PERFORMANCE ANALYSIS OF LIQUID PISTON FLUIDYNE SYSTEMS

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ABSTRACT

Engines and pumps are essential for the smooth running of modern devices. Many of these are very sophisticated and require infrastructure and high levels of technological competence to ensure their correct operation, e.g., some are computer controlled or others require clean hydrocarbon fuels. This work focuses on design, construction and testing of a simple device, which has the ability to pump water and can be easily manufactured, without any special tooling or exotic materials, powered from either the combustion of organic matter or directly from solar heating. The device is a liquid piston engine, in which the fluctuating pressure is harnessed to pump a liquid (water). A simple embodiment of this engine has been designed and constructed. It was tested and recommendations on improvements have been made. The underlying theory of the device is also presented and discussed.

Keywords: heat engines, pumps, stirling engines, novel devices

1. INTRODUCTION

Fluidyne engines require very less tools for manufacturing and maintenance [1]. These can be used to pump ground water in remote places where regular maintenance of devices is not possible [2]. A common configuration of such a system consists of U tube connected at two ends. One of the ends is maintained at hot temperature whereas other end is at cold temperature. The basic principle of a fluidyne is similar to a Stirling engine. A gas when heated expands and if its expansion is confined in a limited space, its temperature rises. This can be understood more easily by following operations as depicted in Fig. 1.

Fig. 1. Motion of a displacer piston in cylinder  
Fig. 2. Motion of displacer piston
Initially, the displacer piston is at centre, with half of the gas in hot side and other half of gas in cold side of cylinder. The pressure gauge remains neutral.

As the displacer piston moves towards the cold end, the gas is displaced towards the hot end through the connecting tube and its pressure goes up as indicated by the gauge.

As the piston moves towards the hot side, the gas is displaced towards the cold end, its pressure falls. These changes in the displacer pressure can be used to drive another piston, known as the power piston. When the gas pressure is high, the power piston moves towards the open end of the cylinder, hence, producing some useful work, which can be used to pump water or to rotate a crankshaft.

But, when the gas pressure is low, the power piston returns to its original position, for which work is needed. This work is lower as compared to the work available from the previous stroke. Hence, there is an excess of energy that can be used for pumping operation or other tasks.

By suitable arrangements, some of the power available from the power piston can be used, in turn, to drive the displacer piston. Thus, the oscillatory motion of fluid provides a feedback force, essential for movement of the displacer piston in the U-shape tube, as well as the possibility of extracting work from this engine. Previous works have been done to analyze motion of fluidyne systems. West described the detailed motion of this system [3]. Fauvel studied the scope of work extraction, using hydrodynamic coupling [4]. Stammers described formula for a low temperature difference fluidyne system [5]. Wong used this system for pumping water up to a certain height [6]. Slavin used computer simulations to study the fluid motion in this engine [7]. Markides has used electrical analogy to study the fluid flow in a similar device [8]. Gupta made such a novel device, having a flow rate of 850 liters/hour, pumping water to 8.4 m height [9]. Kongtragool devised a fluidyne working at 90°C temperature difference, operating at 20 RPM speed [10, 11].

A fluidyne engine can be constructed using two columns. One of these is a hot column, whereas other one is the cold column. The two columns are connected at two ends maintained at hot and cold temperatures.

Various phases of operation of a fluidyne can be divided as shown in Figures 6-10:

a) **stage 1** (Fig. 6), when no heat is applied and levels of liquid in both columns is equal;

b) **stage 2** (Fig. 7), as heat is applied at the hot end, the air is heated up, expanding...
and moving towards the cold end, through the connecting arm. This pushes the fluid to top dead center (TDC) at the hot end and bottom dead center (BDC) at the cold end. The fluid comes out of the output column.

![Diagram of fluidyne](image1)

*Fig. 6. Neutral Stage of operation of a fluidyne*

*Fig. 7. Expansion Stage of operation of a fluidyne*

c) **stage 3** (Fig. 8): the air comes in contact with fluid at cold end and contracts; once the fluid has reached its extreme positions at both columns of the U tube, the inertia of weight of extra risen fluid tries to bring down the raised levels of fluid to mean positions;

d) **stage 4** (Fig. 9): as this happens, the air is transferred, again, from cold end to hot end, through the connecting space; the level of fluid overshoots the mean positions at both hot side and cold end and, hence, the fluid is, again, sucked back in the output column;

e) **stage 5**: inertia of weight tries to restore the levels of fluids, equal at both ends, and, hence, cycle starts again.

![Diagram of fluidyne](image2)

*Fig. 8. Neutral Stage of operation of a fluidyne*

*Fig. 9. Compresion Stage of operation of a fluidyne*

## 2. EXPERIMENTAL

Tests were done on a prototype of fluidyne engine, having specifications as presented in Table 1.

<table>
<thead>
<tr>
<th>Table 1. Engine Specifications</th>
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</thead>
<tbody>
<tr>
<td>Diameter of hot column</td>
</tr>
<tr>
<td>Displacer length</td>
</tr>
<tr>
<td>Displacer diameter</td>
</tr>
<tr>
<td>Pumping column diameter</td>
</tr>
<tr>
<td>Connecting arm length</td>
</tr>
<tr>
<td>Connecting arm diameter</td>
</tr>
<tr>
<td>frequency</td>
</tr>
<tr>
<td>Pumping height</td>
</tr>
</tbody>
</table>
The chosen design is easy to assemble and transport. Relative manufacturing cost was also low. The aim of this design is to pump water up to a certain height, using a liquid piston engine. U-shaped copper tubes were used for hot air column, whereas PVC U tubes were used as displacer column with elbow joints for connections at the two ends. Ethanol was used as source of heat, as shown in Fig. 10.

