Problems

In

Ideal Steam Engine Cycles

By

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Problems in Ideal Steam Engine Cycles.

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The following problems in ideal steam engine cycles are virtually comparisons of the economy and total output of working steam according to the various cycles.

1st. In the Carnot cycle in which a specific volume of steam, a pound, is taken into a non-conducting cylinder and expanded adiabatically, then cooled at constant temperature, then compressed adiabatically to the original condition.

(a) The Carnot cycle of the non-condensing type.

(b) The Carnot cycle of the condensing type.

For this cycle is assumed the conversion of 12 pounds of water into steam per pound of fuel, the feed water being at the boiling point corresponding to temperature of prime steam at initial pressure, and only latent heat of evaporization being supplied by the fuel.

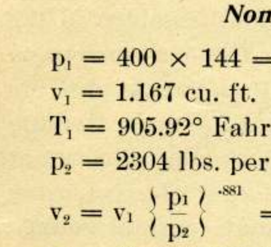
2d. In the Rankine cycle, in which a pound of steam is admitted to a non-conducting cylinder to point of cutoff, then expanded adiabatically to 7 pounds absolute in the condensing type and to 21 pounds in the non-condensing type, then cooled at constant volume to 2 pounds absolute in the case of condensing type and to 16 pounds absolute in the case of non-condensing type, then cooled at constant pressure of 2 pounds absolute in the case of condensing type to the initial volume, then heated at constant volume to initial temperature and pressure.

3d. In the third cycle the same two cases were taken, and the cycles are in each sense the same as the second case except the cylinder is a jacketed one and the steam is supposed to be kept dry and saturated throughout at the expense of the jacket steam.

In the Rankine cycle the assumption is made that steam is supplied by boiler having an efficiency such as to evaporate 9 pounds of water per pound of fuel, in the case of the condensing engine taking feed water from a hot well, and 10 pounds for the non-condensing engine,—the temperature being 120 degrees Fahr. for hot well for condensing type, and 200 degrees Fahr. for heater of the non-condensing type.

CASE I.—THE CARNOT CYCLE.

(a) In this case the problem has been discussed, and the computations made are upon the assumption of an efficiency of boiler such as to give an evaporation of 12 lbs. of water from the temperature of prime steam into dry and saturated steam at the pressure here taken of 400 lbs. per sq. in. for 1 pound of fuel, the temperature of feed water being the same as the sensible heat of the steam at the pressure noted and only the latent heat of evaporation being supplied by the fuel.



Non-Condensing Type.

$p_1 = 400 \times 144 = 57600$ lbs per sq. ft.

$v_1 = 1.167$ cu. ft.

$T_1 = 905.92°$ Fahr. absolute.

$p_2 = 2304$ lbs. per sq. ft.

$$v_2 = v_1 \left\{ \frac{p_1}{p_2} \right\}^{.881} = 20.83 \text{ cu. ft.}$$

$T_2 = 677.347°$ Fahr. absolute.

$\log p_1 = 4.760422$ $\qquad \log \left\{ \frac{p_1}{p_2} \right\}^{.881} = 1.251585$

$\log p_2 = \underline{3.362482}$ $\qquad \log v_1 = \underline{.067071}$

$\log \frac{p_1}{p_2} = 1.397940$ $\qquad \log v_2 = 1.318656$

$v_2 = 20.83$ $\qquad L_1 = 797.94$ B. T. U.

$$r = \text{ratio of expansion} = \frac{v_2}{v_1} = \frac{20.83}{1.167} = 17.85$$

J = 778 ft. lbs. per heat unit.

$$\text{Efficiency} = \frac{T_1 - T_2}{T_1} = \frac{905.92 - 677.347}{905.02} = 25.3\%$$

U = net work per pound of steam expressed in foot pounds.

= H_1 × Efficiency = 620797 × .25 3 = 157.062 foot pounds.

