CALDWELL

Refrigeration in Connection with Central Stations

Electrical Engineering

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REFRIGERATION
IN CONNECTION WITH CENTRAL STATIONS

BY

BRICE JOHN CALDWELL

THESIS

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Brice John Caldwell

ENTITLED Refrigeration in Connection with Central Stations

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Electrical Engineering

Edw. H. Waldo.
Instructor in Charge.

APPROVED: Ernst Berg

HEAD OF DEPARTMENT OF Electrical Engineering

A Central Station supplying energy for lighting a community presents the unfortunate condition of a plant running at full capacity for only three or four hours in twenty four. An examination of the load curves submitted with this thesis shows that for sixteen hours the load factor varies from 10% to 20%. The average load factor per day varies from 18.2% in July to 33.8% in December, with an average daily load factor of 26.1% for the year. It is thus seen that while the owner is paying interest on the total investment, he gets full returns from the investment only one fourth of the time. Since people will not pay an exorbitant price for power, the owner must either be content with a small percent profit or seek some means to profitably increase the load factor.

In manufacturing communities this may be done by selling power in the day time, but in the average city of five thousand inhabitants in the middle west, other means must be resorted to, Many such plants have lately put in refrigerating plants and it is the purpose of this thesis to determine whether or not it will pay a central station to operate an ice plant in connection with the lighting plant.

A refrigerating plant fits in almost ideally with a lighting plant. The demand for ice is largest in summer when the lighting load is smallest. Ice may be made during the off-peak load of the lighting plant and thus most of the work of operating the ice plant can be done by the operators of the lighting plant.

The office force need not be materially increased by the addition of the light plant. The exhaust steam from the lighting plant may be utilized as distilled water for making ice.

We will select for our example, a typical city of five thousand inhabitants located in the middle western part of the United States near the fortieth degree of latitude. This city has a total electrical output of 250 Kilowatts used for street and house lighting. It supplies energy both day and night but practically none of it is used for power.

We will make the folloeing assumptions: The exhaust steam is used for heating in winter, and since therefore the owner is not particularly desirous of a low steam consumption, we will assume that the prime movers are Simple Non-condensing Corliss Engines, the water rate of which is shown by the curve on Plate 13. This is the total water rate including the auxiliaries. The initial steam pressure is 150 pounds absolute and the back pressure is 18 pounds absolute. Exhaust steam is used for heating the business district of the city in winter and the surplus is used to heat the feed water. It will be necessary at times to generate live steam to be used in the refrigerating plant. The boiler will never be working at less than 10% of full load capacity and we will assume the average efficiency of the boiler and grate above 10% of full load capacity to be 60%. We will assume that the coal costs $2.50 per ton and averages 12000 B.T.U. per pound. We will assume that electric energy for driving the pumps etc. costs 1.5 cents per Kilowatt Hour.

The principle of refrigeration is briefly as follows: The medium is compressed (adiabatically in the ideal case) and

its temperature is thus raised above the temperature of the surrounding atmosphere. Heat is then allowed to flow from the medium to the surrounding atmosphere until the medium is liquefied. The medium is then conducted into the room to be cooled. Here it expands and vaporizes; absorbing the heat of vaporization from the cool room. The medium is then compressed and the cycle repeated. The medium may be air, carbon dioxide, sulphur dioxide, ammonia or other suitable gas. Ammonia (NH_3) is most generally used and will be in this case.

There are two principle systems of refrigeration, viz.: compression and absorption. Plate 15 shows the necessary parts of both systems. In the compression system, the ammonia is drawn by suction into a compressor, compressed and discharged into a condenser where it is cooled and then sent into a receiver. It goes from the receiver into the expansion coils through an expansion valve, as needed; the expansion coils being in the cool room. From the expansion coils, it goes to the compressor and the cycle is repeated. In the absorption system, the compressor is replaced by an absorber, an ammonia pump and a generator. The ammonia is drawn, by suction of the pump, into the absorber where it is absorbed by water. It is then pumped into the generator where, by means of heat, the ammonia is driven off under pressure to the condenser and the water returns to the absorber. The condenserm receiver and expansion coils are the same in both systems. There are two systems of cooling the cool room, viz.: by direct expansion and by brine. In the direct expansion system, the expansion coils are led through the cool room and the ammonia absorbs heat directly from the atmosphere. In the brine

system, the expansion coils are immersed in brine from which the ammonia absorbs heat and in turn the brine absorbs heat from the air in cold storage rooms or from water in ice making plants. The direct expansion system is more economical for large installations continuously operated. For small plants the efficiencies are practically equal and the brine system has the advantage that the plant may be shut down and the refrigeration continued by running the brine circulating pumps. The brine system will, therefore, be used in this installation. The brine is made of NaCl or $CaCl_2$. The latter is preferable since it exerts less friction on the pipes and the tendency to rust iron pipes is less. It is made by mixing about two and one half pounds of $CaCl_2$ to one gallon of water.

Ice is made by either the can system or the plate system. In the former, water is contained in cans 11" x 22" x 44" for a 300 pound block and requires sixty hours to freeze it. In the plate system, the coils are in a hollow iron plate and the water is congealed on this plate. The blocks of ice are 16' x 8' x 11" and must be sawed and harvested. Ice can be made about 25% cheaper by the plate system, but the first cost is greater and it has the disadvantage of requiring a large force of men to harvest it quickly. Therefore, the can system will be used in this installation, since ice can be harvested while it is being made. To obtain pure clear ice, distilled water must be used. In addition it should be reboiled, skimmed and filtered.

As to the merits of the compression system against the absorption system; this is, at present, a subject for much discussion among eminent refrigerating engineers. Some claim

that the absorption system is better, while others favor the compression system. Since both systems have their defenders among eminent refrigerating engineers, we will not attempt to decide which one is the more efficient, but will agree that they are equal in efficiency. It is generally agreed that the highest efficiency is obtained by a combination of the two systems but such a plant increases the first cost and operating expenses too much for a plant of our size and it will be necessary, therefore, to select either a compression system or an absorption system.

One of the main objects of our plant, is to utilize profitably the machinery which we already have installed. It is not practical to use the same engine, that operates the lighting plant, to run the compressor. It will be better to have the compression machinery in one unit, using steam at boiler pressure. It is thus seen that the two systems will each utilize the same part of the lighting plant machinery, viz: the boilers. The main advantage of using the compression plant is, that it can be operated during the off-peak loads by the same men who operate the lighting plant. However, as will be seen, the greatest cost is in handling the ice, which is the same in both systems, and since the peak load of the lighting plant lasts only three or four hours per day in summer, the operation of the absorption system will require very little, if any, additional expense for operators. Since the absorption system uses steam directly for its energy (in the generator) we can, by using this system, utilize the exhaust steam from the lighting plant. The low pressure absorption system has been developed greatly in the past three years. Since the absorption is theoretically more efficient

than the compression system, it is very likely that the former will soon outstrip the latter in point of efficiency. Therefore, since we agree that the efficiency of the two systems are equal, we will select the absorption system, since it utilizes exhaust steam from the lighting plant, while the compression system not only does not utilize this exhaust steam, for energy, but makes more exhaust steam to be taken care of. The absorption system is slightly more expensive in first cost but will pay in the end.

To obtain the desired efficiency, an absorption system must have more parts than are shown on Plate 15. Plate 16 shows the necessary parts of a present day absorption plant. Its operation is as follows: Cold ammonia vapor leaves the top of the brine cooler and goes to the absorber where it is joined by weak liquor from the weak liquor cooler. Heat is evolved by the absorption of ammonia into weak liquor. The ammonia is cooled by the counter current system in which the warmer outgoing cooling water cools the weak aqua ammonia and the cooler incoming water reduces the temperature of the warmer ammonia on its way to the generator. From the absorber, the strong liquor (ammonia and water) is forced by the ammonia pump into the exchanger. In the exchanger, the hot weak liquor, which must eventually be cooled, gives up heat to the cooler rich liquor, which must eventually be heated in the generator. This economizes water in the absorber and heat in the generator. The medium next goes to the analyzer where the rich liquor trickles down over metal trays where the exchange of heat is still further continued. The hot ammonia vapor from the generator entrains more or less aqueous vapor as it rises from the surface of the liquid in the generator, and in

passing up through analyzer, on its way to the condenser, it encounters the rain of cool rich liquor on its way to the generator. In the rectifier, the gas passes through water cooled pipes of sufficient area to insure the condensation of all aqueous vapor that has reached it. In the condenser, the dry vapor, which is under pressure, gives up its heat to the cooling water and is reduced to a liquid. From the condenser, the liquid goes to the receiver from which it flows, as needed, through an expansion valve into the brine cooler. Plate 17 shows the paths of the strong liquor, weak liquor and cooling water.

The next thing to be consisered is the size of the plant needed for this city. The unit of ice making capacity is one ton per twenty four hours from and at 32 degrees Fahrenheit. Taking the latent heat of water as 142.6 B.T.U., a one ton plant must absorb 2853000 B.T.U. in 24 hours from the water to be frozen. Since the initial temperature of the water is about 65 degrees F. and the ice is chilled to about 20 degrees F., it will require a plant of approximately one and one fourth tons capacity to make one ton of ice. Statistics of ice consumption taken from twelve cities of from 3000 to 10000 inhabitants, situated in Iowa Illinois, Indiana, Ohio and Pennsylvania, show that the ice consumption per year per inhabitant, for the year 1909, varied from .56 tons to 3 tons with an average value of 1.355 tons of ice per year per capita. For a city of 5000 inhabitants this would be an average of 18.6 tons per day for the year. The sale of ice will vary each month according to the curve on Plate 14, the ordinates of which, represent the average daily sales of ice for the respective months. It is seen, from this curve, that the

maximum daily sales is 240% of the average daily sales. Since our average daily sales are 18.6 tons, we will need a plant capable of making 45 tons of ice daily. However in a city of this size, there is either an ice plant already doing business or there is a supply of natural ice. Also, it will be better to decide that this installation will not pay than to decide that it will pay and find out afterwards that it does not through lack of sales. Therefore we will assume that our average daily sales for the year are 14.6 tons and our plant will then need to be 35 actual tons of ice capacity. It will be unnecessary for us to decide what the theoretical capacity of this plant should be, for, when buying it, we will ask the maker to guarantee that the plant will make 35 tons of ice in 24 hours with steam at 18 pounds absolute and cooling water at 65 degrees F. We will assume that the present building merely houses the lighting plant and we will therefore be required to erect a building for the ice plant. Cooling water will be obtained from a well 165 feet deep. Its temperature ranges from 60 degrees F. in winter to 65 degrees F. in summer.

The following table taken from the U.S. weather bureau report gives the average monthly temperatures at Springfield Ill.

Month	Temperature Degrees F.	Month	Temperature Degrees F.
January	25.5	July	76
February	30.3	August	73.4
March	39.2	September	66.4
April	53.4	October	55
May	62.4	November	40.9
June	72.2	December	32.8

An examination of this table shows that heating will have to be done for at least seven months in the year. In practice, the heating contracts run from October 15 to May 15 in some cases, and from October 1 to May 1 in other cases. We will assume that the lighting plant uses the exhaust steam for heating from October 1 to May 1. In practice, it is only during the peak loads that enough steam is exhausted to supply the demand for heating. During the off-peak load, except on warm days, live steam must be used in the heating mains. Therefore during these seven months we will assume that at no time do we have any exhaust steam for use in the ice plant, but must use live steam in the generator and reboiler.

The exhaust steam, which is used for making ice, must first pass through an oil separator. After leaving the oil separator it is divided, about 60% entering the coils of the generator of the ice machine where it is condensed and becomes distilled water and flows into a receiver. The remaining 40% passes into an exhaust steam condenser over which the spent cooling water, from the ice machine, flows and is condensed into steam. The distilled water from this, also goes to the receiver where it mingles with that from the generator. From this receiver it is drawn by a pump and discharged into a reboiler where it is further boiled to free it from any gases etc, that may have been absorbed during condensation. It is then skimmed and filtered after which it is ready to be made into ice. The cooling water after it leaves the rectifier, (Plate 17) will go to the distilled water condenser after which it will be used as feed water for the boiler. There will be more than enough of this

cooling water to make up for the condensate used in ice making.

We will now consider the range of pressures through which to work the ammonia. For the maximum efficiency, the ammonia should be worked through as short a range of pressures as possible. This is just the opposite to the case of a heat engine and the refrigerating machine is, in fact, a reversed heat engine. This calls for temperatures as low as possible in the condenser, and as high as possible in the expansion coils. This is limited in the first case by the necessary cooling surface and supply of cooling water and in the second case by the desired or necessary temperature of the brine. For the greatest efficiency, therefore, we should have a high boiling point. However, the boiling point must be at a temperature lower than that of the brine in order that the heat may flow. For the best results the temperature of the brine should be about 20 degrees F. and the boiling point of the ammonia about 10 degrees lower than that or 10 degrees F. This corresponds to a pressure of 33.8 pounds per square inch absolute. We will assume that the temperature in the condenser is 80 degrees F. which corresponds to a pressure of 154 pounds absolute. These are average values used in practice.

