DOMESTIC MOTOR.

A THESIS BY

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CHAMPAIGN ILL.

1874.
To those whose curiosity may induce them to look through this involuntary production, I would say that I shall not exhaust the subject which I intend to discuss somewhat in the following pages, but that there will be left a sufficiently large field for any one to exercise his genius, should his interest and inclination run in that direction.
"Labor is irksome."

Man always did shun labor and wherever it was possible for him to shift a task from his own shoulders to those of another — or anything else — he was sure to avail himself of the opportunity. This is not only true of the past, but may as well be said of the present. I am, however, glad to believe that the tendency of the age is to honor labor; yet, people will avail it wherever circumstances will permit.

Animals of different kinds have, in all ages, been pressed into service where it was practicable to make them work for man. But in the course of time as the ingenuity and reasoning power of man developed, he wanted more help than that which the animals could render him. The limited use he could make of them did no longer meet his increased wants. This induced him to study the natural forces and from time to time he succeeded in bringing some of them into service. Thus, we derive, at the present day, in-
valuable services from the currents of air that constantly pass over the hills and plains; from gravitation which unceasingly urges the water over the falls and dams; from heat in its various applications and from electricity, perhaps the least understood as yet, but not by any means the least useful.

It is comparatively of a recent date that some of the most remarkable results have been obtained from natural forces. It was in the latter half of the eighteenth century (1763-64) that the laws of steam were first studied by James Watt, and he subsequently improved the steam engine— which up to that time existed only in a very rude form—according to scientific principles. In due time steam was used for propelling boats and driving locomotives etc. until at the present day there is hardly a limit to its application.

Before passing, I desire to state that I do not wish to be understood to say,
as it may appear in the beginning, that indolence is the motive to invention and discovery, although many a man works harder to contrive means to avoid a task than would be required to do it at once. It is not only to reduce labor that the inventor works for, but there are higher motives that urge him onward. But it is not my object now to discuss the motives of the inventor, so I will pass on. Everybody knows what a great good the steam engine is to the world. It has been the means of bringing within our reach innumerable comforts and luxuries of life. It has been introduced into almost every industry, and its value and power is felt all over the land. But there is one place where it has not been introduced, or if it has, it has been only to a very limited extent, and that is the domestic circle. Now, steam, or machinery being so valuable
in all the industries of the world, why can it not also be introduced into the domestic circle? Is there no work about the home that could be performed with machinery and thus relieve the maîtresse de famille of many a difficult and time-consuming "job"? There certainly is enough work to which steam, or some other motor, could be applied with sufficient economy to meet with general favor.

The reason that steam is not more used for domestic purposes, may be found in the fact that its use is frequently attended with violent and dangerous explosions. This danger also increases in proportion as the operatives are lacking in the knowledge of the laws of steam and in skill of manipulating machinery. In consideration of these facts, it is necessary to modify the modern steam engine, in some way or other, or the steam must be replaced by some other fluid which can be used without
danger of explosion, if it is to be more generally introduced into family use.

It might be suggested that air heated in a reservoir might be a good substitute for steam, if sufficient power can be developed from it; for, in the first place, it can be obtained in any desired quantity, free of charge, and then it has not the explosive property of steam, which we are so desirous to get rid of. Air engines have been used with good results; hence, why would it not make a good Domestic Motor? Let us examine it a little closer and make some calculations, if possible, to see how it may compare with the steam engine.

The best Air Engine seems to be one in which the same air is used over and over again and in which the temperature of the air is changed at constant volume. Fig. 1. represents a vertical section of the principal parts of such an engine.
A is the piston, BB' the cylinder and CDEFGEDC the receiver in which the air is alternately heated and cooled. This receiver consists of two vessels, an inner and an outer one, as shown at CD, aE, etc. From D to E, between these two vessels, is the Regenerator which consists of vertical strips of some material adapted for that purpose, generally a good conductor of heat. From D to C are placed circular coils of pipes made of some good conductor of heat, as copper. Through these pipes a constant stream of water flows while the engine is in motion. This part of the apparatus constitutes the Refrigerator. From a to a', the bottom and above c, the top, of the inner vessel is perforated so as to allow the air to pass through it while the plunger &c. displaces it from the upper part of the vessel and vice versa. the reason of which will appear in the sequel.

Now, to trace clearly the working of this engine, suppose the piston to be at
The end B of the cylinder, just ready to start on its forward stroke and the plunger A in the upper part of the receiver. The air will, of course be in the lower part of the receiver. If now heat be applied at E, the air will be heated and consequently it will expand and drive the piston forward. As soon as the piston reaches the end (or a little before) of its forward stroke, the plunger G descends to the lower part of the receiver and drives the working air into the up-per part, taking the course shown by the arrows.

