Coil pump design as an object of meaningful learning

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Abstract. Coil pumps can be a suitable solution to solve the pumping problem in isolate communities. This type of pump is easy to build, cheap and the maintenance can be performed for nonqualified personal. In addition, the pumping energy is provided by the river, so no fuel or electricity is required to the pumping process. The previous advantages constitute an attractive subject mainly for students whose water needs are no completely resolved as rural students. The design of this type of pumps demands mainly the application of concepts of fluid mechanics and energy. In this research is proposed a method to teach the design and implementation of a coil pump system in a simple way by a step by step methodology to impel the meaningful learning of the involved concepts in the design stage.

1. Introduction
The lack or the high-cost of conventional energy sources i.e. electricity or fossil fuels in rural areas affect the water supply and consequently its development and compromise the rural survival. Among the possible solutions, non-conventional pumping systems, as the coil pump, is gaining the attention for its low cost and easy implementation. This type of pump works transforming the kinetic energy of the stream (i.e. a river) in potential energy expressed by water high pressure in the pump outlet without the consumption of electricity or fossil fuels.

The coil pump is an easy building system, which is based on evolved prototypes of the Arquimedes pump. The first version of coil pump was proposed by Andrew Wirtz (1749) [1]. Later, in 1979, in the Blair Research Lab in Zimbabwe was designed a coil pump, called a hydrostatic or manometric pump [2]. Next, researches tackled the problem from an analytical perspective. In [3] is proposed a coil pump analytical model to be used in the design and building stages. Based on this a coil pump is tested to determine efficiency as a function of rotational speed, immersion relation and the pumping performance with different hose layers [4]. On the other hand, the determination of the relation between the number of coil layers and the outlet pressure and with the flow rate is investigated in [5] concluding that a more layers of hose more pressure without any effect in the water flow rate. In other research [6] is determined a growth in the outlet water flow rate as a result of two factors: first, an increase of the rotational speed and, second, a rising the submergence ratio, in both cases it is produced the same outlet pressure.

In this work, a step by step design procedure of a coil pump is explained to produce a meaningful learning of thermodynamics and fluid mechanics concepts in engineering students mainly belonging of rural areas, concepts which are involved in the operation of this type of green pump.
2. Theoretical framework

The coil pump, as shown in Figure 1, is a positive displacement pump which uses its rotation to produce an incremental pressure differential to pump liquids. This pump is composed of a flexible pipe usually a hose wrapped around a cylindrical structure submerged in the fluid to be pumped. The energy supply source to operate this pump is usually obtained from the kinetic energy of the stream, which contains the liquid to be pumped, transformed via a turbine coupled to the main frame of the coil pump.

![Diagram of a coil pump](image)

**Figure 1.** Schematic representation of a coil pump [7].

In operation, coil pumps form a series of alternating water and air packets which constitute a manometers sequence with pressure differentials. The pump outlet high-pressure is the result of the summation of these differentials. Therefore, in coil pumps, the number of hose layers, number of water columns, determines the net discharge head (see Figure 2).

![Diagram of water and air packets](image)

**Figure 2.** Plugs of water and air inside of hose [8].
The coil pump analytical model to determine the flow rate and the net discharge head was proposed by [9] as presented by Equations (1) and (2).

\[ Q_P = N_S \cdot \pi r^2 \cdot L_{W,1} \]  
\[ H_P = H_T - H_A = \sum_{i}^{N} h_i \]  

Where \( Q_P \) is the outlet flow rate of liquid, \( r \) is radius of the flexible pipe, \( N_S \) is the cylinder rotational velocity in cycles per minute, and \( L_{W,1} \) is the length of the first packet at the pump inlet. Thus, the pump average volume flow rate is defined by the flexible pipe cross-section, submergence ratio defined by the first packet and the pump velocity of rotation.

In Equation (2), \( H_P \) is the discharge head, \( H_T \) is the absolute net discharge head, \( H_A \) is the atmospheric pressure and \( h_i \) is the produced pressure differential for each water packet, for the \( N \) produced packets inside of the flexible pipe. Air packets lengths are the result of the path of the pump inlet rotating above the water level. The presence of consecutive water and air packets produce an intermittent liquid deliver. These air packets are subject to contraction and stretching due to the different pressures along the flexible pipe around the cylinder from inlet to outlet (see Figure 3).

