Analysis and assessment of Davey's Atmospheric Engine from 1885

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The engine

Probably the last commercial atmospheric engine was built in the 1880's by Hathorn, Davey and Co. of Leeds / England. The engine, a double acting atmospheric engine without steam expansion, was intended for small businesses, and the advantages listed then were very similar to those we see today:

1. simplicity,

2. low working temperature,

3. operation at atmospheric and negative pressures (i.e. safety regulations are much less stringent than for high pressure engines, and the machine can be installed practically anywhere)

4. cost-effectiveness.

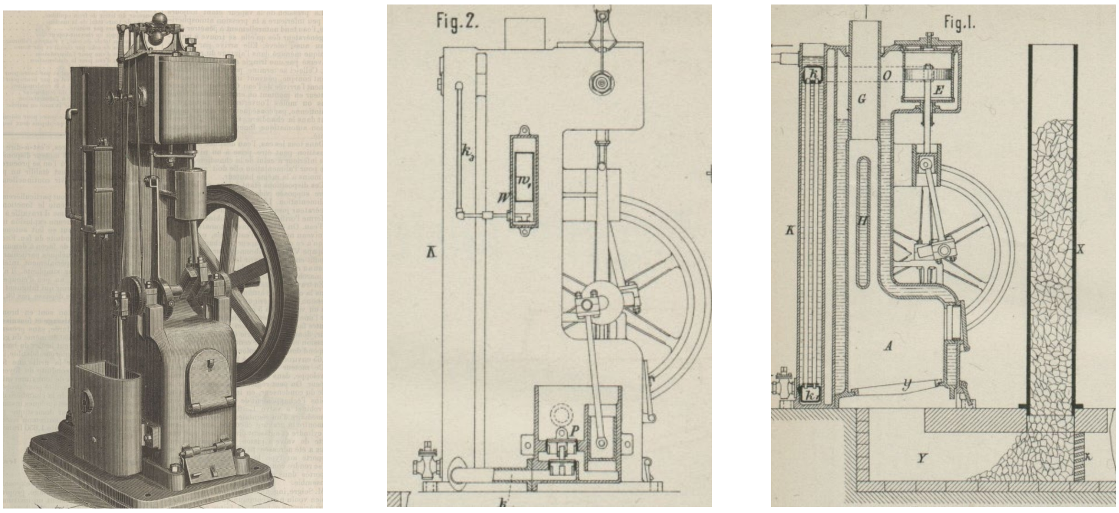
It is described in *Revue Industrielle* (1885), and *Dingler's Polytechnisches Journal* (1886).

Dimensions:

Fig. 1a shows the engine itself, Fig. 1b and 1c the technical details. Unfortunately, no dimensions are given in the drawings. It was however possible to determine the approximate piston area and stroke length from the power, speed and pressure information given in the two articles, Fig. 2.

a. The cylinder had an inner diameter of 190 mm (7.5"?), and a stroke length of 150 (6"?) mm (approximate values).
b. With a pressure difference of 85 kPa, the power output was just about 1.1 bhp (or Cheveaux-Vapeur - CV as the French say) or 0.8 kW. A 600 mm diameter flywheel smoothened the power output.
c. Davey's engine had an overall space requirement of approximately 0.9 × 0.9 m area, and a height of around 1.6m. The total weight of the machine was an incredible 900 kg.

For the actual analysis of the engine efficiency etc. the dimensions are not necessary, so that the calculations can bee considered as accurate.



(a) (b) (c)

Fig. 1: Davey's Engine from 1885, (a) Overall view, (b) Side elevation, (c) Cross section

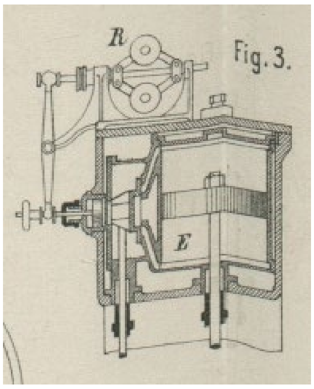


Fig. 2: Cross section of cylinder:

Reported tests

In the article in *Revue Industrielle*, test results are given in table 1. The engine ran with a speed between 118 and 125.6 rpm, and delivered between 0.99 and 1.11 bhp (0.728 to 0.816 kW). Unfortunately, no efficiency figures is given in the article. However, the information given in the article also allowed to calculate the efficiency of the engine from the steam demand of the cylinder as well as from the water demand for the boiler (as cross check).