For every ton of ice manufactured, the ammonia must absorb about 3,570,000B.T.U. in 24 hours or 2475 B.T.U. per minute. This heat must in turn be absorbed from the ammonia by the cooling water, which must also absorb the heat imparted to the ammonia in the generator. Assuming that each pound of water absorbs 30 B.T.U., we would need 82.5 pounds or 11. gallons of water per minute. However, more than one half of this heat is extracted from the strong liquor by the weak liquor in the analyzer and exchanger.

The efficiency depends largely on the quantity of cooling water available. Our water must be pumped from a 165 foot well and we should use the right amount so that the power required to pump it will not overbalance the gain in efficiency. About five gallons per minute per ton of ice made will give maximum efficiency with lowest pumping cost.

Since the latent heat of water is 142 B.T.U. and the heat of vaporization of ammonia is 561.6 B.T.U. at 23.8 pounds absolute, it will require about one pound of ammonia to make four pounds of ice. For one ton of ice we must actually circulate about 650 pounds of ammonia. We will assume that the ammonia enters the absorber at 39 degrees F. and enters the condenser at 260 degrees F. The heat necessary to effect this change, taking the specific heat of ammonia as 0.5,is 675 B.T.U. per pound of ammonia. Therefore between the absorber and the receiver we must supply the ammonia with 440000 B.T.U. in 24 hours or 18000 B.T.U. per hour per ton of ice made. Taking the heat of vaporization of water as 965 B.T.U. we would need 18.7 pounds of steam per hour in the generator. However, on account of radiation and other losses, the results obtained in practice differ somewhat from this. With the best improvements, such as shown on Plate 16 the generator will require 60 pounds of steam per hour per ton of ice made. This is 1440 pounds of steam in 24 hours. Since it requires 2300 pounds (allowing 15% waste) of exhaust steam to supply distilled water for one ton of ice, it is seen that even if we use 60 pounds of steam per hour in the generator we will still have 860 pounds left in 24 hours. This will be used in the reboiler and the surplus will be condensed. It is seen, then, that the

steam consumption of the ice plant is 96 pounds per hour per ton of ice made, or just enough to supply the necessary distilled water.

The pumps etc. will require the following power:

Cooling Water Pump	.333	mechanical H.P. per ton of ice made.
Ammonia Pump	.12	" " " " "
Distilled Water Pump	.0067	" " " " "
Brine Agitator	.067	" " " " "
Air Compressor for Ice Crane	.0133	" " " " "
Total	.54	" " " " "

These will be electrically driven. Assuming the average efficiencies of the motors to be 85% the total electrical energy consumed is .475 Kilowatts per ton of ice made. The total energy required to operate this ice plant is then: 96 pounds of exhaust steam and .475 Kilowatts of electrical energy per hour per ton of ice made.

During the months of January, Februery and March we will make 4.8 tons of ice daily. As was shown, there will be no exhaust steam for ice making during these months. We will need 96 pounds of distilled water per hour per ton to operate the plant. It was shown that we need only 60% of this steam at 3 pounds back pressure for use in the generator. If we use steam at 150 pounds absolute we will need less than 60% of it in the generator and then more than 40% of the steam will go into the distilled water condenser. This will in turn heat the spent cooling water higher than if we had used steam at 18 pounds absolute. This spent cooling water is to be used as feed water and therefore we do not lose much heat by using steam at 150 pounds pressure in

the ice plant instead of at 18 pounds absolute.

If we should operate the ice plant during these months continually at 4.8 tons capacity we would be running at a rather low rate of efficiency. In practice the plant would be operated at full capacity, except during peak loads of the lighting plant, when the ice plant would be shut down and the brine circulating pumps only would be kept running. After 35 tons of ice was made, the plant would be shut down until more ice was needed. In order to show the relative cost of making ice each month, we will consider that the plant is run at 4.8 tons capacity daily but at an efficiency equal to full capacity. During the peak loads of the lighting plant there is usually more exhaust steam than is needed to supply the demand for heating and feed water heating. This might be utilized in the ice plant but to do this would require another operator for the ice plant since the lighting plant attendants are usually kept busy in the lighting plant during the peak loads. Therefore it will pay to operate with live steam during off-peak loads and operate the plant with men from the lighting plant. If there is a return main on the heating system, this distilled water might be used to make ice with but this will hardly pay since it must be brought to 212 degrees F. in the reboiler.

During these months we will charge the ice plant with 2.28 kilowatts of electric energy daily and 460 pounds of steam per hour at 18 pounds absolute though in reality it is used at 150 pounds absolute. Coal burned will be that necessary to heat the feed water at 120 degrees F. to steam at 18 pounds absolute.

During five months in the year no exhaust steam is used

for heating. Therefore this exhaust steam, except that used for feed water heating may be used in the ice plant. We will consider first the month of July. During this month the ice plant is running at full capacity daily and the lighting plant at almost its lowest load factor. Therefore, if there is enough surplus exhaust steam to supply the ice plant during July, there will be enough to supply it during all months except steam heating months. For every pound of exhaust steam we have 966 B.T.U. (heat of vaporization) with which to heat the feed water to 212 degrees F. Taking the initial temperature of the feed water as 65 degrees F. (that of well water), one pound of exhaust steam will heat 6.5 pounds of feed water to 212 degrees F. and as a result we will have 7.5 pounds of feed water at 212 degrees F. Therefore 13.4% of the exhaust steam is required to heat the feed water; the remainder may be used in the ice plant. From the load curve for July and the steam consumption curve of the lighting plant, we have the following exhaust steam at our disposal after subtracting the 13.4% used for heating the feed water.

Hour	Exhaust Steam - Pounds.
From 12 to 1 A.M.	262000
" 1 " 2 " "	211000
" 2 " 3 " "	189000
" 3 " 4 " "	167500
" 4 " 5 " "	200000
" 5 " 6 " "	256000
" 6 " 7 " "	290000
" 7 " 8 " "	277000
" 8 " 9 " "	248000

From	9	to	10 A.M.	222000
"	10	"	11 " "	227000
"	11	"	12 " "	216000
"	12	"	1 " "	205000
"	1	"	2 " "	216000
"	2	"	3 " "	227000
"	3	"	4 " "	248000
"	4	"	5 " "	324000
"	5	"	6 " "	437000
"	6	"	7 " "	624000
"	7	"	8 " "	728000
"	8	"	9 " "	770000
"	9	"	10 " "	742000
"	10	"	11 " "	650000
"	11	"	12 " "	422000

To run at 35 tons capacity requires 3350 pounds of exhaust steam per hour. It is seen that during these five months there will be more than enough exhaust steam at all times to supply the ice plant. During these five months we will charge the ice plant only with the electric energy used.

In the following table the costs are based on 1.5 cents per kilowatt hour for electric energy and $2.50 per ton for coal containing 12000 B.T.U. per pound. Boiler and grate efficiency is 60% and feed water is at 120 degrees F. and final pressure of steam is 18 pounds absolute.

Month	ice made daily tons	K.W. per hour	hours	total K.W. hours	total steam pounds
January	4.8	2.28	744	1700	343000
February	4.8	2.28	672	1530	309000
March	4.8	2.28	744	1700	343000
April	6.15	2.92	720	2100	425000
May	10.2	4.85	744	3610	0
June	23.35	11.1	720	8000	0
July	35	16.65	744	12400	0
August	32.1	15.25	744	11350	0
September	26.6	12.65	720	9120	0
October	14.3	8.23	744	6130	1020000
November	9.05	4.3	720	3100	626000
December	5.25	2.5	744	1860	376000

Month	total coal -lb.	cost of coal - $	cost of elec. $	total cost $
January	50500	63.00	25.50	88.50
February	45500	47.00	22.95	69.95
March	50500	63.00	25.50	88.50
April	62500	78.00	31.50	109.50
May	0	0	54.50	54.50
June	0	0	120.00	120.00
July	0	0	186.00	186.00
August	0	0	170.50	170.50
September	0	0	136.90	136.90
October	150000	187.50	92.00	279.50
November	92000	115.00	46.50	161.50
December	55300	69.00	27.90	96.90

These results may be summarized as follows:

total ice sold per year-tons	5325
total cost of energy per year	$1562.25
cost of energy per ton of ice- average	.293
cost of energy per ton of ice during steam heating months	.595
cost of energy per ton of ice during other months	.172

From October 1 to June 1 the plant will be running at less than one half full capacity and can therefore be operated during off-peak loads by men from the lighting plant. The chief engineer can look after both plants. From June 1 to October 1 the plant will be operated during off-peak loads by the lighting plant force but will require an additional operator at night. He should be of the same ability as the light plant operators and his wages will be $2.50 per day. The office force will also have to be increased from June 1 to October 1 by one clerk at $12.00 per week. No increase of force will be needed in the boiler room.

The ice is made in 300 pound blocks and there will be 234 blocks in 35 tons. One man can, with the assistance of a hoist which handles two blocks at a time, easily harvest 20 blocks per hour. From November 1 to June 1 the ice will be harvested by the drivers. From June 1 to November 1 one laborer will be needed to harvest ice. He will work an average of 10 hours per day and his average wages will be $1.75 per day.

The percentage of wholesale trade will vary in different cities and will be greater in winter than in summer. A good average to assume for the year is 60% retail and 40% wholesale.

The retail delivery wagons will require one man each and the wholesale wagons will require two men. In a city of this size one retail driver can deliver two tons per day while a wholesale wagon can deliver 8 tons per day. The usual method is for the owner to furnish the wagon and the driver to furnish the team of horses. One man and a team of horses are worth $4.50 per day while the assistant for the wholesale wagon is worth $1.75 per day.

In the following table showing help needed, Sundays are counted out according to the calendar of 1911.

Employee	Ice puller	Operator	Clerk	Retail wagon	Wholesale wagon		
Wages $ per day	1.75	2.50	2.00	4.50	6.25		
Month						Working ice puller & operator	Days others
January	0	0	0	1	0	31	26
February	0	0	0	1	0	28	24
March	0	0	0	1	0	31	27
April	0	0	0	0	1	30	25
May	0	0	0	2	1	31	27
June	1	1	1	8	1	30	26
July	1	1	1	10	2	31	26
August	1	1	1	10	2	31	27
September	1	1	1	8	1	30	26
October	1	0	0	3	1	31	26
November	0	0	0	2	1	30	26
December	0	0	0	1	0	31	27

All expenses will be divided as follows:

Fixed Charges

Interest and depreciation on investment in machinery	12.5%
Interest and depreciation on wagons	15%
Interest and depreciation on building	7.5%
Interest on ground	5%
Taxes on entire investment	1%
Insurance on building and machinery	0.5%

Operating Costs

Labor and Attendance

Energy cost

Oil waste and supplies @ $.35 per day

Repairs and maintenance @ 2% on machinery and wagons

Incidental expenses

Incidental expenses covers purchase of ammonia, additional labor that may be necessary, advertising, unpaid bills etc. The total sum is $1200.00 per year divided monthly according to the amount of ice made.

Operating costs may be tabulated as follows:

$\frac{1478.80}{532.10} = 2.[illegible]5$

Month	Ice made daily tons	Labor and attendance $	Cost of energy $	Oil waste & supplies $	Repairs & maintenance $	Incidentals $	Total $
January	4.8	117.00	88.50	10.85	59.66	32.70	308.71
February	4.8	108.00	69.95	9.80	59.67	32.70	280.12
March	4.8	121.50	88.50	10.85	59.66	32.70	313.21
April	6.15	156.25	109.50	10.50	59.67	41.90	377.82
May	10.2	406.75	54.40	10.85	59.66	69.50	601.16
June	23.35	1261.00	120.00	10.50	59.67	159.00	1610.17
July	35	1647.50	186.00	10.85	59.66	237.50	2141.51
August	32.1	1711.25	170.50	10.85	59.67	217.50	2169.77
September	26.6	1261.00	136.90	10.50	59.66	182.00	1650.06
October	14.3	559.00	279.50	10.85	59.67	97.50	1006.52
November	9.05	402.25	161.50	10.50	59.66	61.20	695.11
December	5.25	121.50	96.90	10.85	59.67	35.80	324.72
						total	11478.88

A manufacturing company was asked for prices on this machine but no attention was paid the communication. Therefore it was necessary to estimate the cost of this plant, which was done in the following manner: The Carbondale Machine Co. of Carbondale Pa. estimated that a 150 ton plant of this kind would cost $80000.00 installed. From the " Electrical World" of May 4, 1911 was found an estimate of $13000.00 for a 10 ton plant of this kind. This gives an average of about $920.00 per ton from which this 35 ton plant would cost $32200.00.