H_1 = heat expended per pound steam in foot pounds.
= J L_1 = 797.95 × 778 = 620797.

$$\text{M. E. P.}' = \frac{U}{v_2} \text{ in pounds per sq. ft.} = 7540.$$

$$\text{M. E. P.}'' = \frac{\text{M. E. P.}'}{144} = 52.4 \text{ lbs. per sq. in.}$$

$$A = \text{B. T. U. per H. P per hour} = \frac{\frac{33000 \times 60}{778}}{\text{Efficiency.}}$$

$$= \frac{2545}{\text{Efficiency}} = \frac{2545}{.25\,3} = 10{,}059$$

This value of A is, however, for an efficiency of boiler of one, but according to the assumption of the problem the boiler efficiency was such as to evaporate 12 lbs. of water per pound of coal of 10000 B. T. U. If the efficiency were one, then the number of pounds evaporated would be $\frac{10000}{797.94}$ = 13.79 lbs.

Then A′ = B. T. U. supplied to boiler and equals $\frac{A}{\text{Efficiency of boiler}}$. Efficiency of boiler = $\frac{12}{13.97}$ = 87.01%

$$A' = \frac{A}{.8701} = \frac{10059}{.8701} = 11558 \text{ B. T. U. per I. H. P.}$$

B = pounds of steam per I. H. P. per hour for efficiency of unity = $\frac{1980000}{H_1} = \frac{1980000}{620797}$ = 3.19 lbs.

C = pounds of steam per I. H. P. per hour for actual efficiency = $\frac{B}{.253}$ = 12.6 lbs.

W = equivalent water rate from and at 212° Fahr.

$$= \frac{A}{966.069} = \frac{10059}{966.069} = 10.41 \text{ lbs.}$$

F = pounds of fuel per H. P. pr. hr. for efficiency unity.

$$= \frac{A}{10000} = \frac{10059}{10000} = 1.0059 \text{ lb.}$$

F' = lbs. of fuel per H. P. per hour for efficiency of boiler of $87.01\% = \frac{F}{.8701} = \frac{1.0059}{.8701} = 1.15$ lbs.

D = piston displacement per I. H. P. per hour.

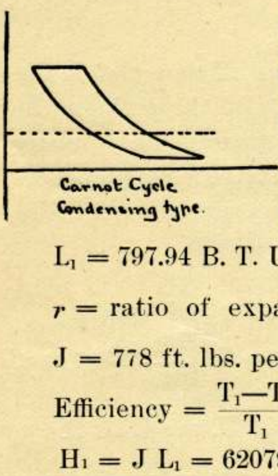
$$= C\, v_2 \text{ cu. ft.} = 12.6 \times 20.83 = 262.46.$$

D' = piston displacement per I. H. P. per minute.

$$= \frac{D}{60} = \frac{262.46}{60} = 4.347 \text{ cu. ft.}$$

CARNOT'S CYCLE.

(b) Condensing Type.



$p_1 = 400 \times 144 = 57600$ lbs. per sq. ft.

$v_1 = 1.167$ cu ft.

$T_1 = 905.92°$ Fahr. absolute.

$p_2 = 2 \times 144 = 288$ lbs. per sq. ft.

$$v_2 = v_1 \left\{ \frac{p_1}{p_2} \right\}^{.881} = 106.45.$$

$T_2 = 587.302$ Fahr. absolute.

$L_1 = 797.94$ B. T. U.

$$r = \text{ratio of expansion} = \frac{v_2}{v_1} = \frac{106.45}{1.167} = 91.23.$$

$J = 778$ ft. lbs. per heat unit.

$$\text{Efficiency} = \frac{T_1 - T_2}{T_1} = \frac{905.92 - 587.302}{905.92} = 35.17\%.$$

$H_1 = J\, L_1 = 620797.$

$U = H_1 \times \text{Efficiency} = 620797 \times .3517 = 218332.$

$$\text{M. E. P.}' = \frac{U}{v_2} \text{ in pounds per sq. ft.} = 2050.1.$$

$$\text{M. E. P.}'' = \frac{\text{M. E. P.}'}{144} = 14.2 \text{ lbs. per sq. in.}$$

