Title: 
Letter, 'Improvement in the air pump' from John Smeaton to John Ellicott

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To
Mr. John Elliott F.R.S.
I have been informed by some of my Friends that my endeavours towards completing the air-pump have been mentioned with approbation to the royal Society, by Mr. Short & Mr. Watson. I understand likewise, the letter of those Gentleman has in a very obliging manner expressed an inclination, that I should lay before them a particular Account of my Improvements therein.

I shall always esteem it a singular Honour to be thought capable of producing any thing worthy the attention of the royal Society; and to be my duty & Interest so to do, upon the least intimation of that kind; and more especially so, as I am much indebted to the Philosophical Transactions for the Acquaintance I have been able to take with Mechanics in general.

Your superior skill in those Arts, as well as the assistance you have given me, in making trial of my pumps, against every good of the common construction, together with the countenance and Encouragement you have in general afforded me; encourages me to trouble you, with communicating the following to that Society, of which you are a distinguished Member, and who,
of all others, are the most proper judges. In particular,
I shall not trouble you with a recital of the errors
that I have taken from time to time, for near 2 years
past, in order to remove some obstacles, which I imagined
hindered the effects, that the theory I put out upon seemed
to promise. It will be sufficient, that I give an account
of what has appeared to me to answer best, after a vast
number of different trials. Which, tho' the short of what
I at first expected, yet as this Pump performs much
better than the common ones, perhaps my labour may not
be thought wholly useless; if the respect I have to
the Society, would still have prevented me, from
troubling you or them about it at this time, could I
have thought of any alteration, that was likely to impro
it.

The principal causes of imperfection in the
common pumps arise, first, from the difficulties
in opening the valve at the bottom of the barrel,
and 2dly, from the piston's not fitting exactly, when
put close down to the bottom, which leaves a pegent
for air, that cannot be got out of the barrel, and
proves of bad effect, as I shall shew in the course of
this paper.

In regard to the first of these causes, the

values of air pumps are commonly made of a bit of thin bladder, stretched over a hole, whose greater than one tenth of an inch Diameter; to prevent the air from passing between the bladder and the plate, upon which it is spread, the valve must always be kept moist with soap or water.

It is well known that at each stroke of the pump the air is more and more rarified, in a certain proportion, which would be such, that an equal proportion of the remainder would be taken away, was it not affected by the impediments I have mentioned: so that when the spring of the air in the receiver becomes so weak, as not to be able to overcome the cohesion of the bladder to the plate, occasioned by the fluid between them, the weight of the bladder, the resistance that it makes by being stretched, the rarefaction cannot be carried farther, tho’ the pump should still continue to be worked.

It is evident that the larger the hole is, over which the bladder is laid, a proportionally greater force is exerted upon it by the included air, in order to lift it up, but the aperture of the hole cannot

* If we examine the force that air rarified 100 times can exert in a common valve through a hole of 1/10 of an inch Diameter, we shall find it not to exceed 6 grains at a medium.
be made very large, because the pressure of the
incumbent air, would either burst the valve, or
so force it down into the cavity, as to prevent
its lying flat and close upon the plate, which
is absolutely necessary.

To avoid these inconveniences as much as
possible, instead of one hole, I have made use of
7, all of equal size and shape; one being in the
center, and the other 6 round it; so that the valve
is supported at proper distances, by a kind of grating,
made by the solid parts between these holes; and to
render the points of contact between the bladder &
grating, as few as possible, the holes are made hexagonal
and the partitions filed almost to an edge. By the
whole pressure of the atmosphere can never be exerted
upon this valve, in the construction made use of in
this Pump; and as the bladder is fastened in place,
instead of 2, I have made the breadth of the semi-circle
3 tenths of an inch; so that the surface of each of
them is more than 9 times greater than common;
but as the circumference of each hole, is more
than 3 times greater than common; and as the
force, that holds down the valve, arising from cohesion,
is, in the first moment of the air's exerting its

force, proportionable to the circumference of the hole; the valve over any of these holes, will be raised with three times more ease than common: but as the raising of the valve over the centre hole, is assisted on all sides by those placed round it; as they all together contribute as much to raise the bladder over the centre hole, as the air immediately acting under it, upon this account, the valve will be raised with double the edge, that we have before supposed; or with a 6th part of the force commonly necessary.

It is not material to consider the force of the cohesion, after the first instant: for after the bladder begins to rise, it exposes a greater surface to the air underneath, which makes it move more easily. I have not brought into this account, the force that keeps down the valve, that arises from the weight of the bladder. If the resistance from its being stretched, for I look upon there as small in comparison of the other.

I was not however contented with this construction of the bladder, till I had tried what effect would be produced, when they were opened by the motion of the winch, independent of the
the spring of the air; and that the circumstance I made use of, seemed to me less liable to objection than any thing I was acquainted with, that had been designed for that purpose; yet I did not find it to answer the end, better than what I have already described. I therefore laid it aside, as it rendered the machinery much more complex, and troublesome to execute.