As the air passes through the regenerator a part of its heat is stored up in it and some more is carried off by the refrigerator as the air passes through it into the upper part of the receiver. The air being now cooled off again and its pressure reduced, the piston will be free to return to B. On reaching the end, or nearly the end of the return stroke, the plunger will again be raised to force the air back again through the refrigerator.
thence through the regenerator and into the lower part of the receiver. As the air passes through the regenerator, the heat previously stored up in it is given out again to the air and thus this amount of heat is saved at every stroke in expanding the air. It will also be seen that as the working air returns and passes through the perforated bottom, it is set, more or less, into commotion and thus the convection of heat to the air is greatly facilitated. The air being now in the bottom of the receiver it is again heated up and the forward stroke commences only to repeat the same cycle of operations.

Fig. 1 explains itself to be a single acting engine. It can, of course, be made double acting by having two receivers or heaters, one connecting with each end of the cylinder.
Analysis.

To analyze the working of the air of this engine, let us assume one pound of the working air, and let fig. 2 represent the conditions of it at different parts of the stroke of the piston, i.e., let POV (= 90°) be co-ordinate axes, the origin being at O. Let the abscissas, measured parallel to OV, be the volumes and the ordinates, measured parallel to OP, the pressures of the air under the different conditions, as follows:

The point A gives the pressure and volume of the air at the beginning of the forward stroke and B the same at the end of the forward stroke.

Now, as the source of heat is supposed to be constant, the air will have a constant temperature while the piston is in motion, and hence AB is an iso-thermal curve whose co-ordinates axe the pressure and volume at any part of the stroke.

The piston having arrived at the end of its for-
ward stroke, the air is suddenly cooled to the absolute temperature \( \tau_2 \) by passing through the regenerator into the upper part of the receiver and \( C \) will represent its volume and pressure at the beginning of the return stroke.

At the end of the return stroke, \( DC \) as \( AB \) being an isothermal curve. The air is transferred, through the regenerator, to the heating chamber where its temperature is raised again to \( \tau_1 \). This brings us to \( A \) again, the condition of the air at the beginning of the forward stroke, and the diagram is complete, or, the air has undergone all the changes that are necessary for a complete revolution of the engine.

In the following, we will use the notation as given below.

\( v \) = Volume of one pound of the working air.

\( P \) = Pressure on the square foot.

The subscripts \( a, b, c \) etc. refer to the corresponding capital letters on the diagrams.

\( \tau_1 \) = The higher limit of absolute
temperature.

$\tau_2 =$ The lower limit of absolute temperature.

$\nu =$ The ratio of expansion $= \frac{v_0}{v_0}.$

$J =$ Joules' mechanical equivalent of heat = 772 foot pounds per degree of Fahrenheit.

$q_1 =$ The quantity of heat, per pound per stroke, transmitted to the air during expansion.

$q_2 =$ The quantity of heat, as above, rejected during compression.

$U =$ The work performed per pound of air per stroke.

Also $v_0 = v_0$ and $v_5 = v_5$ since the temperature is changed while the volume remains constant.

Treat air as a perfect gas, which we may do without any appreciable difference in the calculations, we have for the pressures of the air under the different conditions of the four points of the diagram:

$P_B = \frac{P_2}{v_2} \frac{v_2}{v_1},$ since $\frac{v_2}{v_1} = \nu_1.$

$P_C = \frac{P_2}{v_2} \frac{v_2}{v_1} = \frac{P_2}{v_2} \frac{v_2}{v_1}.$

$P_B = \frac{P_2}{v_2} \frac{v_2}{v_1} = \frac{P_2}{v_2} \frac{v_2}{v_1}.$

Likewise the columns are:
\[ \frac{v_a}{v_c} = \frac{P_a}{P_c} \]

The subscript (0) refers to the condition of the air at some standard temperature, as the freezing point of water.

\[ \frac{v_b}{v_c} = \frac{P_a}{P_b} \]

\[ \frac{v_a}{v_c} = \frac{P_a}{P_b} \]

**Heat expanded and work performed.**

The quantity of heat transmitted to or from any gas, for any change of condition whatever, is given by the following equation:

\[ q = \int c \, dv + \frac{1}{6} \int P \, dv. \]

(6. Clausius' Mechanical Theory of Heat, pages 227 and 341.)

