Designing of Liquid Piston Fluidyne Engines

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Abstract: *Engines and pumps are common engineering devices which have become essential to the smooth running of modern society. Many of these are very sophisticated and require infrastructure and high levels of technological competence to ensure their correct operation, for example, some are computer controlled, others require stable three phase electrical supplies, or clean hydrocarbon fuels. This work focuses on the identification, design, construction and testing of a simple, yet elegant, device which has the ability to pump water but which can be manufactured easily without any special tooling or exotic materials and which can be powered from either combustion of organic matter or directly from solar heating. The device, which has many of the elements of a Stirling engine is a liquid piston engine in which the fluctuating pressure is harnessed to pump a liquid (water). A simple embodiment of this engine/pump has been designed and constructed. It has been tested and recommendations on how it might be improved are made. The underlying theory of the device is also presented and discussed.*

Keywords*: Liquid Piston Engines; Novel Pumps*

1. Introduction

Water is an important basic amenity to sustain life on our planet. Out of the total water resources on earth, just 3% of water is available around us as fresh water in form of rivers, lakes, streams etc. [1]. Rest 97% of water available is saline thus unfit for direct use. On an average a human being needs about 20-25 litres of water for daily use. Growth of human population has caused extreme shortage of available resources on our planet. Given that the amount of fresh water available on this planet is very less in percentage, human population has been subjected to acute shortage of water. This problem is more severe in developing nations of Asia and Africa. Figure no1 presents a glimpse of water crisis amongst human population living in African nations:

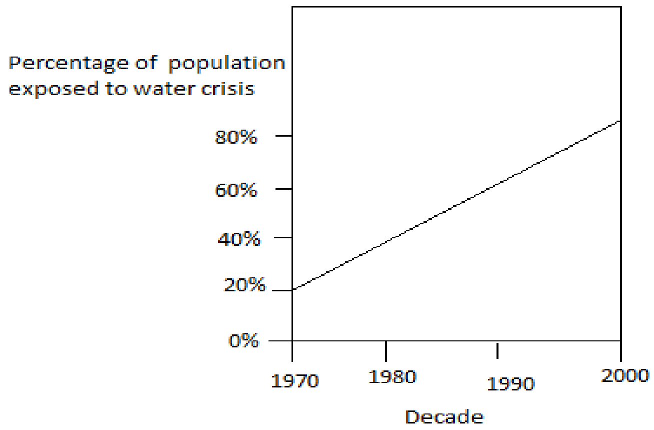

Fig. 1. Water crisis in Africa [2]

A major percent of fresh water bodies are being contaminated by industrial or human activity making fresh water available scare for human use. This has also led to water borne disorders amongst human population. In such a scenario ground water presents an excellent option for human use as it is available as a source of pure water. About 31% of fresh water sources available on earth is in form of ground water. It is available in form of porous rock known as aquifer. This source of water needs to be pumped using suitable mechanical machines. Extent of ground water withdrawal is shown in the following figure.