A = B. T. U. per H. P. per hour

$$= \frac{2545}{\text{Efficiency}} = \frac{2545}{.3517} = 7236 \text{ B. T. U.}$$

$$A' = \frac{A}{\text{Efficiency of boiler}}.\ \text{Efficiency of boiler} = 87.01\%$$

$$= \frac{7236}{.8701} = 8317.$$

$$B = \frac{1980000}{H_1} = \frac{1980000}{620797} = 3.19.$$

$$C = \frac{B}{\text{Efficiency}} = \frac{B}{.3517} = \frac{3.19}{.3517} = 9.07.$$

$$W = \frac{A}{966.069} = 7.49 \text{ lbs.}$$

$F = \frac{A}{10000}$ = lbs. fuel per I. H. P. per hour for efficiency unity of boiler, and taking 10000 as the B. T. U. in one lb. coal.

$$= \frac{7236}{10000} = .7236 \text{ lbs.}$$

F' = lbs. coal for actual efficiency of boiler,

$= \frac{F}{.87} = .837$ lb. coal per H. P. per hour.

D = piston displacement per I. H. P. per hour.

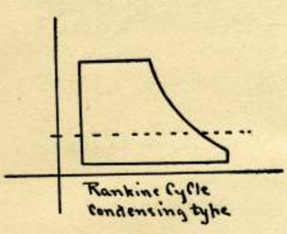
$= C\, v_2$ cu. ft. $= 9.07 \times 106.45 = 976.15$.

D' = piston displacement per I. H. P. per minute.

$= \frac{D}{60} = 16.27$ cu. ft.

CASE II.---RANKINE CYCLE.---Non-Conducting Cylinder.

(a) Condensing Type.



$p_1 = 400 \times 144 = 57600$ lb. per sq. ft.

$v_1 = 1.167$ cu. ft.

$T_1 = 905.92°$ Fahr. absolute.

$p_2 = 7 \times 144 = 1008$ lbs. per sq. ft.

$$v_2 = v_1 \left\{\frac{p_1}{p_2}\right\}^{\frac{1}{1.135}} = v_1 \left\{\frac{p_1}{p_2}\right\}^{.881}$$

$T_2 = 639.945°$ Fahr. absolute.

$v_2 = 41.205$.

$$r = \frac{v_2}{v_1} = \left\{\frac{p_1}{p_2}\right\}^{.881} = 35.3.$$

$p_3 = 2 \times 144 = 288$ lbs. sq. ft.

$J = 778$ ft. lb. per heat unit.

$\log p_1 = 4.760422.$

$\log p_2 = 3.003461$

$\quad\quad\quad\; 1.756961$

$$\log \left\{\frac{p_1}{p_2}\right\}^{.881} = 1.547883.$$

$\log v_1 = .067071.$

$\log v_2 = 1.614954.$

$T_3 = 587.302°$ Fahr. absolute.

$T_4 = 120 + 461 = 581°$ Fahr. absolute.

H_T = total heat of evaporation above 32° in B. T. U. at p = 1217.7 lbs. per sq. ft.

q_4 = heat in feed water above 32° at T_4 in B. T. U.

$= 581° - (461 + 32) = 581 - 493 = 88.$

U = net work of a pound of steam in foot pounds for efficiency of engine.

$$= J\left\{T_1 - T_2\left(1 + \log_e \frac{T_1}{T_2}\right)\right\} + \frac{(T_1 - T_2)\,H'}{T_1} + v_2\,(p_2 - p_3)$$

$$= 778\,[905.92 - 639.945\,(1.3365)\,] + \frac{265.975}{905.92}$$ 620,997

$$+ 41.205 \times 720 = 778 \times 48.39 + .295\ H' + 296676$$

$$= 67315 + .295\ H' = 250470 \text{ foot pounds.}$$

L_1 = latent heat evaporation at p in B. T. U. = 797.94.

H' = latent heat evaporation at p in foot pounds $= J\,L_1 = 620997.$

H_1 = heat expended per pound of steam in ft. pounds.

$= J\,(H_T - q_4) = 778\,(1217.7 - 88) = 878806.6.$

$$\text{Efficiency} = \frac{U}{H_1} = \frac{250470}{878706} = 28.5\%$$

$$\text{M. E. P.}' = \frac{U}{r\,v_1} = \frac{U}{v_2} = \text{in lbs. per sq. ft.} = 6979.$$

$$\text{M. E. P.}'' = \frac{\text{M. E. P.}'}{144} = 42.115 \text{ lbs. per sq. inch.}$$

B = pounds steam per I. H. P. per hour for efficiency unity $= \dfrac{1980000}{H_1} = 2.36$ lbs.

