

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, April 27th, 1898.

The 124th meeting of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS was held this date, at 12 West 31st Street, and was called to order at 8:30 P. M. by the Secretary.

THE SECRETARY:—The Vice-Presidents and Managers who are on the standardizing committee are engaged in quite an important session, and they will be in attendance later. Meanwhile we will proceed with the business of the evening, and if some gentleman would be kind enough to nominate a Chairman to act until the President arrives, I will entertain the motion.

MR. JOSEPH WETZLER:—I move that Mr. Leonard occupy the Chair temporarily in the absence of the President.

The motion was carried, and Mr. H. Ward Leonard took the Chair.

THE SECRETARY:—At the meeting of the Executive Committee this afternoon the following associate members were elected:

Name.	Address.	Endorsed by
ALLEN, WYATT H.	Care H. F. Allen, 202 California St., San Francisco, Cal.	Louis Duncan. H. S. Hering. Alex. Stratton.
FITZHUGH, WM. H.	Supt. Bay City Electric Plant, Bay City, Mich.	F. B. Rae. F. S. Hunting. Thomas Duncan.
FLEMING, JOHN BRECKENRIDGE.	Mill Superintendent and Cons Engineer, Austin Mining Co., Austin, Nev.	R. W. Pope. Edw. Caldwell. W. F. C. Hasson.
HENRY, GEO. J. JR.,	Engineer for N. Y. Branch, The Pelton Water Wheel Co., 143 Liberty St., N. Y. City.	W. W. Blunt. P. N. Nunn. J. N. LeConte
HOPKINS, N. S.	Ass't Engineer, General Electric Co. Box 825, Schenectady, N. Y.	H. G. Reist. A. L. Rohrer. C. P. Steinmetz,

LINDSAY, ROBERT	General Supt. The Cleveland Elec. Ill. Co., 717 Cuyahoga Building, Cleveland, Ohio.	M. C. Canfield W. S. Barstow. J. W. Lieb, Jr.
MUSCHENHEIM, FRED'K A.	Electrical Engineer, Western Electric Co., 57 Bethune St., residence, 41 W. 31st St., N. Y. City.	H. F. Albright. E. S. Keefer. Geo. A. Hamilton.
SCHLOSS, NEWTON L.	Consulting Engineer, 39 Cortlandt St., residence, Stuart House, N. Y. City.	Jos. Wetzler. T. C. Martin. R. W. Pope.
TOLMAN, CLARENCE M.	Electrical Engineer, with Edw. G. Stoiber, Silverton, Colo.	C. E. Doolittle. E. Friedlaender. H. G. Reist.
VINTEN, ERNEST STILES	Draughtsman, Walker Co., New Haven, Conn.; residence, 89 Pearl St., New Haven, Conn.	Chas. N. Black. H. McL. Harding. F. G. Daniell.
Total, 10.		

The following paper on "An Economy Test of a Central Station" was presented by the Secretary in the absence of the author:

AN ECONOMY TEST OF A CENTRAL STATION.

BY W. E. GOLDSBOROUGH.

INTRODUCTION.

During the summer of 1895, I made a study of one of the large electric lighting stations of Baltimore city, from an economic stand-point. A series of somewhat general observations, led, finally, to a decision to subject the plant to a number of rigid economy tests, to determine along what lines, if any, the method of operating the station could be modified to improve its efficiency. The tests were initiated largely as a matter of engineering interest; for the station, even at that time, was adjudged efficient. Arrangements for these tests were perfected about the end of the summer, and in the following pages is given an account of the more interesting matters that came to my notice during their progress.

Since 1895, the station has been so extensively improved, both as the result of these investigations and the natural growth of business, that the paper can hardly be said to be a record of the economic performance of any at present existing plant. New boilers have been added, as well as new engines. With but one or two exceptions the old engines have been refitted with new cylinders and valves, and the electrical units, dating as far back as the tests, have been so thoroughly renovated as to be practically new.

The station is to-day, without doubt, more efficient than in 1895, and the improvement is in a great measure due to the removal of the defects to which your attention will be called. Tests of the character of those discussed have an undoubted value, and there is many another plant to be studied and regu-

lated in virtually the same manner before it attains the maximum efficiency. A combination of boilers, engines and generators, however efficient they may be severally, do not necessarily produce an efficient station. Each station must be regarded as a special problem by the engineer, and must be studied as such.

The interest taken in investigations of this character by Mr. James Frank Morrison, general manager of the company controlling the station, made the tests possible, and it is through his kindness in consenting to the partial publication of the results obtained, that I am privileged to read before the INSTITUTE this abstract of my report. If the facts do not appear in some cases to bear out the conclusions, it must be remembered that it has been possible for me to embody in this paper only a small part of the original data.

Purdue University, La Fayette, Ind.,
March 1898.

THE STATION.

The West Pratt Street Station of the Edison Electric Illuminating Company of Baltimore city is situated on the north-west corner of Pratt and Penn streets, Baltimore, Maryland.

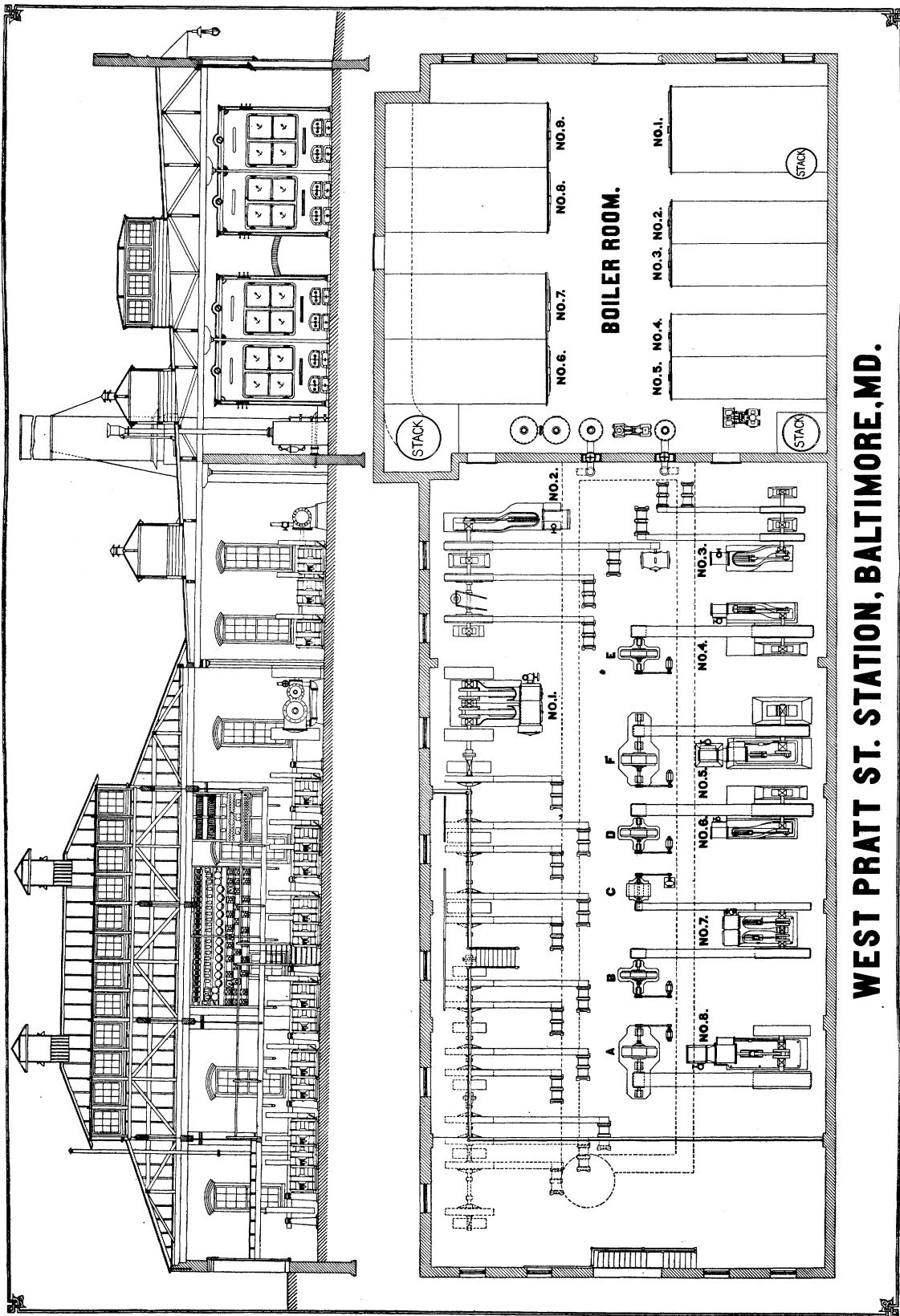
The station occupies a substantial one-story brick building that fronts on Pratt street and extends back 178 feet to King street. The general character of the building is very well illustrated in the ground plan and elevation of it that is contained in this paper. The Pratt street end contains the boiler plant; this room is 60 feet long and 67 feet wide. North of the boiler room is the engine room; it is 118 feet long and 60 feet wide.

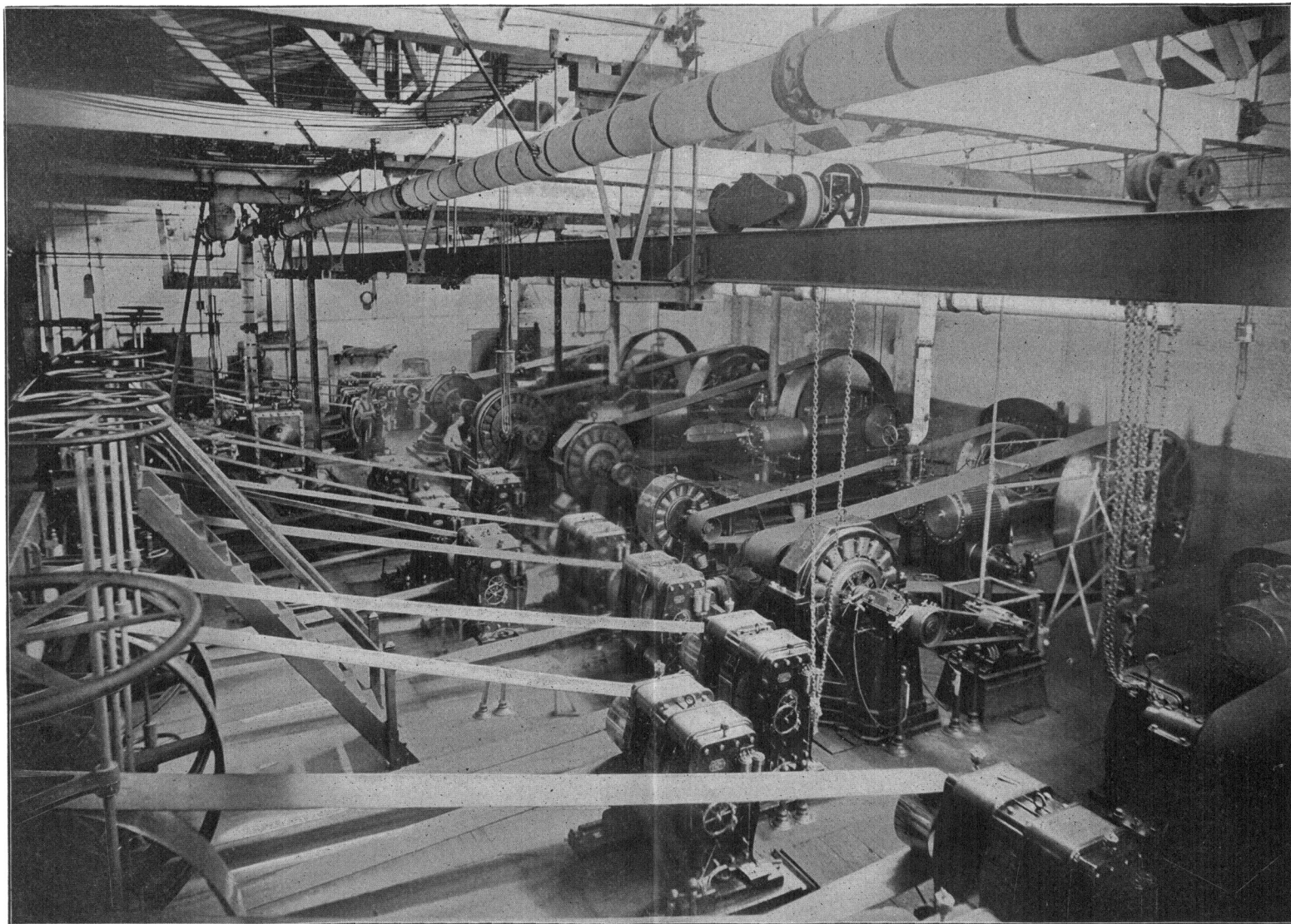
From Pratt street the station presents a pleasing appearance. Its front is rectangular, 35 feet high and broken by large double doors and windows.

The Boiler Room.—The boiler room contains nine water-tube boilers of the type manufactured by the Campbell and Zell Company which are arranged in four batteries of two each, with one large boiler in the south-west corner by itself.

The boilers have a total rated capacity of 1,750 horse-power.

As shown by the ground plan of the station above referred to, the boiler plant is equipped with three large iron stacks. One of these receives the products of combustion from the furnace of boiler No. 1. Another is in the northwest corner of the boiler room and forms the continuation of the flues of boilers Nos. 2,





ENGINE ROOM, WEST PRATT STREET STATION, BALTIMORE, MD.

3, 4 and 5. The third is in the northeast corner of the boiler room and is built to accommodate the large boilers, Nos. 6, 7, 8 and 9, on the east side of the station.

The location of the steam mains is not shown in the station drawing. A single 10-inch main extends along the west side of the boiler room over boilers Nos. 1, 2, 3, 4 and 5. It is carried through the north wall and terminates in a "straight line" centrifugal separator placed just inside the engine room. On the east side of the station a similar line of 16-inch pipe extends over and collects the steam from boilers Nos. 6, 7, 8 and 9. It is extended on into the engine room. The east and west steam mains are connected by a 10-inch pipe which runs parallel to the dividing wall just inside the boiler room. The cross main is equipped with a large stop valve and an equalizer connection.

The equipment of the boiler room also includes one 500 H. P. "national" feed water heater, one 500 H. P. "excelsior" heater and purifier and one 1500 H. P. double open and closed feed water heater made at the Bass Foundry and Machine Works.

There are three duplex pumps at the north end of the boiler room, where the heaters are also placed. The steam cylinders of these pumps are 12" x 12" and the water cylinders 7" x 12"

As a rule it is found that one pump is sufficient to supply the boilers, and during the tests made upon the station, only one pump was used. The feed water flows from the city mains directly to the heaters in which it is heated by the exhaust steam from the engines. It is drawn from the heaters and forced into the boilers by the pumps. During the tests the heaters were found to be very effective. They do not apparently increase the back pressure in the exhaust mains and yet save over 11 per cent. of the fuel.

The Engine Room.—The newer part of the station building north of the boiler room contains the engines and the electrical machinery. The floor of this room is about level with the ground. The foundations of the engines all extend above the floor and there are no wheel pits, etc. in the station. The aggregate rating of the engines is 2065 H. P.

The piping between the engines and boilers is ample in its dimensions. Engines Nos. 1, 2, 3, 5 and 8 are on the east side main. This main is constructed of 16-inch pipe up to the point where the supply pipe of No. 1 engine is connected.

Beyond this point it is reduced to 10-inch pipe and is carried over to the west side of the station; it is then extended north over engines Nos. 5 and 8. Where the east main crosses the middle of the station a "straight line" centrifugal separator has been inserted. This is the only separator on this line of pipe.

The pipe connections between engines Nos. 1, 2, 5 and 8, and the east main are quite direct and short; the connection to No. 3 is however, necessarily long; it extends entirely across the station.

Engines Nos. 4, 6 and 7 are connected to the west side steam main. This main extends almost due north from the boiler room and is composed of 10-inch pipe throughout its entire length.

The exhaust mains extend north and south underneath the floor. They connect directly with the heaters, and all waste steam not condensed by the feed water is discharged through exhaust heads into the air. All of the engines exhaust into these mains except engine No. 1, which exhausts directly into the atmosphere through an exhaust head.

The normal steam pressure at which the engines are operated is 130 pounds by gauge. The entire plant is non-condensing.

The station is equipped with electrical machinery designed to supply 13,000 16 c. p. incandescent lamps and 1,420 2,000 c. p. arc lamps. The arrangement of the units is shown on the ground plan of the station. They are all belted to the engines.

The dynamo leads are carried to the switchboard, which is raised nine feet above the floor of the station, through subways underneath the floor. From the switchboard the leads are carried out of the station on suitable racks through the skylight that covers the greater portion of the roof of the engine room.

A very good idea of the appearance of the station and the general arrangement and setting of the machinery can be obtained from the cut of the engine room. The cut brings out the arrangement of the steam piping and wiring very clearly.

