Diagram of the water-steam cycle

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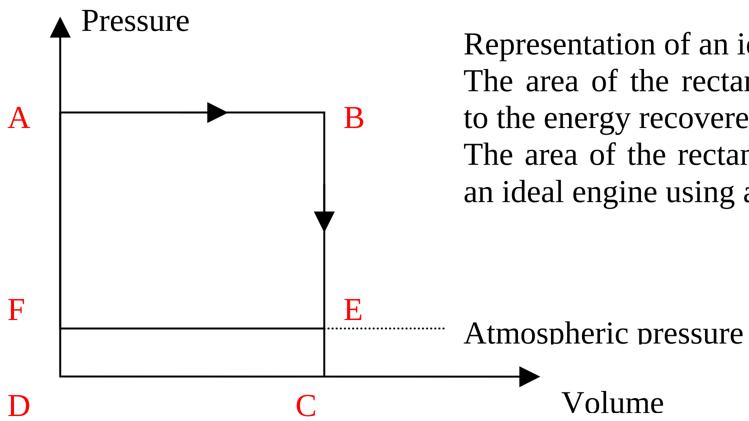
Usually, for a **steam turbine** the cycle is represented on a Mollier diagram. This is justified by the fact that for any power and any place in the cycle the conditions (pressure, temperature, flow) are stable. This representation allows performing steam balance and optimization of the cycle. One can vulgarize by saying that any molecule of H_2O proceeds through the whole cycle : water tank→ feed pump → boiler (heater, vaporizer, over heater) → turbine → condenser → water tank. Sorry for the purists! Deaerator, fresh water generator, steam bleedings… are voluntarily omitted.

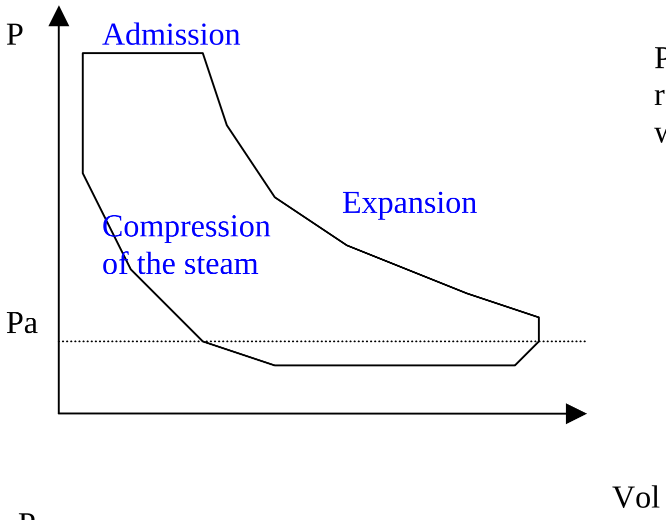
For a **diesel engine** classically the cycle is represented on a pressure-volume diagram, the volume being the one of the combustion chamber, i.e. the one limited by the piston.

For a **reciprocating steam engine** (in practice they are no longer being built) it was common to use – as for a diesel engine – a pressure-volume diagram. (Note that building this engine with an external combustion has been stopped due to its poor efficiency. Approx 10%.)

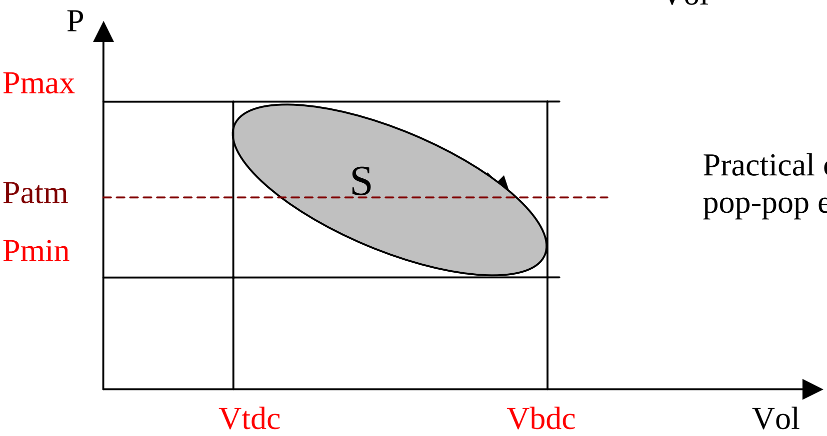
When a **pop-pop engine** is made of a copper pipe (coiled or not), or when the drum is made of copper and contains only steam in operation, one can consider that the water-steam interface is a piston. And therefore the pressure-volume representation can be used.



Representation of an ideal theoretical engine :
The area of the rectangle ABEF is proportional to the energy recovered on one period.
The area of the rectangle ABCD corresponds to an ideal engine using a vacuum condenser.



