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Efficiency of the Electric Lighting Plant of the Rhode Island College of Agriculture and Mechanic Arts

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The main idea in the testing of an electric lighting plant is to ascertain whether or not the different parts of the mechanism that help make it are giving the greatest possible efficiency, or in other words whether each part of the machinery is doing its share of the work.

The real value of the test is to see under what conditions and loads the machines can be placed, and yet be run economically.

The plant of the Rhode Island College includes all the buildings owned by the College, also the experiment station. The system is not an old one, having been in existence but three years, but in this time it has grown wonderfully, now having the large direct current dynamos, a number of smaller ones, also a large alternating current generator. It has two engines, a vertical and a horizontal, but of the factors that has been mentioned, the largest direct dynamo and the horizontal engine are the ones that will now be considered. There are also two large boilers of 60 H.P. each.

The tests of the factors above mentioned naturally commence with the fuel.

The importance of this test may seem evident to ones mind. For instance, if a boiler is taking a great quantity of fuel a great deal more than it is rated at, the manager or superintendent would thing at first there was something the matter with the boiler, the flues needed blowing off or two much heat went up the chimney in form of gases, while perhaps the real fault may have been in the amount of combustible matter in the fuel used. So it is seen that it is of the greatest importance that the quality of the fuel be taken into consideration.

The percentage of moisture and combustible matter is found and of course by having as good coal as possible, the amount of labor that must be expended in feeding the furnace is reduced

The test of the fuel consists of finding the percentage of moisture in it and is usually done by using some factor as a standard namely one pound moisture in one hundred pounds of fuel represents one per cent of moisture.

Then again the test for finding the amount of combustible matters in fuel which plays a very important part as has been stated.

We now come to the boilers which have to undergo two separate tests, the evaporative and the calorimetric. The former is performed by letting all the water out of the boiler that is possible. Then read the water meter. Great care should be taken to have the ashes and clinkers cleaned out before commencing the test. Fill the boiler until it registers about the one-fourth the height of the guage glass. Read the water meter again. Now by means of a piece of colored cyayon mark the height of water in guage glass. Then allow the water to run in until it raises seven or eight inches in glass and once more read the water meter. The difference between this reading and previous one gives the numder of cubic feet of water to be evaporated. Its temperature should also be noted. This having been done the fire is started and all kindling and coal should be accurately weighed, allowing four-tenths of a pound of coal for each pouhd of wood used. The boiler should be steamed, slowly at first and later, it may be safe to steam more rapidly. The boiler is kept under steam pressure until thw water drops to the crayon on guage glass. The highest pressure on steam guage is noted and its temperature is obtained from tables.

Having gone through the operation as described above one has sufficient data to obtain the evaporative power of the boiler. The following data was obtained.

Let R_b = reading of water meter before letting water into the boiler.

Let R_a = reading after.

Also let P_h = highest steam pressure.

R_b = 563,306 cu.ft.

$R_a = 563,406$ cu.ft.

Then $R_a - R_b = 100.5$ cu.ft. the amount of water evaporated.

1 cubic foot of water weighs 62.42 lbs. 100.5 cu.ft. weighs 6,271.2 lbs $= W_e$.

$P_h = 75$ lbs. Let W be the weight of coal used including wood = 713 lbs. w, clinker, c plus a, ashes = 96.255 percentage of moisture is 1 lb in every 100 lbs or 1% total moisture = 71.3 and let this be denoted as M_t. Then total amount coal actually consumed is $W - (M_t \text{ plus } W_c \text{ plus } a) =$ 713 -(71.3 plus 96.255) = 545,445 lbs $= W_{cm}$. Percentage of combustible matter in coal is $W_{cm} \div W = 545,445 \div 713 = 85\%$. The number of pounds of water evaporated per piund of combustible matter equals $W_e \div W_{cm} = 6271.2 \div 545445 = 11.483$ lbs.

The number of pounds of water evaporated per pound of coal used equals $W_e \div W$ equals $6271.2 \div 713$ equals 8.71 lbs. Determination of mumder of heat units in one pound of steam at P_h or 75 lbs.

Temperature at P_h as given in tables 320.089°F $= T_e$ Let 212°F equal normal boiling temperature of water = T. Let .305 equal the increase in heat units for every degree above 212 F. Let 1178.6 equal total No. of heat units, as given in table in one pound of steam at 212 F equals H_t.

Then ((T_h - T) .305) plus H_t = ((320.039° - 212°)305) plus 1178.6 = 1211.5518 = H_{ph}.

Determine the factor of evaporation. Let 1211.5518 or H_{ph} equals total number of heat units in one pound of steam at 320.039° or T_h.

Let 65.011 equal heat units in feed water at 60 F. equals H_{fw}.