The Arc Lighting Plant.—In the arc lighting plant, the usual American practice of transmitting power to numerous dynamos from one engine by means of shafting and belting is followed. The entire equipment is divided into three sets.

Engine No. 1, which is a 600 H. P. horizontal cross-compound high-speed Ball and Wood engine, is directly connected to a line shaft that extends along the east side of the station, and to which

twelve 80-light Wood 2,000 c. p. arc light machines are belted. Each of these dynamos will safely develop 38.4 k. w. or 51.47 h. p., making a possible total load of 618 h. p. for the engine, over and above the friction load due to the line shafting.

Engine No. 2 is also directly connected to a line shaft extending along the eastern wall of the station. The engine is a simple four valve horizontal high-speed Russell engine of 170 h. p. and drives a 10 k. w. 500-volt Wenstrom generator and three 80-light Wood 2,000 c. p. arc light dynamos, which are all belted to its line shaft. The total maximum rated electrical output of this equipment is 168 h. p.

Engine No. 3 is a 125 h. p. simple single valve, high-speed horizontal Russell engine. It drives two 80-light and one 60-light Wood 2,000 c. p. arc light dynamos that are belted to pulleys on a short extension of the engine shaft. The total normal rated output of this equipment is 141.5 e. h. p.

The normal current output of the arc machinery is 9.6 amperes. The practice at the station, however, is to regulate the machines at about 9.5 amperes, and this current value was used during the tests, except in the case of machines Nos. 4 and 6, which supply the arc motor circuits and are operated above their normal capacity at 10 amperes.

The Incandescent Plant.—The single-phase alternating current system is exclusively employed for the distribution of power to the incandescent lighting circuits. A uniform pressure of 1000 volts is supplied to the distributing mains, and this is reduced by means of transformers to 50 volts at points where it is supplied to consumers.

To meet the increasing demands upon the station and to admit of the most economical adjustment of the load under existing conditions the incandescent plant has been enlarged from time to time until at present it comprises five distinct equipments each operated by a separate engine. The arrangement of this machinery is very well exhibited in the cut of the ground plan and side elevation of the station contained in this paper. Referring to it:

Alternator A, is a 150 k. w. Wood machine compounded for 1000 volts. It is operated by a 300 h. p. tandem compound "ideal" engine.

Alternator B, is a 100 k. w. compound Slattery machine.

Alternator C, a 50 k. w. Thomson-Houston machine, both of which are operated by a 300 h. p. cross-compound Ball and Wood engine.

Alternator D, is a 100 k. w. Slattery machine, driven by a 145 h. p. Buckeye engine.

Alternator E, is also a 100 k. w. Slattery machine and is driven by a 145 h. p. Buckeye engine.

Alternator F, is a 150 k. w. compound Wood machine and is driven by a 300 h. p. Ide engine.

As the diagram indicates, all of the alternators are belted, solid leather belts being used. Their exciters are supported on separate bases, and are belted to pulleys placed on the collector ends of the shafts of the alternators.

THE TESTS.

The tests that were made upon the station took place during the last week in August, and the first week in September, 1895.

In planning for the tests *no effort was made to improve the condition of the plant in any respect.* The engines and other machines were operated just as they had been running during the months previous, and absolutely no modifications were made in the methods of adjusting the load to the various units, in the way in which the boiler plant was handled, or in the usual control of the water and coal supply; except on Sept. 1st and 2nd as explained later. The station employees were in no wise instructed to modify their habitual practice, and they were at all times left perfectly free to perform their accustomed duties.

In carrying out the details of the tests, in the construction of additional apparatus, the calibration of instruments and the fitting and adjustment of the same, in fact, for the perfection of all the varied requirements of so large an undertaking, competent extra help was employed.

Every effort was made to have each detail of the general plan accurately outlined, worked up and perfected. For the measurement of the water supply a large weir was built on the north-east corner of the boiler room roof almost directly over the 1500 h. p. feed water heater. Measurements were taken of the water level in the weir at 5 minute intervals throughout the entire period of the tests with a Boyden hook gauge, and a continuous record was also obtained with a very sensitively adjusted chronograph. As a check upon these readings, the water-meter, through which all the water passed that entered the station, was read at 15-minute intervals. Furthermore every water connection, through which leakage could possibly occur, was tested, and made water tight if found imperfect.

In figuring up the amount of water that was supplied to the boilers, the levels shown by the hook gauge and the chronograph records were checked against one another, and the chronograph records were all integrated with an Amsler planimeter. The results that were obtained in this way were then compared graphically with the water meter readings. The weir and water meter curves follow one another quite closely, and show that up to the rate of flow of 2200 pounds of water per hour the water meter registers *less* than the true amount of water, but that over that rate it measures *more* than the true amount of water.

The scales used in measuring the coal were made by Fairbanks, and their accuracy was assured by testing them with a block of iron, the weight of which had previously been ascertained on the standard scales at the United States Sub-treasury.

Each barrow of coal was passed over the scales and balanced accurately for 400 pounds of coal before being carried into the station.

All the steam gauges used in connection with the tests, were standardized by comparing them with a *new* Thomson and Robertson gauge testing set. The thermometers used in making calorimetric tests of the quality of the steam had been calibrated previous to the tests and were calibrated again immediately after the tests. These calibrations were found to correspond. The calorimeters used were three carefully constructed throttling calorimeters and one Carpenter separating calorimeter. The pyrometer used in measuring the temperature of the flue gases was calibrated by inserting it into a steam pipe and comparing its readings with determinations made of the temperature of the steam from the readings of two calibrated gauges connected to the same steam pipe. During the tests, each steam cylinder of the engines and the pump was equipped with a steam indicator, and proper indicator riggings were fitted up to ensure the accuracy of the cards taken. Engines Nos. 1, 5, 7 and 8 were equipped with two-way cocks in connection with the indicator fittings, but on the other engines, valves placed on either side of the indicator had to be relied upon when taking cards from the opposite ends of the cylinders.

The speed of each of the engines was taken every 15 minutes with the usual form of Starrett hand speed indicator. The speed of engine No. 1 was always taken at the time the indicator cards were made, and the speeds of the other engines immediately

thereafter. This method is not so exact as that of using tachometers or constant speed counters, but owing to the fact that there were no *sudden* changes in the load on any of the engines, the plan adopted was considered sufficiently accurate.

Testing Instruments.—For taking the record of the output of the arc dynamos quite an amount of special wiring was necessary. Three standard high range Weston voltmeters were available for determining voltage readings. Three tables were therefore constructed with a double row of mercury contacts arranged along one side of the top. The tables were nailed to the floor and connections made between the terminals of each of the arc machines and a pair of the mercury contacts. One of the standard voltmeters was placed on each table, and was used to take the voltage readings of the machines connected to that table by successively inserting a flexible insulated connector into the mercury contacts.

As it was impossible to provide ammeters for all the arc circuits, one standard Weston direct current ammeter was used for testing all of them. A test was made of all the circuits every 15 minutes during the five minutes immediately preceding the time for taking the general station readings. It was found that the currents remained practically constant as the loads were subject to only slight variations.

The voltmeters and alternating current indicators employed on the alternator circuits are of the older types supplied by the makers of the machinery, but the ammeters on the distributing mains are of the most improved Wood pattern. Wirt lightning arresters are used on all the distributing circuits.

The arrangement of the switchboard connections is such that it is possible to connect any one alternator to only about half of the distributing circuits at any one time. The changing of a circuit from one alternator to another is effected by the manipulation of a series of double-throw switches, which when placed in a certain order to bring a proper load on one alternator, may prevent the completion of the combination of connections that would be most advantageous in loading some other machine. The restrictions imposed by the switchboard have the effect at times of causing the operation of a dynamo which could be dispensed with were a thoroughly flexible system of switchboard connections provided. The remodelling of the board would in fact greatly facilitate the economical operation of this portion of the

station, and would result in a considerable saving in the operating expenses. This point is well brought out in the tests made upon the plant.

In this station each alternator is operated entirely independent of any other, *i. e.*, parallel working of the machines is not attempted.

Calibration of Instruments.—To ensure the thorough reliability of the readings of the electrical switchboard instruments they were all carefully calibrated by comparing them with standard Weston instruments obtained especially for this purpose direct from the Weston Electrical Instrument Company.

The calibration of the switchboard voltmeters was effected by connecting a standard 110-volt Weston alternating and direct current voltmeter, and a multiplying coil that multiplied its readings by 10, directly across the 1,000-volt mains and comparing its readings with the readings of the switchboard instrument undergoing calibration. The switchboard instruments were not removed from their normal positions or their connections disturbed in the least, the variations in the voltage between the leads to which the instruments were attached being produced by changing the field excitation of the respective dynamos to which they were connected.

The calibrations of the switchboard ammeters were effected by employing an indirect, though perfectly successful, method. A large non-inductive resistance was constructed by stretching a quantity of No. 17 B. & S. gauge german silver wire on a number of 12-foot boards by passing it around porcelain insulators screwed to the boards. These resistances were then connected to an old arc light switchboard so that any number of them could be connected either in series or in parallel as the case might require. A switch was fixed so that the arc switchboard with the resistances could be short-circuited when not in use. The lead that connected the ammeter to be tested with its dynamo was disconnected and led to one side of the arc switchboard just described. After being made to pass through the non-inductive resistance of the board, the circuit was then connected to the current terminals of a standard Weston wattmeter. From the other current terminal of the wattmeter the circuit was connected to the ammeter to be tested. The ammeter was in this way placed in series with the non-inductive resistance and the current coil of the wattmeter. The voltage terminals of the wattmeter were

connected as a shunt around the non-inductive resistance, and a standard Weston voltmeter was arranged to measure the fall of potential through the non-inductive resistance, *i. e.*, it was also shunted around the resistance. In this way means were provided for measuring the power absorbed in the resistance by the wattmeter, and by dividing the wattmeter reading by the reading of the standard voltmeter the current flowing through the resistance and therefore through the switchboard ammeter tested, could be determined. By varying the load on the alternators the current readings of the ammeters were varied over the working range of the respective machines, and the readings of the ammeters were then compared with the determinations of the true values of the currents made as described above.

The calibration tests indicated that the instruments were not very far out, and but a slight correction in the results recorded during the tests was necessary. The necessary correction was made in every case.

Determination of Power Factors.—On transformer circuits the power factor is not a constant, as the inductance of the line varies with the number of incandescent lamps that are turned on. Under ordinary circumstances, however, the power factor for any given circuit will be very nearly a constant for any given load on the circuit, whatever be the distribution of the load between the several secondary circuits supplied; it is therefore possible to plot a curve showing the relation of the apparent power to the real power for all loads for any given circuit, and having once obtained this curve the real power can always be obtained from the apparent power by reference to it.

As the standard Weston wattmeter already referred to was obtained on the 4th of September, and all tests had to be completed before the 8th of September, it was impossible to determine the power factors for each of the circuits. It was possible however, to make these determinations collectively for the several circuits supplied by "A" and "F" alternators during their all-day runs on September 6th and 7th respectively, and from the results so obtained a very fair estimate of the power factors that should be used for the tests has been arrived at.

The power factor varies between 88.2 and 99.6 per cent., with the majority of the points falling at about 91 per cent.

These results are for the *day load*. After carefully reviewing the results of both of the tests of the incandescent plant, and

making numerous comparisons, it was decided to use the power curve for all determinations of the *real power* developed by the several alternators, between 7 A. M. and 6 P. M., and 12 P. M., and 7 A. M., on each day on which tests were made, but between 6 P. M. and 12 P. M. a factor of *100 per cent.* was used for all circuits. This course was followed, since between 6 P. M. and 12 P. M., the load on the station is very heavy and therefore all the factors very high.

Any error that may be introduced by this procedure is slight at most, as the uniformity of the efficiencies obtained during the day and night runs plainly indicates.

DURATION OF TESTS.

The first test began at 7 A. M. on August 31st and continued until 7 A. M. on September 1st. During this time measurements were taken, as already described, on all the machinery and boilers operated in the station. During the hours of the heavy load, between 6 P. M. and midnight, 41 men were employed in taking readings.

The second test began at 5:45 P. M. on September 1st, and continued till 5 A. M. on September 2nd. This test was made to determine the efficiency of engine No. 1 and boilers Nos. 6, 7 and 8. It was made on Sunday night, because, owing to the arrangement of the steam piping and the large load on the station at other times during the week, the necessary adjustment of the boiler plant could only be effected at this time. For this test 24 men were employed.

The third test began at 7 A. M. on September 7th and ended at 7 A. M. on September 8th. It was carried out in all respects like the first test. The maximum number of men engaged in taking readings at any one time on this day was 42.

Each of the tests was thoroughly successful, and although a very severe storm raged during the afternoon of August 31st, the test made on that day was not seriously interfered with. On the contrary, the men showed remarkable coolness in carrying on their work quietly and in an orderly manner in the face of considerable danger.

The plan adopted for recording the results was to take simultaneous readings every 15 minutes from all the instruments, etc., at a signal given by blowing a steam whistle in the engine room.

THE BOILER TESTS.

The Boilers :—The boiler plant of the station is composed of four batteries of two boilers each, and one odd boiler. They are all of the water tube type and of the same general design, as they were built by the same company, but on account of having been placed in the station at different times, they differ somewhat from one another in the minor details of their construction.

The data on the dimensions and capacity of the boilers that are given in table 1 were obtained from the representatives of the Campbell and Zell Company, the makers of the boilers, and they have been checked up with the drawings from which the boilers were made and by measurements taken in the boiler room.

Boiler No. 1 was the first to be placed in the station; it is a double boiler and is rated by the builders, as a 250 H. P. boiler. The present practice of the builders, as stated on page 59 of their catalogue, is to rate their boilers on the basis of "11½ square feet of heating surface in the water tubes alone," per horse power. If this method of determining the capacity of boiler No. 1 is followed, its rated capacity figures out to be 186.5 horse power. (See item 34, table 1.)

Boilers Nos. 2, 3, 4 and 5 occupy space on the west side of the boiler room and form batteries 2 and 3. They were placed in position some time after boiler No. 1, and are of a more recent design. Their capacity by the original builders rating is 125 H. P. per boiler, and on the basis of "11.5 square feet of heating surface in the tubes alone," it is 61.2 H. P. per boiler.

Boilers Nos. 6, 7, 8 and 9 are of quite recent design. The builders rate them at 250 H. P. each, but their capacity figured on the 11.5 square feet of heating surface basis is 242.6 H. P. per boiler.

Summing up we find that the total rated capacity of the boiler plant is 1750 H. P., or 1401.7 H. P. when figured on the basis of 11.5 square feet of heating surface per horse power, *in the tubes alone*.

On the mornings of each of the days on which the tests were made, the fires under boilers 6, 7, 8 and 9 were burning bright, were clean and all the ashes had been removed from the ash pits.

The ashes that accumulated during the 24 hours' run were carefully weighed before being wet, and the fires burning at the end of the tests were left as nearly as possible in the same condi-

tion as were those which were burning when the tests began. In determining the moisture in the coal, samples were selected from the coal yard and dried.

In determining the moisture in the coal used Aug. 31st, account had to be taken of the fact that there was a heavy rain fall in the afternoon. In view of the fact however, that another determination was made of the moisture in the coal on the next day,

TABLE 1.

Designation of the Boilers by the Edison Elec. Illuminating Co. ...	Boiler. No. 1.	Batteries. No. 1 and No. 2.		Batteries. No. 3 and No. 4.	
	No. 1.	Boilers 2, 3, 4 and 5.		Boilers 6, 7, 8 and 9.	
1. Length of tubes.....	16'	14'	14'	18'	18'
2. Tubes per section.....	4	2	2	4	4
3. No. of sections.....	32	24	24	37	37
4. Total No. of tubes, per boiler..	128	48	48	148	148
5. Diameter of tubes.....	4"	4"	4"	4"	4"
6. Length of water drums.....	18'	16'	16'	20'	20'
7. No. " " " " " " " " " " " "	4	1	1	2	2
8. Diameter of water drums ..	18"	18"	18"	30"	30"
9. Sq. ft. heating surface per tube.	16.752	14.658	14.658	18.846	18.846
10. " " " " " " " " " " " "	67.068	29.316	29.316	73.384	73.384
11. Total sq. ft. heating surface in tubes	2144.3	703.58	703.58	2789.2	2789.2
12. Sq. ft. heating surface per drum	75.74	67.34	67.34	139.72	139.72
13. Total sq. ft. heating surface in drums.	302.96	67.34	67.34	279.44	279.44
14. Total sq. ft. heating surface... ..	2447.3	770.92	770.92	3068.6	3068.6
15. Width of grate surface in ins..	120	47	47	90	90
16. Length of grate surface in ins.	78	72	72	84	84
17. Area of grate surface in sq. ft..	65	23.52	23.52	52.5	52.5
18. Ratio heating to grate surface..	37.65	32.77	32.77	58.43	58.43
19. Ratio heating to super-heating surface					
20. Super-heating surface					
21. Length of tubes, inches	156	138*	138*	177.5	177.5
22. No. of tubes	16	6*	6*	12	12
23. Diameter of tubes.....	4"	4"	4"	4"	4"
24. Sq. ft. heating surface per tube.	11.52	12.03*	12.03*	15.479	15.479
25. Total heating surface sq. ft. ...	184.32	72.18*	72.18*	185.75	185.75
26. Area cyl. one water drum sq. ft.	84.18	75.36	75.36	157.08	157.08
27. Super-heating area one water drum sq. ft.	9.04	8.02	8.02	17.36	17.36
28. Total for water drums sq. ft....	36.16	8.02	8.02	34.72	34.72
29. Length of steam drum, inches.	120	47	47	90	90
30. Diam. of steam drum, inches..	42				
31. Area of cylinder of steam drum sq. ft.....	109.96	42*	42*	42	42
32. Total super-heating surface....	330.44	43.1	43.1	82.47	82.47
33. Horse-power allowing 11.5 sq. ft. of heating surface per H. P. in tubes alone.....	186.5	123.3	123.3	302.94	302.94
34. Horse-power allowing 11.5 sq. ft. of heating surface per H. P. in tubes and drums	212.8	61.2	61.2	242.6	242.6
35. Rated horse-power of boilers..	250.	67.02	67.02	267.	267.
		125.	125.	250.	250.