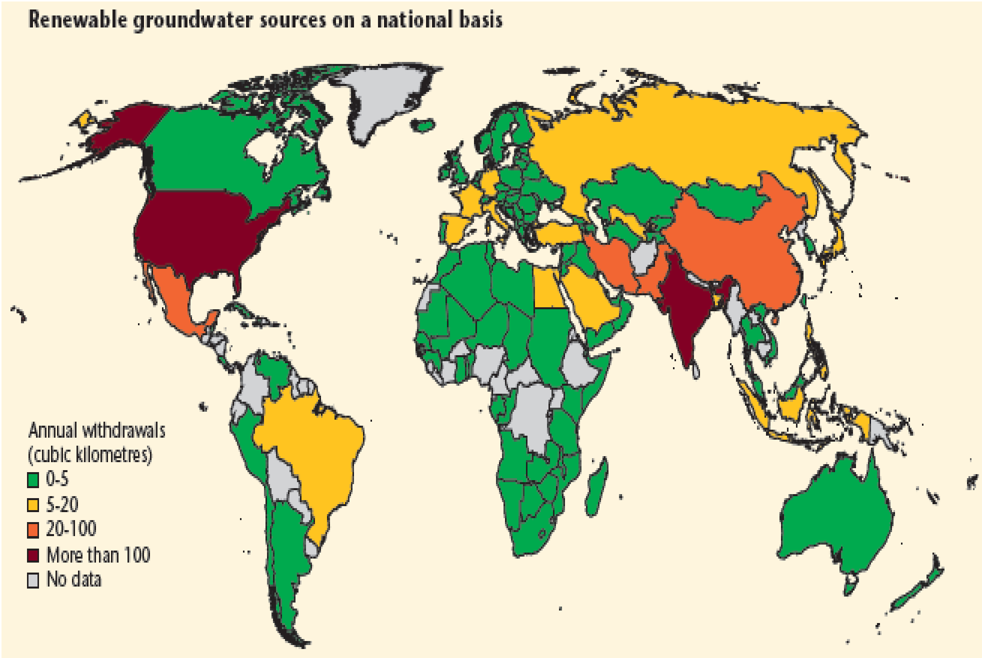

Fig. 2. Global withdrawal of ground water [3]

Solar energy is an important source of renewable energy available around us. Earth receives about 174 PW of solar flux daily, of which about 30% is reflected back into space. The remaining 70% is used to heat up surface of earth [4]. This energy has been utilized for various commercial purposes. The heat from solar energy can be used to run novel liquid piston fluidyne engines which in turn can be used to withdraw ground water for human use.

2. Novel pumps

There are several examples of natural pumps found around us. Some of these pumps are discussed in the next section of this work. These pumps are based on clever natural mechanisms and work without use of external power sources.

a) Capillary Action - This mechanism is found in plants and is based on bonding between cellulose cells found in Xylum tissues of plants and water present in the soil.

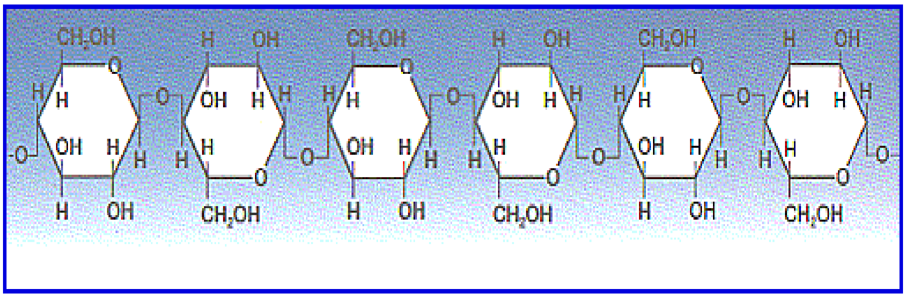

Fig. 3. Water cellulose bonding [5]

b) Human Heart - Human heart is an excellent example of a natural pump. It has four chambers known as auricles and ventricles.

Impure blood flows from right atrium to right ventricle through tricuspid valve and is sent to lungs for oxygen enrichment .From lungs the enriched blood flows to left atrium and then to left ventricle through mitral valve. Pure bold is then distributed to all parts of human body through aorta.[6]

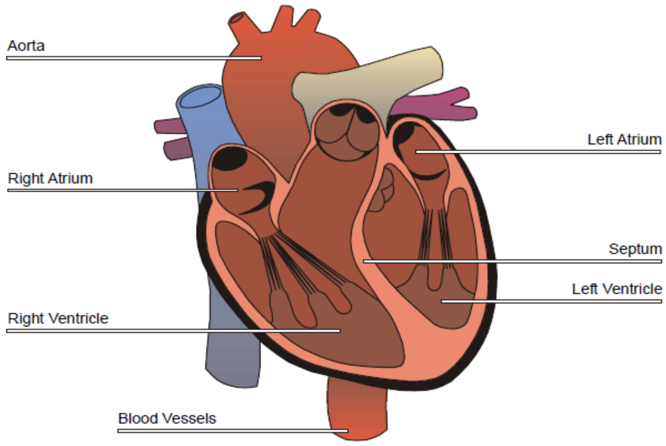

Fig. 4. Human heart [6]

c) Human Neurons - Human nerve cells are based on a sodium potassium pump known as Na-K-ATPase system. This system pumps 3 sodium ions into cell & 2 potassium ions out of a cell which causes excitation leading to human stimuli [7].

