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 devvices

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 limitd space, its temperature rises. This can be understood more easily by following operations as depicted in Fig. 1.
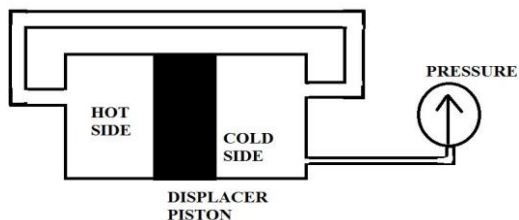

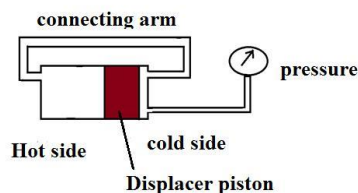Fig. 1. Motion of a displacer piston in cylinder

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.
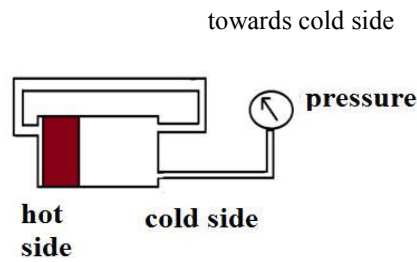
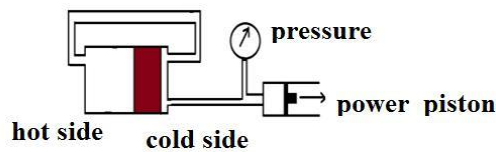towards cold side

Fig.3. Motion of displacer piston towards hot side

Fig. 4. Motion of displacer piston and power piston(expansion)

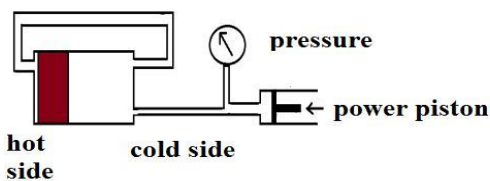Fig. 5. Motion of displacer piston and power piston (compression)

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

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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.

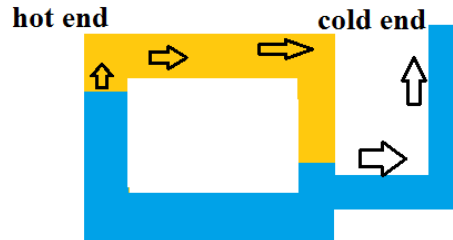Fig. 6. Neutral Stage of operation of a fluidyne

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) s**tage 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.
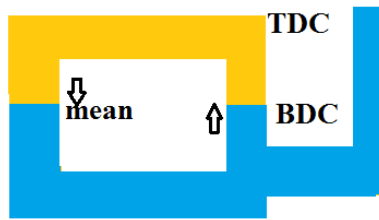

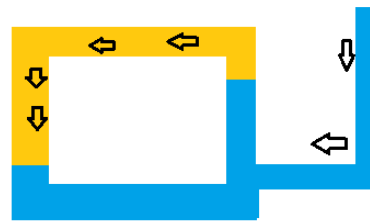Fig. 8. Neutral Stage of operation of a fluidyne

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 1. Engine Specifications

Diameter of hot column	5 mm
Displacer length	10 mm
Displacer diameter	20 cm
Pumping column diameter	2 mm
Connecting arm length	5 mm
Connecting arm diameter	2 mm
frequency	1 Hz
Pumping height	1.1 mm

The chosen design is ease 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.
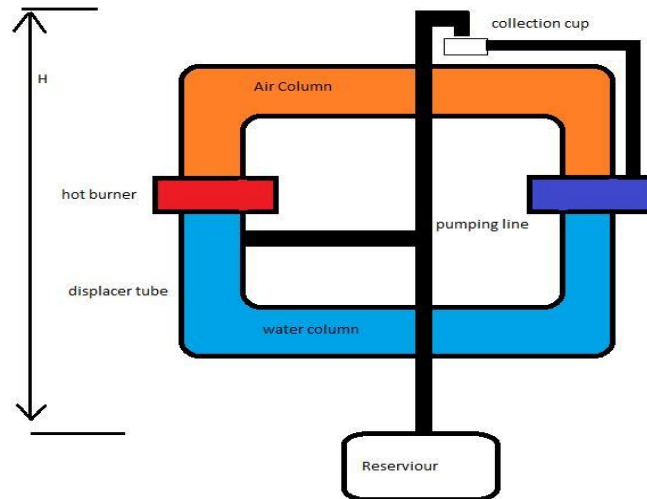
Fig. 10. Layout arrangement