*No positive data—approximated. Data is given per boiler.

it was possible to approximate the true percentage of moisture for the whole test with a considerable degree of accuracy.

The engineer's and the assistant engineer's reports show that the same firemen were on duty during the same hours on Aug. 31 and on Sept. 7. So that the results of the two day's tests are as thoroughly comparable from this stand-point as from any other.

The Boiler Test of August 31st:—This test began at 7 o'clock on the morning of August 31st and ended just 24 hours later. During this time the station was operated according to the usual daily schedule and no attempt was made to modify or better the usual conditions in any way.

The log of the boiler test is exhibited graphically in Fig. 1. Table 2 contains the data and calculated results upon which the report of the boiler test given in table 4, column 1, is largely based, and it explains the method used for determining the true average grate surface, heating surface and horse power rating of the boilers. Such a process had to be resorted to in view of the

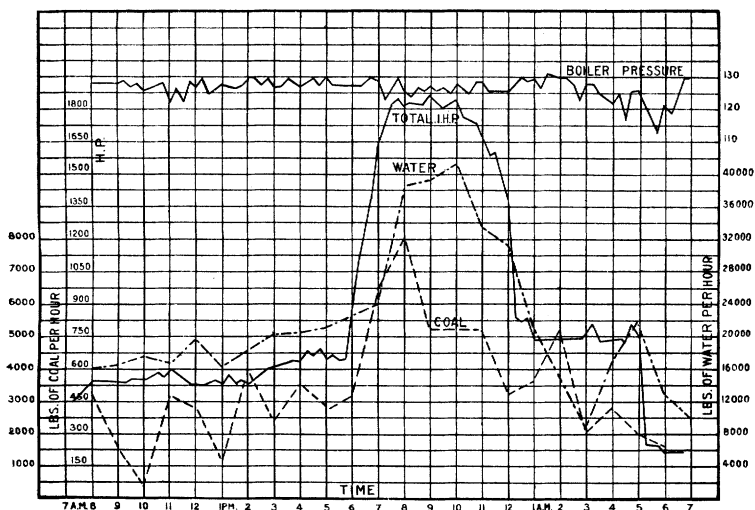


FIG. 1.—Pratt Street Station, Graphical Record, Aug. 31, Sept. 1, 1895.

fact that all of the boilers were not in service all of the time.

All of them were in service some of the time, and some of them were in service all of the time.

In view of the fact that great care was taken during the trial to have the coal and water supplied to the boilers in just the proportions that were necessary to meet the demands made upon the boilers by the engines, it has been thought advisable to work up the data of the boiler trial over the portions of time during which certain of the boilers were in continuous service, in order that an estimate might be gained of the relative evaporative efficiency of the different batteries.

In column 3 of table 4 are presented the results of the boiler trial between 7 A. M. and 1 P. M. on Aug. 31. During this time boilers 6, 7, 8 and 9 were continuously in service and operated alone.

In column 5 of table 4 are presented the results of the boiler trial between 3 P. M. of August 31st and 1 A. M. of September 1st. During this time the entire boiler plant was in continuous service.

In column 7 of table 4 the results of the boiler trial during the hours of the heavy load, between 7 P. M. and midnight of Aug. 31 are given.

These results, when studied in connection with those of the trial of Sept. 7, reveal much valuable information regarding the efficiency of the boilers as well as the most economical methods to be employed in operating the boiler plant.

The Boiler Test of Sept. 7th.:—The boiler test of Sept. 7th was similar in all its details to the tests made on Aug. 31.

The records of the test are contained in tables 3 and 4. By comparing the data in tables 2 and 3 it will be found that the boilers were cut in and out on Sept. 7, at almost the same hours as the same boilers were cut in and out on Aug. 31. For example the trials were commenced on both days with boilers 6, 7, 8 and 9 in service; at about 2:20 P. M., boilers 1, 2, 3, 4 and 5 were cut in and from that time on till 1:45 A. M. of the second day of each test, none of the boilers were cut out. This fact has made it possible to report the trials in precisely the same manner. The general report for the entire 24 hours is given in table 4, column 2. The results here recorded are based upon boiler log and the average square feet of grate surface, water heating surface and horse power rating that are given in table 3. The "average rated horse power" is based upon the basis of the builders horse power rating, and the "average real horse power" is determined upon the basis of 11.5 square feet of heating surface in the boiler tubes being the equivalent of one horse power. This explanation also applies to items 44—44.5—45 and 45.5 of the boiler reports.

A report on the trial of boilers, 6, 7, 8 and 9 between the hours of 7 A. M. and 1 P. M. of Sept. 7 is set forth in column 4 of table 4. During this time the boilers mentioned were the only ones in service.

TABLE 2.

RECORD OF TEST OF STATION. AUGUST 31 AND SEPTEMBER 1, 1895.

Table showing the number of hours during which the respective boilers were in service.

No. of Boilers.	Hour started, Aug. 31.	Hour stopped, Sept. 1.	No. of hours in service, Hrs. Min.	Sq. ft. grate surface.	Sq. ft. grate surface, hours.	Sq. ft. water heating surface, face.	Sq. ft. water heating surface, hours.	Rated Horse-power.	Rated Horse-power hours.	Real Horse-power.	Real Horse-power hours.
1	2:15 p. m.	3:25 a. m.	13 10	65.	855.40	2447.3	32206.46	250	3290.00	186.5	2454.34
2	" "	2:50 "	12 35	23.52	295.88	770.92	9698.17	125	1572.50	61.2	769.896
3	" "	2:50 "	12 35	23.52	295.88	770.92	9698.17	125	1572.50	61.2	769.896
4	" "	1:45 "	11 30	23.52	270.38	770.92	8865.58	125	1437.50	61.2	703.80
5	" "	1:45 "	11 30	23.52	270.38	770.92	8865.58	125	1437.50	61.2	703.80
6	7:00 a. m.		24	52.5	1260.00	3068.6	73646.40	250	6000.00	242.6	5822.40
7	" "		24	52.5	1260.00	3068.6	73646.40	250	6000.00	242.6	5822.40
8	" "	5:45 "	22 45	52.5	1194.37	3068.6	69810.65	250	5687.50	242.6	5519.15
9	" "	5:30 "	22 30	52.5	1181.25	3068.6	69043.50	250	5625.00	242.6	5458.50
Totals,					6883.54		355480.98		32621.50		28024.182

Average square feet grate surface $\frac{6883.545}{24} = 286.73$

Average rated horse-power $\frac{32621.50}{24} = 1359.2$

Average square feet water heating surface $\frac{355480.98}{24} = 14811.7$

Average real horse-power $\frac{28024.182}{24} = 1167.66$

TABLE 3.

RECORD OF TEST OF STATION. SEPTEMBER 7-8, 1895.

Table showing the number of hours during which the respective boilers were in service.

No. of Boilers.	Hour started Sept. 7.	Hour stopped Sept. 8.	No. of hours in service. Hrs. Min.	Sq. ft. grate surface.	Sq. ft. water heating surface.	Sq. ft. water heating surface.	Rated Horse-power.	Rated Horse-power hours.	Real Horse-power.	Real Horse-power hours.
1	2:25 p. m.	6:00 a. m.	15 35	65.	1012.895	2447.3	250	3895.75	186.5	2996.229
2	" "	3:15 "	12 50	23.52	301.76	770.92	125	1603.75	61.2	785.196
3	" "	" "	12 50	23.52	301.76	770.92	125	1603.75	61.2	785.196
4	" "	3:20 "	12 55	23.52	303.64	770.92	125	1613.75	61.2	794.892
5	" "	" "	12 55	23.52	303.64	770.92	125	1613.75	61.2	794.892
6	7:00 a. m.	" "	24	52.5	1260.00	3068.6	250	6300.00	242.6	5822.4
7	" "	" "	24	52.5	1260.00	3068.6	250	6300.00	242.6	5822.4
8	" "	12:45 "	17 45	52.5	931.87	3068.6	250	4437.50	242.6	4306.150
9	" "	5:50 "	22 50	52.5	1198.57	3068.6	250	5625.00	242.6	5538.558
Totals				6874.135	350382.89			32393.25		27555.913

Average square feet grate surface	$\frac{6874.135}{24} = 286.45$	Average rated horse-power	$\frac{32393.25}{24} = 1345.71$
Average square feet water heating surface	$\frac{350382.89}{24} = 14599.7$	Average real horse-power	$\frac{27555.913}{24} = 1147.32$

In column 6 of table 4 the results contained in the boiler log between the hours of 3 P. M. Sept. 7, and 1 A. M., Sept. 8, are given in the form of a report on a test of all the boilers in the station operating at one time, and in column 8 a similar record is reported of the economy of the plant when working under the heavy load that comes on the station between 7 P. M. and midnight.

The graphical records of this boiler trial are presented in Fig. 2 and for the value of the comparison the total indicated horse power curve is plotted, in connection with the curves that pertain purely to the boiler tests.

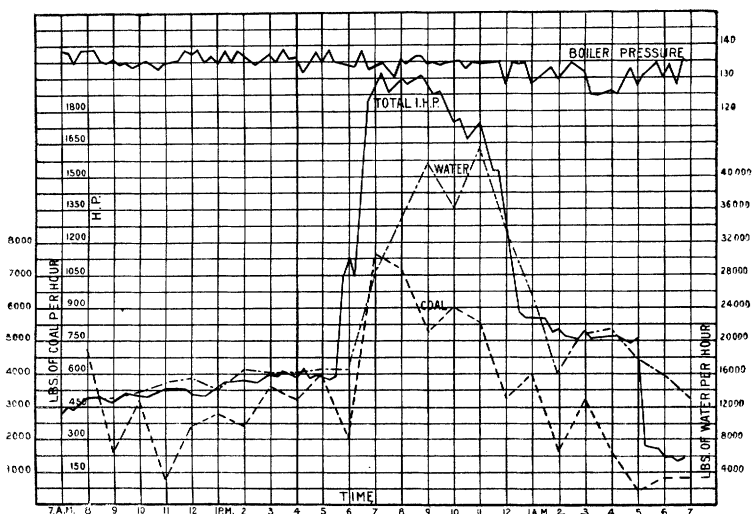


FIG 2.—Pratt Street Station, Graphical Record, Sept. 7, 1895.

REVIEW OF THE BOILER TESTS.

As the tests and portions of tests that have been reported amount to nine in all, and require a table containing ten columns, it is necessary to refer to the tabulated quantities by numbers.

The signification of the numbers is as follows:

1. Number of boilers in service.
2. Duration of trial.
3. Boiler pressure by gauge.
13. Temperature of steam.
15. Temperature of feedwater leaving heater.
- 15.5 Temperature of feedwater entering heater.

17. Per cent. of moisture in coal.
19. Per cent. of refuse in coal.
24. Per cent. of moisture in steam.
31. Water actually evaporated per pound of dry coal, from actual temperature and pressure.
32. Equivalent water evaporated per pound of dry coal, from and at 212 degrees Fah.
33. Equivalent water evaporated per pound of combustible from and at 212 degrees Fah.
35. Dry coal actually burned per sq. ft. of grate surface per hour.
39. Water evaporated from and at 212 degrees Fah. per sq. ft. of heating surface per hour.
43. Commercial horse power.
44. Horse power by builder's rating.
- 44.5 Horse power on a basis of 11.5 sq. ft. of heating surface in the tubes per horse power.
45. Per cent. of item 43 below item 44.
- 45.5 Per cent. of item 43 below item 44.5.

TABLE 4.
BOILER TEST DATA.

o	1	2	3	4	5	6	7	8	9
Number	7 A. M. Aug. 31, to 7 A. M. Sept. 1.	7 A. M. Sept. 7, to 7 A. M. Sept. 8.	7 A. M. Aug. 31, to 1 P. M. Aug. 31.	7 A. M. Sept. 7, to 1 P. M. Sept. 7.	3 P. M. Aug. 31, to 1 A. M. Sept. 1.	3 P. M. Sept. 7, to 1 A. M. Sept. 8.	7 P. M. Aug. 31, to 12 M. M.	7 P. M. Sept. 7, to 12 M. M.	6 P. M. Sept. 1, to 5 A. M. Sept. 2.
1	ALL AT TIMES.		{ 6, 7, 8, } { and 9. }		{ 1, 2, 3, 4, 5, } { 6, 7, 8, 9. }		{ 1, 2, 3, 4, 5, } { 6, 7, 8, 9. }		{ 6, 7, } { and 8. }
2	24	24	6	6	10	10	5	5	11
7	126	134	127	136	127	135	126	135	126
13	353	357	352	357	354	357	353	358	353
15	200	200	207	200	205	200	206	200	191
15.5	71.3	70.5	71.4	70.8	71.3	70.5	71.3	70.0	71.4
17	13.8	6.26	3.1	6.26	13.8	6.26	13.8	6.26	3.1
19	10.4	10.	10.4	10.	10.4	10.	10.4	10.	10.5
24	.81	.97	.70	.83	.90	1.04	.95	.91	.87
31	7.18	7.04	8.33	5.80	7.23	6.48	7.88	7.40	10.1
32	7.59	7.46	8.87	6.15	7.77	6.86	8.34	7.84	10.7
33	8.32	8.29	9.90	6.83	8.77	7.62	9.31	8.71	12.0
35	10.4	10.6	9.53	11.6	10.8	12.2	12.5	13.8	11.4
39	1.53	1.54	1.46	1.22	1.79	1.73	2.11	2.24	2.09
43	655	654	515	439	900	895	1116	1158	557
44	1359	1359	1000	1000	1750	1750	1750	1750	750
44.5	1168	1147	970	970	1402	1402	1402	1402	728
45	51.7	51.8	48.5	56.6	48.5	49.0	36.2	33.8	25.7
45.5	43.8	43.9	46.9	55.2	35.7	36.1	20.5	17.5	25.4

The quality of the coal fired to the boilers during the tests was only fair, and as shown in item 19, contained quite an amount of ash and other refuse. The coal was soft and a great deal of it very fine, and it crumbled to pieces under very slight pressure. Altogether I should say that its quality was considerably below the average of the coal that is mined at George's Creek, western Maryland, the point from which the coal in question was obtained.

Nevertheless the evaporative efficiency of the plant is very fair. Item 31 shows that the evaporation per pound of coal varied from 7.04 to 10.1 pounds of water under actual conditions, and the equivalent evaporation from and at 212° F. varied from 8.29 to 12 pounds of water per pound of combustible as stated in item 33. The fluctuation in these values is due partly to the fact that some of the boilers are more efficient than others, but the most potent factor in the reduction of the economy is the inefficient loading of the plant.

During the greater portion of the time the boilers were not developing 60 per cent. of their capacity based upon 11.5 square feet of heating surface in the tubes per horse-power, and at

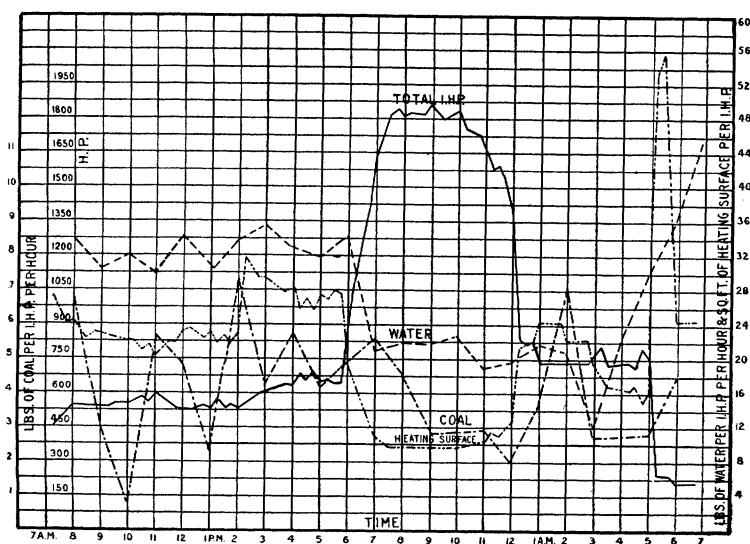


FIG. 3.—Pratt Street Station, Economy Record, Aug. 31, Sept. 1, 1895.

other times they were not developing half of their capacity. This statement is equivalent to saying that during a considerable portion of the test a good share of the heat of the furnaces was used up in heating the iron frame work and the walls, instead of being utilized in evaporating water into steam.

