Educational Research on a Water Elevator

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Abstract: This project involves modeling a water elevator in order to study its behavior and relate its mechanical advantages to various fluid mechanics properties. The reason that this small scale water elevator was constructed was to get a better understanding of such real world applications. As developing engineers, students have to grasp how to implement the theory they learn in the classroom. The properties of the water elevator were described with the energy equation, conservation of mass, volumetric flow rate, and hydrostatic pressure. After conducting various tests, theoretical and experimental values were compared and an analysis of the data was assembled allowing for the development of a more thorough understanding of fluid mechanics.

Key words: Elevator, experimentation, theory, engineering, educational research, project based learning.

1. Introduction

Egyptians were the first to engineer different ways to lift heavy objects through the usage of water. In Egypt, devices used for water elevation were the shaduf and ordinary grain elevators. In the shaduf, water was used as the primary medium of lifting. The ordinary grain elevators were constructed with belt tighteners so that the length was either elongated or shortened depending if the water rose or fell. This design allowed the elevator to lift heavy loads [1, 2]. In the 17th century there were prototypes of elevators located in the palace of England and France [3]. Furthermore, the science behind the construction of elevators was used in other projects. One of the most iconic structures built was the Panama Canal, an engineered waterway. Such designs play a big role in the free flow of international trade and goods in the western hemisphere [4-6]. As more people experimented with technology, the birth of hydraulic and electricity allowed for hydraulic elevators to be invented and used to transport goods.

As engineering students, the theory behind why a water elevator works is taught through the courses of fluids mechanics and hydraulics, but it is never applied to real life. Therefore, a diverse team of undergraduates at California State University, Northridge designed and built a model of a water elevator. The idea was to transport a “boat” between different elevations. This would be accomplished by using a tank and dividing it into three sections, and pumping water into the tank until the boat reached the canal. The purpose of this experiment was to explain the relationships between volumetric flow rate, velocity, work done and time. This was done in order for students to apply theoretical concepts from mechanical courses into experimental practice. Therefore, the curiosity among the inclusive group allowed them to hone in on their research skills and have academic success.

2. Experimental Details

Plexiglass was used as the material for constructing the tank (Fig. 1). The material was cut into two 20" × 11.75" and two 20" × 9" and placed in the tank using a sealant, as shown in Fig. 2. One side of the middle tank contained a single gate, while the other side had two tanks (Fig. 3). Magnets were attached to each gate to prevent the water leakage. Moreover, by replacing the ½" × 5" × 2" angle fendue, the movement of the gates was controlled perfectly in this project. A pipe was used as
the foundation of the canal, which was glued into the side tank. Also, a small hole in the plexiglass was created to accommodate the pump to be installed (Fig. 4).

After constructing and testing, a boat was placed on the side that had one gate of the plexiglass. The gate opened and the boat moved into the gate to get inside the elevator. Once the boat was inside, the gate closed and the pump began transmitting water inside to elevate until it reached the upper gate on the other side. At that point, the boat was moved again into the upper gate section after which the upper gate was closed. Following this, the lower gate was opened to allow the water level to settle back.

3. Theoretical Analysis

The volume was calculated for each section of the tank by eliminating the sections inside the elevator to get the exact volume needed to raise the water level to the canal. Also, consider converting the volume needed to the flow rate needed. The ideal flow rate was used to calculate the ideal velocity using the conservation of mass equation. Moreover, the velocity needed from the conservation of mass equation can be calculated since we have the area and the flow rate needed. The first

Fig. 1 Design stage.

Fig. 2 Cutting plexiglass.
challenge the group faced was leakage which was solved. As a factor of safety, a velocity of 0.071 ft/min was considered, so by subtracting ideal velocity from the factor of safety velocity to get the new velocity. Then, the group recalculated the new flow rate, by taking the ratio of flow rate needed, over the new flow rate to get the result 99.76%. This means the flow rate needed is approximately equal to the new flow rate. Furthermore, find the pressure using the hydrostatic pressure equation at certain points in the elevator which span from the hole of the pump at the bottom to the canal level at the top. Also, the energy equation was applied by assuming that $V_1 = V_2$ to find the head of the pump. The head of the pump was used in the work equation in order to find the work needed.