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

$$Q = A(2g \cdot H)^{0.5} \tag{1}$$

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

$$Q = \rho \times Q \times g \times H = 0.01 \, W \tag{2}$$

where ρ 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.
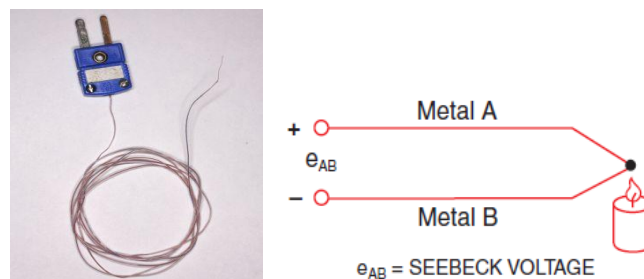
Fig. 11. A thermocouple

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

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.
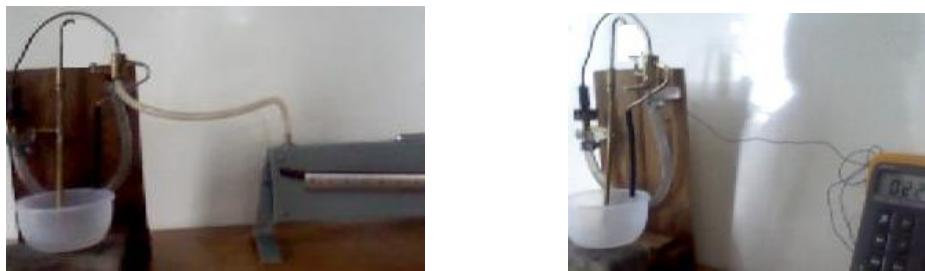

Fig. 13. Experimental setup for finding pressure and temperature

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 2. Variation of pressure and temperature of air with time

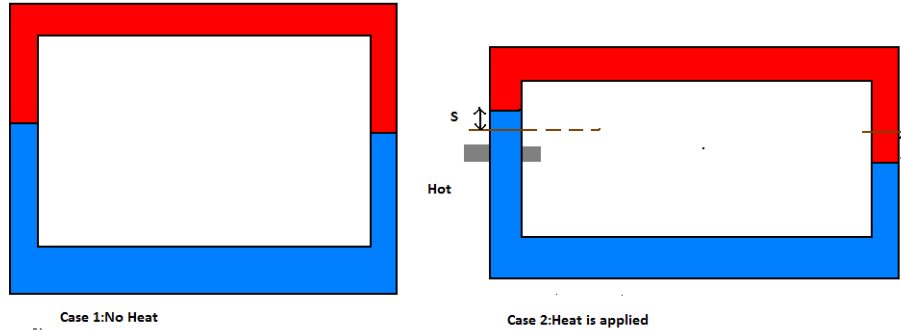| Pressure		Temperature (K)	Time (s)
in mmHg	in Bar		
730	0.96	296	0
988	1.3	298	300
912	1.2	300	320
1216	1.6	305	340
912	1.2	306	360
1368	1.8	308	380
760	1	310	400
1444	1.9	311	420
745	0.98	312	440

Fig. 14. Calculation of the stroke length

According to gas law

$$P_1V_1/T_1=P_2V_2/T_2$$

where P_1 is initial pressure , V_1 is initial volume , T_1 is initial temprature and P_2 is final pressure , V_2 is final volume , T_2 is final temperatue.

The displaced volume of fluid, Vd, is given by:

$$Vd=V_1-V_2= 2(\pi/4D^2S)$$

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 3. Variation of stroke length with time

P_1 mmHg	V_1 (cm³)	T_1 (K)	P_2 mmHg	T_2 (K)	V_2 (cm³)	V_1-V_2 (cm³)	S (cm)	Time (s)
700	22.6	296	988	298	16.8	5.8	1.56	300
950	16.8	294	912	300	18.32	1.5	0.57	320
900	18.32	310	1216	305	13.96	4.3	1.5	340
1100	13.96	311	912	306	18.68	4.5	2	360
912	18.68	313	1368	308	12.53	6	2.5	380
1268	12.53	314	760	310	22.7	9.5	4	400
770	22.7	316	1444	311	11.99	10	4.5	420
1400	11.99	320	745	312	23.31	11	4.7	440

CONCULSIONS

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 absorbing 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.

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