To illustrate this condition of affairs more clearly, an economy record has been plotted in Figs 3 and 4. These plates show the relative amount of coal, water and square feet of heating surface in the boilers per indicated horse-power. The "heating surface" curves are the ones to which I would call your attention at present. It will be noticed that up to 2 o'clock in the afternoon of

each day there was an average of over 22 square feet of heating surface in the part of boiler plant in active operation to each indicated horse-power developed by the engines. Between two o'clock and six o'clock, the ratio of heating surface to horse-power is increased to 29, and it is not until 7 P. M. that the ratio falls within the limits of economic operation. Between 7 P. M. and midnight on August 31, the boiler plant developed within 20 per cent. of its true horse-power and as a result the economic evaporation went up to a very good value—9.3 pounds of water per pound of combustible. The same result was apparent during the same period on the night of September 7, and although the

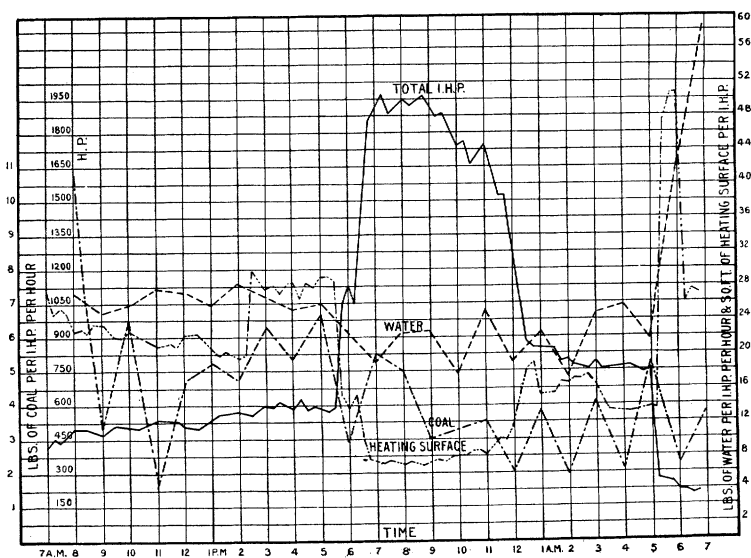


FIG. 4.—Pratt Street Station, Economy Record, Sept. 7 and 8, 1895.

evaporative efficiency is not apparently as high, it is well above the average evaporative efficiency of the plant for the whole 24 hours. In considering the results of the partial tests it must be borne in mind that they are not absolute. They are based on the assumption that the water and coal were supplied to the boilers in just the proportion necessary to meet the requirements of the load, but of course it was not possible to do this with absolute accuracy. For instance, the curves in Figs. 1 and 2 show that proportionally more coal and less water were supplied to the boilers on August 31 between midnight and 7 A. M., than during

the same hours on September 7, and the effect of this is to reduce the apparent evaporative efficiency of the boilers on September 7, during the periods covered by the partial reports. None of the partial reports take in the early morning hours.

It is noticeable, however, that the efficiency of the boilers is relatively lower during the periods when the average heating surface per i. h. p. is high than at other times. Between 3 P. M. and 1 A. M., for instance, when there is an average of about 16 square feet of heating surface per i. h. p., the boilers only develop 64 per cent. of their capacity and only evaporate an average of 8.19 pounds of water per pound of combustible (see item 33).

Some of the boilers seem from the results to be less efficient than others. In bringing out this point let us compare the evaporative efficiency of the "new" boilers on the east side of the station with that of the "old" boilers on the west side of the station. On September 7, between 7 A. M. and 1 P. M., the "new" boilers were the only ones in service. By item 45.5 they were developing only 44.8 per cent. of their capacity, but their evaporative efficiency per pound of combustible averaged 6.8 pounds of water.

On the morning of August 31, the same boilers evaporated 9.9 pounds of water per pound of coal when loaded to only 53 per cent. of their capacity, and on the night of the special test (see column 9, table 4) they evaporated an average of 12 pounds of water per pound of combustible when working under a load of less than 75 per cent. of their capacity. These figures are all excellent when the conditions are taken into consideration and indicate that the "new" boilers are highly efficient.

Now, although the old boilers were never operated alone, and we have no records showing their absolute evaporative efficiency we can nevertheless judge of their economy very accurately by noting the effect they have upon the evaporative efficiency of the plant when they are operated in connection with the "new" boilers. For instance, between 3 P. M. and 1 A. M. of each of the 24-hour tests the whole plant was loaded to 64 per cent. of its capacity and it evaporated an average of only 8.2 pounds of water per pound of coal. This figure does not begin to equal the evaporation of the "new" boilers when operated alone, at a less percentage of their capacity. Again the whole plant even when

operated at an average of 81 per cent. of its capacity between 7 P. M. and midnight did not reach the evaporative efficiency that the "new" boilers developed on the morning of Aug. 31, and did not come within 17 per cent. of the evaporative efficiency of the "new" boilers during the special test, although they were more efficiently loaded.

It seems that sufficient evidence has been produced to establish the assertions that the evaporative efficiency of the "new" boilers is good, and that the evaporative efficiency of the whole plant is only fair. This means that there is a disturbing element present somewhere and the general indications are that the defect lies in the old boilers. It would not be surprising to find that the "old" boilers will not evaporate over 6.5 or 7 pounds of water per pound of coal even under the most favorable conditions of loading and when fired with the best quality of coal. During my stay at the plant, I several times had my attention called to the fact that great difficulty was often experienced in keeping up the steam pressure in the "old" boilers, and this was expressly noticeable whenever the "new" boilers were cut out for any reason and the "old" had to be depended upon to furnish the steam supply.

The quality of the steam evaporated by the boilers remained fairly constant. At no time during any of the tests however was the slightest trace of superheating discernible. The smallest percentage of moisture recorded is that at 2 P. M. on Sept. 7, when only .3 of one per cent. of moisture was apparent. The greatest percentage of moisture was recorded at 6 A. M. on Sept. 7, when there was 1.24 per cent. of moisture in the steam. On the whole however, the percentage of moisture is low and it is also very uniform for all loads. It may be well to note that the pipe condensation, as determined by collecting and weighing all the drainage water from the separators and steam traps, proved to be .505 of one per cent. of the total water actually evaporated on Aug. 31; .31 of one per cent. of the water actually evaporated on Sept. 7; and nearly .5 of one per cent. of the water actually evaporated during the special test. These figures represent to a large extent the proportion of the entrained water and water of condensation that was extracted from the steam by the separators, as most of the drainage water was taken from them, and it is safe to say that the separators extract fully 70 per cent. of the moisture contained in the steam, from the

steam. This leaves the steam practically dry when it passes the separators. The average of about 2 per cent. of moisture that the steam in the steam pipe of engine No. 1, was found to contain on the night of the special test, was largely due to there being no separator between the engine and the boilers.

The greatest amount of coal is fired to the boilers on both days between 7 and 8 o'clock in the evening when the fires are being built up for the heavy night load. At this time the coal is supplied at the rate of 7500 pounds per hour. On this account exception may be taken to the evaporative efficiencies determined for the boilers between 7 P. M. and midnight on the score that the proportion of the coal fired within this time is in excess of the normal requirements of the boilers. In answer to this I will call attention to the fact that the fires were about burnt out at midnight, as the coal curves of Fig. 1 and 2 both show that the rate of firing had to be increased immediately after midnight.

The rate of combustion per square foot of grate surface conforms to the practice common with boilers of this class. The maximum rate maintained was 13.8 pounds on September 7, during the heavy night run, and the lowest appears to have been on the morning of August 31, when it amounted to 9.5 pounds. The maximum efficiency of the boilers will probably be attained when the combustion averages between 12 and 13 pounds of coal per square foot of grate surface per hour. The rate of combustion per square foot of heating surface is also rather low and plainly indicates that even during the heaviest loads the limit of economy in this respect was not reached by 20 or 25 per cent.

Finally, the results of the tests demonstrate the fact that the daily economy of the station would be greatly improved if greater care were exercised in the adjustment of the capacity of the boilers in service to the load. Boilers Nos. 6, 7, 8 and 9 will easily and economically generate an actual indicated horse-power for every eight square feet of their heating surface. This will make the capacity of each boiler, relatively to the demands of the engines, equal to 350 H. P., and will represent a total capacity equivalent to 1,400 I. H. P. If the requirements of the load had been economically met, only boilers 6 and 7 would have been operated between 7 A. M. and 6 P. M. on the days of the tests; between 6 and 7, boilers Nos. 3, 4, 5, 8 and 9 would have been cut in; between 11:30 P. M. and 12:30 A. M., boilers 3, 4 and

5 would have been cut out, and between 12:30 A. M. and 1 A. M. boilers 6 and 7 would have been cut out. This would have left boilers 8 and 9 in service to carry the load until 5 A. M. when one of them could have been cut out and the other left to carry the Sunday load, which is always light. Such a boiler schedule would have entirely eliminated the necessity of operating the entire plant and would have resulted in an average economic evaporation of between 11 and 12 pounds of water per pound of coal.

This would mean a saving of between 25 and 31 per cent. of the coal fired into the boilers. These figures are based on the assumption that boilers 1, 2, 3, 4 and 5 will evaporate the water for one indicated horse-power per hour from each 11.5 square feet of their heating surface, and that boilers 6, 7, 8 and 9 will evaporate the water for an indicated horse-power per hour from each eight square feet of its heating surface. Under these conditions the boilers would be economically loaded and capable of developing their best economy in consequence.

If we compare the actual economy of the station boiler plant with the results that have recently been published by the *National Electric Light Association*, we find that the actual evaporation per pound of coal is above the average, that the actual evaporation per pound of combustible is about equal to the average, and that the evaporation from and at 212 degrees, per pound of combustible, is a little below the average of the figures published for these quantities.

This simply means that there is room for improvement, although it must be admitted that the coal used in the stations exceeding the economy of the Pratt Street Station seems to be of better quality.

During the heavy loads the economy of the boiler plant was above the average of tests reported, and during the "special" test it exceeded everything reported by the *National Electric Light Association*.

NOTES ON THE ARC LIGHTING MACHINERY.

The special test of Engine No. 1 and Dynamos No. 7 to No. 18:—Three tests were made upon engine No. 1 and the arc light machinery driven by it. Two of these, the first and the last, were made in connection with the general station tests of Aug. 31st and Sept. 2nd, but the second was for the special purpose of determining the evaporative efficiency of the newer part of

the boiler plant; namely, boilers Nos. 6, 7, 8, and 9, and the steam consumption per indicated horse power per hour of the engine in question.

For the special test it was decided to use boilers, Nos. 6, 7, and 8, thus providing a total boiler capacity of 750 H. P. to meet the requirements of the load on the engine, which frequently amounted to over 700 H. P.

The stop valves leading to engines Nos. 2, 3, 5, and 8 were securely closed. Suitable small tanks were provided to receive the water that accumulated in the separator in the centre of the station and to catch the condensed steam, when it was removed from the various points at which it collected. The total amount of pipe condensation for the eleven hours' run was 1168.9 pounds or 0.5 of one per cent. of all the water evaporated in the boilers.

The report of the trial of the boilers is given in table 4, column 9. The performance of the boilers was very creditable. The evaporation of 12 pounds of water per pound of combustible from and at 212° Fah. is far above the average evaporation obtained in the central stations throughout the country and will compare favorably with the best tests yet reported upon water tube boilers. The average horse-power developed by the boilers during the test was 25.75 per cent. below the rating of the boilers, allowing 11.5 sq. ft. of heating surface in the tubes per horse-power. The evaporation of 12 pounds of water would therefore probably have been exceeded had the load upon the boilers been heavier, as they are designed to admit of a considerable overload.

The quality of the steam evaporated was determined by a throttling calorimeter placed in the side of the east main between boilers No. 7 and No. 9. The results showed that at no time was there more than 1.07 per cent. of moisture in the steam and that at times this figure was reduced to 0.7 of one per cent.

The pyrometer test of the flue gases showed that their temperature at the base of the stack, where the pyrometer was placed, was about the same as the temperature of the steam generated in the boilers. This indicates that little of the furnace heat is wasted, and speaks well for the design of the boiler.

The load on the engine was practically constant at 700 H. P. during the earlier part of the evening, and was reduced to a value of about 480 H. P. during the latter part.

The average I. H. P. for the whole test is 553.82 H. P. and the average E. H. P. is 382.6 H. P. The ratio of these would give an apparent efficiency of conversion of 69.04 per cent. This is the usual method of determining such efficiencies and it gives a very gratifying result, when we compare it with similar results of tests on lighting plants of this type that have been published. The real average efficiency, however, is the average of the ordinates of the efficiency curve which is 66.7 per cent. This is the lowest value obtained on either of the three tests made upon this engine, a fact that is probably due to the load having been somewhat lighter than during the other tests.

One object of this test, however, was to determine the actual water consumption of the engine. The values were obtained by dividing the pounds of water delivered to the boilers during each hour by the average I. H. P. for the corresponding hour. The amount varies from 26.9 to 38.3 pounds, the average being 32.96 pounds of water per I. H. P. per hour. This value is extremely high for an engine of this type. The theoretical value computed from the indicator cards gives an average of about 18 pounds of water per I. H. P. as the water consumption. If we add to this the percentage for internal condensation that practical experience has shown is necessary, we find that the engine ought not to require over 23 pounds of water per I. H. P. and everything above this value is in excess of the limit of even fair economy. This excessive water rate is partly due to the low ratio of expansion employed, but chiefly to leakage of steam past the pistons of the engine.

An examination was made of the cylinders, and the valves and pistons were tested for leakage. The inside of the high pressure cylinder was found to be quite a good deal cut all round, especially on the left side parallel to the axis of the cylinder. When steam was turned on it blew past the piston uniformly all round, except in one place on the right side where the leakage was somewhat greater. The steam chest cover was removed and the valve examined. The design of the valve is such that it delivers steam from both sides. It seemed to be tight on its seats but the steam leaked through a joint in its center into the receiver.

The steam chest cover and the high pressure cylinder cover were replaced and the low pressure cylinder head removed. The bottom and the sides of the low pressure cylinder half way up,

showed a good deal of wear, the surface of the cylinder being quite rough. With the crank of the high pressure piston on a dead center, steam was turned on. It leaked into the receiver, and the pressure in the receiver rose to 15 pounds gauge pressure in one minute, although steam was blowing past the low pressure piston freely all the time.

Fifteen pounds pressure in the low pressure cylinder should have been sufficient to blow the piston rings out to the sides of the cylinder and stop the leakage past the piston had the piston, its fittings and the sides of the cylinder been in good condition. There can be no reasonable doubt but that there was leakage of steam past the pistons of this engine during its operation. This fact can also be detected from the indicator cards. The results of the calorimeter tests that were made of the quality of the steam in the steam pipe and the receiver during the run of Sept. 1st and 2d, show that at 10 P. M. the steam entering the high pressure cylinder contained 1.86 per cent. of moisture, but that when it was discharged into the receiver it *contained only 0.79 per cent. of moisture*. About this same quality was determined for the steam in the receiver during the entire time of the heavy load, but whenever the load became lighter (500 H. P. or less), so that the steam expanded to about twice its initial volume in the high pressure cylinder, between 7 and 13 per cent. of moisture became apparent in the steam in the receiver. In other words the steam was wet when discharged from the high pressure cylinder. These results were obtained with a throttling calorimeter on the steam pipe, and a throttling and a separating calorimeter on the receiver, and have an important bearing upon the water consumption of the engine.

So far nothing has been said regarding the mechanical efficiency of engine No. 1.

The engine is directly connected to a very large line of shafting extending along the east side of the station a distance of 70 feet. This line shaft is supported on eight evenly spaced pedestal bearings, and is equipped with 12 friction clutch pulleys to which the dynamos are belted.

The average indicated friction horse power of the engine amounted to 54.31 H. P. with the clutches thrown on, and to practically the same (54.1 H. P.) with the clutches thrown off. These are the lowest values of the friction load recorded, and it is a noticeable fact that the friction of the clutch pulleys is about

the same as the friction of the armatures and belts of the dynamos. It would therefore seem that although the use of friction clutches reduces the wear on the dynamos when they are out of service, they do not reduce the friction load.