$A =$ B. T. U. per I. H. P. per hour $= \frac{2545}{\text{Efficiency}} = \frac{2545}{.285}$

$= 8930.$

$C =$ pounds of steam per I. H. P. per hour for actual efficiency $= \frac{B}{\text{Efficiency}} = \frac{236}{.285} = 8.28$ lbs.

$W =$ equivalent rate of water from and at 212° Fahr.

$= \frac{A}{966.069} = 9.24$ lbs.

$F =$ fuel per I. H. P. per hour for efficiency of boiler of unity $= \frac{A}{10000} = .8930.$

$F' =$ actual fuel per I. H. P. per hour of efficiency of 9 lbs. water per lb. coal.

$= \frac{C}{9} = \frac{8.28}{9} = .92$ lbs. coal per I. H. P. per hour.

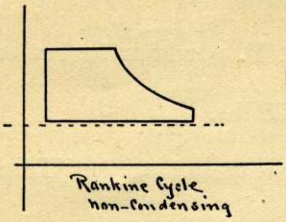
$D =$ piston displacement per I. H. P. per hour.

$= Cv_2$ cu. ft. $= 8.28 \times 41.205 = 241.18$ cu. ft.

$D' =$ piston displacement per I. H. P. per minute.

$= \frac{D'}{60} = \frac{341.18}{60} = 5.68$ cu. ft. per minute.

RANKINE NON-CONDUCTING CYLINDER.



(*b*) *Non-Condensing Type.*

$p_1 = 400 \times 144 = 57600$ lbs. per sq. ft.

$T_1 = 905.92°$ Fahr. absolute.

$v_1 = 1.167$.

$p_2 = 21 \times 144 = 3024$ lbs. per sq. ft.

$$v_2 = v_1 \left(\frac{p_1}{p_2}\right)^{.881}$$

$\log p_1 = 4.760422$

$\log p_2 = \underline{3.480582}$

$\log \frac{p_1}{p_2} = 1.297840$

$\log \left\{\frac{p_1}{p_2}\right\}^{.881} = 1.138539$

$\log v_1 = \underline{.067071}$

$\log v_2 = 1.205610$

$v_2 = 16.06$

$T_2 = 230.565 + 461 = 691.565°$ Fahr. absolute.

$$r = \frac{v_2}{v_1} = \left\{\frac{p_1}{p_2}\right\}^{.881} = 13.7.$$

$J = 778$ ft. lbs. per heat unit.

$T_3 =$ temperature Fahr. degrees absolute of $p_3 = 677.347$.

$T_4 =$ absolute temperature Fahr. feed water $= 461 + 200 = 661$.

$H_T =$ total heat of evaporation in B. T. U. at $p_1 = 1217.7$

$q_4 =$ heat in feed water above 32° at T_4 in B. T. U.
$= T_4 - (461 + 32) = 661 - 493 = 168$.

$p_3 = 144 \times 16 = 2304$.

$L_1 =$ latent heat of evaporation at p_1 in B. T. U. $= 797.94$.

$H' =$ latent heat of evaporation at p_1 in foot pounds $= J\, L_1 = 620797$.

$U =$ net work of a pound of steam in foot pounds for the efficiency of the engine.

$$= J\left\{T_1 - T_2\left(1 + \log_e \frac{T_1}{T_2}\right)\right\} + \frac{(T_1 - T_2)\, H'}{T_1} + v_2\,(p_2 - p_3)$$

$$\frac{T_1}{T_2} = \frac{905.92}{691.565} = 1.31 \qquad \log_e \frac{T_1}{T_2} = .27.$$

$$\frac{T_1 - T_2}{T_1} = \frac{214.36}{905.92} = .2366.$$

$U = 778\ (905.92 - 691.565 \times 1.27) + (.2366 \times 620797)$
$+\ 16.06 \times 720.$

$= 21493.92 + 146880.5 + 11563.2.$

$= 169937.6.$

H_1 = heat expended per pound of steam in ft. pounds.
$= J\ (H_T - q_4) = 778\ (1217.7 - 168) = 816666.6$ foot pounds.

