeated several times at different operating conditions. By comparing the pump parameters predicted by the affinity laws to the measured values after the tests, the students were able to confirm the validity of the affinity laws. Assorted pump characteristics curves are plotted in Figures 4-6, which closely matched with the manufacturer's characteristics.

Conclusions

A low cost pump setup is designed and installed. The pump parameters obtained from tests and affinity laws are compared and verified with the characteristics supplied by the manufacturer. The results are adequately satisfactory. Such inexpensive system does not only help instructors avoid the cookbook approach, but also provides the students valuable experiences in the design of experiments, encourages teamwork, and offers a problem-based learning environment. Design and implementation of such diverse and multidisciplinary systems are a key step towards integrating the practical design environment into the classroom connecting the theory with the practice. It helps satisfy the "*design of experiments*" component of the ABET Outcome requirement B[1]. The pump system developed can be used in future fluid mechanics laboratory experiments. Additionally, the system can be improved further by employing some design modifications and using computer data acquisition and controls to automate the process of data recording and plotting of the operating parameters.

Acknowledgement

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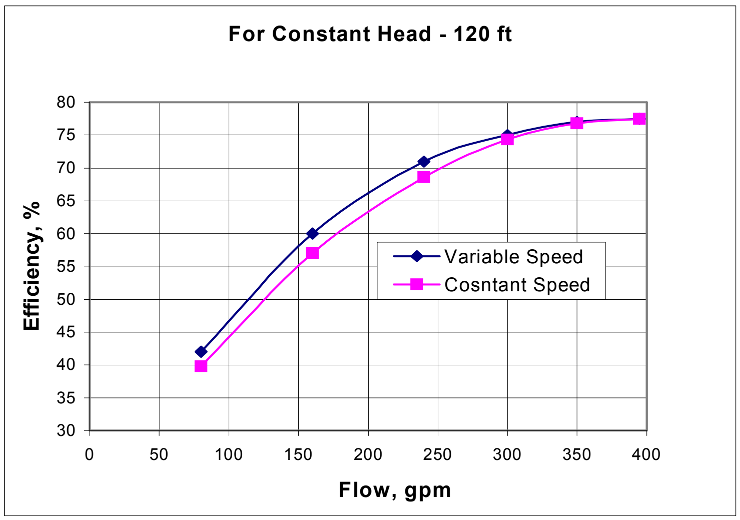

Figure 1: Overall Efficiency of Constant and Variable Speed Pumps [6].

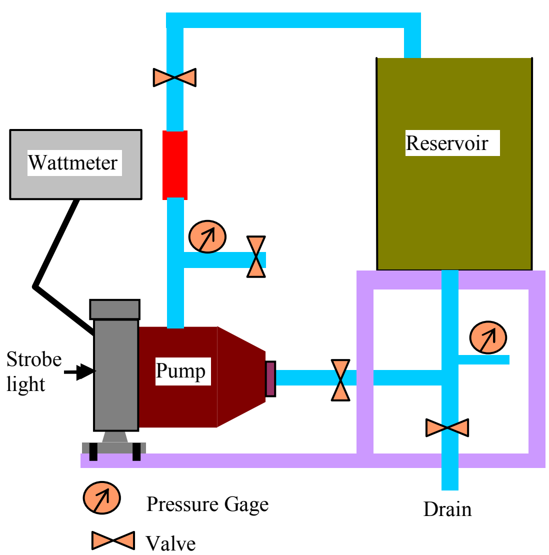

Figure 2. Pump System Setup (Block Diagram)

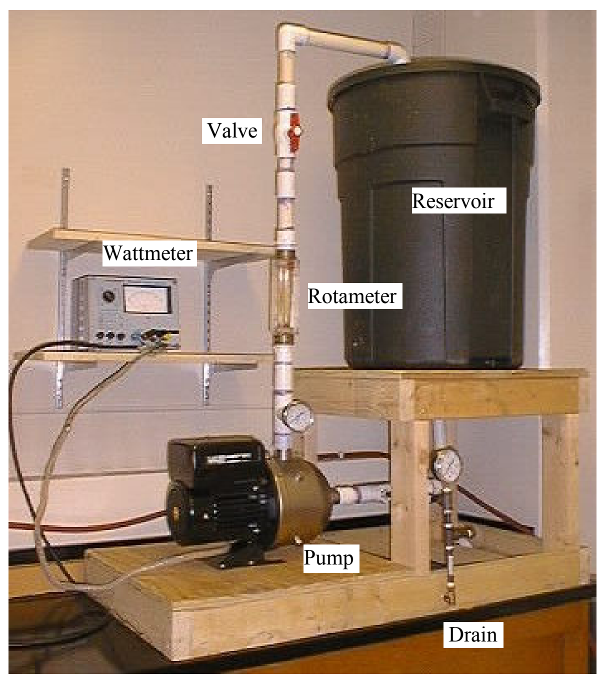

Figure 3. Pump Setup (as installed)