The friction cards taken on Aug. 31st indicated that the power absorbed in the friction of this shafting is often in excess of the

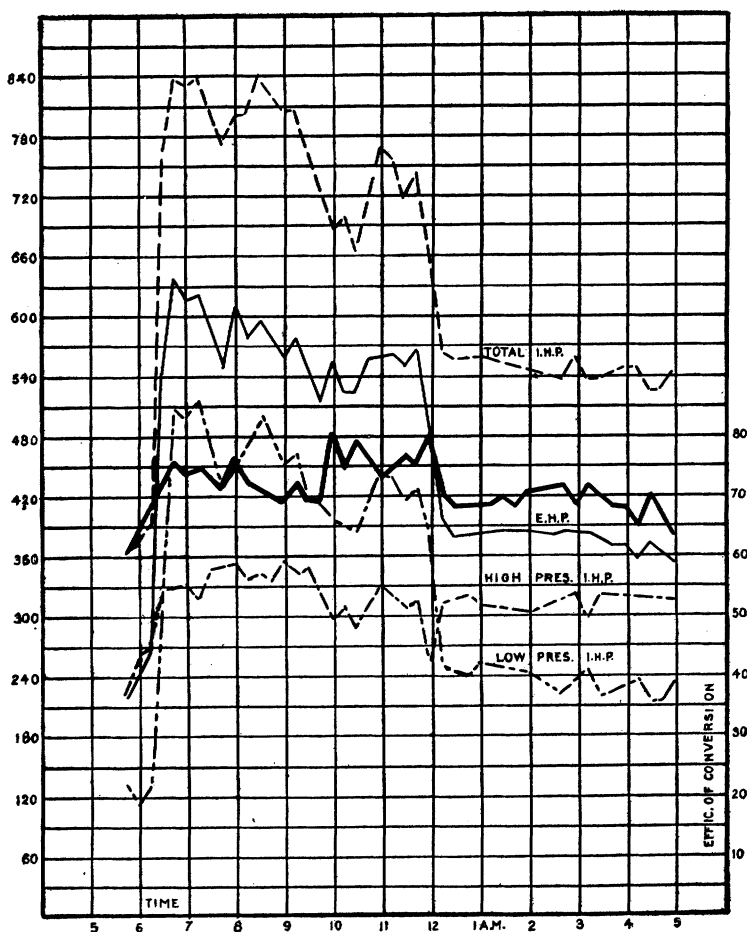


FIG. 5.—Engine No. 1. Dynamos Nos. 7 to 18, Sept. 7 and 8, 1895.

figures just noted. In fact, the results of the tests made on Sept. 1st and 7th show a difference of over 225 H. P. at times between the indicated horse power of the engine and the total electrical horse-power developed. If we allow 40 H. P. of this amount for

the friction of the engine alone, and the same amount for the friction of all the loaded dynamos, 145 H. P. or 18 per cent. of the power developed by the engine still remains unaccounted for, and since an ample allowance has been made for the engine and dynamos, it may be attributed to the friction of the shafting. This excessive friction only occurs during the heavy loads of 700 I. H. P. or over. On the night of August 31st the friction horse-power during the heavy load averages somewhat less than 225 H. P.; only about 150 H. P. in fact. During the lighter loads of 500 H. P. or less, the three tests show a very uniform friction loss of about 145 I. H. P. If we assume therefore that this engine is operated for 11 hours a day during 313 days in the year (which is practically the case) then there is an average total

TABLE 5.
DATA FROM TESTS OF ARC MACHINES.

No. of arc dy- namo.	Resistance.		Average Voltage Developed.			Average electrical efficiency. per cent.
	Armature.	Regulator and series field.	Aug. 31.	Sept. 1.	Sept. 7.	
7	13.63	30.81	3773	3728	3819	90.22
8	13.2	32.42			4097	90.44
9	13.05	31.96	2957	3110	3368	88.01
10	13.47	30.5	2545	3387	3330	88.04
11		30.1	2810	3801	3764	
12	12.43	29.7	3849	2970	3867	89.89
13	13.1	30.55	3606	3667	3896	89.72
14	13.2	30.59	3344	3706	3142	88.80
5	13.05	30.8	3622	3631	3858	89.85
16	13.11	31.09	3450	3320	3690	89.22
17	12.5	29.01	3240	3440	3799	89.83
18	12.51	30.4	3452	3595	3644	89.62

friction loss of 175 H. P., during that time, of which 100 H. P. is due to the friction of the line shaft alone.

Economy of the Arc Machines.—The average commercial efficiencies of the dynamos for the three tests recorded show that an average greater than 76 per cent. was maintained each day. These percentage ratios were obtained by dividing the total E. H. P. by the D. H. P. of the engine and are therefore decreased by the friction losses of the line-shaft and of the dynamo belts. The true efficiencies of the dynamos are therefore higher than these figures would indicate, and although it was impossible to make any exact determination, the following condensations lead us to a very close approximation. In table 5 will be found a statement of the average electrical efficiencies of the dynamos. These are determined from the

measurements that were made of the resistances of the armature and field windings of the machines and the average electrical horse-power developed by each machine during the three tests. The average of these efficiencies is 89.4 per cent., and if 5 per cent. is allowed for the remaining losses, we get 84.91 per cent. as the average commercial efficiency of the dynamos.

If we assume that the average yearly load upon the engine is 606 H. P., 68 per cent. of it is delivered as electrical energy for distribution, about six per cent. is absorbed in overcoming the friction of the engine, 10 per cent. is dissipated as heat due to the electrical and mechanical losses of the dynamos and 16 per cent. is absorbed in running the line-shaft.

Engine No. 2, Arc Machines Nos. 4, 5 and 6, and the Westinghouse Dynamo.—The engine is of the Russell four valve type, and as originally designed was regulated by an automatic fly-wheel governor. As, however, the fly-wheel governor did not work satisfactorily under 125 pounds boiler pressure, it was removed and the engine equipped with a throttling governor after the valve gear had been somewhat modified.

Previous to the tests the engine was thoroughly examined. The cylinder was in good condition. It was found, while measuring the clearance of the cylinder heads, that the piston and valves leaked water, but on the other hand they proved to be tight to steam when it was turned on to its full force.

During the tests a steam gauge was placed on the steam chest and a throttling calorimeter connected near it. These were the only special arrangements made.

The distribution of the power developed by the engine, between the ends of its cylinder was very nearly equal. There seemed however, to be a tendency to over-balance on the head end. But the most striking feature in connection with this engine is the action of the throttling governor. The initial steam pressure shown by the cards and the boiler pressure are graphically exhibited in Fig. 6. It is noticeable that although the boiler pressure is practically constant at something over 125 pounds gauge pressure, the steam chest pressure remains at about 35 pounds all during the day and falls as low as 20 pounds whenever the I. H. P. of the engine falls below 50 H. P. Even when the engine is developing 160 I. H. P. the steam chest pressure does not average above 50 pounds by gauge. This excessive throttling of the steam to from .4 to .16 of its initial pressure is very wasteful of

the heat energy contained in the steam and results in a high water consumption per I. H. P. per hour.

The calorimeter tests made upon the quality of the steam in

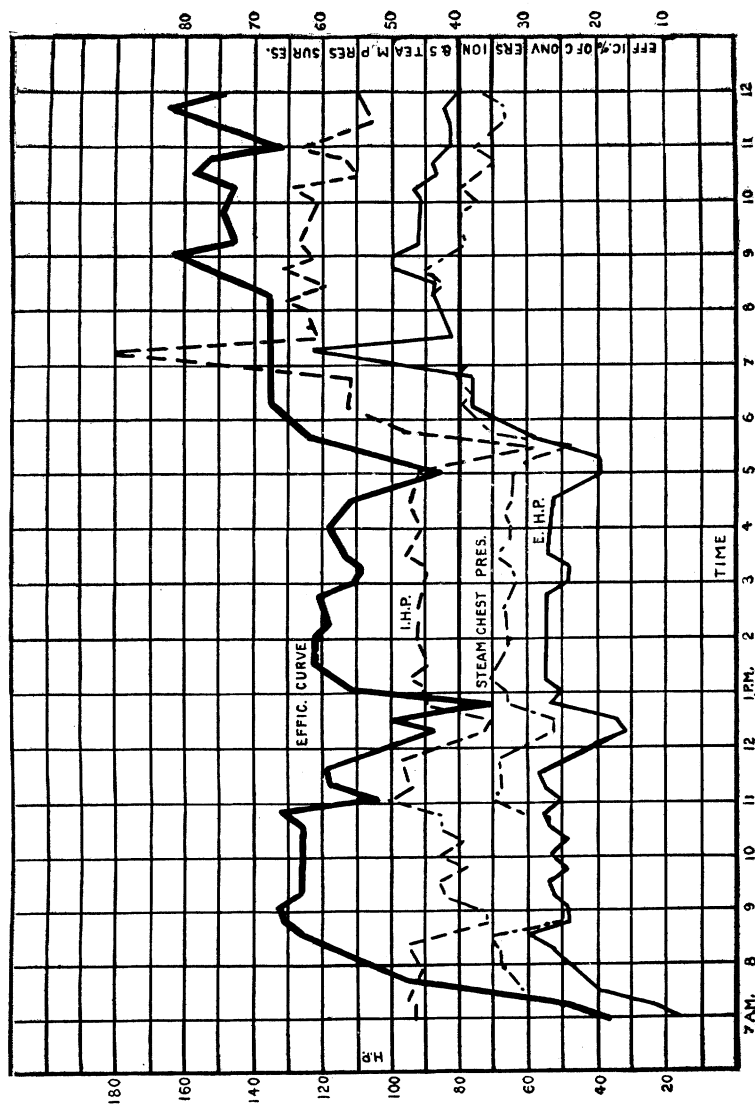


Fig. 6.—Engine No. 2. Dynamos 4, 5, 6 and W. Sept. 7 and 8, 1895.

the steam pipe, and in the steam chest, showed that as high as 24.4 degrees superheat is developed in steam initially containing 1.27 per cent. of entrained water.

In the calculations that have been made of the actual water consumption of the engine per indicated horse-power per hour, the theoretical results have been assumed to be correct, owing to the superheated condition of the steam entering the cylinder, and no allowance is made for cylinder condensation. Even under these conditions, the water consumption is high; during the light loads of about 50 H. P. it amounts to 49 pounds of water and during the heavy loads of 158 H. P. it runs as high as 30 pounds of water. Had the same correction for condensation been made here as in the case of the other simple engines the above figures would have been 64 and 35 pounds of water respectively.

The difference between the I. H. P. and the E. H. P. during the two days tests seem to average about 35 H. P. *for all loads* above 80 I. H. P. of the engine. This shows at once the advantage to be gained by keeping the engine well loaded.

To secure high efficiency it is by all means necessary to operate are dynamos as near full load as possible, their efficiency at half load being little better than 70 per cent. and at one quarter load only about 50 per cent. The bearing of this fact upon the case in hand becomes evident when it is known that during the day all the dynamos operated by this engine are loaded to less than one-half their normal capacity.

Engine No. 3 and Arc Dynamos Nos. 1, 2 and 3:—Upon examination, the equipment was found to be in good order. The engine proved to be sound in every particular.

In view of the fact that this engine, one of the oldest in the station, is in such good condition, and that it is operated under low pressure superheated steam, the temperature of which is almost as high as the temperature of the high pressure steam in the steam pipe, it does not seem probable that the excessive cutting in the cylinders of some of the engines can be due either to grit brought over in the steam from the boilers, or to the temperature of the steam interfering in the least with the cylinder lubrication. It would appear rather to be due to the fact that the engines referred to have not been properly designed for use with such high pressure steam, and that in consequence the piston rings bear upon the cylinders with such force that trouble ensues. Frequently the piston rings break, and then the weak spots in a cylinder suffer severely.

Like engine No. 2, the engine under discussion is regulated by means of a throttling governor, and all of the peculiarities that

were found to be characteristic of engine No. 2 are present in engine No. 3, only in an intensified degree. See Fig. 7.

During the light loads of 40 i. h. p. the water consumption

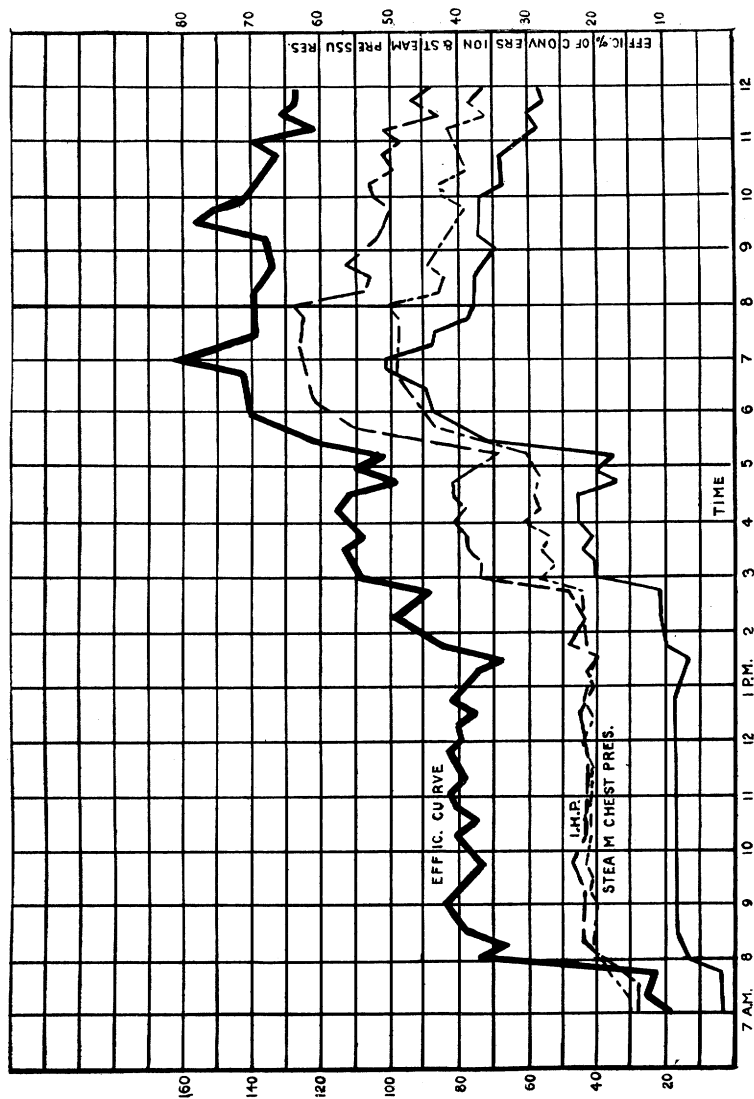


FIG 7.—Engine No. 3. Dynamos Nos. 1, 2 and 3. Sept. 7 and 8, 1895.

accounted for by the cards averages about 55 pounds. For the heavier loads requiring 125 i. h. p. or over, the water consumption by card falls off to 30 pounds. At these loads however it is

doubtful if the superheating is as effective in reducing cylinder condensation as at the lighter loads, both because the ratio of expansion by pressures is increased, and because the throttling of the steam during the heavier loads is very much less. Probably for these loads 25 per cent. should be added to the theoretical value for condensation.

The value of 42.59 pounds of water corresponds to the theoretical value obtained from cards showing about 70 I. H. P.; and, as during these loads the stem is throttled from 130 pounds to 25 pounds by gauge, the theoretical value is assumed to be equal to the real value.

The tests of the Arc Lighting Plant:—Being familiar with the general results of the tests made upon the arc lighting equipments considered independently of one another, it remains to give an account of the economic working of this machinery when considered in the light of a single plant. To this end the results of tests of the three separate equipments have been summed up.

On Aug. 31st the I. H. P. developed by the engines did not amount to over 150 H. P. up to six o'clock in the evening, it then rose to about 975 H. P. as the night load of commercial arc lamps and street lights came on. The total arc load remained about constant until twelve o'clock at night, when engines 1 and 2 were shut down and the commercial circuits opened. After this time the load was carried by No. 1 engine, and it remained about constant at 475 H. P. until the early morning. The efficiency of conversion averages about 61 per cent. between 7 A. M. and 6 P. M. and 12 P. M. and 5 A. M., but between 7 and 11:30 P. M. it averages not far from 77 per cent.

	Aug. 31.	Sept. 7.
The maximum I. H. P. recorded is.....	999	1146
The maximum E. H. P. recorded is.....	760	847
The average I. H. P. recorded is.....	404.8	434.8
The average E. H. P. recorded is	284.2	296.7
The average efficiency of conversion is	66.2%	61.9%

The arc lighting plant record for Sept. 7 and 8, is graphically represented in Fig. 13. The load on Sept. 7, did not average as high during the day as it did during the first test, but at night it made up for it very handsomely. The load increased on engines 2 and 3 about 5:30 P. M. and when engine No. 1 was started at six o'clock it immediately rose to a high value.