$$\text{Efficiency} = \frac{U}{H_1} = \frac{169937.6}{816666.6} = 20.82\%$$

$$\text{M. E. P.}' = \frac{U}{r\ v_1} = \frac{U}{v_2}\ \text{lbs. per sq. ft.} = \frac{169937.6}{1606} = 10581$$

M. E. P.″ = mean effective pressure in pounds per square inch $= \dfrac{\text{M. E. P.}'}{144} = 73.48.$

A = B. T. U. per I. H. P. per hour

$$= \frac{2545}{\text{Efficiency}} = \frac{2545}{.2082} = 12235 \text{ B. T. U.}$$

B = pounds of steam per I. H. P. per hour for efficiency of unity $= \dfrac{1980000}{H_1} = \dfrac{1980000}{816666.6} = 2.42$ lbs.

C = pounds of steam per I. H. P. per hour for actual efficiency of engine $= \dfrac{B}{\text{Efficiency}} = \dfrac{2.42}{.2082} = 11.68$ lbs.

F′ = lbs. coal actual per I. H. P. per hour for efficiency of boiler such as to evaporate 10 pounds water from temperature 200° to steam at 400 pounds per square inch.

$$= \frac{C}{10} = \frac{11.68}{10} = 1.168 \text{ lbs. coal.}$$

W = equivalent water rate from and at 212° Fahr.

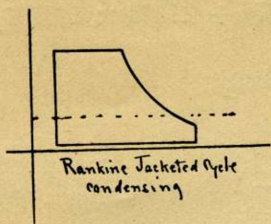
$$= \frac{A}{966.009} = \frac{12235}{966.069} = 13.66 \text{ lbs.}$$

D = piston displacement per I. H. P. per hour.
$= C\ v_2$ cu. ft. $= 11.68 \times 16.06 = 187.58$ cu. ft.

D′ = piston displacement per I. H. P. per minute.

$$= \frac{D}{60} = \frac{187.58}{60} = 3.126 \text{ cu. ft.}$$

CASE III.---RANKINE JACKETED CYCLE.



(*a*) *Condensing Type.*

$p_1 = 400 \times 144 = 57600$ lbs. per sq. ft. absolute.

$v_1 = 1.167$ cu. ft. volume at cut-off of one lb. at pressure p_1.

$T_1 = 905.92°$ Fahr. absolute temperature at cut-off.

$p_2 = 7 \times 144 = 1008$ lbs. per sq. ft. absolute.

$T_2 = 639.945°$ Fahr. absolute of steam at pressure p_2.

v_2 58.89 cu. ft. volume of saturated steam at pressure p_2.

$p_3 = 2 \times 144 = 288$ lbs. per sq. ft. absolute back pressure.

$T_4 = 120° + 461 = 581°$ absolute Fahr. of feed water.

$J = 778$ ft. lbs. per heat unit.

$a = 1{,}117{,}850$ ft. lbs.; a constant.

$b = 544.5$ ft. lbs.; a constant.

H_1 = heat per pound of steam at boiler in ft. lbs.

$= J\ (H_T - q_4) = 878806.6$ ft. lbs.

H_T = total heat of evaporation per lb. steam at pressure p_1 above $32° = 1217.7$ B. T. U.

q_4 = heat in feed water above 32° Fahr.

$= T_4 - (493) = 581 - 493 = 88$ B. T. U.

H'_1 = heat expended per pound working steam in ft. lbs.

$= H_1 +$ heat received from the jacket.

$$= J\ (T_2 - T_4) + a \left\{ 1 + \log_e \frac{T_1}{T_2} \right\} = bT_1$$

$$= J\ (T_2 - T_4) + a\ (1.3365) - bT_1$$

$$= 778\ (58.945) + 1117850 \times 1.3365 - 544.5 \times 905.92.$$

$$= 45863.1 + 1{,}494{,}006.5 - 493273.4.$$

$= 1046596.2$ ft. lbs.

