The ideal pop-pop engine

The ideal (theoretical) pop-pop engine is provided with an evaporator of minimum volume, and the stroke of the liquid piston is maximum; i.e. at the top dead center the gas volume is null and at the bottom dead center it fills the whole pipe. In other words, with following notations:

S=cross section area of the pipe.
L=pipe length.
ρ=specific gravity of water.

- The mean gas volume is half the one of the pipe. V=1/2 SL
- The mean mass of the moving water is M=1/2 ρSL

Knowing that the pressure inside the evaporator is close to atmospheric pressure, and that the mean temperature of the moving water is slightly above the tank one, we will use for the calculations $P=10^5$Pa and $\rho=1000\text{kg/m}^3$.
With legal units (L in m and S in m^2) and considering that the natural frequency of the engine is the one of a classic resonator, we get:

The frequency (Hz) $F = \frac{1}{2\pi}\sqrt{\frac{P.S^2}{MV}} = \frac{10}{\pi L}$ which depends only on the pipe length.

The maximum thrust (N) $T = \frac{\rho\pi^2}{4S}(SLF)^2 = \frac{10^5}{4}S$ which depends only on the cross section.

Reminder: this concerns only the "ideal" engine; i.e. without steam drum.

Let's compare theory with the results of some of our best engines.

Pipe inner diameter (mm)	Theoretical max frequency (Hz)	Measured frequency (Hz)
4 (L=300)	10,6	8
6 (L=480)	6,6	5
8,2 (L=580)	5,5	3
12 (L=745)	4,3	2,4

Roughly, the measured frequencies correspond to the calculated ones. However, they all are lower than the maximum theoretical value. The reason (among others?) is the fact the evaporator volume is not negligible. At the top dead center it remains some gas. We could observe this on many occasions with transparent engines.

For the thrust the results are more disappointing.

Pipe inner diameter (mm)	Theoretical max thrust (mN)	Measured thrust (mN)
4	314	17
6	707	44
8,2	1320	48
12	2827	72

In addition, we know that the thrust measuring device we used indicates slightly more than the actual value (see "Why do we measure more than the theory?").

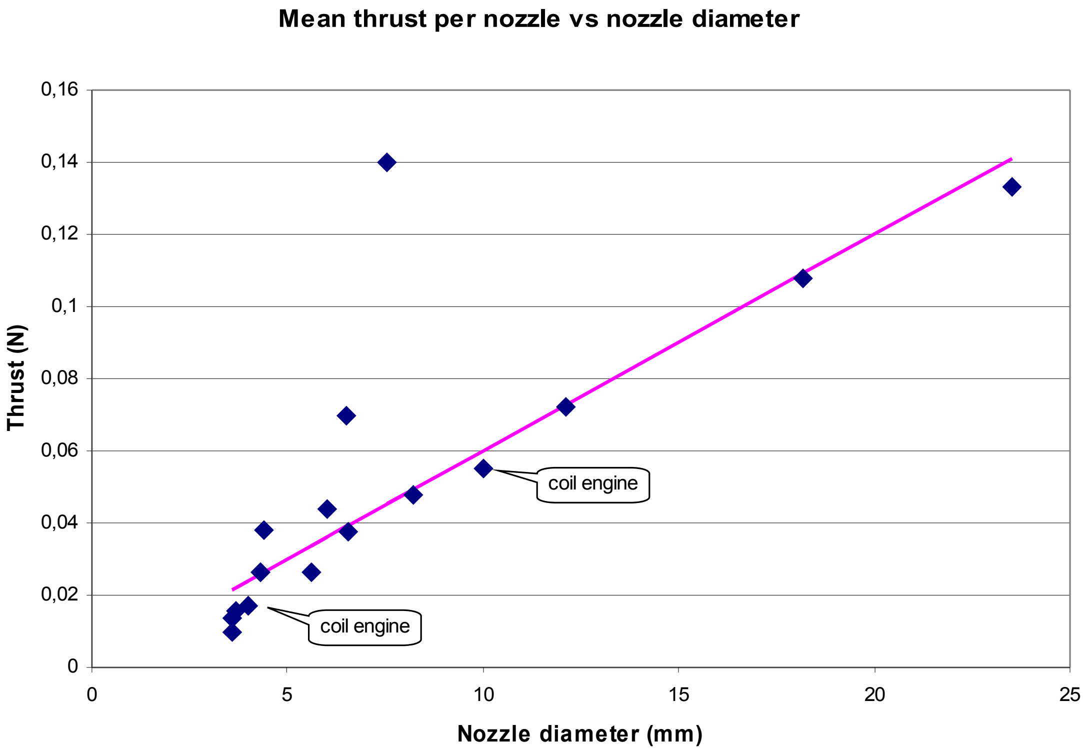
Causes of error:

- Actual stroke shorter than L.
  According to our visual observations this could explain a ratio of approx 2 for small engines. We don't know how much for big ones.
- Actual frequency lower than the theoretical value.
  Intervenes as the square. Could justify a ratio of approx 3. Combined with the previous one, (2x3=6) we still are far from the reality for a small engine.
- Too optimistic assumptions.
- Others???? (Emulsion, specific gravity lower than 1000kg/m3…)

Therefore, the ideal pop-pop engine doesn't exist.