Let 965.7 equal number of heat units required to evaporate one pound of water from and at 212 F. or T then $\frac{H_{ph} - H_{fw}}{965.7}$

equals $\underline{1211.5518 - 65.011}$ = 1.187

The efficiency of a boiler does not depend wholly upon the rate at which the water may be raisedor a certain amount of water evaporated by a certain weight of combustible matter or fuel applied; but it depends upon the quality of steam that is, the percentage of moisture in steam. The test which determines this is called the calorimeter test. The evaporative test really proves little as to the effieiency of a boiler as has been noticed, while on the other hand the calorimeter test also really proves little of the efficiency when taken alone. The combination of these two seems to give the efficiency, the first giving the rapidity with which the steam may be raised and just how much may be expected of a certain number of pounds of coal. The second gives the quality of the percentage of moisture in steam.

A very inexpensive and convenient form of calorimeter is an ordinary gasoline barrel with one end cut off perhaps a foot from the end.

Most any form of scales are good. Then to perform the experiment, weigh very carefully the calorimeter, then let in a number of pounds of cold water and note its temperature.

Then from some source, always from as small a pipe as possible, allow steam to pass in for ten or twelve minutes. Again weigh the calorimeter and also note its average temperature. This having been done one will have sufficient data to find the percentage of water in steam. The following data was obtained. Let Wcl equal the weight of the calorimeter.

" W_w " " " " water put in.

" W_s " " " " " added by condensed steam

Let W_i increase of water by condensed steam.

" T_c equal temperature of cold water.

" T_h " " " hot "

" H_c " heat units contained per pound of original water in calorimeter at a temp. of T_c F.

Let H_h equal heat units contained per pound of water after adding steam, temp. being T_h.

Let P_h equal the highest steam pressure.

Let H_{ph} equal heat units in one pound of dry steam under pressure of Ph.

Then Wc1 equals 48 lbs, Ww equals 200 lbs.

Ws equals 214 lbs . Wi equals Ws - Ww equals 214 - 200 = 14 lbs

Te equals 48 F. Hc equals 48.003 heat units

Th equals 122 F. Hh equals 122.157 " "

Ph equals 60 lbs. Hp equals 1207. 6929

Let 100 be a constant. Then,

$$\frac{(Hph\ .\ \overline{Ws - Ww}\ ) - (\ Hh\ .\ Ws - \overline{Hc\ .\ Ww})\ \text{plus}\ 100}{H_{ph}} =$$

$$\frac{(\ 1207\ 6929\ .\ \overline{214 - 200}\ )\ ) - 122.157\ .\ 214 - \overline{48.003\ .\ 200}}{1207.6929}$$

$$= \frac{36.6702}{1207.6929} .\ 100 = \quad 3.036\%\ \text{of water in steam.}$$

The engine used is of the "Armington and Sims" makeof high speed type. In order to find out the amount of work an engine is doing we go through a test called the "indicator" test. Now to get the best results when testing an engine with an indicator, it is quite essential that the valves should be set as nearly equal as possible, that is, so that the crank end of the piston will do no more or less work than the head end. It was found when the engine was first tested that the head end was doing a greater part of thw work, but, however, the valves had been set so that a very good diagram was obtained at no load, a comparatively poor one was given when the engine was working under one-third of engine.capacity, but when the load was increased the diagram grew better until when the engine was loaded nearly to its rated capacity, it was nearly perfect.

These imperfections cannot be readily accounted for and are true of all high speed engines. It has been stated by some authorities that it is due to the steam being cut off so quickly.

After having obtained the diagram by the indicator test the indicated horse power exerted by the engine during the various loads may be obtained, by finding the area of the diagram made by each end of the piston by means of an instrument, called the planimeter, which is designed for measuring the areas of irregular diagrams. The area having been found it is multiplied by the number of spring used in the indicator and by dividing the product by the length of the diagram in linear inches the quotient will be the mean effective pressure. Then by the formula, I H P equals

$\frac{P\ L\ A\ N}{33,000}$ where P is the mean effective pressure in lbs,

L is length of the stroke in feet,

A is area of piston in square inches.

N is number of strokes per minutes.

Some of the more important diagrams giving the different loads the dynamo was carrying and the indicated horse power the engine developed under such loads are the following.

Load of Dynamo				I. H. P.
112 volts		70 amperes.		16.1
111	"	115	"	23.15
113	"	148	"	31.5
113	"	170	"	39.85
113	"	200	"	48.9
112	"	220	"	53.5

The generator which furnishes the current is of the "Eddy Electric Generator Mf'g Co.", of Windsor, Conn. and type G, number 5, 480. It is a direct current dynamo designed for constant potential at a normal speed of 950 revolutions per minutes and rated at 125 volts and 200 amperes. The peripheral velocity at full speed is 3641.66 feet per minute, and the horse power required to drive it at full load is 33.33...