Table 1 : Test results as given in *Revue Industrielle* 1885 (1 bhp = 1 Chevaux-Vapeur CV = 0.735 kW):

1	**Test Nr**	**1**	**2**	**3**	**4**
2	Test duration (minutes)	108	240	221	600
3	Weight on lever arm (kg)	6	6	6	6
4	Length of lever arm (m)	1	1	1	1
5	Total nr of revolutions	12782	31822	27310	75428
6	Revolutions per minute (rpm)	118.3	132.5	123.6	125.7
7	Power (bhp)	0.99	1.11	1.03	1.07
8	Total fuel consumption (kg)	12	25.5	21	53
9	Fuel consumption per hour (kg/hr)	6.73	5.745	5.530	5.040

10	Water usage in boiler (kg)	70	144	120	300
11	Water volume for condenser (kg)	1310	2756	2400	7600
12	Water demand for boiler (kg/bhp·hr)	39.3	32.4	31.6	28.5
13	Water demand for condenser (kg/bhp·hr)	736	620	632	723
14	Temperature at condenser entry (°C)	20	20	20	20
15	Temperature at condenser exit (°C)	45	47	48	44
16	Temperature for boiler feed water (°C)	27	40	35	35
17	Time required for start-up	30	20	30	37

Analysis

Efficiency:

The analysis first showed, that the engine did not employ steam expansion as was already suggested by the drawings in Fig. 2 (cylinder details).

Table 2: Test results for calculation

Test No	Duration (min)	Revs	rpm	CV	Water ev. (kg)	T exit (°C)	T in (°C)	P (kW)
1	108	12782	118.3	0.99	70	45	37	0.728
2	240	31822	132.5	1.11	144	47	40	0.816
3	221	27310	125.6	1.03	120	48	35	0.758
4	600	75428	125.7	1.07	300	44	35	0.787

The cylinder diameter was estimated as 190 mm, with a stroke of 165 mm. With the cylinder volume of 4,676 cm^3, the theoretical steam demand could be determined. Table 3 shows the calculated thermal power from the cooling water data in column 2, the power of the steam volume determined fr the cylinder volume in column 4, the engine efficiency in column 5, and the maximum theoretical efficiency in column 7.

1	2	3	4	5	6	7
Test No	**E water (kW)**	**V steam (m3/s)**	**E steam (kW)**	**Eff. Total (-)**	**Eff. steam**	**Eff. theory**
1	27.2	0.0095	14.1	0.027	0.052	0.060
2	25.1	0.0106	15.7	0.033	0.052	0.061
3	22.9	0.0099	14.7	0.033	0.051	0.060
4	21.1	0.0102	15.3	0.037	0.051	0.060

The efficiencies then determined from the data given were:

(a) Cylinder efficiency: 5.2% using the steam demand of the cylinder (cylinder volume times speed).

(b) Total efficiency: 2.7 to 3.7%, calculated with the overall energy demand (water volume evaporated). The lower efficiencies were derived from short tests where the warm-up period of the engine probably affected the results.

The second value includes dead space as well as thermal losses, and gives us a benchmark figure of what we can expect from a real engine. The first value really is a check (it must be higher than the total, and lower than the theoretical efficiency) and an indicator of the power conversion efficiency.

The difference between the two values gives us an idea of the total system losses, which amount to 44% of the power output or 31% of the total power production.

Heat exchanger / condenser

The condenser is actually a plate-type heat exchanger with four heat exchange surfaces. The dimensions were approximately 1.2 x 0.4 m, so that the condenser had a heat exchange area of 1.92m^2 for a thermal power of 21 kW.

The HE is the largest component of the engine.

So, what do we learn from the engine?

The most important thing is probably that here we have reliable information about the efficiency. With 3.6%, the engine achieves about 60% of the theoretical efficiency. The efficiency determined from the cylinder steam volume is 5.2%, so clearly there are some gains possible e.g. through a better heat insulation (or any heat insulation at all, Davey's engine does not seem to have such a thing). In a modern engine, the insulation of the cylinder etc. would be much better so that we could expect a better performance.

There are some interesting technical details, regarding the volume of water required for condensation (heat rejection really is an important topic here), the steam valves etc.

References

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