The building required for this plant-Plate 18- is 100' x 35' x 13'-9" including a small storage room for ice made on Sundays etc. The building should have a brick wall with no

plastering necessary and should have a cement floor except under the ice cans which may be dirt. The cost of this building should not run more than 10 cents per cubic foot at which price the cost would be $4800.00. The ground on which the building stands we will estimate to be worth $750.00. The fixed charges are as follows:

Interest and depreciation on machinery	
12.5% of $32200.00	$4025.00
Interest and depreciation on 12 wagons	
15% of $3600.00	540.00
Interest and depreciation on building	
7.5% of $4800.00	360.00
Interest on ground	
5% of $750.00	37.50
Taxes on entire investment	
1% of $41350.00	413.50
Insurance on building and machinery	
0.5% of $40600.00	203.00
Total fixed charges yearly	5384.00

Statistics taken from the 12 cities before mentioned, show that the retail price of ice ranges from 25 cents to 50 cents per 100 pounds with an average price of about 35 cents. The wholesale price ranges from 15 cents to 22.5 cents per 100 pounds. We will assume that we can sell our ice for 30 cents per 100 pounds retail and 15 cents per 100 pounds wholesale. This gives the following income:

3200 tons retail	$22400.00
2125 tons wholesale	6375.00
total	28775.00

Total brought forward	$28775.00
Less 2% for shrinkage while delivering	575.50
Total income	28199.50

these results may be summarized as follows:

Total income per year	$28199.50
Total expenses per year	17362.88
Profit for year	10836.62
Investment	41350.00
% on investment	38.2

There are several ways in which these profits may be still further increased. One way, if there is a demand for it, is to put in a cold storage plant in connection with the ice plant. The temperature of the cold storage room will need to be kept from 32 degrees F. to 40 degrees F. depending on the product stored. The brine will return from the ice cans at a temperature of about 36 degrees F. and can then be piped through the cold storage room. The cool room can be kept at the desired temperature with the expenditure of very little more energy depending on how often the product is changed. The walls of the building should be well insulated.

If the city happens to be a division point of a railroad, a very renumerative business may be worked up by iceing refrigerating cars. The ice for this purpose will have to be sold cheaper than the ordinary wholesale price but there is very little expense in handling the ice. It will no doubt pay to sell ice, if possible, to retailers in other cities. As was seen, there is enough exhaust steam to make much more ice than can probably be sold and additional ice can be made and sold very

cheap.

A way to cut down first cost of machinery is to install a plant of capacity equal to the average daily sales, in this case 14.6 tons. The plant is run at full capacity the year round and ice is stored in winter for use in summer. Brine returning from the ice cans may be piped through the storage room to prevent waste of ice. This stored ice must be washed before sold and the increased cost of handling the ice is such that this method does not usually pay though it does in some instances.

This probably represents the best method of making ice in connection with central stations at the present time. However newer methods bid fair to change things. As long as distilled water is used to make ice, the absorption system is no doubt the more economical, for the energy dissipated in condensing the steam may be used to compress the ammonia. By later methods, however, clear ice may be made from undistilled water. An instance of this is the recent installation in the Blackstone Hotel in Chicago. Here, ice is made by a 50 ton compression ice machine using CO_2 for the medium. It makes clear ice without distilling or reboiling the water and freezes 400 pound blocks in 24 hours with the brine at 0 degrees F. The cans have a jacket around which the brine circulates and in the bottom of each is a non-freezing zone consisting of a shallow rectangular pocket in which is introduced a jet of refrigerated air. This keeps the water agitated and impurities are deposited there. When the blocks are frozen the jet of air, which is at a very low pressure, is automatically shut off.

The public has been educated to want ice made from distilled water. It is more than probable that ice made by the method just described is pure enough for ordinary uses. If the public can be educated to the use of clear ice rather than pure ice, then the method just described would be better than the method described in this thesis.

There are a few discrepancies to be noted in the cost of energy as given in the table. The efficiency of an absorption plant depends very largely on the supply and temperature of the cooling water. In our estimate, the temperature of the cooling water was taken at 65 degrees F. whereas, from a 165 foot well, it will probably never be warmer than this and much of the time, colder. The ice would cost less as the temperature of the cooling water went down. This is compensated for by the fact that the back pressure of the exhaust steam was taken as 18 pounds absolute whereas it will be nearer 16 pounds absolute when the refrigerating plant is not running. In the warmer heating months such as October and April, there would no doubt be some exhaust steam, not needed for heating, that could be utilized for making ice. No account of this was taken. On the whole, these discrepancies tend to counter balance each other and these costs of energy may be taken as being fairly reliable unless, as is very probable, we have figured the cost of the electric energy too high. In figuring the cost of this electric energy, we should figure only the cost of the coal actually burned to produce it and this will usually be less than 1.5 cents per kilowatt hour. However, as was seen, the cost of power is a rather small item in the total cost of producing the ice. The

principal cost is the labor expenses and this will vary somewhat in different localities and will depend largely on the ability of the manager.

In cities of this size the operating expenses should never run higher than this and even if they were twice as large the plant would still pay 6% on the investment.

That the plant should pay, also follows from ordinary reasoning. There are hundreds of ice plants in the United States engaged in ice making only and making money at it. Then if a central station should go into the business they should, by ordinary reasoning, make money since they get their energy for nearly nothing and do not have to figure interest on boilers.

In our estimate we have figured the expenses at least as high as they should be and we have figured the selling price of ice at probably less than it would actually be sold for. In spite of this we make the surprisingly large profit of 38% on investment. One would naturally wonder therefore, why so few central stations are engaged in the ice business. This may be explained partly by lack of capital but principally by opposition from plants already established. We have assumed that we can sell nearly all the ice consumed in this city whereas, in a city of this size there would no doubt be an independent ice plant or else a supply of natural ice. Competition of the latter kind is not so very serious but if there is an ice plant already established, it may not pay a central station to engage in the ice business.

Conclusion: If we assume, as we have a right to, that a reasonable amount of ice can be sold, then the plant will pay.

Discussion of Plates.

Plates 1 to 12 inclusive are average load curves for each month. The one for December is plotted from readings taken in Urbana Illinois: it being an average of the daily readings from December 19 to December 26 inclusive. Owing to the inability to obtain other load curves, the remaining ones were estimated.

Plate 13 shows the water rate of this plant. It is plotted from the water rate curve of a Simple Non-condensing Engine from Gebhardt's "Steam Power Plant Engineering" and the efficiency curve of a generator taken from " Elements of Electrical Engineering" by Franklin and Esty.

Plate 14 shows the average daily sales for each month in the year in this latitude. These will vary with different years.

Plates 15 to 17 inclusive are self explanatory.

Plate 18 shows the building required for this plant and an acceptable arrangement and approximate space required for parts of machinery.

The table shows the average kilowatt output per hour for each month. These values are taken from the load curves.

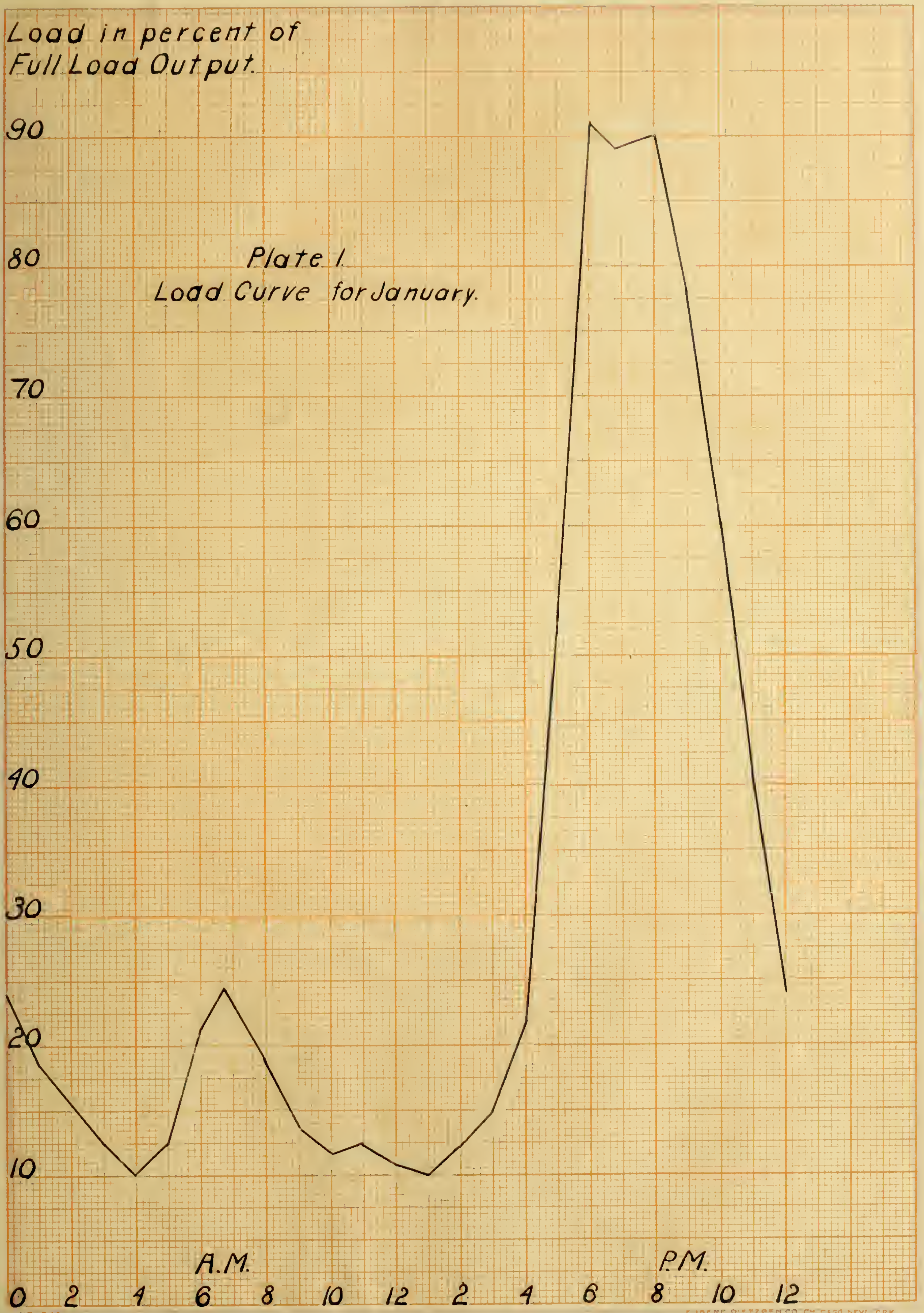
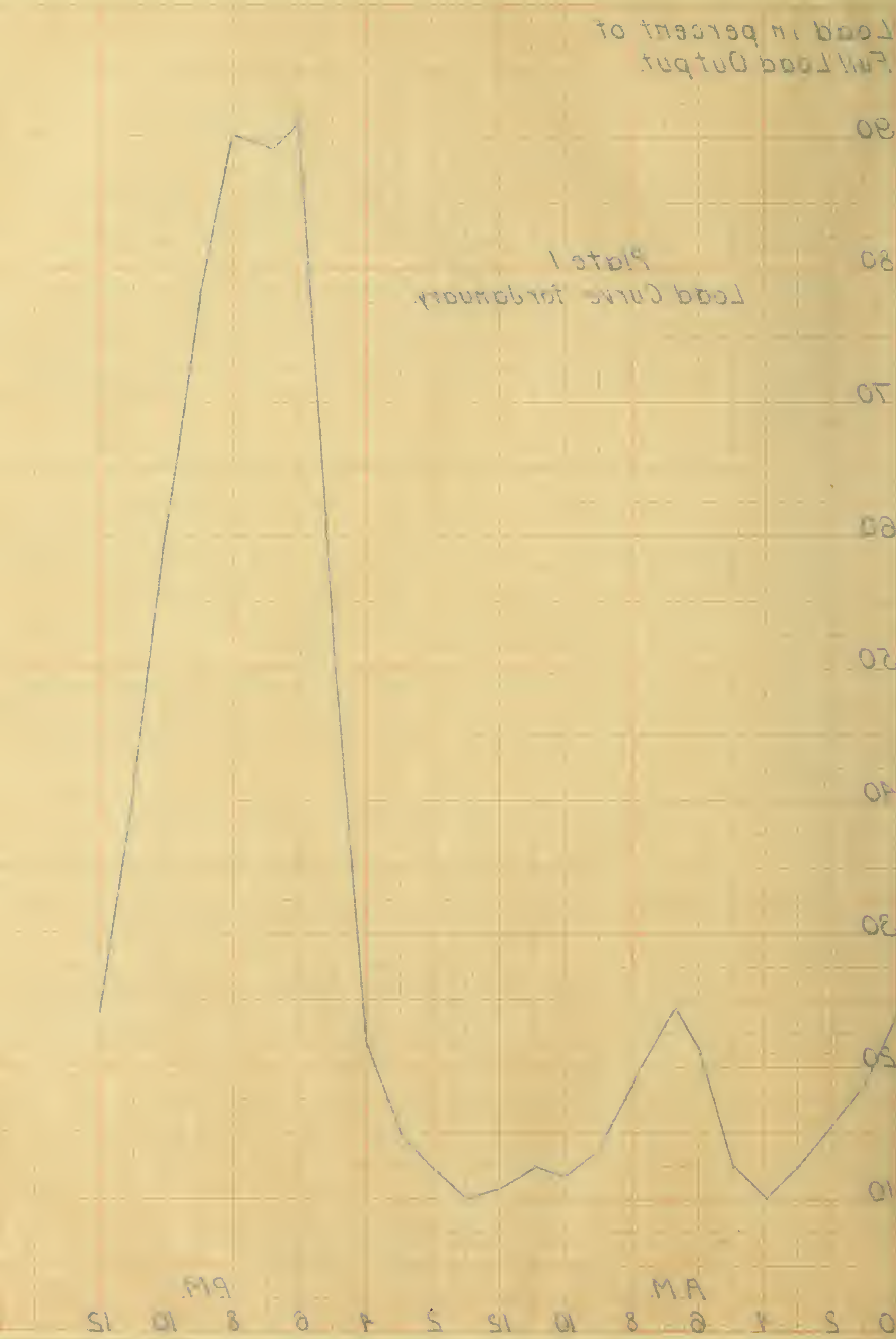


Plate I.
Load Curve for January.