![Layout arrangement](image)

**Fig. 10. Layout arrangement**

Volume of water pumped from pumping column (Q) is given in terms of pumping height (H) and acceleration due to gravity (g) by

\[ Q = A(2g \cdot H)^{0.5} \]  

(1)

For the designed system the value is $7 \times 10^{-5}$ m$^3$/s

The power needed for pumping the water, P, is given by

\[ P = \rho \times Q \times g \times H = 0.01 \text{ W} \]  

(2)

where $\rho$ is fluid density

### 3. RESULTS

The measurement devices used for this experiment are:

- **a)** the thermocouple: it is based on the thermo-electric or Seeback effect, which states that a voltage is generated between two junctions of different metals maintained at different temperatures and this voltage is proportional to the temperature difference.

![Thermocouple](image)

**Fig. 11. A thermocouple**
2) the manometer; these are direct reading devices, used for leak detection, flow measurement and process monitoring. The readings have accuracy of ±0.5 mm.

![Fig. 12. The manometer](image)

Level of mercury in manometer was balanced with a knob, so that air bubble is at centre. The flame was started and one end of manometer was connected with the gap provided in the hot air column. Pressure and temperature readings were noted at various time intervals, using the thermocouple and the manometer, as seen in Fig 13.

![Fig. 13. Experimental setup for finding pressure and temperature](image)

The calculation of stroke of water column was difficult to do due to quick oscillations, however, it can be theoretically found using ideal gas law, which uses observed temperature and pressure readings.

<table>
<thead>
<tr>
<th>Pressure (in mmHg)</th>
<th>Temperature (in K)</th>
<th>Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>730</td>
<td>296</td>
<td>0</td>
</tr>
<tr>
<td>988</td>
<td>298</td>
<td>300</td>
</tr>
<tr>
<td>912</td>
<td>300</td>
<td>320</td>
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<tr>
<td>1216</td>
<td>305</td>
<td>340</td>
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<td>912</td>
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<td>1444</td>
<td>311</td>
<td>420</td>
</tr>
<tr>
<td>745</td>
<td>312</td>
<td>440</td>
</tr>
</tbody>
</table>

*Table 2. Variation of pressure and temperature of air with time*
According to gas law

\[ \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \]

where \( P_1 \) is initial pressure, \( V_1 \) is initial volume, \( T_1 \) is initial temperature and \( P_2 \) is final pressure, \( V_2 \) is final volume, \( T_2 \) is final temperature.

The displaced volume of fluid, \( V_d \), is given by:

\[ V_d = V_1 - V_2 = 2(\pi/4D^2)S \]

where \( S \) is length of stroke and \( D \) is displacer tube diameter.

The temperature of air in the engine was found to increase with time, as it gains more and more heat from the burning fuel. Air pressure was found to fluctuate with time as fluid moves back and forth from hot side towards cold side through the connecting air column. Peak value of pressure was found to be around 1400 mmHg, whereas the peak temperature was found to be around 39°C. This indicates a poor heat transfer to the working gas (air). In order to reduce heat losses, the connecting column was covered with an insulation cover of PTFE tape.

<table>
<thead>
<tr>
<th>( P_1 ) mmHg</th>
<th>( V_1 ) (cm³)</th>
<th>( T_1 ) (K)</th>
<th>( P_2 ) mmHg</th>
<th>( V_2 ) (cm³)</th>
<th>( V_1 - V_2 ) (cm³)</th>
<th>( S ) (cm)</th>
<th>Time (s)</th>
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</thead>
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<tr>
<td>700</td>
<td>22.6</td>
<td>296</td>
<td>988</td>
<td>298</td>
<td>16.8</td>
<td>5.8</td>
<td>1.56</td>
</tr>
<tr>
<td>950</td>
<td>16.8</td>
<td>294</td>
<td>912</td>
<td>300</td>
<td>18.32</td>
<td>1.5</td>
<td>0.57</td>
</tr>
<tr>
<td>900</td>
<td>18.32</td>
<td>310</td>
<td>1216</td>
<td>305</td>
<td>13.96</td>
<td>4.3</td>
<td>1.5</td>
</tr>
<tr>
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<td>13.96</td>
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<td>18.68</td>
<td>4.5</td>
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<td>308</td>
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<td>760</td>
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<td>312</td>
<td>23.31</td>
<td>11</td>
<td>4.7</td>
</tr>
</tbody>
</table>
CONCLUSIONS

In order to increase the efficiency of the designed system, the following improvements may be made in the current design [12-15]:

1) use of bigger diameter displacer tubes-it ensures the greater amount of air flowing between cold and hot side; this can lead to a larger amplitude of oscillations due to higher pressure, but smaller compression ratio, whereas smaller tubing, results in a larger compression ratio;

2) use of a regenerator; the regenerator acts as a thermal sink, releasing and storing heat at various stages, hence, increasing the efficiency of engine. The most common method of heat storage is to obstruct the flow of working fluid by use of metallic mesh, porous material, array of tubes, but this may cause flow losses;

3) better heat exchange, in order to enhance the heat exchange at the hot end, a resistance heating can be used instead of burning fuel along with fins for a greater heat transfer.

REFERENCES