Eleven hundred and forty-six H. P. is just 250 H. P. in excess of the rated capacity of the engines, and if it had been evenly

distributed would have amounted to an overload of 27 per cent. The maximum electrical load was 7.6 per cent. below the rated capacity of the electrical machinery. On account of the load being light during the day, the average efficiency up to six o'clock P. M. is but little better than 51 per cent. and even during the heavy load between 6:30 P. M. and midnight the efficiency averages 4 per cent. lower than it did on the night of Aug. 31. During the morning run, however, when No. 1 engine was operated alone under an average load about 100 H. P. heavier than the load was during the morning of Sept. 1 the efficiency improved upon the first test about six per cent.

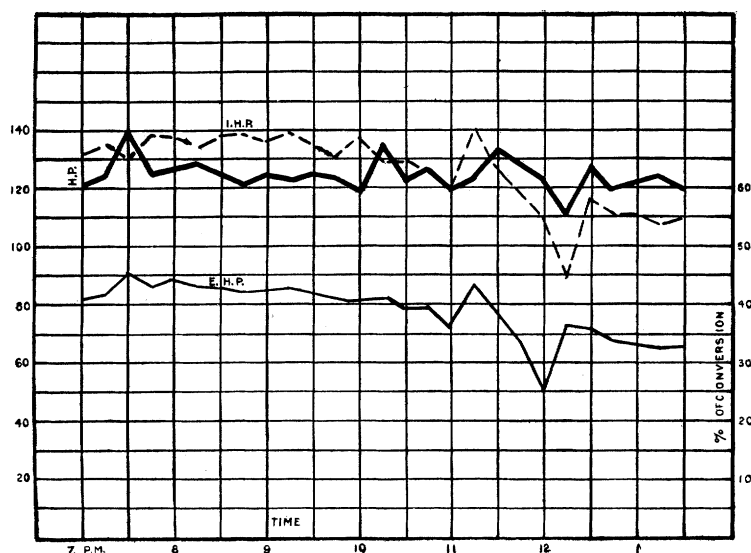


FIG. 8.—Engine No. 4, Dynamo E. Sept. 7 and 8, 1895.

Now the variations in the total efficiency of the arc plant on the two days are simply due to the fact that engines No. 2 and No. 3 were not loaded as heavily on Sept. 7 as they were on Aug. 31, and consequently although the load on the entire plant was heavier on the second day, the inefficient operation of a part of the plant entirely counteracted the good effect that usually comes with good loads.

If we calculate the apparent efficiency and take the ratio of the average I. H. P.'s. to the average E. H. P.'s. we obtain a very gratifying but a very deceptive result.

The apparent efficiency for the run of Aug. 31 is 70 per cent., and the apparent efficiency for the run of Sept. 7 is 68 per cent. A glance at the efficiency curve on Fig. 13 will immediately show that these results are of little value as an aid to gauging the *average hourly efficiency* of the plant. The "apparent efficiency" is however, of great value in determining the daily commercial economy of the machinery, since it equals the ratio of the average hourly product of the indicated horse power and the efficiency of conversion, to the average indicated horse power.

Had the entire day load been carried by engine No. 2, and had engine No. 3 not have been put in service until six o'clock (on either day,) No. 3 would have been just nicely loaded, and would have developed an efficiency of 75 per cent. or over. This would have had the result of making the all day efficiency of the plant about 73 per cent. on Aug. 31st and about 74 per cent. on Sept. 7th, instead of 66 per cent. and 61 per cent. respectively. When we remember that the steam economy of the plant during the day run would have been increased in even a greater proportion, the real increase in economy to be gained by such an arrangement becomes apparent.

NOTES ON THE INCANDESCENT LIGHTING MACHINERY.

Engine No. 4 and Alternator E.—This set consists of a simple horizontal high-speed Buckeye engine that is belted to a 16-pole Slattery alternator.

A very important point brought out by the tests on engine No. 4, is the necessity of having the valve of an engine properly adjusted. Without exception the cards from this engine showed that the admission of steam into the cylinder was far from free.

Between admission and cut-off the steam pressure was reduced about 40 per cent., whereas the corresponding decrease in engine No. 6 was practically negligible. As the steam pipe connections to these engines are of the same dimensions, with the advantage on the part of engine No. 4 of being nearer the boilers on the same steam main, the throttling of the steam must occur in the valve of engine No. 4. The effect of this throttling is to increase the apparent water consumption of engine No. 4, as shown by the cards, 14.7 per cent. above that shown by the cards of engine No. 6.

Engine No. 5 and Alternator F.—The engine runs very smoothly and regulates well, and the dynamo is so well designed and compounded that it needs practically no attention.

The only thing to mar the perfect adjustment of the engine was the fact that the ratios of expansion and the I. H. P. developed during the test were not equalized between the cylinders. The ratio of expansion in the high pressure cylinder was about twice as great as the ratio in the low pressure cylinder. The power indicated in the high pressure cylinder was also much greater than in the low pressure cylinder.

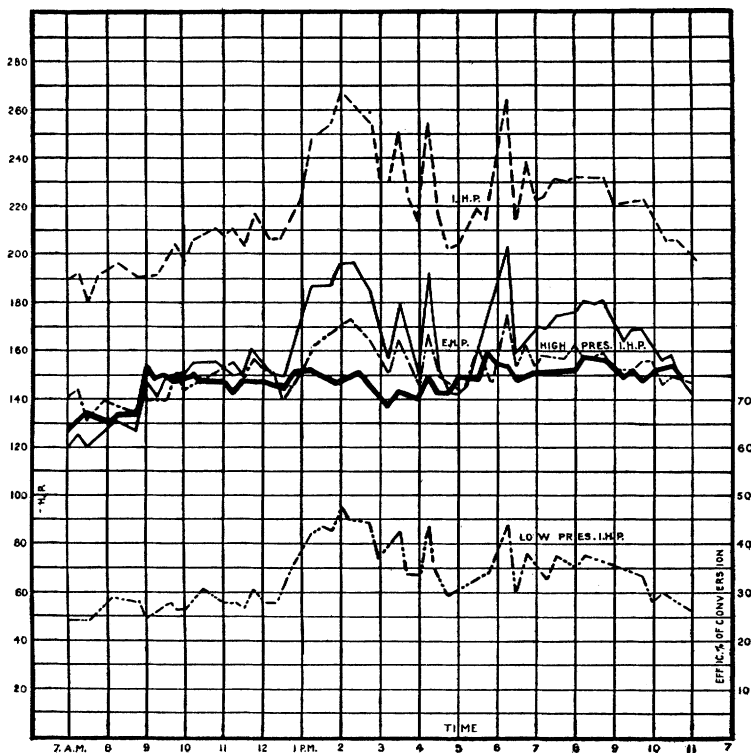


FIG. 9.—Engine No. 5. Dynamo F. Sept. 7 and 8, 1895.

During the tests, the load on the equipment required an average of 216 I. H. P. and there were no fluctuations of long duration on either side of this mean value of over 12 per cent. (see Fig. 9). If, therefore, the valves had been properly set for 216 I. H. P., there would have been a gain of several per cent. in the water consumption economy of the engine.

On the whole the performance of the engine was very creditable. It did not require much over 22 pounds of steam per I. H. P. per hour and the steam was expanded over nine times before being exhausted.

From the measurements that were made of the resistances of the various windings it would appear that the full load electrical efficiency of this dynamo is about 95.5 per cent., including the exciter and the exciter circuit. At full load the alternator develops 201 E. H. P.

The efficiency of the equipment on the basis of a full load of 200 E. H. P. on the dynamo, is 86.5 per cent. for the engine efficiency, 89.5 per cent. for the dynamo efficiency, and 77.3 as the efficiency of conversion.

Engine No. 6 and Alternator D.—The engine and dynamo that form this equipment are counterparts of engine No. 4 and dynamo E.

The dynamo was in good mechanical running order and developed no weak points during the tests.

The determinations that were made of the "actual" water consumption of the engine from representative indicator cards, ranged between 21.39 and 26.21 pounds of initially dry and saturated steam per indicated horse-power per hour, and after a careful review of the results and the conditions governing the test, it has been thought safe to assume that the engine did not consume on an average more than 22.6 pounds of steam per indicated horse-power per hour. The steam was expanded over 4.5 times, both by pressures and volumes.

The commercial efficiency of this set seems to be better than that of engine No. 4 and dynamo "E." In fact there is a difference of about four per cent. for all loads.

The efficiency of the engine is about 84 per cent. when the dynamo is fully loaded, and the efficiency of the dynamo is 88.2. These deductions are based upon the assumption that the full load efficiency of conversion of the equipment under the conditions of a constant load would be 73 per cent.

Engine No. 7 and Alternators B and C.—The engine is of the high speed cross-compound type manufactured by the Ball & Wood Company. Upon examination it proved to be in very good condition.

The records of the power developed in the cylinders indicate that the division of the work between the ends of either of the cylinders considered by itself was very nearly equal, but that the division of the work between the two cylinders was very unequal. During light loads of 150 I. H. P., 73 per cent. of the power of the engine was developed in the high

pressure cylinder, and during the heavy loads of about 240 I. H. P. 60 per cent. of the total power was developed in the high pressure cylinder. Following this same proportion it appears that the power developed in the cylinders would be equal when the engine is indicating 310 H. P.

With the engine loaded to 310 H. P. it is probable that the water consumption shown by the cards and the ratios of expansion of the steam in the two cylinders would be more nearly equal, since in this event the receiver pressure would increase and compression in the high pressure cylinder decrease.

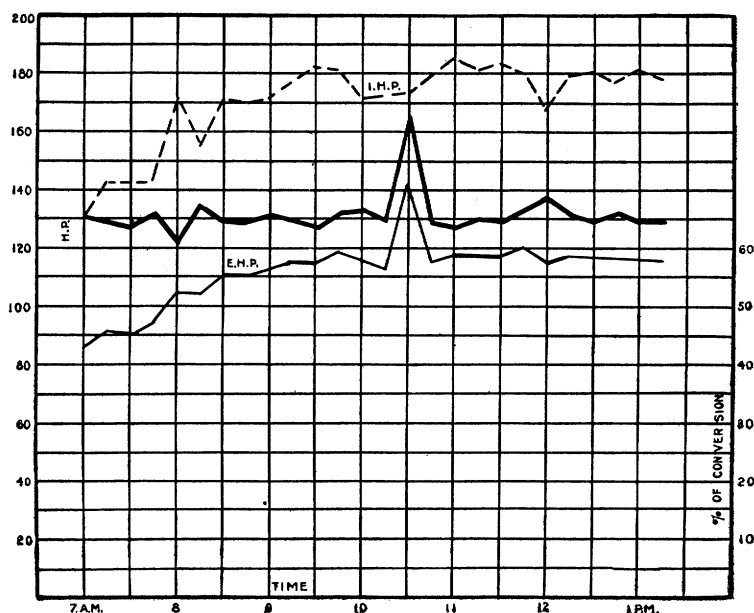


FIG. 10.—Engine No. 6. Dynamo D. Sept. 7 and 8, 1895.

At the time of making the tests, however, the valve setting was not at all adapted to the load. Cut-off in the low pressure cylinder and compression in the high pressure cylinder occurred much too late, and in consequence the receiver pressure is low, and the low pressure piston compresses the steam to a pressure between 10 and 15 pounds higher than the receiver pressure.

These things cause the water consumption shown by the cards to be greater in the low than in the high pressure cylinder. As, however, by far the *greater portion of the work* performed by

the engine is done in the *high pressure cylinder*, and as the ratio of expansion in this cylinder is much higher and, therefore, the cylinder condensation proportionally greater than in the low pressure cylinder, the "actual" water consumption determined from the high pressure cylinder cards is considered to be a fairly accurate determination of the real water consumption per i. h. p. per hour of the engine.

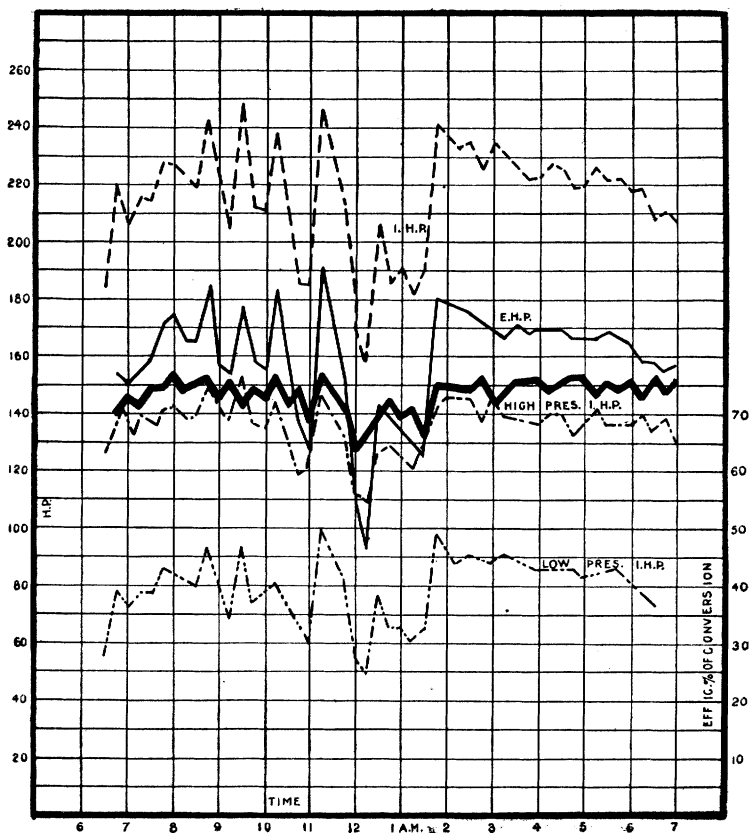


FIG. 11.—Engine No. 7. Dynamos B and C. Sept. 7 and 8, 1895.

Based upon these assumptions, the engine showed an economy of 21.5 pounds of water per i. h. p. per hour during the tests.

The final results of the tests (see Fig. 11.) show that the efficiency of this equipment, in spite of the fact that it contains *two* belted units, is very good. During the run of Aug. 31, the average efficiency of conversion was only 63 per cent. but this

was because the load on the engine was very light during a considerable portion of the time, so that between 4 P. M. and 7 P. M. the efficiency of conversion averaged but little over 55 per cent. Later in the night when the load rose to 240 H. P. the efficiency also improved and averaged above 70 per cent. The importance of keeping units well loaded cannot be too strongly emphasized.

Engine No. 8 and Alternator A.—Alternator A is of the same size and type as Alternator F. The engine is very similar in its general appearance to engine No. 5, and was manufactured by the same company.

Upon examination the engine cylinders were found to be very badly cut. The high pressure cylinder was scarred around the lower half in the middle, the scars beginning and ending about three inches from the cylinder heads. The top of the cylinder was smooth as it was not subjected to the same wear as the lower surface.

The low pressure cylinder piston fitted quite loosely also. The cylinder was badly cut on the right side below the horizontal diameter and extending past the bottom line two or three inches.

When the crank was placed on its dead centers and steam turned on, it leaked past the high pressure piston a little, but *past the piston valve into the receiver to quite an extent*. During the tests it was found that this leakage was sufficient to modify the cards to a marked degree.

The greater proportion of the power was developed in the head ends of the cylinders (see Fig. 12). In fact 63 per cent. of all the work done in the high pressure cylinder was performed in the head end of that cylinder, and 56 per cent. of the work done in the low pressure cylinder was performed in its head end. But the greatest discrepancy was that due to the unbalanced distribution of the load between the cylinders. When the engine was working under light loads of 160 I. H. P. I found that 62 per cent. of the load was carried by the low pressure cylinder. As a rule, it will be remembered, the high pressure cylinder carries the greater portion of the load during the light loads on an engine, and one would naturally expect the same thing to occur in the present case. As the load increases the condition of things is improved very little, and when the engine is indicating between 260 and 300 H. P., between 60 and 65 per cent. of the power is still developed in the *low pressure cylinder*. This is of course

wrong, and it occurs largely on account of the leakage of the steam past the high pressure piston valve into the receiver.