Load in percent of Full Load Output.
Plate I
Load Curve for January.
90
80
70
60
50
40
30
20
10
A.M.
P.M.
0 2 4 6 8 10 12 2 4 6 8 10 12

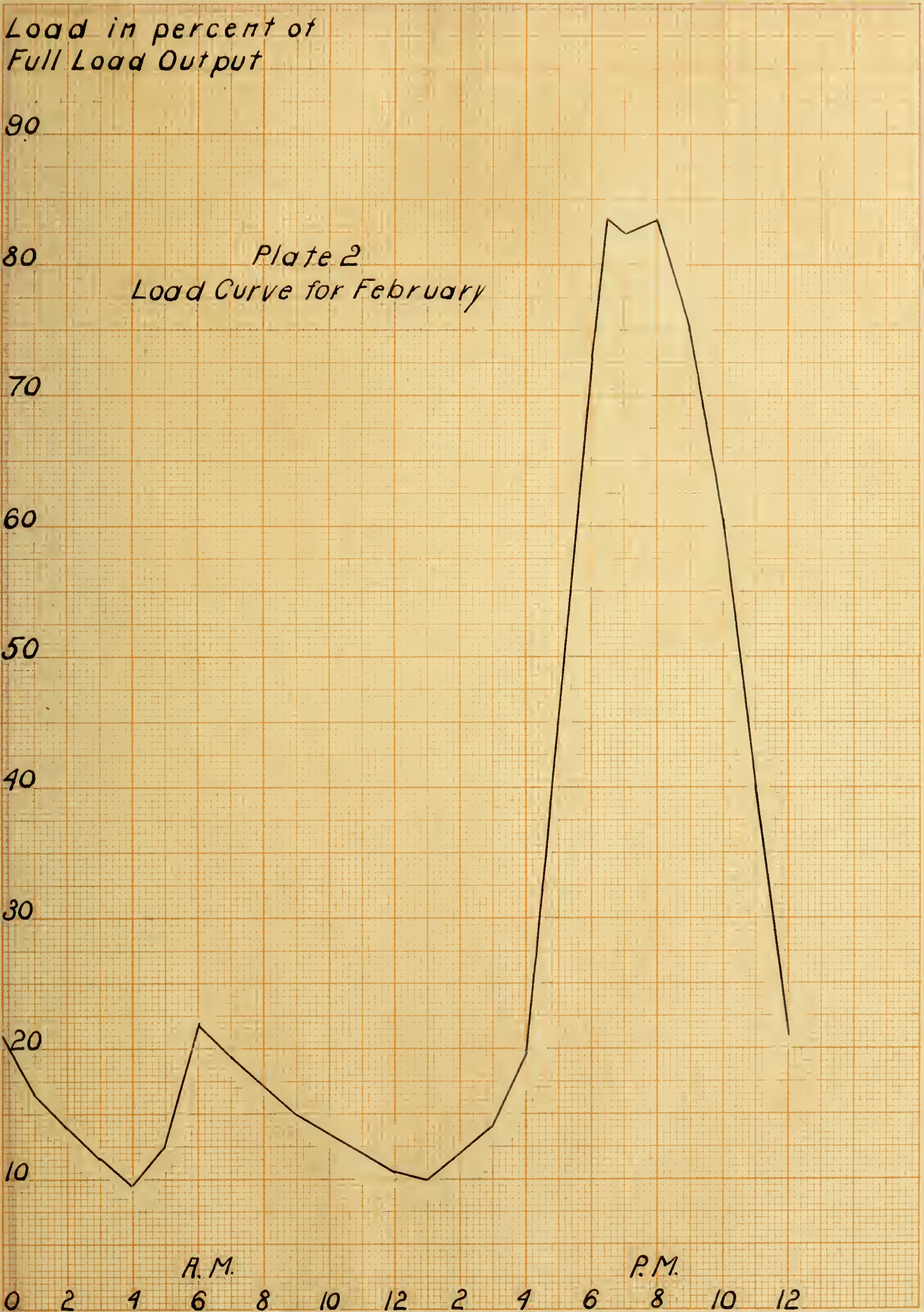
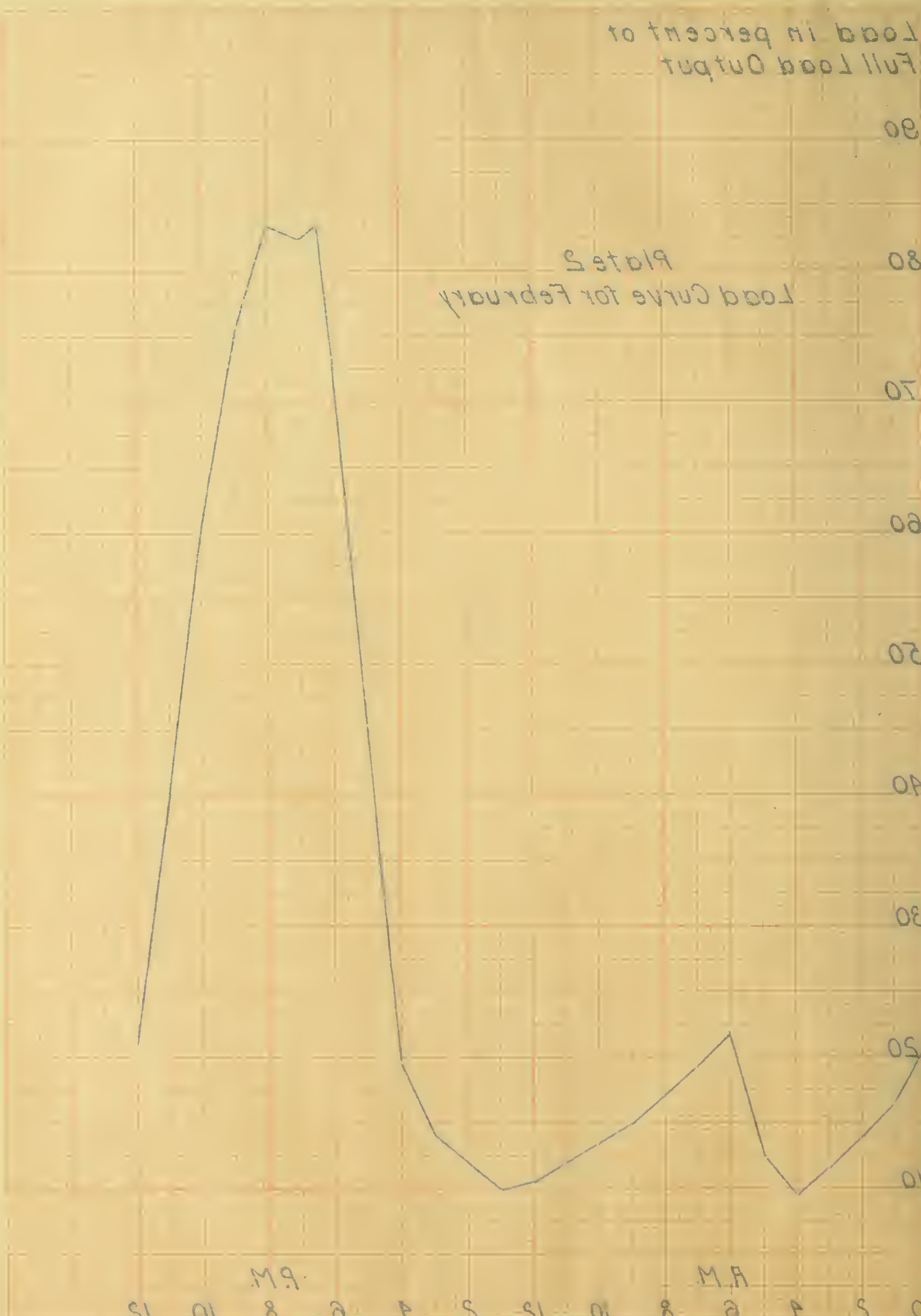
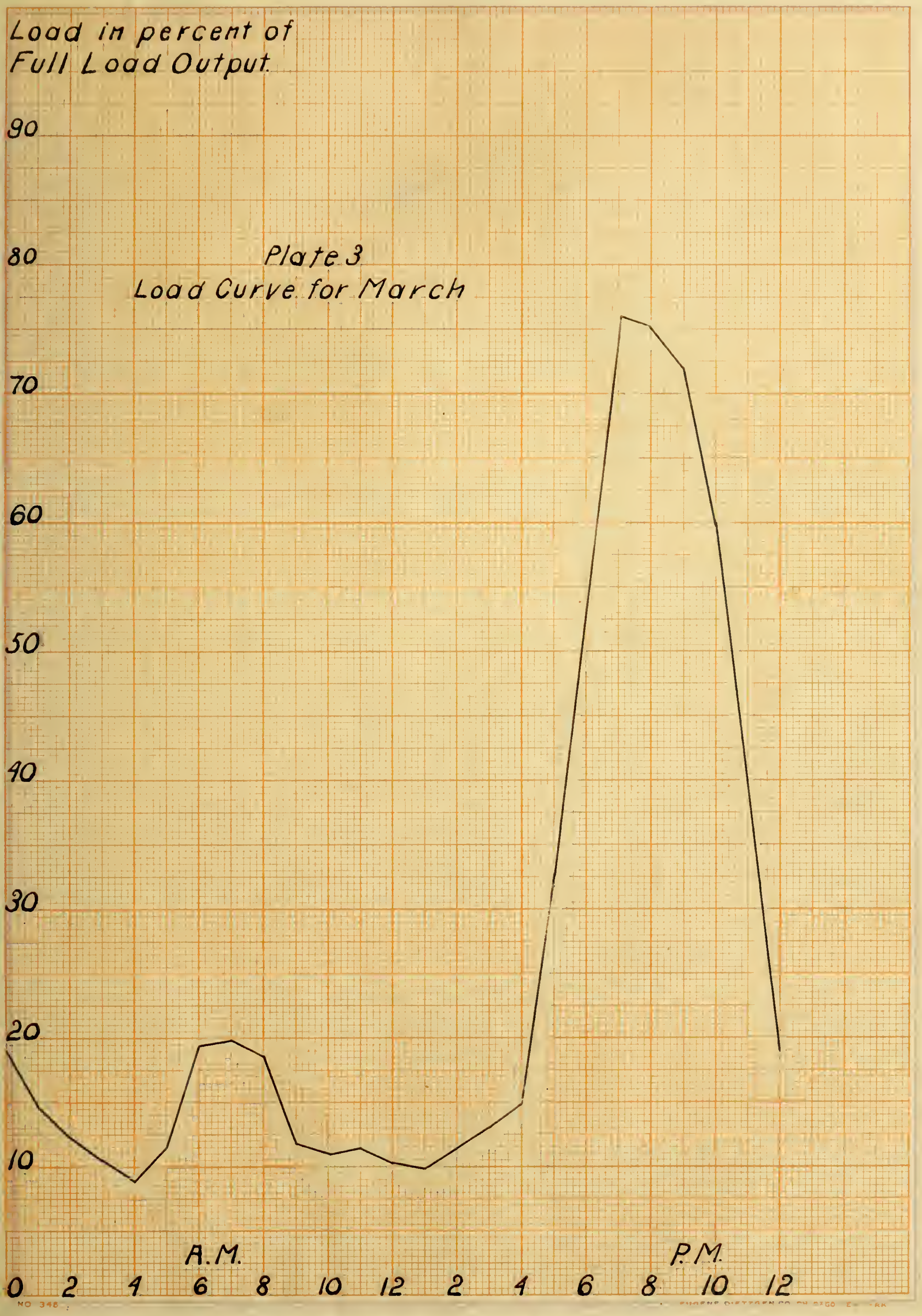
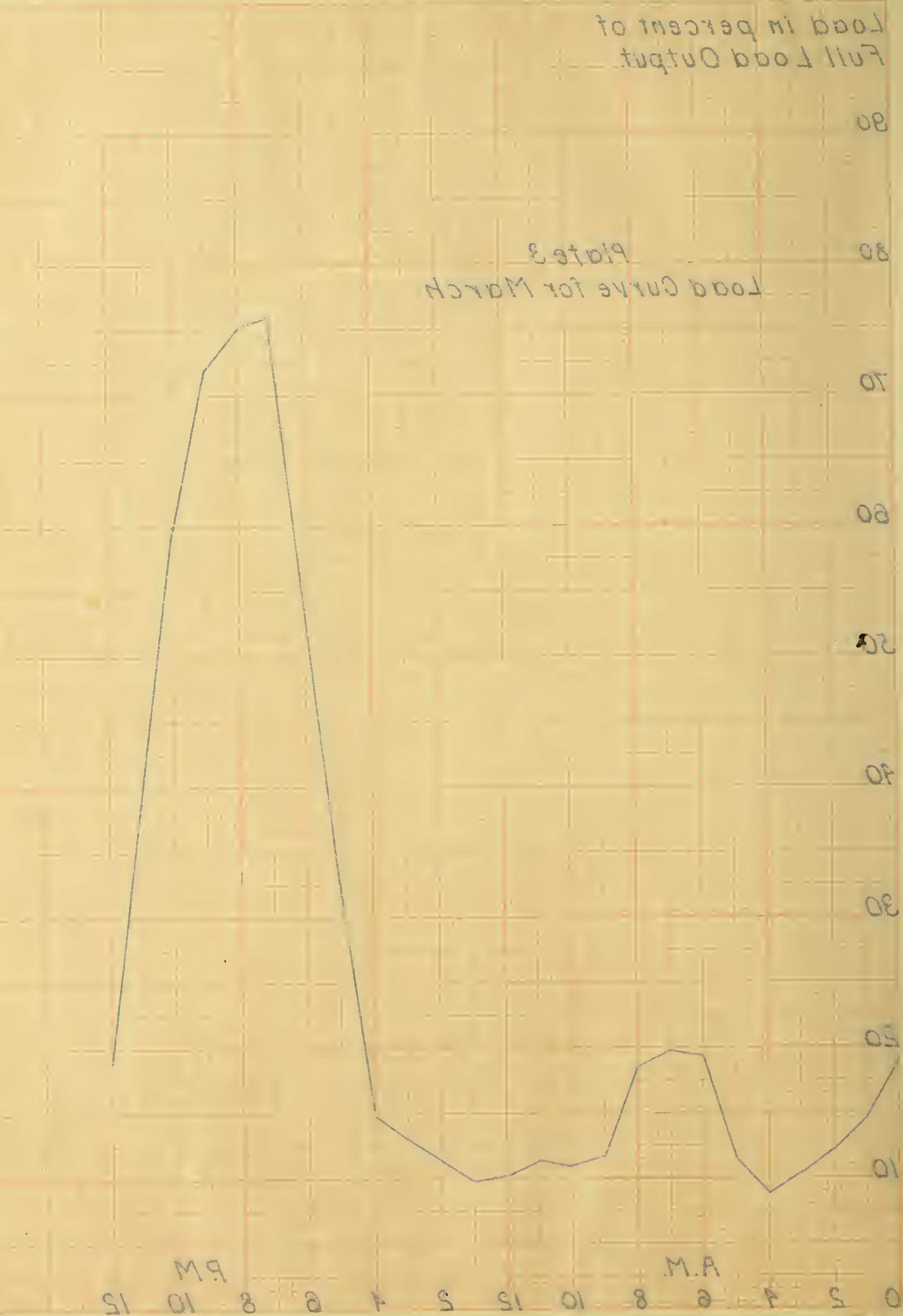