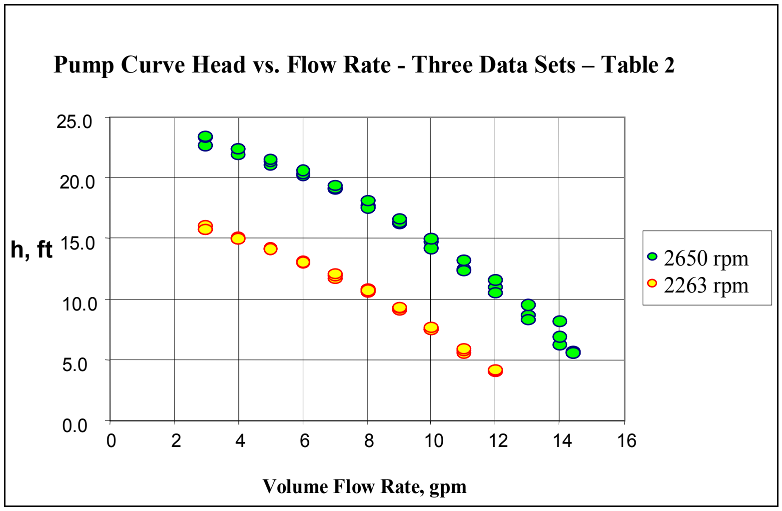

Figure 4. Pump Head vs. Flow rate

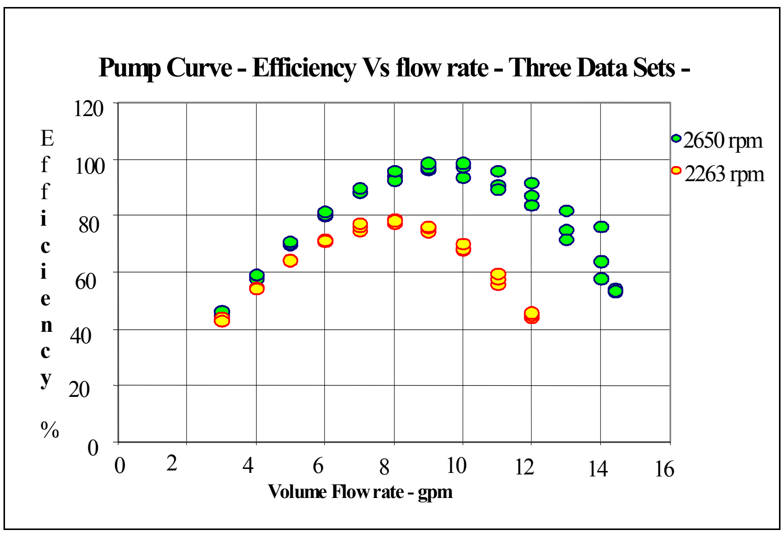

Figure 5: Efficiency vs. Flow rate

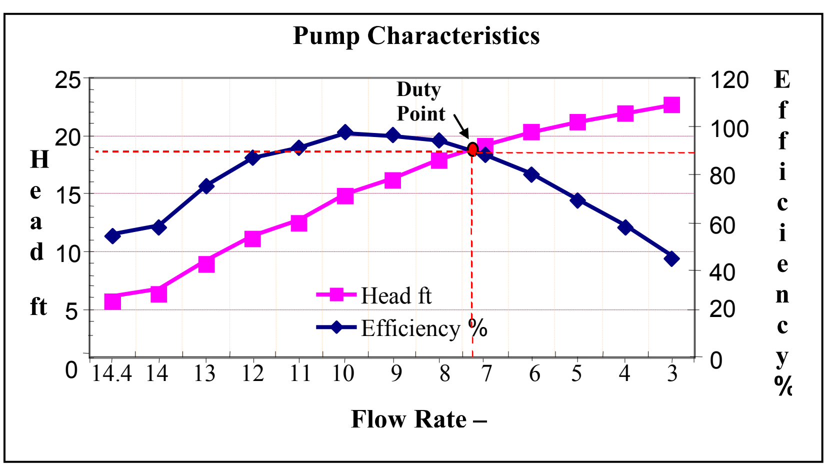

Figure 6. Pump Characteristics Curve