STEAM PLANT OPERATION

BY

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63. Economy of Steam Engines. *a.* It is common practice to state the performance of an engine in terms of its "water rate." The water rate of an engine refers to the pounds of steam that it utilizes per horsepower-hour or per kilowatt-hour of energy produced. The water rate of an engine may be expressed in pounds of steam per indicated horsepower-hour, per brake-horsepower hour, or per kilowatt-hour, depending upon whether the energy referred to is that delivered to the cylinder, the flywheel, or the generator terminals.

The water rate is not the true measure of the economy of an engine. An engine utilizes heat, and the heat that must be supplied to generate a unit of energy is the true measure of economy An engine may receive steam at a low pressure and exhaust against considerable back pressure. The heat per pound of steam available for use in the engine is small, and the steam consumption per unit of energy generated correspondingly high. An engine operating on high-pressure steam and exhausting into a partial vacuum should have a low water rate. The water rate is useful in comparing the daily performance of an engine operating under constant steam and exhaust conditions. The operator can tell how his engine performance compares with the manufacturer's guarantee. In this case it is usually necessary to make corrections for the variation between actual steam and exhaust conditions and those given in connection with the manufacturer's guarantee.

The water rate of an engine is used in determining the size of boiler which will be required to furnish it with steam.

Following are the approximate steam requirements in pounds per indicated horsepower-hour (water rate) of engines utilizing saturated steam at 100 lb. per sq. in. gage pressure.

Single-valve noncondensing.	28
Single-valve condensing.	23
Four-valve noncondensing..	22
Four-valve condensing.	16

The steam consumption of small engines is determined by condensing the exhaust steam and weighing or measuring the condensate. This procedure accounts for the term water rate. In the case of the simple unit the weight of condensate discharged is equal to the weight of steam supplied to the throttle. This is not always true of turbines and compound engines because part of the steam is discharged at intermediate points and does not appear in the final exhaust. Meters are now available for measuring the flow of steam to the engine or turbine. These meters will measure the flow of steam, water or gases. They make it possible to check the daily performance of an engine and detect any decrease in economy

b. The B.t.u. of heat required by an engine to produce a unit of energy is the true measure of the economy of operation. The heat supplied to a simple engine in B.t.u. per indicated horsepower-hour may be found as follows,

$$\text{B.t.u. per i.h.p.} = W(H - h)$$

Where W = steam per indicated horsepower-hour as determined from test.
H = B.t.u. per pound of steam supplied to engine throttle.
h = heat of the liquid as found in steam table, corresponding to pressure of engine exhaust.

This formula takes into account not only the steam supplied but also the heat utilized by the engine.

The thermal efficiency of an engine is found by comparing the actual B.t.u. required to produce a unit of energy to that theoretically required. The heat equivalent to a horsepower hour is 2545 B.t.u.

$$\text{Thermal efficiency} = \frac{2545}{\text{B.t.u. supplied per i.hp.}}$$

The Rankine-cycle ratio is another method of expressing the performance of a steam engine. In this case the heat units required by the actual engine are compared with the heat units that would be required by an ideal engine working on a Rankine cycle. The Rankine cycle assumes an engine taking steam at constant pressure to point of cutoff, adiabatic expansion to exhaust pressure before release occurs (complete expansion), exhaust at constant pressure and temperature (no compression), feedwater returned to the boiler at temperature corresponding to the exhaust pressure. This ideal engine is assumed to operate without throttling, radiation, and friction losses.

The Rankine-cycle ratio which can be expected depends upon the valve mechanism employed, whether saturated or superheated steam is used, and whether the engine is operating condensing or noncondensing. Simple single-valve engines operating on saturated steam have a Rankine-cycle ratio of from 50 to 63 per cent when operating noncondensing and 40 to 50 per cent when operating condensing. Multivalve engines operating on saturated steam have a Rankine-cycle ratio of from 65 to 75 per cent when operating noncondensing and 45 to 60 when operating condensing. Compound and uniflow engines have Rankine-cycle ratios from 5 to 10 per cent higher than multivalve engines. The use of superheated steam increases the ratio from 5 to 15 per cent. The application of steam tables and calculation of cycle efficiencies are presented in detail in advanced work on this subject.

c. The actual steam engine delivers to its flywheel from 50 to 80 per cent of the energy that would be delivered, with a given amount of steam, if the engine were perfect (ideal) This difference in efficiency between the actual and the ideal is caused by various losses which are in part controllable. They may be classified as follows

a. Cylinder condensation.
b. Clearance volume.
c. Wiredrawing of steam.
d. Leakage past rings and valves.
e. Moisture in the steam at admission.
f Friction in the mechanism.
g. Incomplete expansion.
h. Radiation.

Cylinder condensation is by far the largest factor in preventing the actual engine from attaining ideal engine performance. In a counterflow engine the incoming steam comes into contact with the cylinder head and steam passages which have been cooled by the exhaust steam. When saturated steam is used this cooling causes some of the steam to condense. When superheated steam is used the superheat is reduced by this cooling. The effect of condensation is reduced by insulating the cylinder, steam-jacketing, superheating, compounding, increasing speed, decreasing clearance volume, and employing the uniflow principle. The time element is important in considering cylinder condensation because it takes time for the cylinder walls to receive heat from the steam. In the uniflow engine the cool exhaust steam is in contact with the cylinder head a comparatively short time. For this reason the head is not lowered to the temperature of exhaust steam.

Clearance volume is the portion of the cylinder and port volume which is not swept through by the piston. The clearance volume of engines varies from 2 to 10 per cent. Clearance volume increases the cylinder condensation and lowers the economy Theoretically, increasing compression reduces the loss due to clearance. In practice the economy of counterflow engines may not be improved by increasing compression. This is due to the fact that a larger quantity of steam is compressed in the clearance volume to be reexpended on the next stroke.

Wiredrawing is a term applied to the reduction that steam pressure undergoes in passing through the throttle valve and ports of a steam engine. This pressure drop reduces the available energy in the steam.

Leakage past rings and valves is a variable factor that is difficult to determine. The leakage in operation is likely to be very different from that when the engine is at rest.

Moisture carried by the steam does no work in the cylinder Tests show that the consumption of dry steam per horsepower is practically constant, the water acting as an inert quantity There is great danger of the moisture's carrying along impurities that will do serious damage to the equipment.

The difference between the horsepower developed in the cylinder, called indicated horsepower, and the brake horsepower is due to the power consumed in overcoming friction. This loss of power varies from 4 to 20 per cent of the indicated horsepower

The perfect engine is assumed to work on a complete expansion cycle, the steam is expanded to the existing back pressure. With the actual engine this is not practical. The increase in mean effective pressure by complete expansion is small. The cylinder required would be so large that its expense would not be justified. The exhaust valve of the actual engine opens when the pressure in the cylinder is above the exhaust pressure, giving an incomplete expansion cycle.

Radiation is the heat loss from the engine cylinder to the surrounding air. This is effectively reduced by insulating the cylinder.

The efficiency of the steam engine is increased by increasing the initial pressure, by superheating, and by reducing the back pressure.