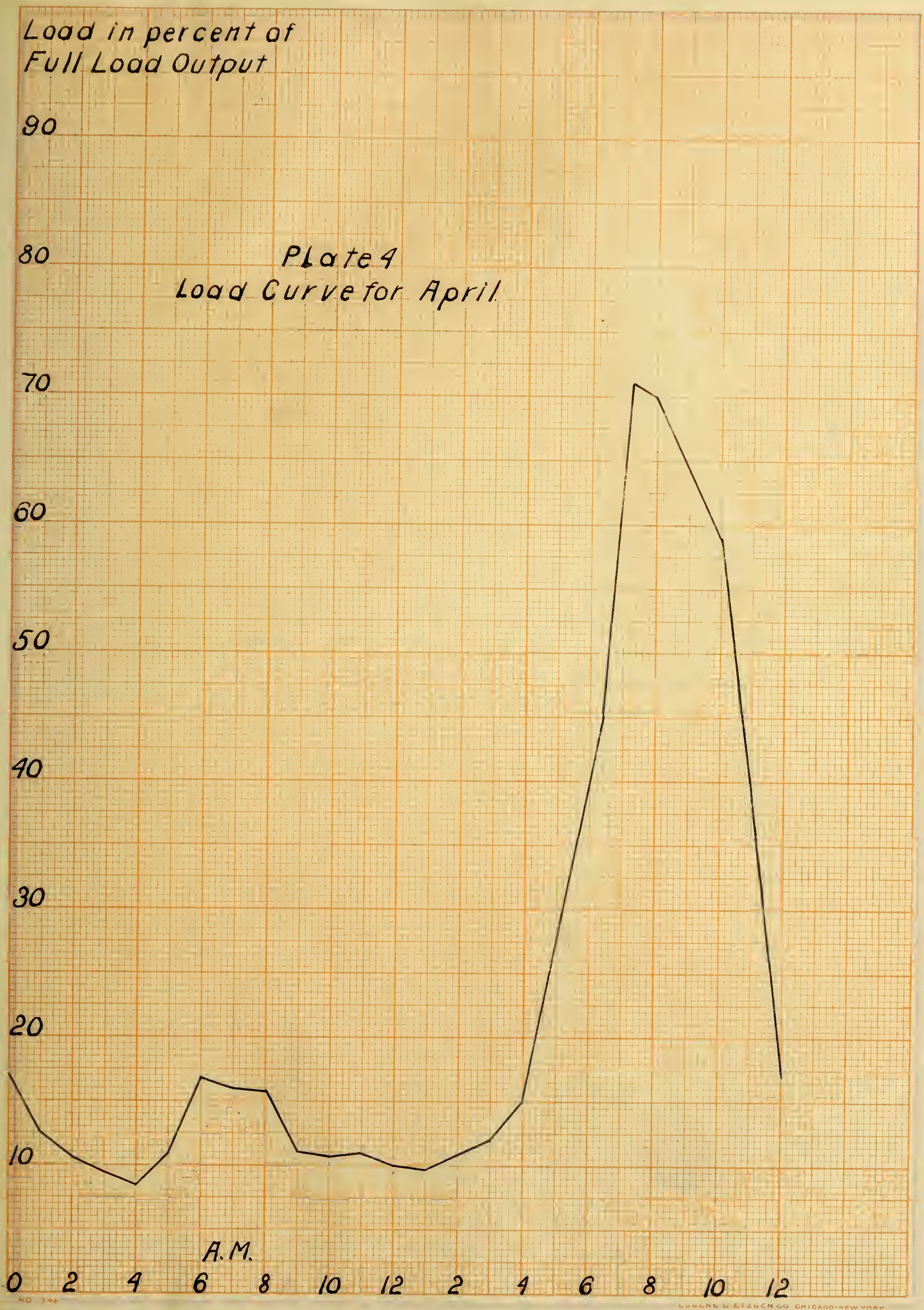
Plate 2
Load Curve for February



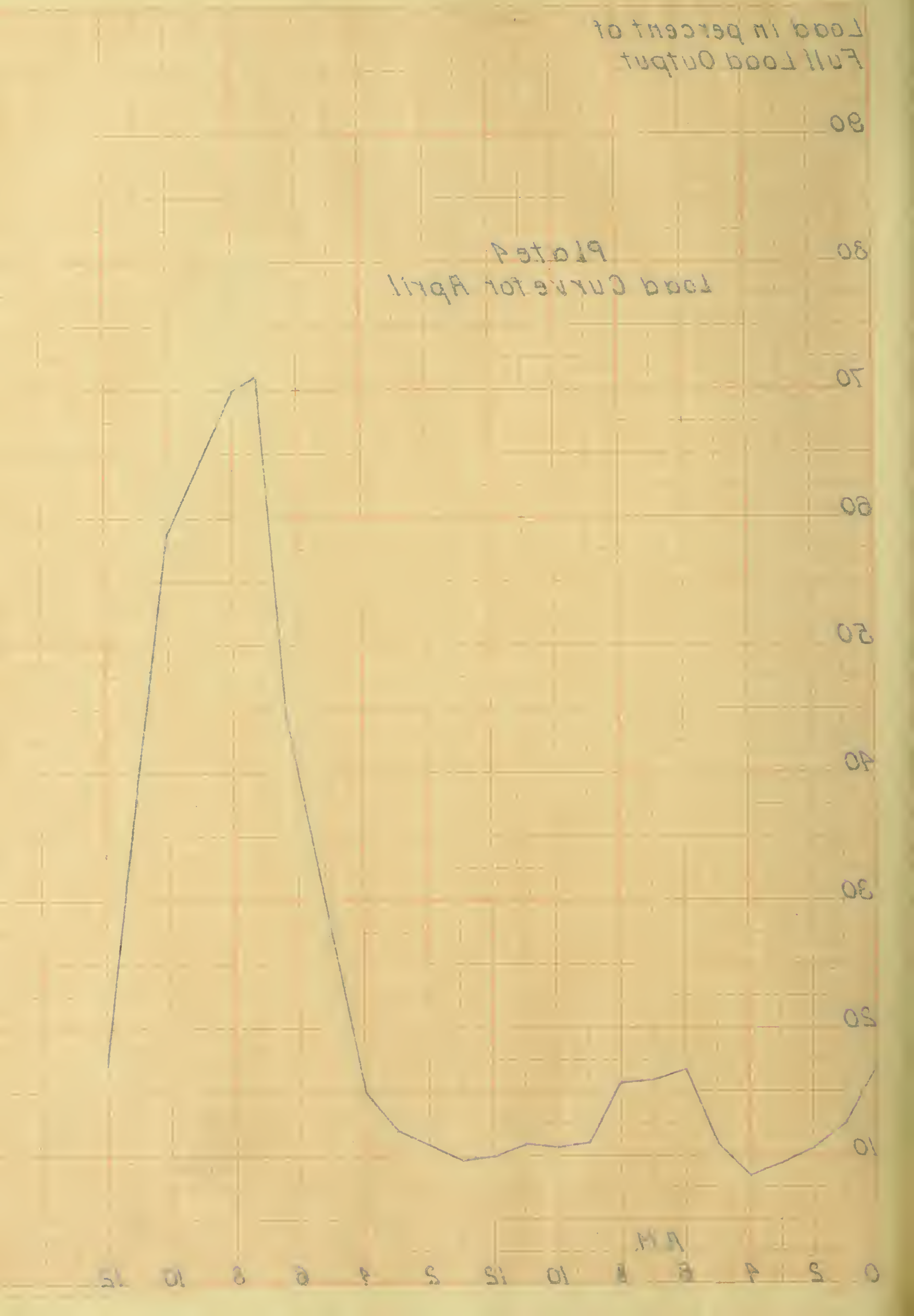
Load in percent of
Full Load Output
Plate 2
Load Curve for February
90
80
70
60
50
40
30
20
10
0
A.M.
P.M.
2
4
6
8
10
12
2
4
6
8
10
12