U = net work done in ft. lbs per lb. working steam

$$= a \log_e \frac{T_1}{T_2} - b(T_1 - T_2) + v_2\ (p_2 - p_3).$$

$$= 1117850 \times .3365 - 544.5 \times 265.965 + 52.89 \times 720.$$

$$= 376156.5 - 146817.2 + 38080.8.$$

$= 267420.1$ ft. lbs.

$$\text{Efficiency} = \frac{U}{H'_1} = \frac{267420.1}{1046596.2} = 25.55\%$$

$$\text{M. E. P.} = \frac{U}{r v_2} = \frac{U}{v_2} \text{ in lbs. per sq. ft.} = 5056.16 \text{ lbs.}$$

$$\text{M. E. P.}'' = \frac{\text{M. E. P.}'}{144} = \text{in lbs. per sq. in.} = 35.11 \text{ lbs.}$$

B = pounds of steam per I. H. P. per hour at boiler, inclusive of jacket steam, for efficiency unity of transformation $= \frac{1980000}{H_1} = \frac{1980000}{878806.6} = 2.25$ lbs.

A = B.T.U. per I.H.P. per hour $= \frac{2545}{\text{Efficiency}} = 9960.9.$

B′ = pounds of working steam per I. H. P. per hour for efficiency unity $= \frac{1980000}{H'_1} = \frac{1980000}{1046596} = 1.89$ lbs.

C = pounds steam per I. H. P. per hour total jacket and cylinder for actual efficiency $= \frac{B}{\text{Efficiency}} = 8.8$ lbs.

C′ = pounds working steam per I. H. P. per hour actual efficiency $= \frac{B'}{\text{Efficiency}} = \frac{1.89}{.2555} = 7.4$ lbs.

W = equivalent water rate from and at 212° Fahr.

$$= \frac{A}{966.069} = 10.3 \text{ lbs.}$$

F = fuel per I. H. P. per hour.

$$= \frac{A}{\text{B. T. U. per lb. coal} = 10000.}$$

= also pounds steam per I. H. P. for actual efficiency engine divided by the pounds coal per pound steam, which in this case is assumed at 9 lbs. $\frac{99609}{10000} = .996$ lbs.

$$F' = \frac{C}{9} = \frac{8.8}{9} = .978 \text{ lbs.}$$

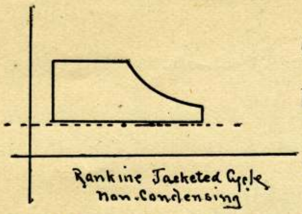
D = piston displacement per I. H. P. per hour.

$= C\,v_2$ cu. ft. $= 8.8 \times 52.89 = 465.4.$

$D' = \frac{D}{144} = 3.25$ cu. ft. displacement per I. H. P. per minute.

r = ratio of expansion $= \frac{v_2}{v_1} = \frac{52.89}{1.167} = 45.3.$

RANKINE JACKETED CYCLE.



(b) Non-Condensing Type.

p_1 400 × 144 = 57600 lbs. per sq. ft. absolute.

v_1 = 1.167 cu. ft. volume at cut-off at pressure p_1.

T_1 = 905.92° Fahr. absolute temperature at cut-off.

p_2 = 21 × 144 = 3024 lbs. sq. ft. absolute.

v_2 = 18.84 cu. feet volume at pressure p_2 of a pound of saturated steam.

T_2 = 691.565° absolute Fahr. temperature saturated steam at p_2v_2.

p_3 = 16 × 144 = 2304 lbs. per sq. ft. absolute.
= back pressure.

T_4 = 200 + 461 = 661° Fahr. absolute temperature of feed water.

J = 778 pounds per heat unit.

a = 1117850 ft. lbs.; a constant.

b = 544.5 ft. lbs.; a constant.

H_T = total heat of evaporation per lb. steam above 32°.
= 1217.7 B. T. U.

q_4 = heat in feed water above 32° Fahr.
= T_4 — (493) = 661 — 493 = 168 B. T. U.

$$r = \text{ratio of expansion} = \frac{v_2}{v_1} = \frac{18.84}{1.167} = 16.14.$$

H_1 = heat per pound steam at boiler in foot pounds.
= $J(H_T - q_4) = 778(1217.7 - 168) = 816666.6$ ft. lbs.