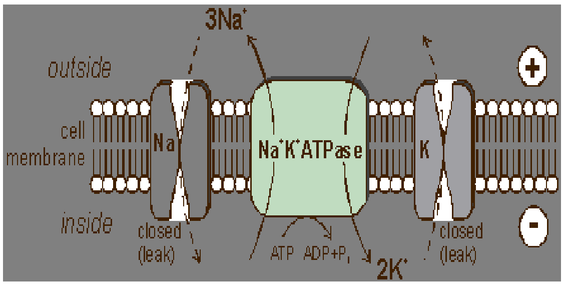

Fig. 5. Human neuron pumps

3. Liquid piston fluidyne pump [8]

A liquid piston engine is a novel engine working on Stirling engine cycle. A gas confined in a closed space expands when heated and contracts on cooling. This expansion and contraction can be used to generate pressure fluctuations which can be used to do useful mechanical work. The working of this pump is reviewed in next section of this work. Initially piston is at central and gauge is neutral indicating equal pressures on both sides. When gas present in hot end of arrangement expands, it pushes piston towards extreme left and moves towards cold end by means of connecting tube increasing pressure at cold end as indicated by gauge. As the gas comes in contact with cold end, it contracts and pressure falls hence pushing piston towards extreme left end. Figures 6-8 indicate this operation.

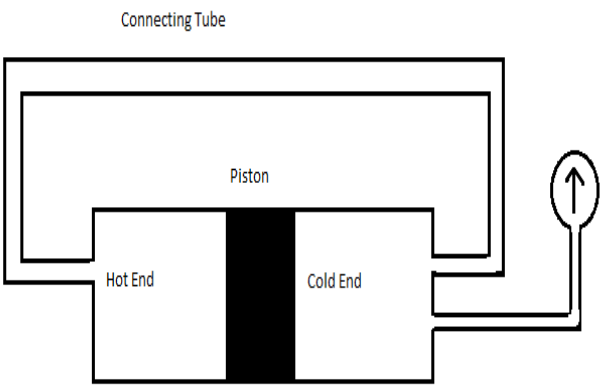

Fig. 6. Neutral position [8]

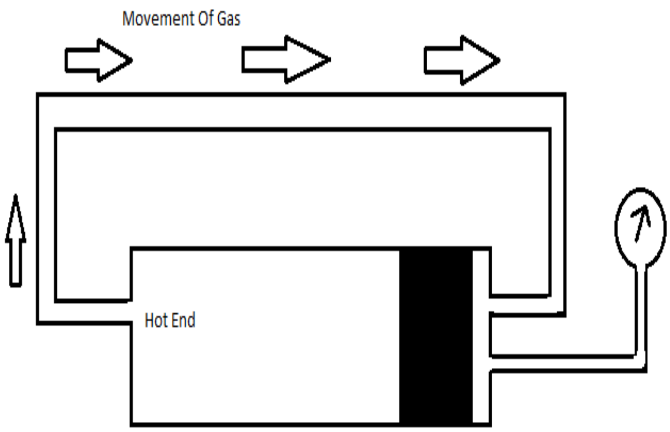

Fig. 7. Expansion phase [8]