Practical cycle of a reciprocating steam engine with condenser



Practical cycle of a pop-pop engine

<u>Definition of Pe, Pi and Pc :</u>

Effective power Pe : It is the power developed at the outlet of the nozzle.
Indicated power Pi : It is the power developed by the steam on the liquid piston.
Pi=S.F with F= frequency of the cycle in s^{-1} and S= area of the cycle in $Pa.m^3$=N.m
The effective power is equal to the indicated power less the friction losses of the liquid column.
Circumscribed power Pc: It is the power that would develop a virtual engine following the cycle defined by the circumscribed rectangle.

<u>Estimation of Pi :</u>

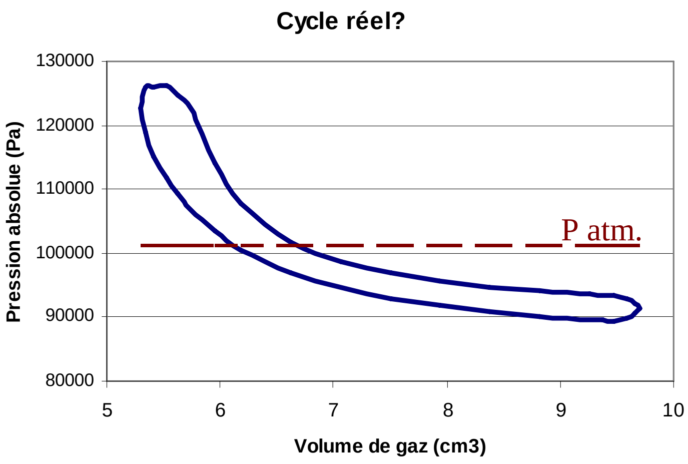
We don’t know the exact shape of the "potatoid" of area S. Nevertheless, we can know the circumscribed rectangle. Application to the engine I know the best: the PPVG engine with single pipe of inner diameter 6mm (Pop-pop with variable geometry, made with parts bolted and not soldering, in order to have the possibility to easily change the specifications).

Pmax = Patm+24917Pa, Pmin=Patm-11870Pa,

Vtdc = 5,3cc = $5{,}3\times10^{-6}m^3$, Vbdc = 9,7cc = $9{,}7\times10^{-6}m^3$, F = 5,1Hz

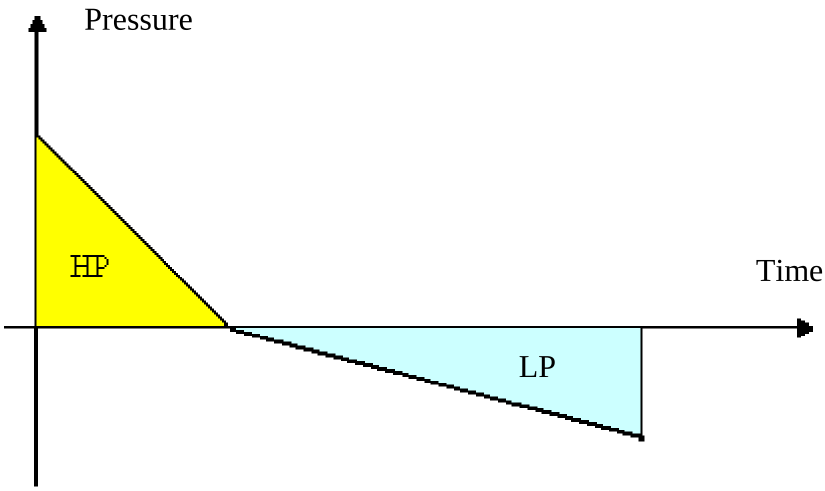
➔(Pmax-Pmin)x(Vbdc-Vtdc) = 36787 x $4{,}4\times10^{-6}$ = 0,162 J et Pc = 0,162 x 5,1 = 0,83 W

Pi is necessarily lower than Pc and higher than Pe. We know how to calculate Pe. (See “Pop-pop engine and momentum theory”). There it is 0.0465W. It is 18 times less than the circumscribed power. A very rough estimate of the friction losses gives 0.1W; i.e. the indicated power is approximately 0.15W. It means that the popatoid is squeezed. Then, it is difficult to say if compression and expansion are more or less isentropic or adiabatic or isothermal. My guess is that it is something in between. And one thing is for sure: due to the fact the absolute value of the min pressure is lower than the one of the max pressure, the diagram has a concavity towards the top right. If not, at each cycle the water snake would climb more down and the engine would stop very soon. Hence, the actual cycle would (conditional is intentional because I cannot prove it) look as on the side diagram.