To get the efficiency of the pump the ratio between the work needed and the ideal work was calculated. The work equation was conducted using the ideal velocity, flow rate, and work based on the specifications described by the pump product description. In addition, to find the velocity, flow rate, and work for the other speed levels multiply each value by one quarter, one half and three quarters. All of the equations used in this project can be found below. Work done in the system is calculated by using Eqs. (1a) and (1b):

$$\frac{p_1}{\gamma} + \frac{v_1^2}{2g} + z_1 + h_p - h_t = \frac{p_2}{\gamma} + \frac{v_2^2}{2g} + z_2 \quad (1a)$$

$$W_{pump} = \gamma.Q.h_p \quad (1b)$$

where $P$ is the pressure, $v$ is the velocity, $z$ is the pressure, $\gamma$ is the...
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elevation, \( h_p \) is the head pump, \( h_l \) is the head loss, \( W_{pump} \) is the power of the pump, \( \gamma \) is the specific gravity, \( g \) is the gravity, and \( Q \) is the flow rate. The geometric properties are calculated by using Eq. (2):

\[ V = L \cdot h \cdot w \]  
(2)

where \( V \) is the volume, \( L \) is the length, \( h \) is the height, and \( w \) is the width. The conservation of mass is calculated by using Eq. (3):

\[ \sum Q_{in} = \sum Q_{out} \]  
(3)

where \( Q_{in} \) stands for the inflowing flow rate, and \( Q_{out} \) stands for the outflowing flow rate. The hydrostatic pressure is calculated by using Eq. (4):

\[ P = \gamma \cdot h \]  
(4)

where \( P \) is the hydrostatic pressure, \( \gamma \) is the specific gravity, and \( h \) is the height from the bottom of the tank to the free surface.

4. Discussion of Results

It is important to note the assumptions made in consideration of the theoretical results. The first assumption made was that flow was steady and one-directional and the second assumption was that fluid was incompressible as the actual testing of the system only utilized water as the working fluid.

Running the experiment, there was leakage due to the gates not being perfectly sealed. Although this leakage was very minimal, the group had decided to factor that into the experimental results by estimating how much water was being lost. The group approximated the amount of water being lost in the small opening by calculating the volume of water found at the end of the test interval. For the losses from both of the gates, the group measured the initial and final heights of all of the tanks and calculated the losses from then.

The experimental results and theoretical values calculated for the ideal time with the ideal time are summarized in Table 1. The experimental data can be considered acceptable as it follows the trendline that the theoretical values are doing. As the power of the pump continues to decrease, which in turn causes the volumetric flow rate, velocity, and work of the pump to be lowered, the time it took to fill the middle tank to the level of the canal increased.

Each of the variables contributes to the rate of flow at which the tank is being filled directly by the pump, as shown in Fig. 5.

After comparing the time calculated to the time that was actually found for each power of the pump, it was found that there is an average of 16% percent error calculated. This was due to the circumstances that the pump is not functioning as efficiently as it was publicized.

5. Educational Objective

The purpose of this educational project was to understand theoretical concepts and apply them practically. Students had to process and assimilate information in order to achieve academic success. The project provided a great opportunity to observe the impact of several courses learned, including, but not limited to, fluid mechanics, thermodynamics and calculus III.

Marine engineers and naval experts can apply the knowledge of a water elevator in building boats. This can be seen in docks and piers where the water elevator can act as a mechanism to lift boats to dock. Additionally, it can also be used in hydroelectric pumped storage facilities in swimming pools. It is very important in controlling heights of swimming pools to

| Power | Velocity (ft/min) | Pumping power (lb-ft/min) | Time (min) | Ideal time (min) | Flow rate (ft³/min) | Ideal flow rate (ft³/min) |
|-------|------------------|---------------------------|------------|------------------|---------------------|--------------------------|
| 1/4   | 0.0451           | 4.259                     | 5.8        | 4.67             | 0.0317              | 0.0441                   |
| 1/2   | 0.0901           | 8.518                     | 4.6        | 4.01             | 0.0634              | 0.0883                   |
| 3/4   | 0.1335           | 12.775                    | 3.8        | 3.38             | 0.0950              | 0.1325                   |
| MAX   | 0.1802           | 17.037                    | 3.0        | 2.67             | 0.1237              | 0.1766                   |
provide a safe swimming experience for swimmers of different height, skill, and age.

The validity of working on this project could be viewed in different dimensions however; education aspect is the key importance. As upcoming engineers, the work field may require working in a collaborative multi-ethnic group. While working on this project, the team composed of women and minorities were able to practice communication skills among peers as well as developing organizational, creativity skills and research skills. Skills learned from this project are essential in securing future careers of the team members.

6. Conclusion

In this educational research, a water lift was designed, constructed, tested and analyzed. Some minor issues rose during the building process, but students worked as a team and used creativity to resolve any issues. The project was successful since the “boat” was transported from one elevation to another. Formulas learned in class were applied to obtain accurate results. For example, the geometric equation was used to get the volume for each part of the inner tank, ideal flow rate and conservation of mass equations were used to calculate ideal velocity and the work equation was used to obtain the efficiency of the pump. It was concluded that there was a 16% error due to minor leakage of water and the pump did not operate at its full capacity according to the product description. Lastly, this student research team was fruitful due to its ethic, racial, and gender diversity.

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