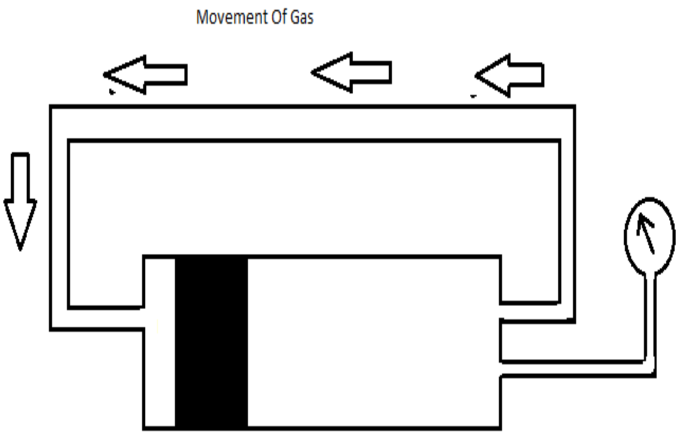

Fig. 8. Contraction phase [8]

The motion of gas causes pressure fluctuations which can be used to drive another engine for extracting useful work, as shown in figure 9. When pressure is high during expansion stroke, piston moves out and vice versa during the contraction stoke. Reciprocating motion of piston can be used to drive a crank shaft for engine motion. A regenerator can be used to increase efficiency of this system, as shown in figure 10.This consists of suitable arrangements of heat exchangers which store heat during expansion phase and release heat during contraction phase of gas.

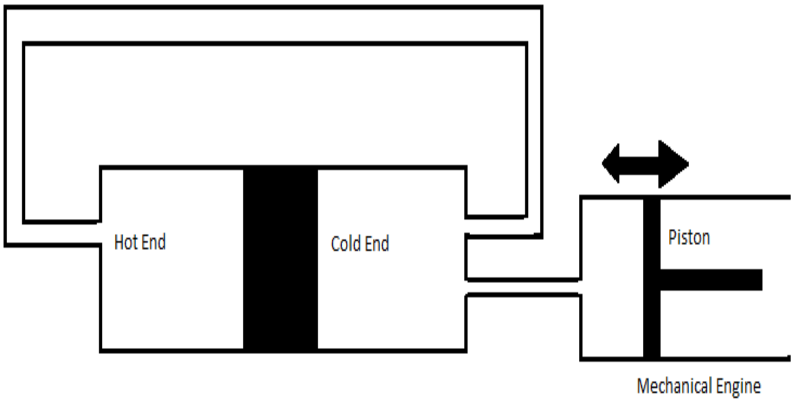

Fig. 9. Extraction of useful work [8]

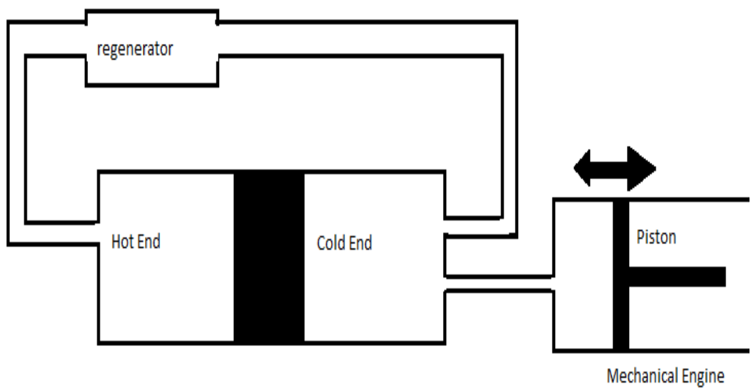

Fig. 10. Regenerator mechanism [8]

4. Motion analysis

Consider a U-tube connected by water space at bottom and air space at top. One end of this arrangement is heated and the other end is held cold.