A machine of this design and type is adapted for incandescent lighting usually on a 110 volt circuit.

The field is of multipolar form constructed upon nearly rectangular shaped cores of brass and in the center a large hole through which a soft iron magnet protrudes nearly to the armature. It is compound wound with a resistance of .4 of an ohm. The size of wire is about 3 mm in diameter and consisting of three strands. The armature is closed coil type drum form and consists of 88 coils. The resistance of armature circuit between brushes is .2 of an ohm. Resistance of a single coil is .003 of an ohm. The size of the armature wire could not be determined. The number of conductors on the armature is 88. The connections of the c oils to commutator bars could not be ascertained. N.B. The brushes are of carbon and twelve in number. Its resistance is regulated by a regulating field rheostat on the switch board. Its perimeter is 3 feet 10 inches and about 80% is covered by the magnet cores of field.

The testing of a compound dynamo consists of finding the various characteristic curves, namely, the series, the internal shunt, the external shunt, the compound, and the armature.

In order to find the first the external circuit must be closed at the start with as little resistance as possible, in order to get the machine to pick up. In this experiment the series coils are alone used. In the shunt, whether external or internal the external circuit may be left open until the machine gas reached its required voltage. In the compound the external circuit is left open until it has reached its required voltage. The armature characteristic is determined by putting a mil-ammeter in series with a regulating rheostat and the field. The field current is plotted as ordinates and the external current as absiccas.

In each of the other curves, however, the volts are plotted as ordinates and the amperes as absiscas. The following are the curves described.

The efficiency of the plant taken as a whole unit seems extremely good, although some parts are more efficient than others as might naturally be expected. Summing up the various tests we find that the fuel used consisted of 1 part moisture, 86 parts combustible matter making a grand total of 87%. This is extremely high, fuel seldom reaching any point above 80% It shows how free from clinker, slate and other non-combustible the coal must have been.

The evaporative test of the boilers also points out the high evaporative power of the boilers. They are capable of evaporating 11.483 lbs of water per pound of combustible matter. The average boiler is capable of evaporating about 8 lbs and in some cases 10 lbs. Here again it shows how economically it can be run and in what shape the tubes must have been in order to get so high an evaporative power. The calorimetric test gave the highest percentage of either of the tests, giving 96.864% pure steam. The average boiler will not give over 88% and in extreme cases reaching 90%

The engine also gave a very satisfactory result being run under a load varying from 3 to 5 H.P. over load and was easily capable of carrying a much greater one.

The last factor gave an exceedingly good account of itself, being run at 25% over-load and did not heat the field coils but a very little.

It is seen from the summation of the tests, that no one part of the mechanism, was below the average, but on the other hand Gave a high efficiency.

Data and results of efficiency test.

Test of compound dynamo made by "Eddy Electric Generator M'f'g Co.,"

Date of test, June, 4, 1900.

Duration of run, 1 hour, 30 minutes,

Kind of generator, direct current, Field, shunt.

Armature, closed coil type, drum form,

Commutator segments, 66.

Resistance of armature, hot .215 ohms cold.2

" " shunt field " .234 " " .2

" " series coils hot .3 " " .2

External resistance, .446 ohms.

Temperature of armature before run 22 C. of room 24 C.

" " " after " 37 " " " 27 "

Potential at terminals 112 volts.

Revolutions per minute 820.

The following are points of the various curves

Compound				External shunt.	
V.	A.	V.	A.	V.	A.
110	2,	97	161	102.5	52
108	8	96	164	99	60
108	10	78	170	95.5	63
105	19	75	178	93	86
104	26	73	180	72	68
108	30	69	181	69	60
108.5	62	57	188	69	54
"	72	-	-	68	60
106	80			65	40
"	88			63	46
108.5	99			59	53
101	109			55	56
"	118			41	52
99.5	132			48	36
98.5	14 3			46	40
98.	154			44	44
				40.5	48

Armature characteristic points.

Field.	External.	Field.	External.
2	0	2.25	130
2.25	2	"	147
"	6	2.49	204
"	10	"	207
"	16	"	218
"	20	"	228
"	23	2.5	252
"	26		
"	56		
"	66		
"	73		
"	79		
2.15	83		
"	85		
"	95		
2.25	110		
"	113		
"	122		

Series characteristic points.

V.	A.	V.	A.
1.5	15	2.35	1
"	16	2.4	0
1.55	12.5		
1.59	10		
1.5	12		
1.7	8		
1.9	6		
2	5		
2.2	2		