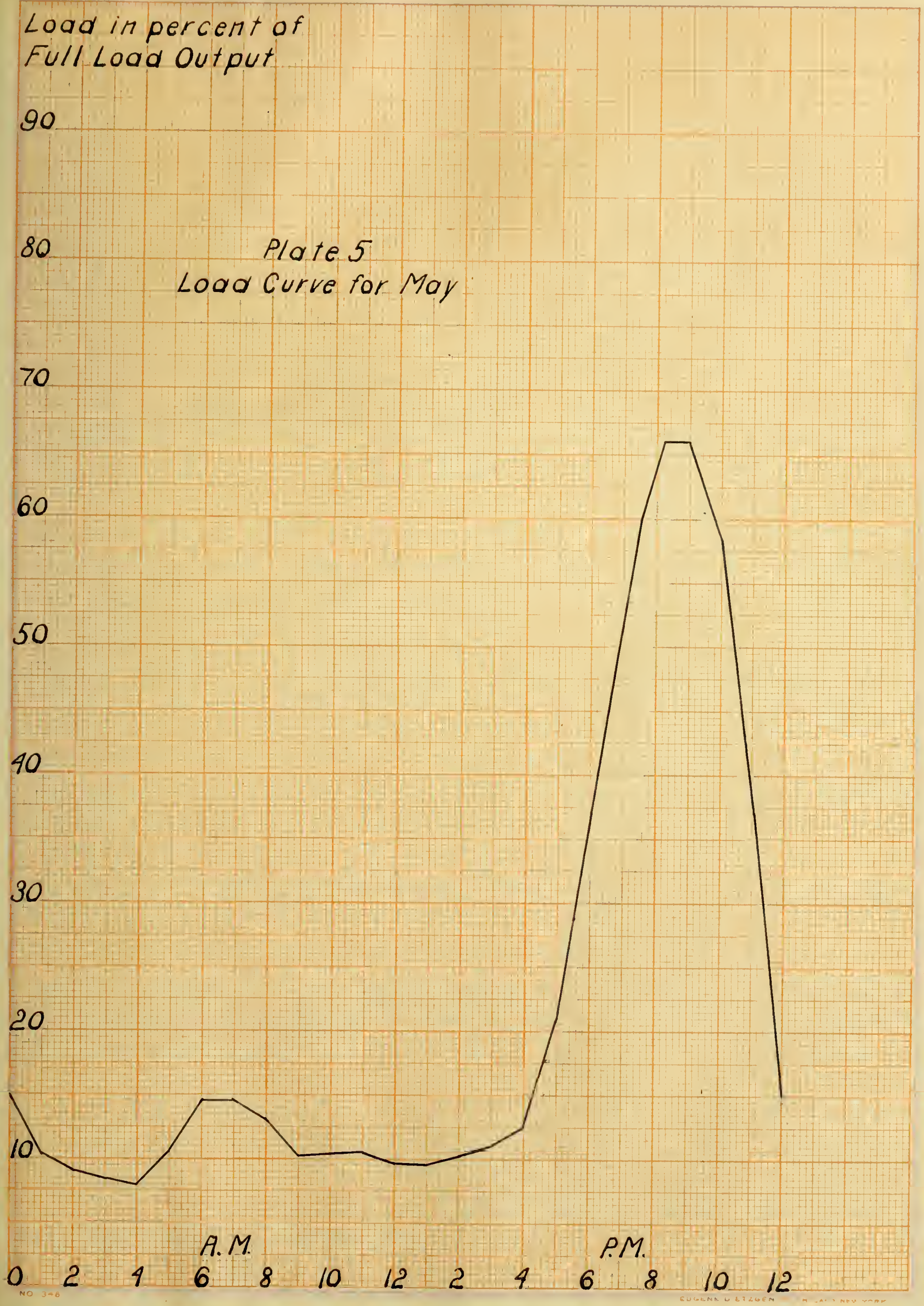

Load in percent of
Full Load Output.
Plate 3
Load Curve for March
90
80
70
60
50
40
30
20
10
A.M.
P.M.
0
2
4
6
8
10
12
2
4
6
8
10
12


Load in percent of Full Load Output
90
80
70
60
50
40
30
20
10
0
Plate 3
Load Curve for March
A.M.
P.M.
0 2 4 6 8 10 12 2 4 6 8 10 12



Load in percent of
Full Load Output
90
80
Plate 4
Load Curve for April
70
60
50
40
30
20
10
A.M.
0
2
4
6
8
10
12
2
4
6
8
10
12
NO 346
EUGENE DIETZGEN CO CHICAGO-NEW YORK


Load in percent of
Full Load Output
Plate 4
Load Curve for April
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12
2
4
6
8
10
12
P.M.


Load in percent of
Full Load Output
Plate 5
Load Curve for May
90
80
70
60
50
40
30
20
10
A. M.
P.M.
0
2
4
6
8
10
12
2
4
6
8
10
12

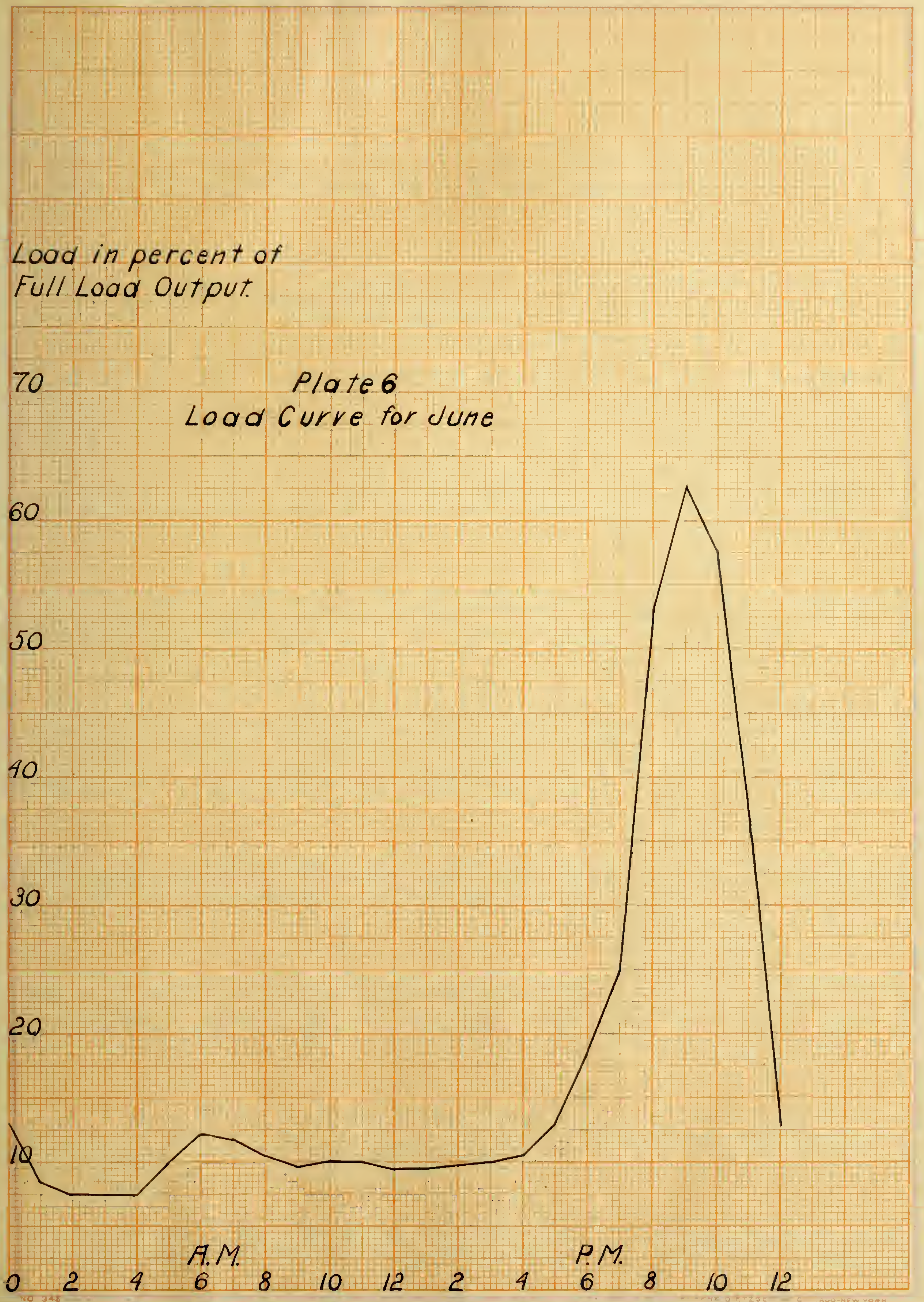
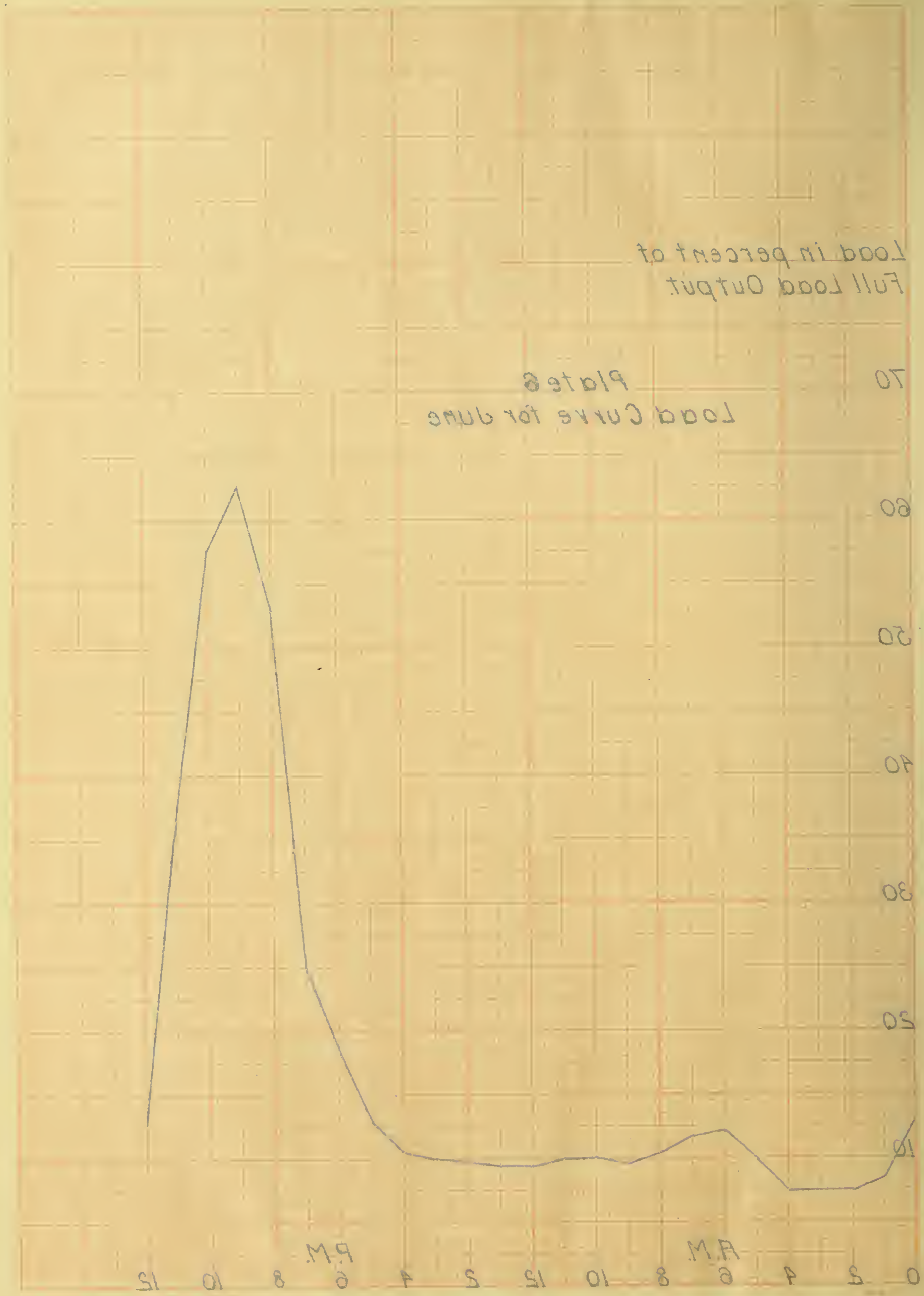
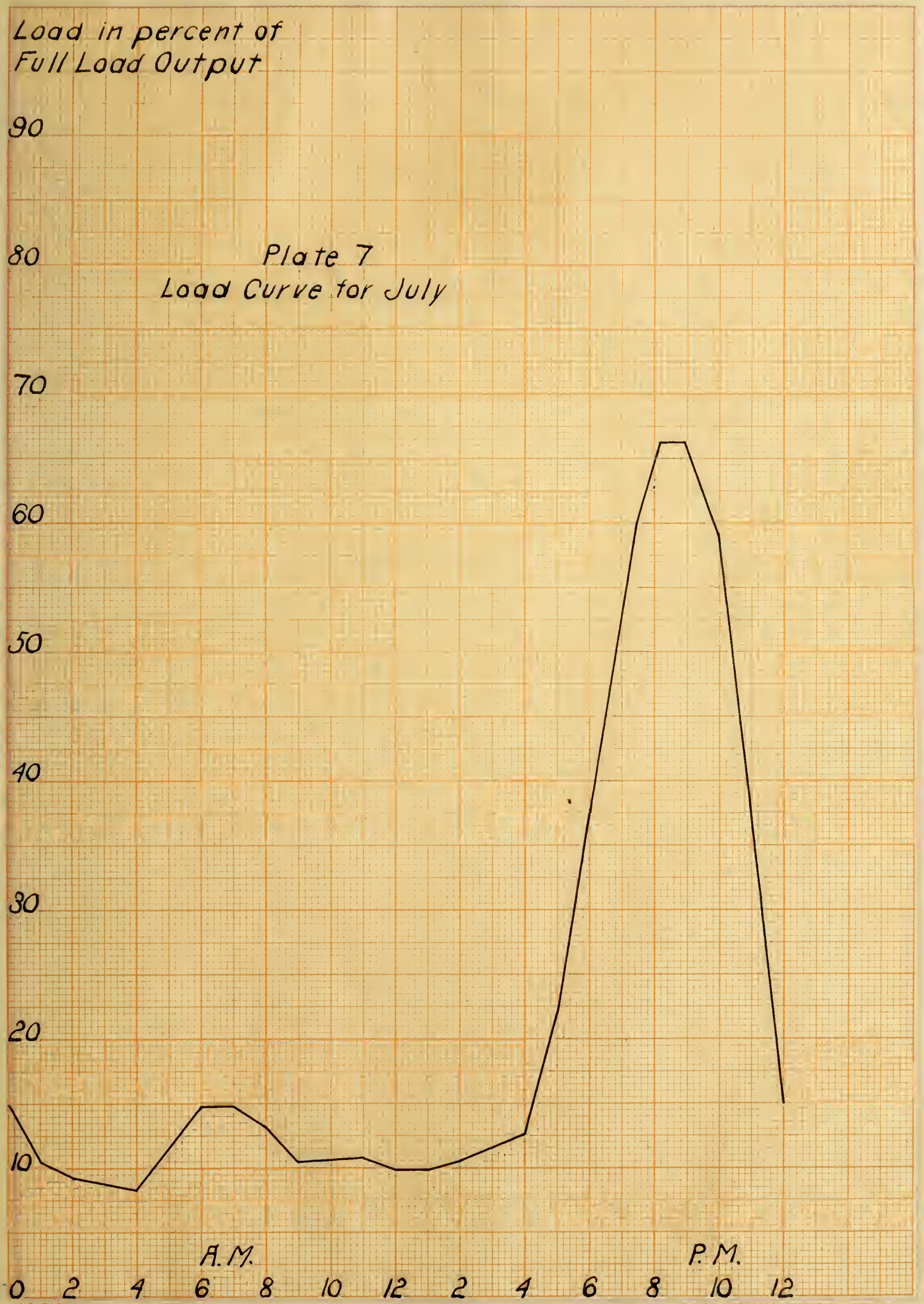
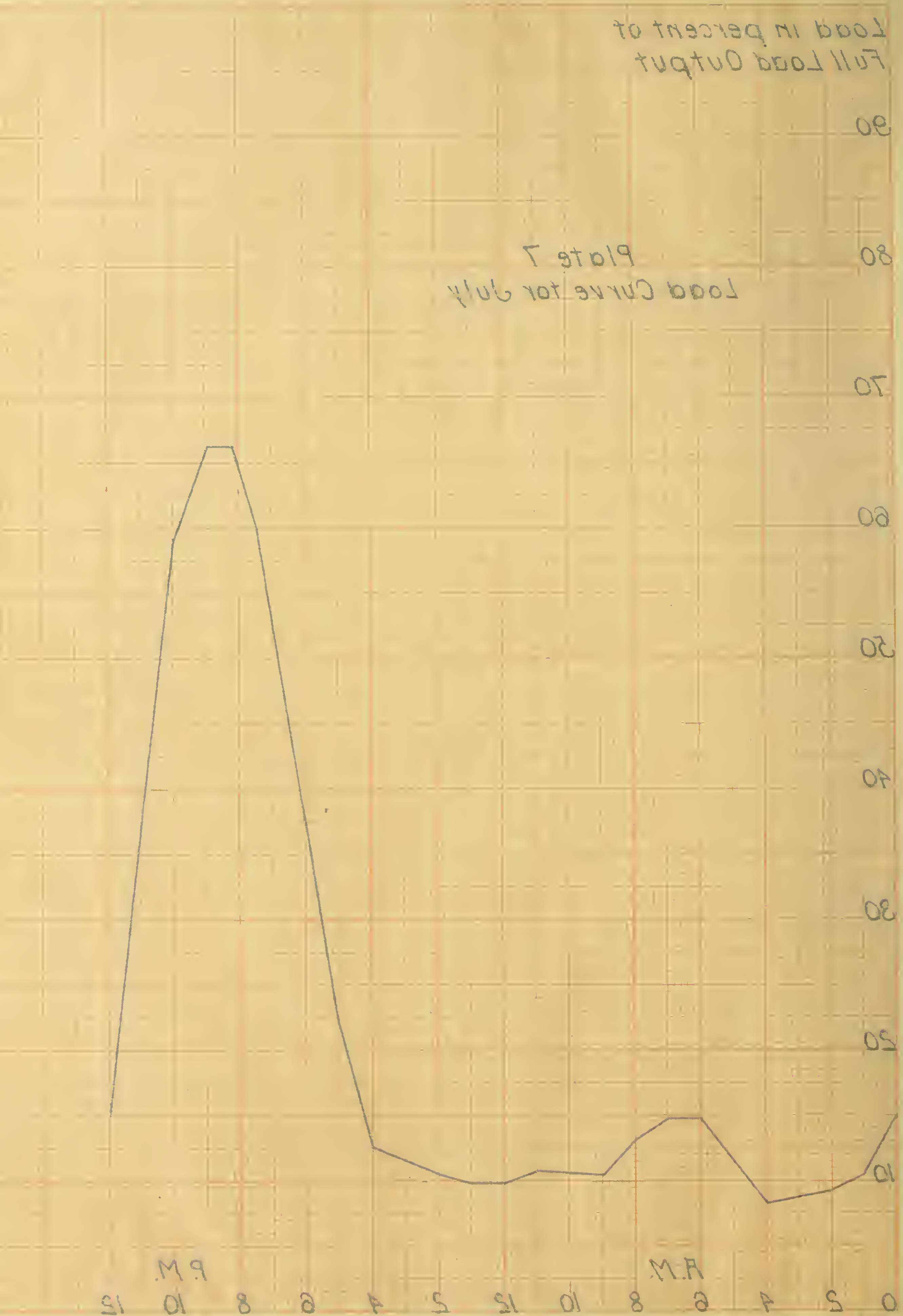