The initial volume of the air packets, specifically for the first coil depends on the drum geometry, the hose internal diameter and the pump submerged percentage. Because the air packet is limited by the water packets next to it, different air pressures are developed. The air pressure can be studied using a polytrophic relation i.e. \( PV^{1.15} = \text{constant} \), where \( P \) as absolute pressure in the air packet and \( V \) is the packet volume.

As the air packets are moving from the inlet to the outlet of the pump, the developed high pressure reduces the air packet volume increasing the water packet volume. This volume change can be calculated using the polytrophic relation mentioned below as stated in Equation (3). When the water packet reaches the crown of the coil a spillback of the water packet can be occurred eliminating the air packet between them. Disappeared air packets involve loss of produced pressure differentials in the coil causing an outlet pressure reduction.

\[ H_A L_A^{1.15} = H_n L_{A,n}^{1.15} \]  

Where \( H_n \) is the absolute pressure head in the \( n \) coil, \( L_{A,n} \) is the air length packet in the coil \( n \), \( H_A \) and \( L_A \) are the head and length of the occupied space by the air in the pump inlet. Therefore, the air packet length change between different coils can be determined by Equation (4).

\[ L_A - L_{A,n} = L_A \left( 1 - \left( \frac{H_A}{H_n} \right)^{0.87} \right) \]  

The established flow pattern in this type of pump is characterized by a sequence of air and water packages produced during the operation of the pump. This discontinuous water flow usually unconsider if the facility is for water storage as is the case in most rural communities. In order to properly design a coil pump, a sequence of calculations needed to meet the given requirements. The most important analytical relations are stated as follows:

Equation (5) provides the coil radius in terms of \( L_{AA} \) and \( L_{BB} \), which are related to the length between the packets in the hose per revolution.

\[ L_{BB} - L_{AA} = 2\pi R \]  

The pump outlet flow is a function of the drum angular velocity, the hose cross-section $A_T$ and the submergence ratio as shown in Equation (6).

$$Q_D = L_{W1} * A_T * \text{rpm} \quad (6)$$

Finally, the required torque $M$ under the established pressure conditions is calculated using Equation (7) as follows.

$$M = (H_D - H_A) * A_T * R \quad (7)$$

Where $H_A$ is the atmospheric pressure, $H_D$ is the total pump outlet pressure, and $R$, is the drum radius.

3. Implementation of a pump coil in a rural area in Colombia

Based on different lab-scale prototypes developed at Universidad Industrial de Santander in the Mechanical Engineering School, a pump coil is proposed, implemented and tested in a rural community in Santander, Colombia. The pump is composed of a metallic frame to hold all the pump elements including the floats[10]. This frame has a metallic bumper impact absorber in the front to attenuate the impact energy of any material carried by the stream. In addition, the coil pump is also made up of the following parts:

A flexible pipe coil: This part is responsible for generating the water and air packets required to pump the liquid. This coil can be built using irrigation pipe which is an economic option easily available in rural areas.

Turbine blades: This component transforms the stream kinetic energy in rotational mechanical energy. These blades can be constructed using transversal cuts of PVC pipes which are suitable, cheap, common and corrosion resistance.

Rotating joint pipe fitting: This part provides a tightness couple between the stationary discharge hose and the rotating coil. Next in the Figure 4, a coil pump schematic representation and an actual picture of the implemented pump is shown, in explode view.
Conclusions

The coil pump design provides a meaningful learning model, due to discuss an essential problem, which is the search for alternative sources of energy to obtain basics conditions like water availability. The coil pumps design includes concepts on disciplines such as thermodynamics and fluid mechanics, which are important in the engineer formation.

On the other hand, a coil pump were designed and implemented to supply water to an isolated rural community in Colombia by undergraduate mechanical engineering students as a part of their thesis. This prototype was used to validate the design process and to satisfy the water needs in this community. The pump was installed in a mighty river that acts as an energy source in such a way that meets the required energy to pump water from the level of the river to a storage tank located 70 m uphill to the stream.

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