Under these conditions it is not surprising that the calculations for the water consumption of the engine should result in high values being obtained from the low pressure cards. Under the

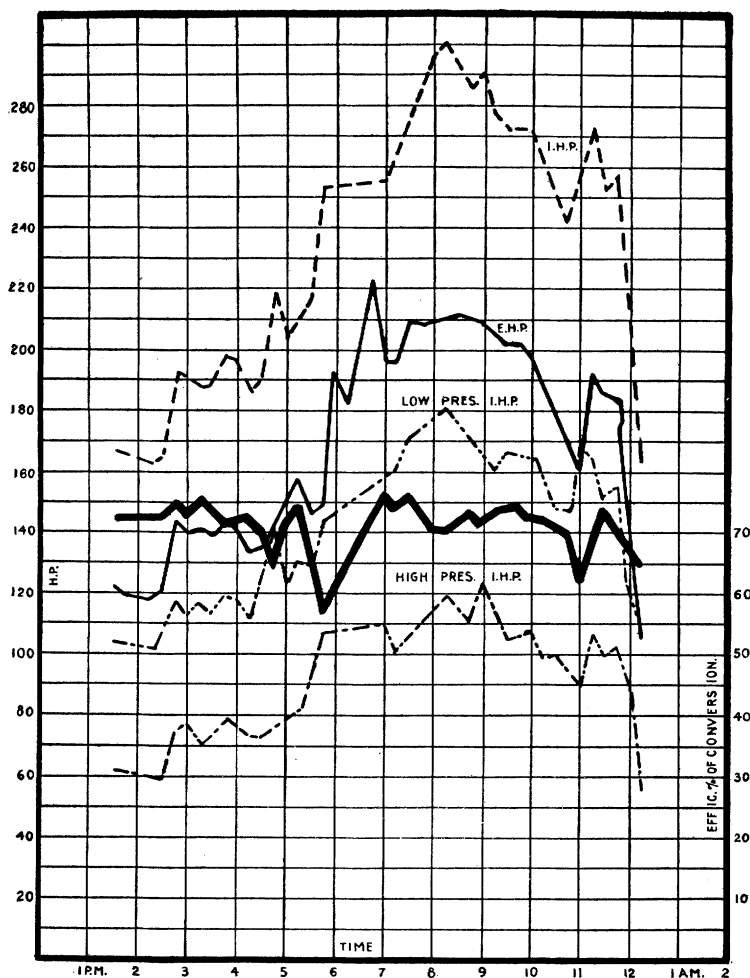


FIG. 12.—Engine No. 8. Dynamo A. Sept. 7 and 8, 1895.

circumstances the value of 29 pounds of water per indicated horse-power per hour, recorded as the average performance of the engine during the tests, should be regarded as a conservative estimate, and it is fortunate if the engine did not make a greater demand upon the boilers than these figures indicate.

The Tests of the Incandescent Lighting Plant.—We now come to a point where it will be interesting to discuss the tests that were made upon the incandescent lighting equipments collectively. It has been shown that it is possible under favorable conditions to operate these equipments at an average efficiency of conversion of 75 per cent., and it is of importance to know just what proportion of this figure was attained. If we take the average of the daily efficiencies actually attained by the several

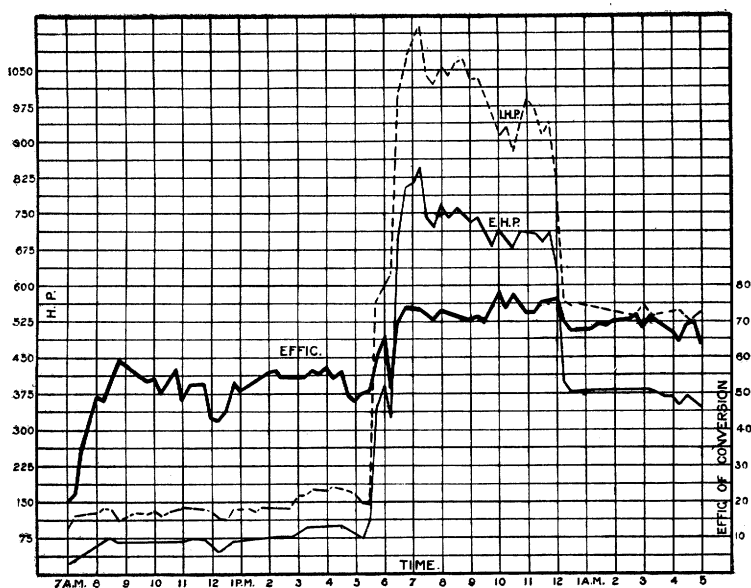


FIG. 13.—Arc Lighting Plant, Load Curves. Sept. 7 and 8, 1895.

equipments, we obtain 66.48 per cent. from the figures for Aug. 31, and 69.30 per cent. from those for September 7. These results are hardly accurate, however, as they neglect the fact that all of the engines were not operated for the same length of time, and that the parts of the load they severally carried varied in amount quite as much as did the lengths of the runs.

The correct method to be followed is to sum up the indicated and the electrical powers developed for the machines for each set of readings, and from these results calculate the hourly efficiency of the incandescent plant. The average of the hourly efficiencies determined in this way will be the real average daily efficiency of conversion of the plant.

This method has been followed in making the determinations of economy that are set forth in Fig. 14.

The load diagrams show that the incandescent load of the station varied about the same on both days, both as regards the time of the variations and their amount. It starts at 7 A. M., at 350 H. P. and rises gradually to 500 H. P. which it reaches about 6 P. M.; between 6 and 8 P. M. it rises rapidly, the crest of the curve being reached about 8:15 P. M.

During the time of the maximum load about 850 I. H. P. and 625 E. H. P. are developed, but this only lasts about an hour and a half, after which it rounds off gradually and finally drops to 250 H. P. about one o'clock in the morning. From this time on

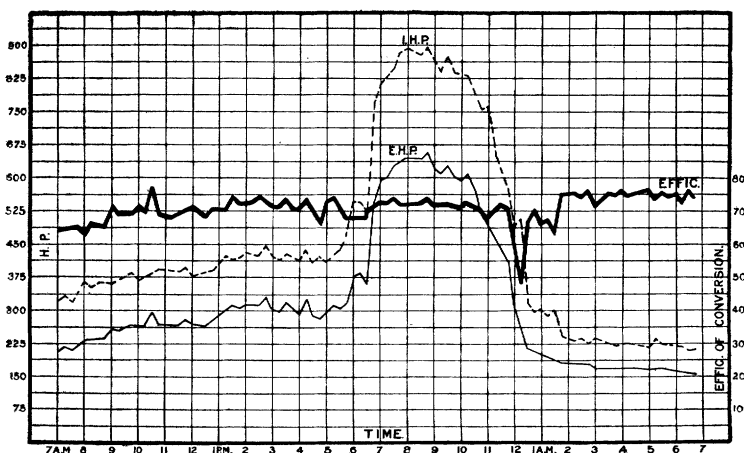


FIG. 14.—Load Curve for Incandescent Machines. Sept. 7 and 8, 1895.

it remains practically constant till the end of the tests.

On account of the greater portion of the load having been carried by the most efficient of the equipments, and the fact that all of the equipments were fairly well loaded, the efficiency of the plant remains very nearly constant during the 24 hours, and the average efficiencies are higher than the figures mentioned earlier in the discussion.

	Aug. 31.	Sept. 7.
The maximum I. H. P. recorded is	876	900
The maximum E. H. P. recorded is.....	598	661
The average I. H. P. recorded is	458.0	451.0
The average E. H. P. recorded is.....	317.0	332.8
The average efficiency of conversion is.....	69.0	71.0

The average efficiency maintained on September 7 of 71 per cent. is very creditable when it is remembered that at times the load was divided between four belted equipments. It would seem, however, that even this result could be improved upon if it were possible to distribute the load to the best advantage between the electrical units.

In table 6 is given in tabulated form the results of a careful comparison of the actual electrical load upon the incandescent plant with the actual *rated* capacity of the electrical apparatus supplying the power, and an additional statement is given of the nearest approximation that could be made to the actual load *without going above the rated capacity of any of the electrical units*. The comparisons are expressed in terms of the per cent. that the rated power is above the power actually developed.

TABLE 6.

Time.	Per cent. of the rated capacity of dynamos running above the load.		Per cent. of the rated capacity of the best arrangement of dynamos above the load.	
	August 31.	September 7.	August 31.	September 7.
8:30 A. M.	33	42	7	19
12:30 P. M.	45	10	21	10
4:30 P. M.	60	40	7	12
8:30 P. M.	23	13	5	13
12:30 A. M.	25	60	25	30
4:30 A. M.	33	22	33	22

In some cases the rated capacity of the machines is 60 per cent. higher than the load, *i. e.*, the rated capacity was over twice as great as the load; and it never approaches it nearer than 25 per cent. on August 31, and 10 per cent. on September 7. The table shows, however, that in almost every case the conditions could have been greatly improved without overloading any of the machines, and if an allowable percentage of overloading were indulged in, a very much greater improvement could be made.

If the above suggestions were carried out in practice, there would not be the least element of danger introduced on account of running the machines near the limit of their rated capacity, as the overloading that every good machine can stand will amply provide for unusually rapid changes in the load.

The load diagram for every day in the week should be constructed and studied by the switchboard attendant, and he should also be informed regarding the load curves of each of the feeders leaving the station, in order that he may be able to make the best possible distribution of the load at all times. This end can, however, only be accomplished by having a very flexible arrangement of the switchboard connections and having the lighting circuits planned out and wired so as to come within the limit of the capacity of the various units.

There are some twelve incandescent circuits leaving the station, and it would appear that a more economical adjustment of the

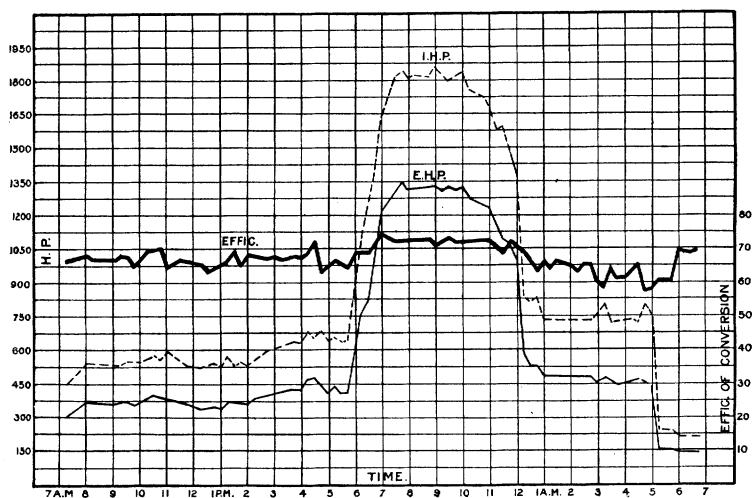


FIG. 15.—Pratt Street Station, Load Curves. Aug. 31, and Sept. 1. 1895.

load could be made were sufficient switchboard appliances provided. In spite of the fact that the load on the plant *never* reached the capacity of the machines in operation, some of the units were nevertheless overloaded at times, and in one instance alternator A was overloaded over 30 per cent. for quite a while.

It would appear from glancing over the records that engine No. 4 was needlessly operated for about four hours on August 31, and that engine No. 6 was run for even a longer period on September 7 without apparent cause.

These are the things that reduce the efficiency of a plant. They not only increase the losses between the boilers and the engines but also the losses between the engines and the switch-board.

STATION ECONOMY.

The Tests of the Station Lighting Plant.—As the heading implies, the matter that follows deals with the economy attained by the various equipments in the engine room, taken collectively, or as if they had formed but one unit. A log of the hours of starting up and stopping the engines on the two days, upon which tests of the plant were made, is given below in table 7. The data in the table only refer to the runs that were made by the en-

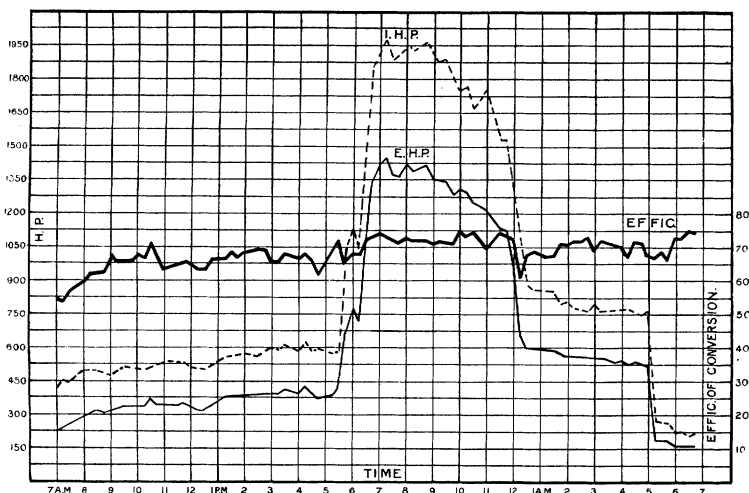


FIG. 16.—Pratt Street Station, Load Curves. Sept. 7 and 8, 1895.

gines for the purpose of developing electricity for the lighting circuits; it does not include the "friction runs." It will be noticed that the schedules upon which the engines were operated were very much the same on both days. The only differences of any importance were caused by interchanging the hours of operating engines Nos. 7 and 8.

The hourly records of the total indicated and electrical power developed by the station machinery are given in the graphical records constructed on Figs. 15 and 16. It is noticeable that the

station load diagrams bear a strong resemblance to the load diagrams of the arc lighting plant for corresponding days, and this is especially true of the load curve for the test of September 7. This is due to the fact that the differences between the day and night loads of the incandescent plant are not so marked as are those of the arc plant. The station load diagrams for the two days are also very much like one another, and except for the peaks on the curves of Sept. 7 and 8, that occur between 7 and 8 o'clock in the evening, the curves would practically coincide if plotted on the same chart. There is also a marked similarity in

TABLE 7.
HOURS OF STARTING AND STOPPING ENGINES.

No. of Engine.	August 31.			September 7.		
	Time of Starting.	Time of stopping.	Duration in hours.	Time of Starting.	Time of stopping.	Duration in hours.
1	5:50 P. M.	5:00 A. M.	11.16	5:30 P. M.	5:10 A. M.	11.67
2	7:00 A. M.	12:05 "	17.08	7:00 A. M.	12:05 "	17.08
3	7:00 "	12:05 "	17.08	7:00 "	12:05 "	17.08
3	5:00 "	6:00 "	1.00	5:10 "	5:45 "	.58
4	7:00 "	7:20 "	.33	6:45 P. M.	1:32 "	6.78
4	6:50 P. M.	10:45 P. M.	3.92			
5	7:00 A. M.	12:55 A. M.	18.92	7:00 A. M.	11:03 P. M.	16.05
6	7:20 "	10:55 "	3.58	7:00 "	1:20 "	6.33
7	2:00 P. M.	11:45 P. M.	9.75	6:30 P. M.	7:00 A. M.	12.50
8	10:45 A. M.	2:00 "	3.25	1:20 "	12:20 "	11.00
8	4:25 P. M.	6:55 A. M.	14.50			

the efficiency curves between the hours of 9 A. M. and 12 P. M. The low point at which the efficiency curve of Fig. 16 begins is due to the light load on the arc machinery at that time. The curve in Fig. 15 would have had the same appearance, probably, if the electrical readings from the arc machines No. 1, 2 and 3 had been obtained during the first hour of the run of Aug. 31.

Between 9 A. M. and 5:45 P. M. the I. H. P. curve rises gradually from 475 to 610 H. P. There is a noticeable drop in both the load and efficiency curves at noon when the arc motors are shut down, since the efficiency of the arc plant is lowered and the effect is necessarily transmitted to and made apparent in the station curves. During the day the efficiency averages about 67 per cent.

The heavy load comes on the station between 6:30 and 7 P. M. The load curves are rising very rapidly at this time, and the jump from 600 to 1800 H. P. takes place within an hour. As is to be expected, the efficiency of the station increases as the load comes on. Between 7 o'clock and midnight on Aug. 31, the load on the engines averages over 1700 H. P. and the efficiency of conversion fully 73 per cent. The efficiency attained on Sept. 7, during this period of the test averages about the same, although it is to be noticed that during the very height of the load, when the I. H. P. averages 1900 H. P. the efficiency is only about 71.5 per cent.

The lowering of the efficiency during the very heaviest load is rather peculiar. If we trace it back, we find that it comes from the load curves of the arc lighting plant and it can finally be traced to engine No. 1. At this time it will be remembered engine No. 1 indicated over 800 H. P., but an examination of the records shows that the equipment operated by this engine reaches its maximum efficiency when the engine indicates about 700 H. P. and that for loads above this value the efficiency falls off.

The greatest difference, however, between the efficiency curves of the two station tests occur during the early morning. Between 1 A. M. and 6 A. M. on Sept. 1, the load was carried by engines Nos. 8 and 1. Between 1 A. M. and 5 A. M. on Sept. 8, the load was carried by engines Nos. 7 and 1; and the variation in the efficiency is largely due to the better economy attained by the equipment driven by engine No. 7 relatively to that of the equipment driven by engine No. 8. The variation in the efficiency of engine No. 1, on the two mornings is also marked, and No. 8 is really only about half responsible for the drop in the curve.

Summing up the results, it appears that:—

	Aug. 31.	Sept. 7.
The maximum I. H. P. developed is.....	1863	1975
The maximum E. H. P. developed is.....	1347	1421
The average I. H. P. developed is.....	863	895
The average E. H. P. developed is....	601	629
The average efficiency of conversion is.....	68.10	68.50

The average efficiency attained is excellent, and shows that the station is operated far more efficiently than is to be expected when the numerous drawbacks that have to be contended with

are remembered. A high *average* efficiency means much more than a high "apparent" or, more properly perhaps, a high "commercial" efficiency. A *high average efficiency* means that the plant is working economically *all the time*, for a low efficiency of conversion maintained for a very few hours will play havoc with the average efficiency for the day.