H'_1 = heat expended per pound working steam in ft. lbs.
= H_1 + heat received from the jacket.

$$= J(T_2 - T_4) + a\left\{1 + \log_e \frac{T_1}{T_2}\right\} - bT_1$$

$$= 778\,(300.565) + (1117850 \times 1.27) - (544.5 \times 905.92)$$

$$= 233839.5 + 1419669.5 - 493273.4$$

$$= 1,160,235.5$$

U = net work done in ft. lbs. per lb. working steam.

$= a \log_e \frac{T_1}{T_2} - b\,(T_1 - T_2) + v_2\,(p_2 - p_3).$

$= 301819.5 - 116719 + 13264.8$

$= 198365.3$ ft. lbs.

$\text{Efficiency} = \frac{U}{H'_1} = \frac{198365.3}{1160235.5} = 17.9\%$

B = pounds steam per I. H. P. per hour at boiler, inclusive of jacket steam, for efficiency transformation.

$= \frac{1890000}{H_1} = \frac{1980000}{816666.6} = 2.42$ lbs.

B′ = pounds of working steam per I. H. P. per hour for efficiency unity.

$= \frac{1980000}{H'_1} = \frac{1980000}{1160235.5} = 1.707.$

A = B. T. U. per I. H. P. per hour for actual efficiency

$= \frac{2545}{\text{Efficiency}} = \frac{2545}{.179} = 14220.$

$\text{M. E. P.}' = \frac{U}{r v_1} = \frac{U}{v_2} = \frac{198365.3}{18.84} = 10529$ cu.ft.per sq.ft.

$\text{M. E. P.}'' = \frac{\text{M. E. P.}'}{144} = 73.1$ lbs. per sq. in.

C = pounds steam per I. H. P., total jacket and cylinder, for actual efficiency,

$= \frac{B}{\text{Efficiency}} = \frac{2.42}{.179} = 13.5$ lbs.

C′ = pounds working steam per I. H. P. per hour actual efficiency,

$= \frac{B'}{\text{Efficiency}} = \frac{1.707}{.179} = 9.5$ lbs.

W = equivalent water rate from and at 212° Fahr.

$= \frac{A}{966.069} = \frac{14220}{966.069} = 14.7$ lbs.

$F = \text{fuel per I. H. P. per hour} = \frac{A}{\text{B. T. U. one lb.}} = \frac{A}{1000}.$

$F' = \frac{C}{\text{lbs. water per 1 lb. coal}} = \frac{13.5}{10} = 1.35$ lbs.

D = piston displacement per I. H. P. per hour
$= Cv_2 = 254.34$ cu. ft.
D' = piston displacement per I. H. P. per minute
$= \frac{D}{60} = 4.24$ cu. ft.

IDEAL STEAM ENGINE CYCLES.

	Carnot Cycle.		Rankine Non-Conducting Cycle.		Rankine Jacketed Cycle.	
	Con-densing	Non-Con-densing	Con-densing	Non-Con-densing	Con-densing	Non-Con-densing
Ratio of expansion.	17.85	91.23	35.3	13.7	45.3	16.14
p_1	57600	57600	57600	57600	57600	57600
p_2	288	2304	1008	3024	1008	3024
p_3	288	2304	288	2304	288	2304
T_1	905.92	905.92	905.92	905.92	905.92	905.92
T_2	587.3	677.34	639.9	691.56	639.94	691.56
T_3	587.3	677.347	587.3	677.347	587.3	677.34
T_4	905.92	905.92	581	661	581	661
v_2	106.45	20.83	41.2	16.06	52.89	18.84
H_1	620797	620797	898806	816666	878806	816666
U	218332	157062	250470	169937	267420	198365
Efficiency *pr. ct.*	35.17	25.3	28.5	20.82	25.55	17.9
M. E. P.′	2050	7540	6079	10581	5056	10529
M. E. P.″	14.2	52.4	42.2	73.48	35.11	73.1
A	7236	10059	8930	12235	9960.7	14220
B	3.19	3.19	2.36	2.42	2.25	2.42
C	9.07	12.6	8.28	11.68	8.8	13.5
W	7.49	10.41	9.24	13.66	10.3	14.7
F′	.83	1.15	.92	1.168	.978	1.35
D	976.1	262.46	341.1	187.58	465.4	254.3
D′	16.27	4.374	5.68	3.126	3.25	4.24