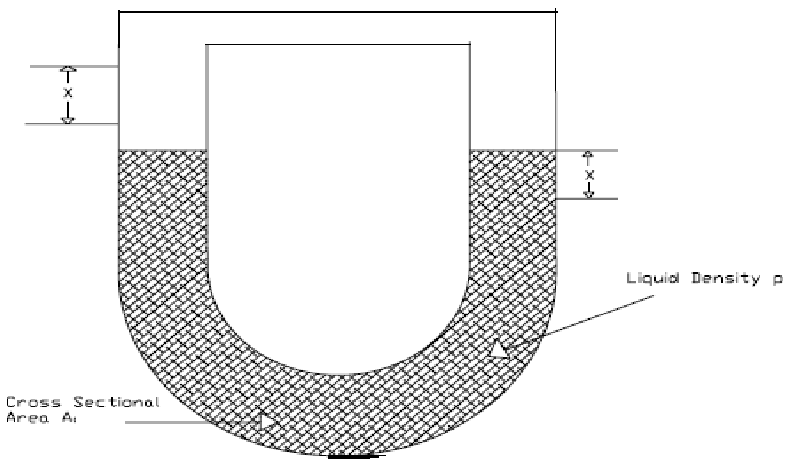

Fig. 11. U Tube arrangement [8]

If the fluid at one end falls by a distance X, then it rises at other end by same distance so that net difference between volumes is 2 ρAX. Net force acting on column is equal to $\rho ALX''$.
Also

$$\rho ALX'' = 2\rho AXg \tag{1}$$

where L is total length of pipe.
Acceleration of fluid is given:

$$X'' = 2X \frac{g}{L} \tag{2}$$

$$\omega = \frac{\sqrt{2g}}{L} \text{ rad/s} \tag{3}$$

Frequency of oscillations is given by $f = \frac{\omega}{2\pi}$ (4)

5. Experimental set up

A test rig was designed and developed to gather more information about working of fluidyne engine. This setup used a displacer pipe of 45cm length (L) and 1.2 cm in diameter (D). Pumping line used had 15 cm height (H) & 0.78 cm in diameter (d). Methanol spirit was used as a fuel to heat up hot end. A typical layout of system is shown in fig 12.

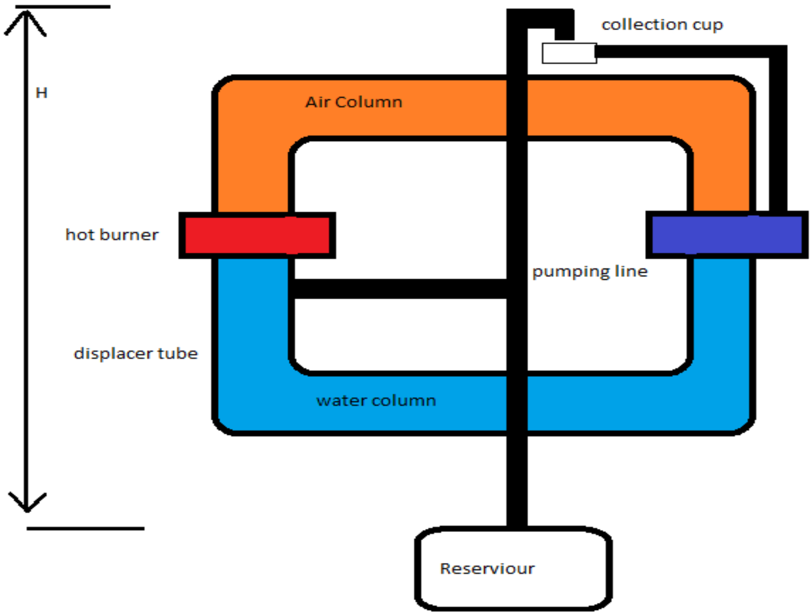

Fig. 12. Layout arrangement

Frequency of oscillations was found to be 1.57Hz using equation no 4.Volume of water pumped from pumping column is given by Q:

$Q = A \times \sqrt{2gH}$ =8.19 cm^3/s =8.19×10^{-6} m^3/s

Power needed to pump water $= \rho x Q\ x\ g\ x\ H$ =1000 x 8.19 x 10^{-6} x 9.8 x 0.15=0.012 W.