Now, the temperature is constant while the air expands from \( v_a \) to \( v_b \) and the pressure at any point of the curve \( AB \) is

\[ P = \frac{P_a v_b}{v_a} \]

Substituting these values in equation 6 and integrating between the limits \( A \) and \( B \), we get the quantity of heat expanded during the forward stroke. Substituting and reducing we have:
\[ q' = \int \frac{cdv}{v_a} + \frac{1}{4} \int \frac{pdv}{v_a} = \frac{6 \nu}{\sqrt{v_0}} \frac{1}{v_a} \cdot \frac{d^2v}{dv^2} \]

\[ q'' = \frac{6 \nu}{\sqrt{v_0}} \cdot N \cdot \log \frac{v}{v_0} = \frac{6 \nu}{\sqrt{v_0}} \cdot N \cdot \log \frac{v}{v_0} \]

This equation may be further reduced by substituting the following:

\[ \frac{6 \nu}{\sqrt{v_0}} = 53.15 \text{ foot pounds per degree of Fahrenheit (Rankine's Steam Engine page 347)} \]

\[ N \cdot \log \frac{v}{v_0} = \frac{\log v}{\log m} \]

\[ N \cdot \log v \text{ being the Naperian logarithm of } \log v \text{, the common logarithm of } v \text{ and } m \approx 4.343 \]

nearly, the modulus of the common system of logarithms. Substituting in equation 7, we have:

\[ q' = \frac{122.38 T}{\log v} \]

In a similar manner we get

\[ q'' = \int \frac{cdv}{v_4} + \frac{1}{4} \int \frac{pdv}{v_4} = \frac{122.38 T}{\log v} \]

Now the quantity of heat used, per pound per stroke, in performing work, is

\[ q'' - q' \]

and the work performed is
\[ U = J (q_1 - q_2) = 122.38 \log r (\gamma - \kappa) \text{ 10.} \]

**Efficiency.**

Owing to the imperfect action of the regenerator there is some heat lost by conduction, radiation, etc. In order that the working of the engine may be kept up, this amount of heat must be supplied by the fuel in addition to that expressed by equation 8; hence that equation does not exactly give the quantity of heat expended. This, however, does not effect equation 10, but must be considered in determining the efficiency. Let \( m c (\gamma - \kappa) \) be the heat thus lost by the regenerator.

\( c \) = specific heat of the air at constant volume, and

\( m \) being a constant determined by experiment — found to vary from \( \frac{1}{10} \) to \( \frac{1}{20} \).

The actual amount of heat expended is then

\[ q' = q_1 + m c (\gamma - \kappa) \text{ 11.} \]
Letting $E$ be the efficiency of the engine, we have

$$E = \frac{U}{122.38 \log \gamma + JmC (\gamma_1 - \gamma_2)}$$

But $Jc = 13.0$, and taking $m = \frac{t}{b}$ we have

$$E = \frac{122.38 \log \gamma (\gamma_1 - \gamma_2)}{122.38 \log \gamma + JmC (\gamma_1 - \gamma_2)}$$

Total volume of air.

Equations 4. and 5. give only the volume of the working air and not of the total amount of air, which is the sum of the working and the cushion air.

The cushion air is that which fills up the clearance space. The clearance is all the space within the apparatus except that beneath the plunger when it is at its highest point, which is the greatest volume of the working air.

To get the total volume...
of air in the apparatus we must add the volumes of
the cushion air to those of
the working air.

In fig. 3, let \( V_1, R, K \) and \( S \) be the volumes
of the cushion air at the
pressures \( a, b, c \) and \( d \)
respectively.

\( V' = \text{Volume of clearance.} \)

\( V_m = \text{The least total volume,} \)

or the total volume when
the piston is at the begin-
ning of its forward stroke.

\( \mu = \frac{V'}{V_c} = \text{The ratio of the vol}-

\text{of clearance to the greatest vol}-

\text{of the working air.} \)

In determining the
volumes of the cushion air,
we may suppose its temper-
ature to be constant. It is
very nearly so, if not entirely,
because it always remains
in the clearance space and
does not come in contact
with the heating surface.

For the volume
of clearance we evidently have

\[ V' = V_m - V_c. \] 13.