Plate 6
Load Curve for June

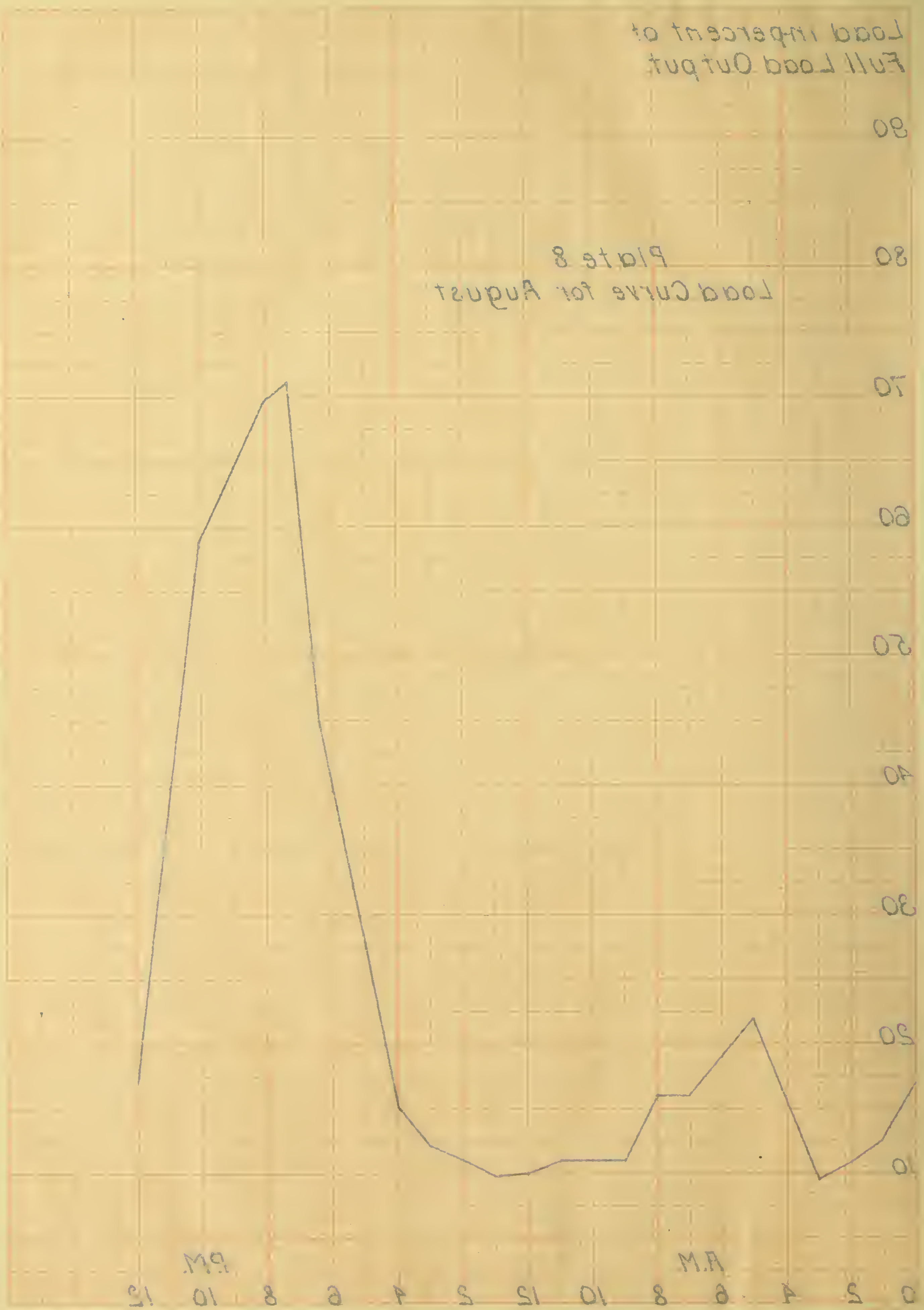


Load in percent of
Full Load Output
Plate 6
Load Curve for June
70
60
50
40
30
20
10
0
A.M.
P.M.
2
4
6
8
10
12
2
4
6
8
10
12


Load in percent of
Full Load Output
90
80
Plate 7
Load Curve for July
70
60
50
40
30
20
10
A.M.
P.M.
0
2
4
6
8
10
12
2
4
6
8
10
12


Load in percent of
Full Load Output
Plate 7
Load Curve for July
90
80
70
60
50
40
30
20
10
A.M.
P.M.
0 2 4 6 8 10 12 2 4 6 8 10 12


Load in-percent of
Full Load Output.
90
80
Plate 8
Load Curve for August
70
60
50
40
30
20
10
A.M.
P.M.
0
2
4
6
8
10
12
2
4
6
8
10
12


Load in percent of Full Load Output
90
80
70
60
50
40
30
20
10
Plate 8
Load Curve for August
A.M.
P.M.
0 2 4 6 8 10 12 2 4 6 8 10 12