But supposing all those difficulties to be absolutely over come; the other defect that I mentioned in the common construction, would hinder the sake faction, from being carried on beyond a certain degree; for as the piston cannot be made to fall so close to the bottom of the barrel as totally to exclude all the air; as the piston rises, the air will expand itself, but still pressing upon the valve, according to its density, hindering the air within the receiver, from coming out. Now was this vacancy, to equal the 150 part of the capacity of the whole barrel, the air could ever yep out of the receiver, when expanded 150 times, though the piston was constantly drawn to the top, because the air in the receiver would be in a negligible state with that in the barrel, when in its most expanded state.
This I have endeavoured to overcome, by shutting up the top of the barrel with a plate, having in the middle a collar of leathers, through which the cylindrical rod works, that carries the piston. By this means, the internal air is prevented from pressing upon the piston; but that the air that passes through the valve of the piston from below, may be discharged out of the barrel, there is also a valve applied to the plate at the top, that opens upwards. The consequence of this construction is, that when the piston is put down to the bottom of the cylinder, the air in the segment under the piston will evacuate itself so much the more, as the valve of the piston opens more easily, when acted on by the raised air above it, than when pressed by the whole weight of the atmosphere. Hence, as the piston may be made to fit, as nearly to the top of the cylinder, as it can to the bottom; the air may be raised as much above the piston, as it could before have been in the receiver. It follows therefore, that the air may now be raised in the receiver, a number of times, equal to the square of what it could be upon the common principle; every thing else being supposed perfect.
more safe: Because tho' the pressure of a column of
air equal to the diagonal of the piston-rod still presses
upon it, yet as there is only the friction of one piston
and that not loaded with the weight of the chamer.
the friction of the leather against the side of the barrel
and the friction of the cork of wheel is much less, with
withstanding the addition of friction in the body of leather.
Another advantage of this construction, that the
the pump is composed of a single barrel, yet the
piston of the outside air being taken off by the
upper plate, the piston is worked with more ease
than the common pumps with a barrel: and not
only so, but where a considerable degree of perfection
is desired, it will do it quicker; for the terms of
the series expressing the quantity of air taken away
at each stroke, do not diminish so fast as the series
answering to the common one.

I have found the gages that have been hitherto
made use of, for measuring the expansion of the air,
very unsafe to determine, in an experiment of so much
necessity. I have therefore contrived one of a different sort,
which measures the expansion with certainty, to much
less than 1000th part of the whole. It consists of
a Bulb of glass, something in the shape of a pear,
and sufficient to hold about half a pound of Quick
Silver. It is open at one end, & the other is a tube
hermetically closed at top. By the help of a nice
pair of Scales, I found what proportion of weight
a column of mercury of a certain length contained in
the tube, bore to that which filled the whole vessel.
By these means, I was enabled to mark divisions upon
the
The bulb of the gage may be emptied of its quicksilver without taking that out of the tube. If the tube be held horizontal, the column of mercury in it will have no power to contract or expand the air at the top.
the tube, answering to a 1000th part of the whole capacity, which being of about one tenth of an inch each way by estimation, be easily subdivided into smaller parts. This gase, during the exhausting of the receiver, is suspended therein by a slip vine. When the pump is worked as much as shall be thought necessary, the gase is pushed down till the open end is immerged in a certain of quicksilver placed underneath the air being then let in, the quicksilver will be driven into the gase, till the air remaining in it becomes of the same density with the external; if as the air always takes the highest place, the tube being uppermost, the expansion will be determined by the number of divisions occupied by the air in the tube.

The degree to which I have been able to rarify the air in experiment, has generally been about 1000 times, when the pump is put clean together. But the moisture that adheres to inside of the tube, as well as other internal parts, upon letting in the air, is in the succeeding tryals worked together with the quicksilver, which soon causes it so glutinous as to obstruct the action of the pump, upon a fluid so subtle as the air is when so much expanded; but in this case it seldom fails to act upon the air in the receiver.
till it is expanded 500 times; and this I have found it to do, after being frequently used for several months, without cleaning. I have also generally found it to perform best the first time of each time of using, the nothing had been done at it, from the time preceding, which, after a great many trials made with this view, I also attribute to the depressions of the air, mixing with the dry. An experiment, where the air was expanded 1000 times, was tried about 2 years since in your presence, by which also Mr. Knigle and Mr. Bentinck did the same thing with Mr. Wotton. The pumps that I intend my self the honour of shewing the Society, is the same as I just now mentioned, of the 2 that I made with a view to improve upon this principle.

The degree of evaporation produced by the rest of the 3 pumps, that you procured the trial of, and which you esteemed good in their kind, if in complete order, never exceeded 150, when tried by the gage above described.