As an example of this it is worth while to recall the average efficiency of 73 per cent. maintained by engine No. 5 for a period of 16 hours on Sept. 7. The apparent or commercial efficiency of this equipment was also 73 per cent. A *low average efficiency* means that the plant is working uneconomically all the time or very uneconomically part of the time. As an example of this, it is only necessary to turn to the test of the arc lighting plant for Sept. 7. The commercial efficiency developed by this plant was 68.31 per cent. and the average efficiency of the plant was 62 per cent.

The commercial efficiency of the station on Aug. 31, was 70 per cent. and the commercial efficiency on Sept 7, was 71 per cent. These figures speak for themselves, and are values not often attained with the prevailing central station methods.

As regards the distribution of the load on the station throughout the entire 24 hours it is interesting to note that 42 per cent. of the total watt-hour output of the station is developed during the five hours preceding midnight. The remaining 57 per cent. is distributed fairly evenly over the rest of the day. During the heavy load 8.6 per cent. of the total daily output of the station is developed per hour, while during the other portions of the day only about 3 per cent. per hour is developed.

The Engines and Dynamos:—A review of the results obtained during the tests of the machinery in the engine room will necessarily involve numerous comparisons.

In table 9 a complete summary is given of the economic performance of all the equipments and of the station.

These results have been collected from the data given in the reports on the several equipments, and the quantities tabulated are primarily based upon measurements taken from the indicator cards.

In the case of engine No. 1, however, the water consumption is based upon the results of the special test made upon it on Sept. 1, and the values given for the water economy of the station are deducted from the general results of the tests as follows:

TABLE 8.
STATION ECONOMY.

Items.	Aug. 31.	Sept. 7.
1. Pounds of water actually evaporated corrected for moisture.....	513364	511992
2. Pounds water actually evaporated per hour corrected for moisture.....	21390	21330
3. Pounds of dry coal actually fired to the boilers.....	71506	72667
4. Pounds of dry coal actually fired to the boilers per hour.....	2980	2985
5. Average I. H. P. developed by engines.....	862.8	885.3
6. Average E. H. P. developed by dynamos.....		
7. Commercial efficiency.....	69.68	71.11
8. Average pounds water per I. H. P. per hour.....	24.79	24.90
9. Average pounds coal per I. H. P. per hour.....	3.454	3.372
10. Watt-hour output per lb. of coal.....	150.5	157.3

Referring to table 8, items 1 and 3 were taken from the boiler reports, and items 5 and 6 are the averages of the total horse-power records. The commercial efficiency is the ratio of the average E. H. P. to the average I. H. P. and it is made use of in deriving item 10 from item 9. In table 9 the "pounds of coal per I. H. P. per hour" are obtained by dividing the "pounds of water per I. H. P. per hour" by the economic evaporation of the boilers. The watt-hour output is obtained from the "coal per I. H. P." as stated above.

Table 9 also contains the average results of the horse-power records, the average efficiencies of conversion, the commercial efficiencies of all the equipments of the arc and incandescent lighting plants and of the station. It is an interesting fact that a comparison of the "average" and "commercial" efficiencies shows in every case whether or not there is a great variation in the hourly efficiency of conversion of an equipment.

Table 9 also contains a comparison of the actual average water consumption per I. H. P. per hour, with the average water consumption of the engines per I. H. P. per hour calculated upon the basis of the water consumption of the engines determined from the indicator cards, and the per cent. of the total output of the station developed by the corresponding equipments.

The calculated average water consumption per I. H. P. per hour for August 31 is 31.18 pounds of water which is 20.60 per cent. greater than the actual average water consumption. The calculated result for September 7 is 28.66 pounds of water per I. H. P. per hour, which is 16 per cent. higher than the actual water consumption.

The differences between the actual and calculated values are partly due to the fact that the water consumption of the engines was not constant for all loads as it is assumed to be, since the water consumptions were figured from cards that showed an indicated power equal to the average indicated power of the engines. It must also be remembered that the amounts of the leakage that was present in the cylinders and valves of engines No. 1 and No. 8, are quantities that undoubtedly varied at times. The comparison is valuable since it shows that the water consumption credited to the engines is at least *not too low*.

The general summary contained in the table just described shows that the greater part of the output of the incandescent plant was carried by its most efficient units, engines 5 and 7, and that consequently the average commercial efficiency and water economy of the incandescent plant are higher than the corresponding results for the arc plant. Although the incandescent plant developed 52.7 per cent. of the total output of the plant, it required only about 42 per cent. of the total amounts of water and coal that were used on August 31. On September 7, owing to the fact that engine No. 8 was not operated for so long a time and engine No. 7 substituted for it, the economy of the plant is even better and apparently it consumed only 40 per cent. of the coal and water, while at the same time it developed a commercial efficiency of 73.8 per cent.

The arc lighting plant necessarily, in view of what has just been said, suffers by comparison with the incandescent lighting plant. The great difference in the economy is due to the fact that the arc lighting equipment is working at a disadvantage from every point of view. Not only is the electrical efficiency of arc lighting dynamos lower than that of incandescent machines, but the additional shafting and belting necessary for their operation introduces still other disturbing elements. When to these things is added the fact that the engines themselves are relatively less efficient than the engines driving the incandescent machinery, it is not surprising that they do not make a better showing. The

mere fact that engine No. 1, which operates an equipment developing 36 per cent. of the total output, requires over 30 pounds of water per I. H. P. per hour, is sufficient to explain any difference in economy.

TABLE. 9.
ECONOMY RECORD.

No of Engine.	Pounds water per I. H. P. per hour.		Pounds coal per I. H. P. per hour.		Watt-hour output per lb. of coal.		Dynamo driven by engine No.	Total watt-hour output		Output in per cent. of station watt-hour putput.	
	Aug. 31.	Sept. 7.	Aug. 31.	Sept. 7.	Aug. 31.	Sept. 7.		Aug. 31.	Sept. 7.	Aug. 31.	Sept. 7.
1	32.96	32.96	4.584	4.682	114.30	114.8	1	3509000	3946000	37.75	35.02
2	32.81	34.52	4.571	4.904	116.70	96.80	2	1014000	819000	9.42	7.27
3	42.59	42.59	5.022	6.049	80.08	72.30	3	564600	546600	6.07	4.85
4	25.87	25.52	3.604	3.625	128.31	127.79	4	140350	541300	1.30	4.80
5	22.42	22.42	3.118	3.185	171.08	171.20	5	2122900	1942200	19.73	17.23
6	22.55	22.55	3.136	3.203	156.71	152.80	6	349650	542900	3.25	4.82
7	21.40	21.40	2.088	3.053	162.60	170.60	7	840100	1542300	8.82	13.68
8	29.03	29.03	4.037	4.124	127.30	131.00	8	212000	1389400	19.61	12.33
Station.	24.79	24.09	4.124	3.372	150.5	137.3	Arc.	5687800	5394000	47.28	47.14
.....	Sept. 1.	.....	Sept. 1.	.....	Sept. 1.	.....	Incan.	5958100	5938000	52.72	52.86
1	32.96	.....	3.18	.....	158.5	.....	Station.	10701800	11279700	100.00	100.00

No. of Engine.	Pounds water per I. H. P. per hour.		Proportional part of water used by engine.		Average indicated horse-power.		Average electrical horse-power.		Average efficiency of conversion.		Commercial efficiency.	
	Aug. 31.	Sept. 7.	Aug. 31.	Sept. 7.	Aug. 31.	Sept. 7.	Aug. 31.	Sept. 7.	Aug. 31.	Sept. 7.	Aug. 31.	Sept. 7.
1	32.96	32.96	12.44	11.54	588.00	644.15	413.09	460.05	68.8	71.03	70.22	71.41
2	32.81	34.52	3.09	2.51	110.10	100.71	78.80	63.05	69.6	64.3	71.51	63.21
3	42.59	42.59	2.58	2.06	71.94	72.53	45.75	42.47	55.2	51.3	63.60	58.55
4	25.87	25.52	.34	1.22	115.08	126.17	70.4	78.4	61.9	62.1	61.97	62.14
5	22.42	22.42	4.42	3.86	214.70	218.95	154.70	160.20	71.9	75.1	72.03	73.16
6	22.55	22.55	.73	1.08	179.43	170.51	117.21	111.95	65.00	65.6	65.32	65.66
7	21.49	21.49	1.89	2.94	203.12	217.62	132.54	159.30	63.80	73.5	65.23	73.20
8	29.03	29.03	5.69	3.45	226.79	232.12	157.3	169.3	68.90	72.4	69.33	72.92
Arc.	.....	.....	.....	.....	404.8	434.3	284.2	296.7	66.23	61.90	70.21	68.31
Incan.	.....	.....	.....	.....	458.0	451.0	317.0	332.8	69.00	71.00	69.20	73.80
Station.	24.79	24.09	Special test of engine	.....	862.8	885.30	601.2	609.5	68.10	68.50	69.68	71.11
Data.	31.1	28.66	No. 1.	.....	553.82	.....	382.6	.....	66.7	.....	69.08	.....

Per cent. excess of the calculated water consumption of the station above the actual water consumption, Aug. 31, 20.66, Sept. 7, 16.00.

Per cent. excess of the calculated water consumption of the station above the actual water consumption, Aug. 31, 20.60, Sept. 7, 16.00.

The effect that the engines have upon the average water consumption of the station is very well illustrated in Figs. 3 and 4.

In the mornings when engines 2, 3, 6 and 5 are in operation, the water rate averages 32 pounds of water per I. H. P. per hour on August 31, and 28 pounds per I. H. P. per hour on September 7. The difference is due to the fact that the morning load was lighter on September 7 than on August 31, and consequently the engines, especially engines 2 and 3, were relatively less efficient.

During the latter part of the test of August 31, the water rate falls to about 21.5 pounds per I. H. P. per hour, which is a remarkably good showing and indicates that some of the engines, probably Nos. 5 and 7, were operating very efficiently. At the same time on September 7 the water rate is somewhat higher. It averages fully 22.5 pounds of water to the horse-power, and the difference is probably due to the fact that engine No. 1 required more water proportionally on the latter night owing to its heavier load.

The coal economy can hardly be approximated from the curves owing to the fact that they are so very irregular. If it were possible to have the firing done constantly and regularly it might then be possible to obtain more uniform results for plotting purposes, but where it is only done at intervals, "when the fires seem to need more coal," very regular results cannot be obtained.

It may be interesting, in connection with this review, to estimate what maximum economy could be secured under the most favorable conditions which it is probable could be obtained at the station.

If we assume that the boilers in service are kept loaded to their full capacity, they will probably develop an economic evaporation of 10 pounds of water per pound of coal. This figure is slightly less than the actual evaporation per pound of coal developed by boilers 6, 7 and 8 on the night of September 7. Furthermore, if the engines and dynamos are kept up to the point of their maximum efficiency; if there are no leaks in the valves or past the pistons of the engines, if the governors and valves are properly adjusted to give the most economical distribution of the steam between the cylinders of the engines, if the dynamos are kept in good order, with well balanced armatures, low resistance contacts and sparkless commutation, and if good lubrication is maintained and all line shafts and bearings are kept properly lined up, then an economy such as is outlined in table 10 may possibly be

secured. This table represents the high-water mark of economy of the station. It may be thought that the values given are rather extreme, and that the percentage increase represents an impossible gain in economy, and yet it can be demonstrated that there are power plants of similar and even smaller capacity that are giving better results than these figures indicate. The plants referred to are not, however, electric lighting plants. It must furthermore be remembered that a very large proportion of this increase, in fact 40 odd per cent. of it would be due to the increased economic evaporation of the boilers, and it cannot for a moment be questioned but that the station economy has been greatly improved in this direction.

TABLE 10.
MAXIMUM ECONOMY.

No of Engine.	Average I. H. P.	Average E. H. P.	Average efficiency of conversion.	Lbs. water per I. H. P. per hour.	Pounds coal per I. H. P. per hour.	Watt-hour output per lb. of coal.	Per cent. increase in output.
1	600	420	74.0	18	1.8	307	167
2	170	131	77.0	28	2.8	205	75.
3	135	103	76.0	30	3.0	180	51.
4	145	106	73.0	21	2.1	259	100.
5	260	201	77.3	19	1.9	303	76.
6	145	106	73.0	21	2.1	259	66.
7	270	201	75.0	19	1.9	294	63.
8	260	201	77.3	19	1.9	303	132.

In the report presented to the *National Electric Light Association* on May 7, 1896, by its committee on data, attention is called to the fact that in a recent statement of the economy of the Chestnut Hill Pumping Station, at Boston, it was found that in actual water lifted, a horse-power was produced by the consumption of 1.34 pounds of coal. Assuming that the efficiency of pumps compares favorably with the efficiency of generators, and making no allowance for variation in load, one pound of anthracite coal used with the same economy in electrical work should produce 557 watt-hours. Although it is not to be forgotten that the economy reported for the pumping station was obtained under most favorable conditions, with dry high pressure steam and multiple cylinder engines, and although the relative conditions under which it and the present tests were made are not at

all comparable, the fact still remains that the report represents an economy of 400 watt-hours per pound of coal over and above the economy of the Pratt Street Station, or in other words it represents an increased economy of 255 per cent.

Now under the conditions outlined in table 10 the station would develop an economy of about 300 watt-hours per pound of coal. This would be an increase of 91 per cent. over its present economy and certainly represents a result worth striving for.

Now that we have discussed what the station could do under favorable conditions, let us see what it does do under actual conditions in comparison with other central stations of the country. This side of the situation is certainly as interesting as the other, since it brings us into immediate touch with the commercial competitors with whom the station has to contend.

For this purpose we cannot do better than turn again to the report of 1896 of the committee of the *National Electric Light Association*. The information published is certainly not below the economy of the stations represented, as contributors would tend to over-rate rather than under-rate their equipments in gauging their output; and again, we have the statement of the committee to the effect that although it realizes "that in the case of alternating currents the product of the amperes times the volts may not give the absolute watts, this method has been considered sufficiently accurate for this work." Of course "this method" increases the figure for the watt-hour output above its true value.

It is also certain that the statements contained in the report have been obtained from thoroughly representative plants, as their watt-hour per day output is too large for them to be otherwise.

Referring to the data contained in the report we find that the Pratt Street Station stands 15th in the order of the merit of producing the greatest watt-hour output per pound of coal; 15th in a list of 82 stations represented. Of the 14 stations that give a better record of economy only 3 have a greater watt-hour output per day. Of all the plants represented 7 have greater watt-hour outputs per day. "The average efficiency of the 81 reports using coal as fuel is 108 watts-hours per pound of coal," and the Pratt Street Station shows an economy of 45 per cent. in excess of this figure. One station, that has a watt hour per day output of 3207392 watt-hours, reports an economy of 237 watt-hours per pound of coal. The Pratt Street Station develops 65 per cent. of this economy.

The average watt-hour output of all the 14 plants that show a greater economy than the Pratt Street Station is 175 watt-hours per pound of coal, and the Pratt Street Station develops 90 per cent. of this economy.

All the plants that make a better showing than the subject of this paper seem to be better equipped from an economic standpoint.

Of the fourteen, three are equipped with triple expansion condensing engines; six are equipped with compound Corliss condensing engines; one is equipped with simple condensing Corliss, and high speed compound condensing engines belted direct to dynamos: three are equipped with high speed compound condensing engines belted direct to dynamos; and one with simple high speed condensing engines, belted direct to the dynamos. As regards their electrical machinery, two are equipped with direct connected multipolar dynamos; three are equipped with alternating current dynamos; one is equipped with bi-polar dynamos belted from jack shaft; and in the copy of the report that I have the others are not designated. In five of these plants water tube boilers are used alone; in two of them water tube and horizontal tubular boilers are used; and in the others horizontal tubular boilers are used alone.

It will be noted that the engines of the above mentioned plants are condensing, and it will be interesting now to review the non-condensing plants.

Of the 82 plants reported upon, 44 of them are operated with non-condensing engines. Of these, a number seem to be very well equipped. For instance, two are reported having compound Corliss and high speed compound engines, water tube boilers and alternating current dynamos. Six others are reported as having high speed compound engines, with various types of dynamos and boilers, and in only one of them do the dynamos seem to be belted from jack-shafts.

In speaking of the plants that are running with non-condensing engines, the committee makes the following comparison:

"In engine efficiency, eight stations report the water consumption per I. H. P. The triple expansions lead in economy, report 80 showing a consumption of 15.5 pounds, and report 3 showing 18 pounds of water per I. H. P.; these comparing reasonably with report 29, where an I. H. P. is produced by non-condensing engines with 26 pounds of water."

In the Pratt Street Station an indicated horse power is developed with 24 pounds of water.

The committee further says:

“Attention is called to the reports from plants running with non-condensing engines, in which report 26 is able to show 129 watt-hours per pound of coal; report 32, 113 watt-hours; report 33, 109 watt-hours; report 37, 100 watt-hours; and report 38, 95 watt-hours.”

The Pratt Street Station shows an economy of 157 watt-hours per pound of coal, and develops an economy 22 per cent. in excess of the best showing made by the 44 plants running with non-condensing engines.