6. Results

Heat was supplied at hot end by ignition of methanol soaked wick. Open end manometer and thermo meter was used to note the pressures & temperatures at both hot ends after regular time intervals.

Fig.13. Pressure & temperature measurements by manometer & thermo couple

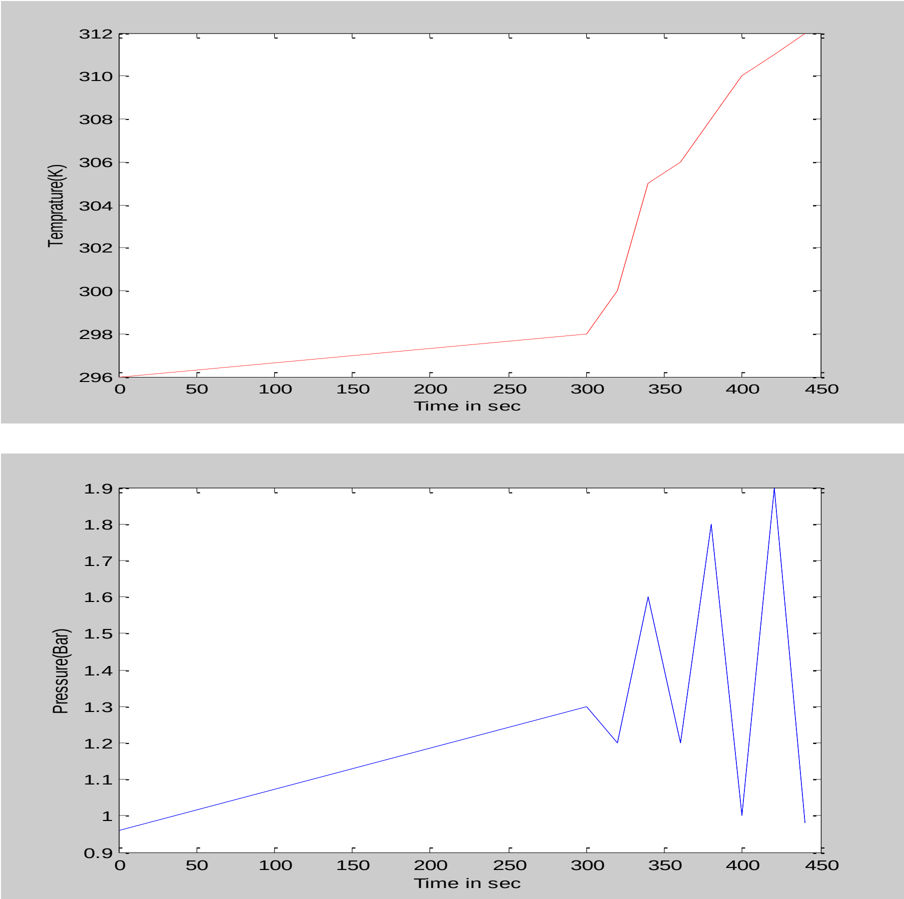

Fig. 14. Variation of pressure & temperatures

Practically it was difficult to observe the stroke length, however using ideal gas laws it was easier to find the theoretical stroke length visualizing the device as a wobbling column of fluid, as shown in figure no 15. Assuming air occupying connecting tube as ideal gas we have:

$$V_1 = \frac{\pi D^2}{4} \tag{5}$$

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \tag{6}$$

$$V_d = V_1 - V_2 = 2\left(\frac{\pi D^2 S}{4}\right) \tag{7}$$

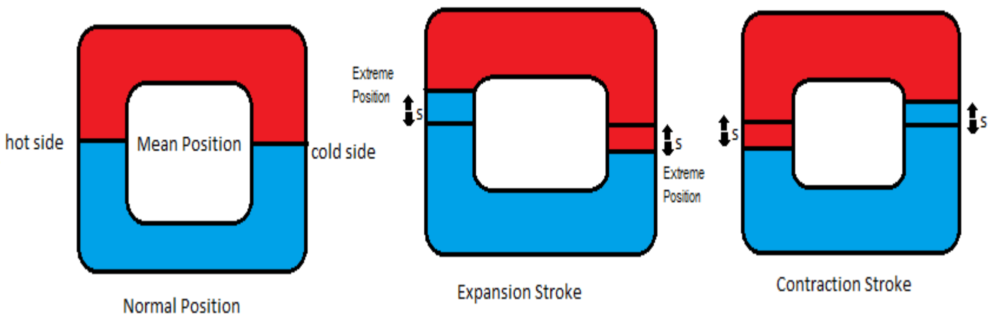

Fig. 15. Wobbling fluid column

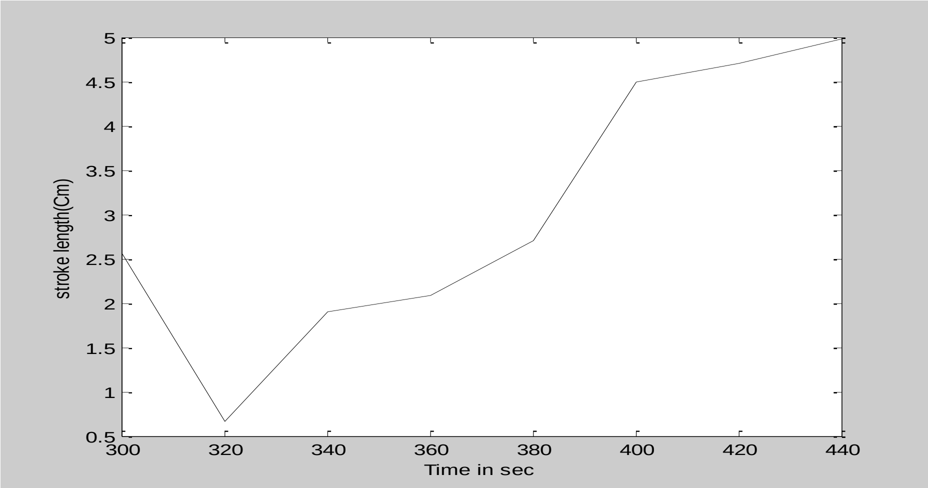

Fig. 16. Variation of stroke length

TABLE 1: Recorded values of pressures & temperatures

Pressure (mm of Hg)	Pressure (Bar)	Temperature (K)	Time(s)
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

TABLE 2: Calculation of stroke length

P_1 (mm of Hg)	V_1 (Cm^3)	T_1 (K)	P_2 (mm of Hg)	T_2 (K)	V_2 (Cm^3)	V_1-V_2 (Cm^3)	S (cm)	Time(s)
733	22.6	296	988	29S	16.8	5.8	2.56	300
988	16.8	298	912	300	18.32	1.52	0.67	320
912	18.32	300	1216	305	13.96	4.36	1.9	340
1216	13.96	305	912	306	18.68	4.72	2.085	360
912	18.68	306	1368	308	12.53	6.15	2.7	380
1368	12.53	30S	760	310	22.7	10.17	4.5	400
760	22.7	310	1444	311	11.99	10.71	4.7	420
1444	11.99	311	745	312	23.31	11.32	4.98	440

7. Conclusion

Both temperature & pressure of air in the fluidyne rose with time as it gains more and more heat from the burning fuel. Pressure fluctuated & peak pressure was found to be around 1400 mm of Hg, whereas the peak temperature was found to be around 39°C indicating poor heat transfer to the working gas (air). In order to reduce heat losses, the connecting column can be covered with an insulation covering of polytetraflouroethylene tape. Further in order to improve the heat transfer rate, bigger connections can be used so that more mass of air is able to gain heat from the burning fuel. Commercial form of such fluidyne engines can be developed by using solar energy as source of heat to create pressure oscillations, thus pumping ground water from a certain depth.

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