I have also endeavoured to render the pneumatic apparatus more simple and commodious, by making the air pumps act as a condensing engine of pleasure, by simply turning a wheel.
This not only enables us, to try any experiment under different circumstances of pressure, without changing the apparatus, but reduces the pump an universal engine, for shewing any effect that arises from an alteration in the density or spring of the air. Thus, with a little addition of apparatus, it shews the experiments of the air containing wind from the.

This is done in the following manner.

The air above the piston, being forcibly driven out of the barrel at each stroke, and having no where to escape, but by the value at the top, if this value be connected with the receiver, by means of a pipe, and at the same time the value at the bottom, instead of communicating with the receiver, be made to communicate with the external air, the pumps will then perform as a condenser.

The mechanism is thus ordered. There is a cock with 3 pipes, placed round it, at equal distances, the key is so placed, that any two may be made to communicate, while the other is left open to the external air. One of these pipes goes to the value at the bottom of the barrel;
Fig. 1 is a perspective view of the principal parts of the pumps together.  

A is the Barrel.  
B the cylinder in which are included the cock, with several joints, if are covered with water to keep them air tight. A little cock to let the water out of this cylinder is marked 6.  
C e e is the triangular handle of the key of the cock, which by the wheels on its arms, shows how it must be turned, that the pumps may produce the effect desired.  
D H is the pipe of communication between the cock & the receiver.  
E is the pipe, that communicates between the cock of the valve, on the upper part, plate of the barrel.  
F is the upper plate of the pump, which contains the collar of leathers 6, and 7 of the valve, which is covered by the piece 7.  
G I is the syphon gauge, which serves on and off and is adapted to common purposes. It consists of a glass tube hermetically sealed at e, and furnished with quick silver in each leg; which before the pumps begins to work, must be level in the line a b: The space be being filled with air of
the common density. When the pump exhausts the air in be expands, and the quicksilver in the opposite leg rises till it becomes a counter balance to it. Its rise is shown upon the scale I a, by which the expansion of the air in the receiver may be nearly judged of. When the pump condenses, the quicksilver rises in the other leg of the scale may be nearly judged of, by the contraction of the air in be; marks being placed at $\frac{1}{4}$ and $\frac{1}{2}$ of the length of be from c: which shows when the receiver contains double or triple its common quantity.

KL is a screw frame to hold down the receiver in condensing experiments, which takes off at pleasure, and is sufficient to hold down a receiver, the diameter of whose base is 7 inches, when charged with a triple atmosphere; in which case it acts with a force of above 800 pounds against the screw frame.

M is a screw that fastens a bolt, which slides up and down in that leg, by means whereof the machine is made to stand fast on uneven ground.

Fig 2. is a perpendicular section of the Barrel & cock, &c., where,

AB represents the barrel.

CD the rod of the piston which passes through...
the plate that closes the top of the barrel.

K is the collar of leather, through which the piston and pipes. When the piston is at the bottom of the cylinder the upper part of K is covered by the caps at D, to keep out dust.

L is the valve on the upper plate, which is covered by the piece OP, which is connected with the pipe LR, which makes the communication between the valve and cock.

CE is the piston or
EFF is the piston valve
II are a little holes to let the air pass from the piston valve into the upper part of the barrel.

GK is the principal valve at the bottom of the cylinder.

HH is a piece of metal into which the valve G is fixed and that closes the bottom of the cylinder; out of which also is composed the cock.

SS the cock, &

KTT the duct from the cock to the bottom of the barrel.

WWW is the key of the cock

X the stem of

VV the handle.
Fig. 3 is an horizontal section of the cock through the middle of the duct TT.

AB represents the bigness of the circular plate that closes the bottom of the cock.

CD represents the bigness of the inside of the Barel.

EFG is the body of the cock; the outward shell being pierced with 8 holes at equal distances, it corresponds to the three pumps Berts HH, II, KK.

HH is the duct that goes to the bottom of the barel.

II, the duct that communicates with the top of the Barel.

KK is the duct that passes from the cock to the Receiver.

LMN is the Key or solid part of the cock, moveable round the shell EFG. When the canal LM answers to the ducts HH & KK, the pump exhausts, & the air is discharged by the perforation N. But the key LMN being turned till the canal LM answers to II & KK, the perforation N, will then answer to HH & in this case the pumps condenses. Lastly when N answers to KK the air is then let in or discharged from the receiver as the circumstance requires.

Fig. 4 is the plan of the principal valve.

ABCD represents the bladder fastened in places
and sheetl over the 7 Holes IK formed into an hexagonal grating, which I shall call the Honey comb.

E F G H shows where the metal is a little protrusent, to hinder the piston from striking against the caddor.

Fig 5 represents the new gage, which I call the year gage. It is open at A, B C is the graduated tube, which is hermetically closed at E, it is suspended by the piece of flax DE, that is hollowed into a portion of a cylinder, T claps the tube.