From 13 we have

\[ V_m = V_c + V' = V_c \left(1 + \frac{V'}{V_c}\right) = V_c (1 + \mu) \] 14.
Volume of cushion air.

\[ V_i (\text{Eq. 3}) = V_{in} - V_a = V_c (1 + \mu) - V_a \]

\[ = V_a \mu (1 + \mu) - V_a = V_a \{ \mu(1 + \mu) - 1 \} \quad 15. \]

\[ V_j = \frac{P_a V_i}{P_b} = \frac{\mu V_a}{P_b} \{ \mu(1 + \mu) - 1 \} \quad 16. \]

Since \( \frac{P_c}{P_b} = \frac{\pi}{\theta} \),

\[ V_k = \frac{P_c V_j}{P_a} = \frac{\pi V_a}{P_a} \{ \mu(1 + \mu) - 1 \} \quad 17. \]

Total Volume determined.

In fig. 4 MUSN represents the actual form of the indicator diagram in which the total volumes per pound of working air are PM, VN, WU and YS, corresponding respectively to the pressures \( P_a, P_b, P_c \) and \( P_d \).

\( V_m \) = least total volume, is given by equation 14. Since we have only to determine the three remaining volumes \( V_n, V_o \) and \( V_s \).
\[ \dot{V}_a = \dot{V}_b + \dot{V}_c = V_c + \nu_c \left\{ \nu(1+\mu) - 1 \right\} = \nu_c^2 \left[ \nu(1+\mu) - 1 \right] \quad \text{... 19.} \]

\[ \dot{V}_b = \dot{V}_c + \dot{V}_l = \nu_c + \nu_c \frac{T}{\mu} \left\{ \nu(1+\mu) - 1 \right\} = \nu_c \left\{ 1 + \frac{T}{\mu} \left[ \nu(1+\mu) - 1 \right] \right\} \quad \text{... 20.} \]

\[ \dot{V}_l = \dot{V}_a + \dot{V}_k = V_a + \nu_a \frac{T}{\mu} \left\{ \nu(1+\mu) - 1 \right\} = \nu_a \left\{ 1 + \frac{T}{\mu} \left[ \nu(1+\mu) - 1 \right] \right\} \quad \text{... 21.} \]

Volume swept through by the piston per pound of air per stroke is

\[ V_b - V_m = \nu_c \left\{ 1 + \frac{T}{\mu} \left[ \nu(1+\mu) - 1 \right] - 1 - \mu \right\} = V_c \left\{ \frac{T}{\mu} (\mu - 1) + \mu \left( \frac{T}{\mu} - 1 \right) \right\} \quad \text{... 22.} \]

The mean effective pressure is

\[ \frac{U}{V_b - V_m} \]

See Rankine Steam Engine & other...
The following data have been taken, by Stearns, from one of his kind of engines in actual operation:

\[ t_1 = 650^\circ \quad \tau_1 = 1111.2^\circ \]
\[ t_2 = 150^\circ \quad \tau_2 = 611.2^\circ \]
\[ \rho = 34,560. \]
\[ \mu = .05 \]
\[ \frac{v_5 - v_m}{v_e} = 0.5 \]

Taking the above data we get from equation 12.

\[ E = \frac{500 \log r}{\log r + 53} \]

From equation 22, we have

\[ r = \frac{1}{1 + \mu} \left( \frac{\tau_2}{\tau_1} \left( \frac{v_5 - v_m}{v_e} + \mu \right) + 1 \right) \]

Substituting in this equation the data at hand and reducing, we get

\[ r = 1.24 \]

and hence

\[ E = \frac{500 \times .09}{1111.2 \times .09 + 53} = 0.3 \]

The efficiency of steam engines generally varies from .10 to .17; hence we see that the efficiency of this air engine is nearly twice as large as that of the steam engine, or that the heat returned in
the form of mechanical energy by the air engine is from thirteen to twenty per cent. greater than that of the steam engine and hence is more economical in the use of fuel than the latter. So much more, then, in favor of an Air Motor, in addition to the advantages already stated. But it is objected that the air engine is too bulky to be desirable, that is; of two engines of the same power, the air engine takes up much more space than the steam engine, owing to the large bulk of working air necessary. This inconvenience might, however, be contented with in using it for a Domestic Motor since the steam engine is unsafe in unskilled hands.

There may be other difficulties connected with this engine which can only be found by experiment, yet there is no doubt that it could be made a success.

The design of an air engine for domestic use may, of course, be made in different ways, to suit cir-
cumstances and purposes for which it is to be used. It might be arranged to set it on a stove and thus have it (stove) take the place of the furnace. Or, perhaps the engine might be run by the "wast heat" of the stove. But I suppose it would be most convenient to make it portable and use a lamp for heating the air.

Want of tine preventing a further development of the subject, I will here refer the reader to "Future" for the completion of it, un-
Fig. 2.
Fig. 4.