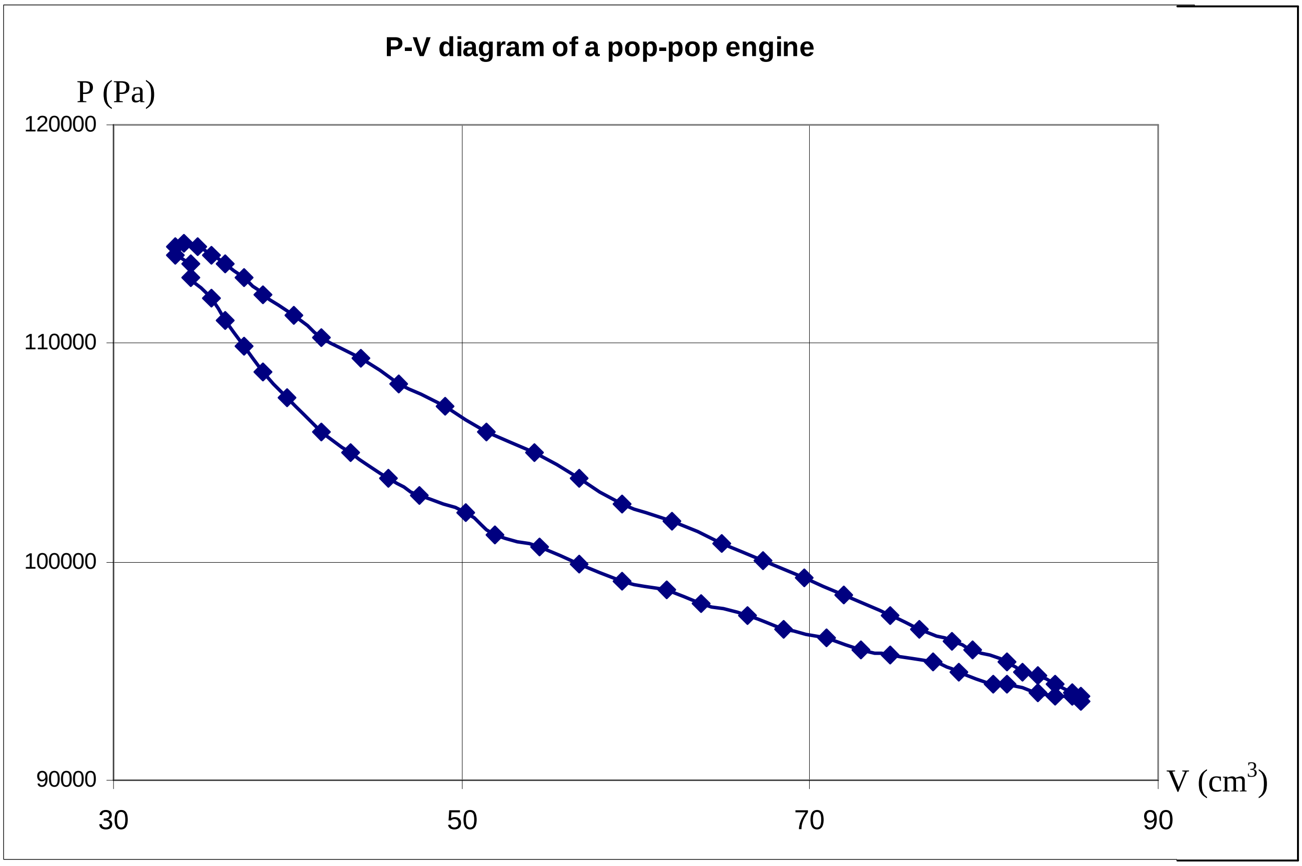


*)In order to simplify we can suppose that the mean pressure into the chamber is the atmospheric pressure and only think in terms of effective pressure. When a drop of water vaporizes there is a (relatively) high pressure. For example 0.2 bar. The other extreme is a negative pressure, when the water snake creates a vaccum into the chamber, due to its intertia. This vacuum is in absolute value less high (because at the interface some hot water vaporizes). For example -0.1 bar. I measured ont two different engines that the absolute value of "high pressure" is higher than the "low pressure".

Proof by contradiction : if between these two extremes the variation of pressure was linear, the mean pressure would be +0.05 bar, thus the water snake would move toward the pipe outlet and in the best case after only a few seconds there would be only steam. To have a mean pressure equal to zero on the whole cycle, it's necessary that the time spent under positive pressure be lower the time spent under negative pressure.



All what precedes was written before spring 2008. End of 2009 we succeeded to record pressure and volume versus time on a pop-pop engine. These data allowed drawing the P-V diagram at different powers. Here is one:



It corresponds to a bigger engine than the PPVG one used for the previous calculation. However it gives confirmation of the global shape of the cycle: squeezed potatoïd with concavity towards the top right.