For what concerns the frequency, we could get a lower result by using a big evaporator, but in the other way it is impossible to get a frequency higher than the theoretical value as defined by the previous formula.

For what concerns the thrust, it increases with the pipe diameter. It can be seen on the following graph.



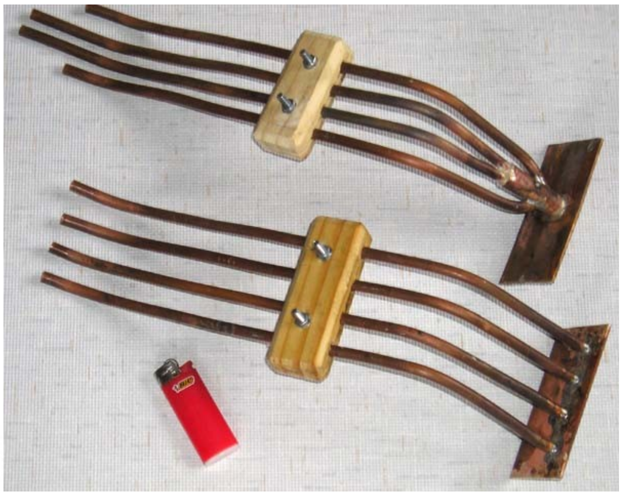
Note: what is called "mean thrust" is the average of a 15 minute record. Instantaneous thrusts up to 30 times higher than the average were recorded, but they are rare and they don't influence the average because they are generally followed by several seconds with no visible thrust.

This graph sets as evident a quasi-linearity between the diameter (in abscissa) and the thrust (in ordinate), but not between section and thrust as I expected. That's a pity!

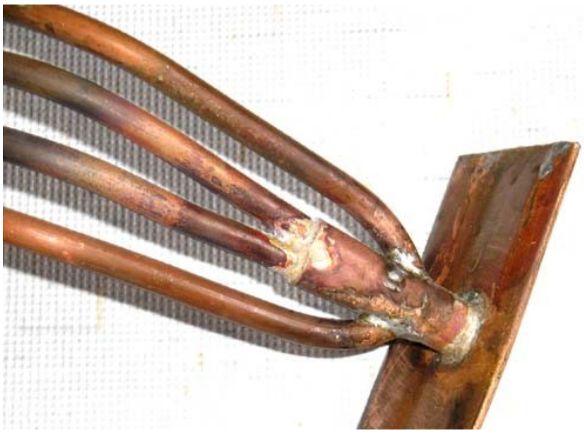
Consequently, two pipes of section S are more performing than a single pipe of section 2S. Even though this disappoints me, it seems evident at this knowledge level. The Burmese boat with 3 pipes, or Daryl's one with 4 pipes are interesting tracks we have to follow. Since that time, I have built engines with up to 8 pipes and Daryl built up to 10.

My feeing is that the theory of the resonator is not so bad. The main problem is at the thermodynamics level. How could we excite a big resonator to get a long stroke? The difficulty comes from the fact everything doesn't follow the scaling factor. For instance, on one side the mass increases as the cube while the area increases only as the square. On the other side, cooling is ensured mainly by the pipe and by the thin layer of water during the climbing down of the water snake. We have to work on the evaporator.

On a single pipe engine I tried an evaporator with pipes inside to increase the area of the hot source. Nothing bad or good to report.



Then I tried to compare two 4 pipe engines, one with a manifold and one with individual connections to the evaporator. No visible difference in thrust.



Since that time, we are working on different basic designs.

Daryl who builds the more performing engines that I know set as evident the fact some materials are better than others. His best engines have a vaporizer made of copper, connected to brass pipes prolonged by aluminum ones. Stainless steel seems also to be interesting. And tube thickness seems to play a role as well. There are so many materials and parameters that it is difficult to build a serious comparative analysis.

On one hand, cooling of the pipe due to surrounding air is not much important. We proved this by running an engine with its tube insulated. On the other hand, some pop-pop engines using a thin and bad thermal conductor tube work fine. What condenses/cools the gas is essentially the water layer that deposited when the water column climbs down. Therefore, the condensation/cooling capability depends on 3 parameters:

1°) Thickness of the water layer that adhere to the wall.
2°) Temperature of the deposited water.
3°) Internal area of the wall which makes the condenser/cooler.

The influence of the water layer adherence has been demonstrated by Guus with his glass engines. The same engine depending upon its cleaning by means of phosphoric acid or not had very different performances. It would be interesting to cover the inside of the tubes with a porous material or a one with capillary effect in order to retain an optimum water layer.

When engine is running, the top of the water column seems to be at about 60-70°C according to all our records. And this, whatever the temperature of the water into the tank. This being known, the best water layer thickness can be determined accordingly.

For the same tube(s) cross section area, the area of the inner wall used as condenser/cooler can be easily increased by lowering the tube diameter and increasing the tube quantity. It is also to be considered that some interesting tests were performed with square tubes. Less interesting results were got with more or less flattened tubes. But the lack of rigor doesn't allow to build comparisons (because different materials, different thicknesses, different cross section areas...). It can be easily understood that for the same volume and the same length, square tubes have simultaneously a large inner surface and retain more water in the angles. If that is true, it could be even better by using a star section with 5, 6 or even more branches.

To be continued…