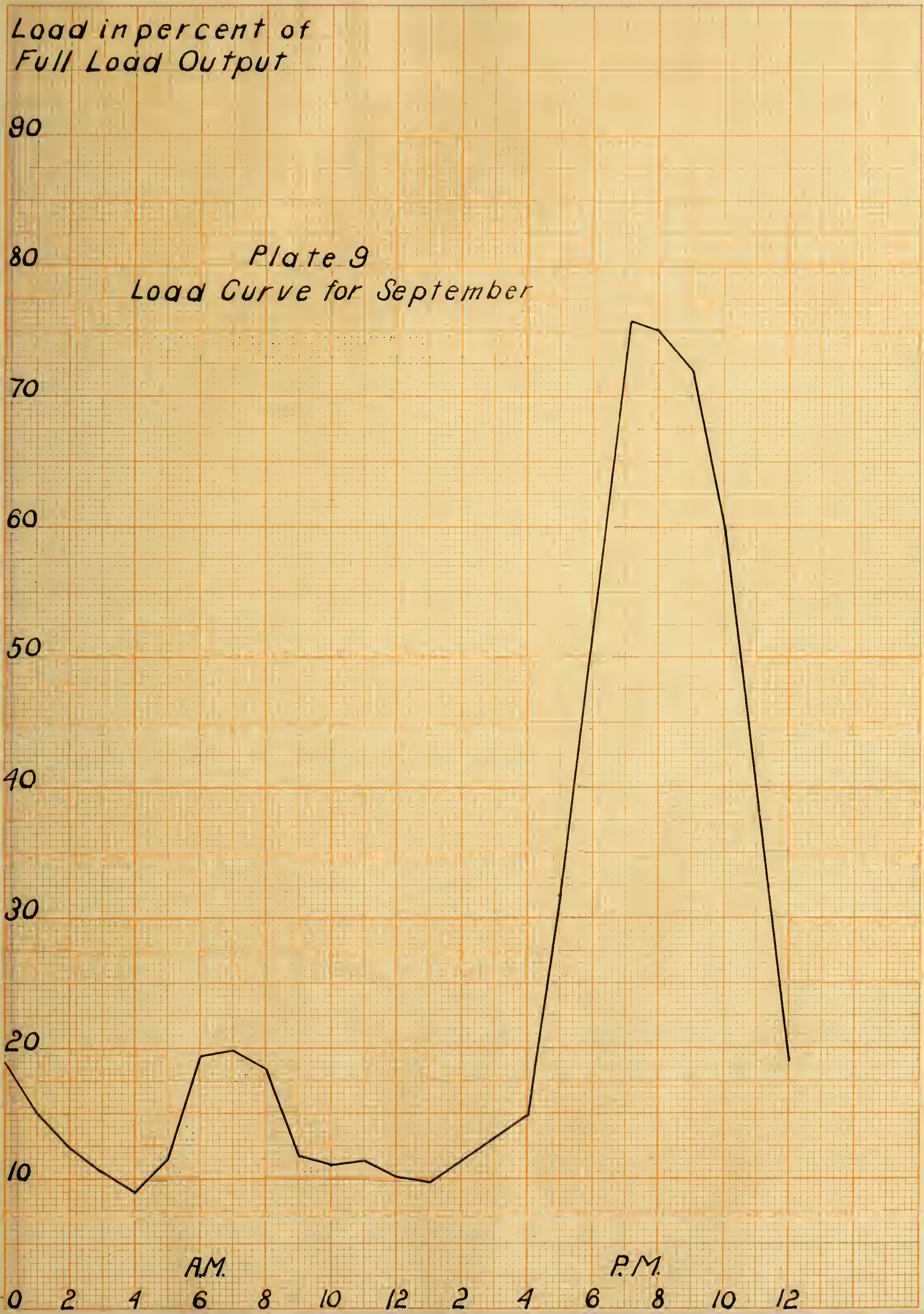
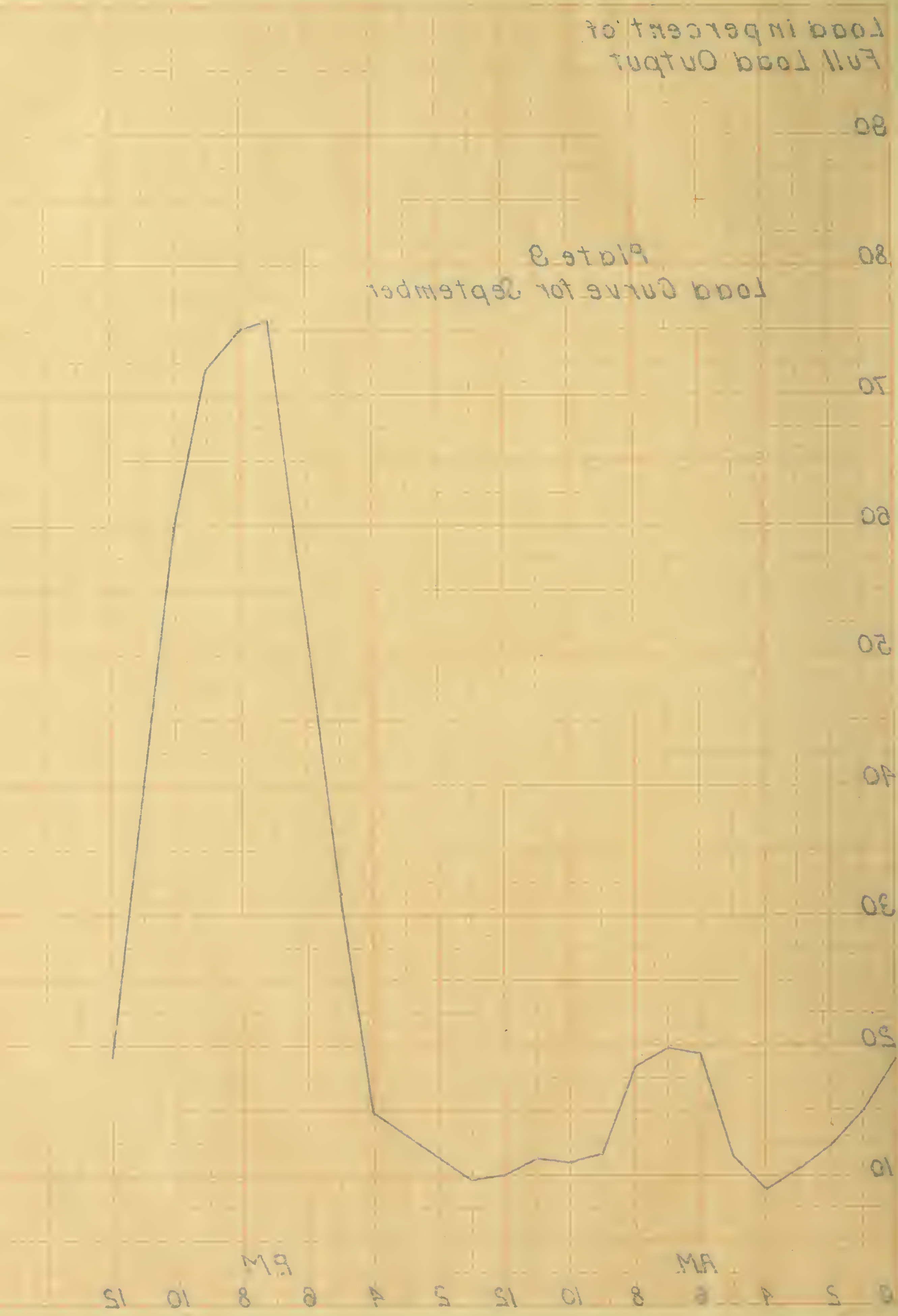
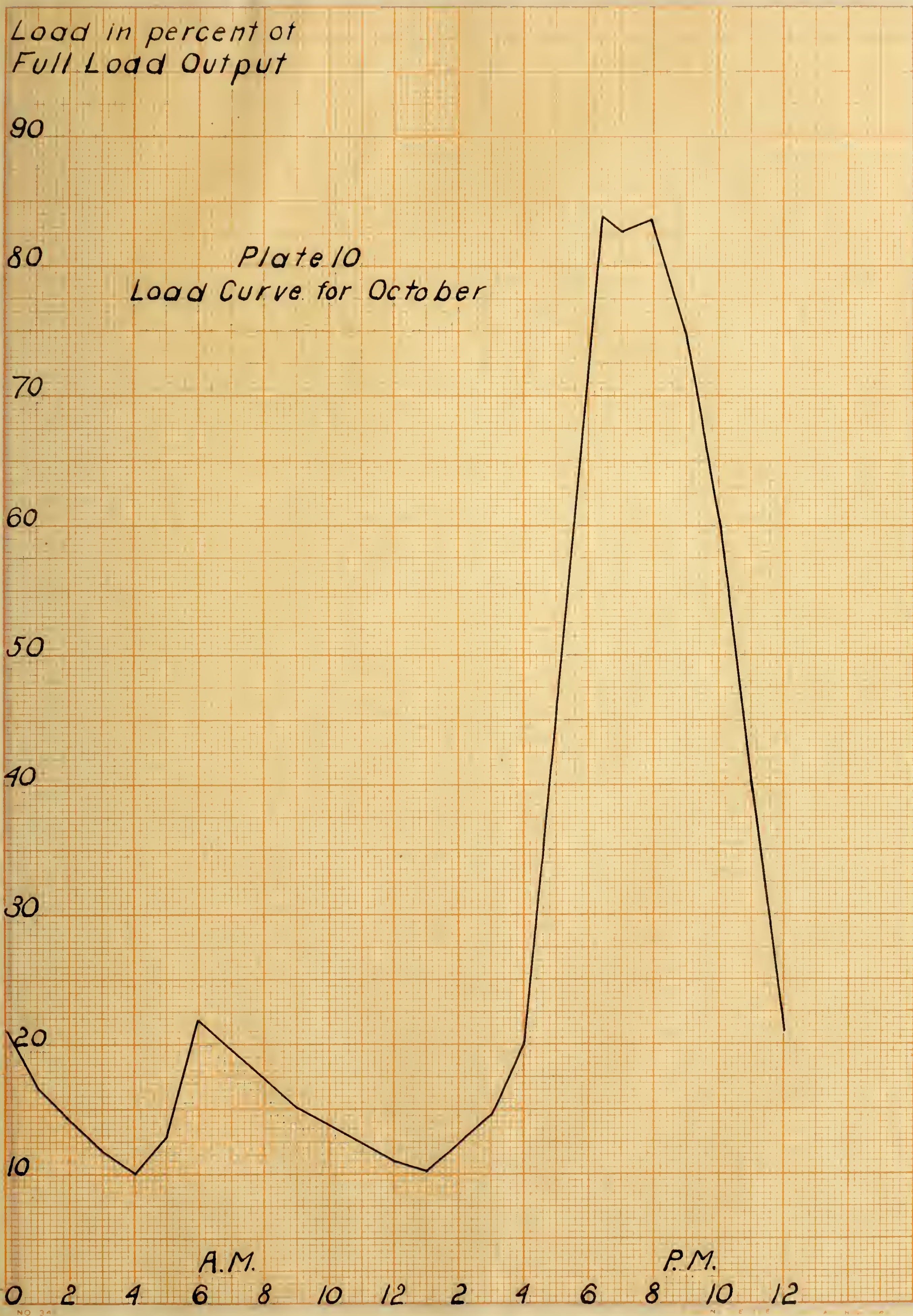
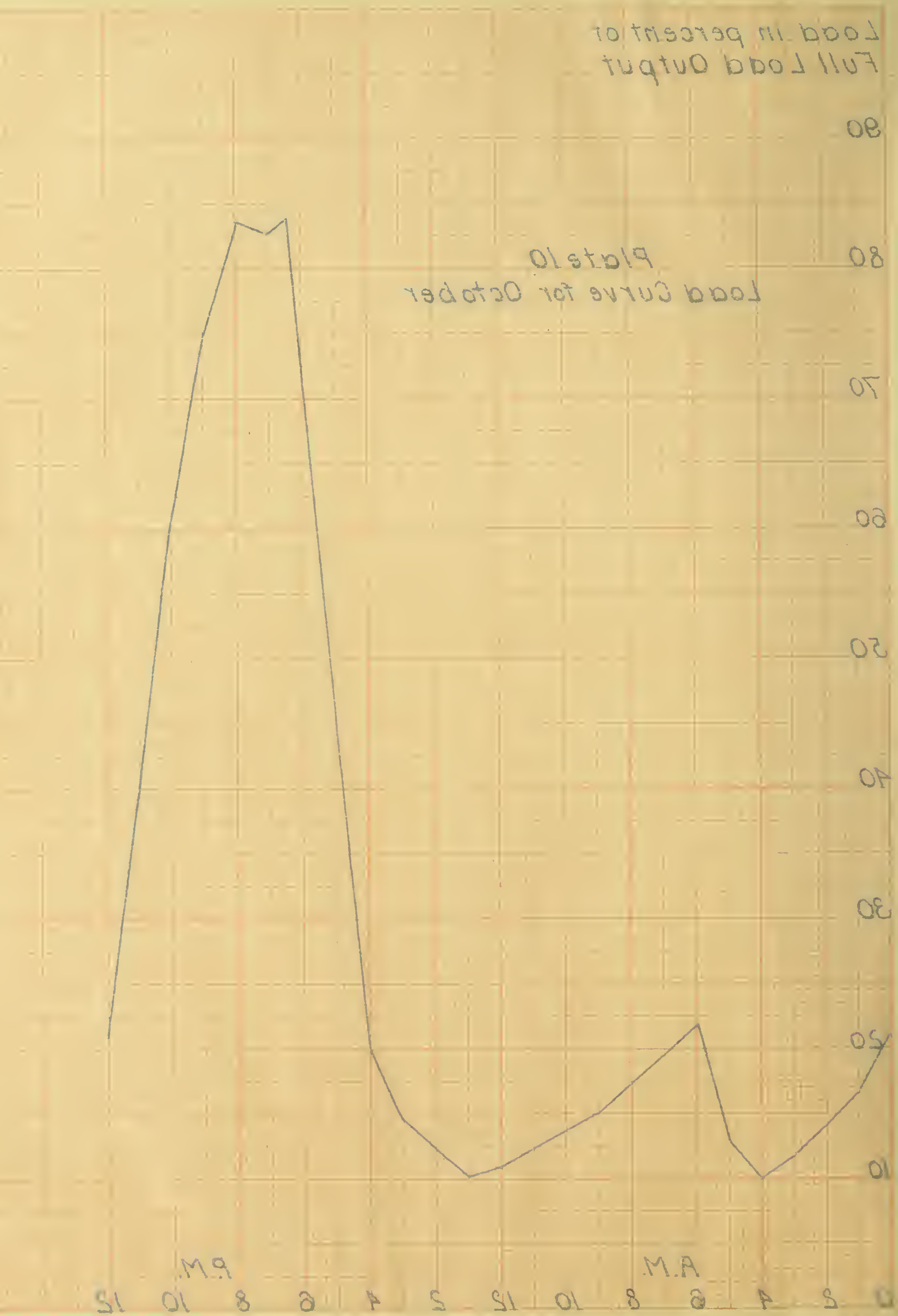


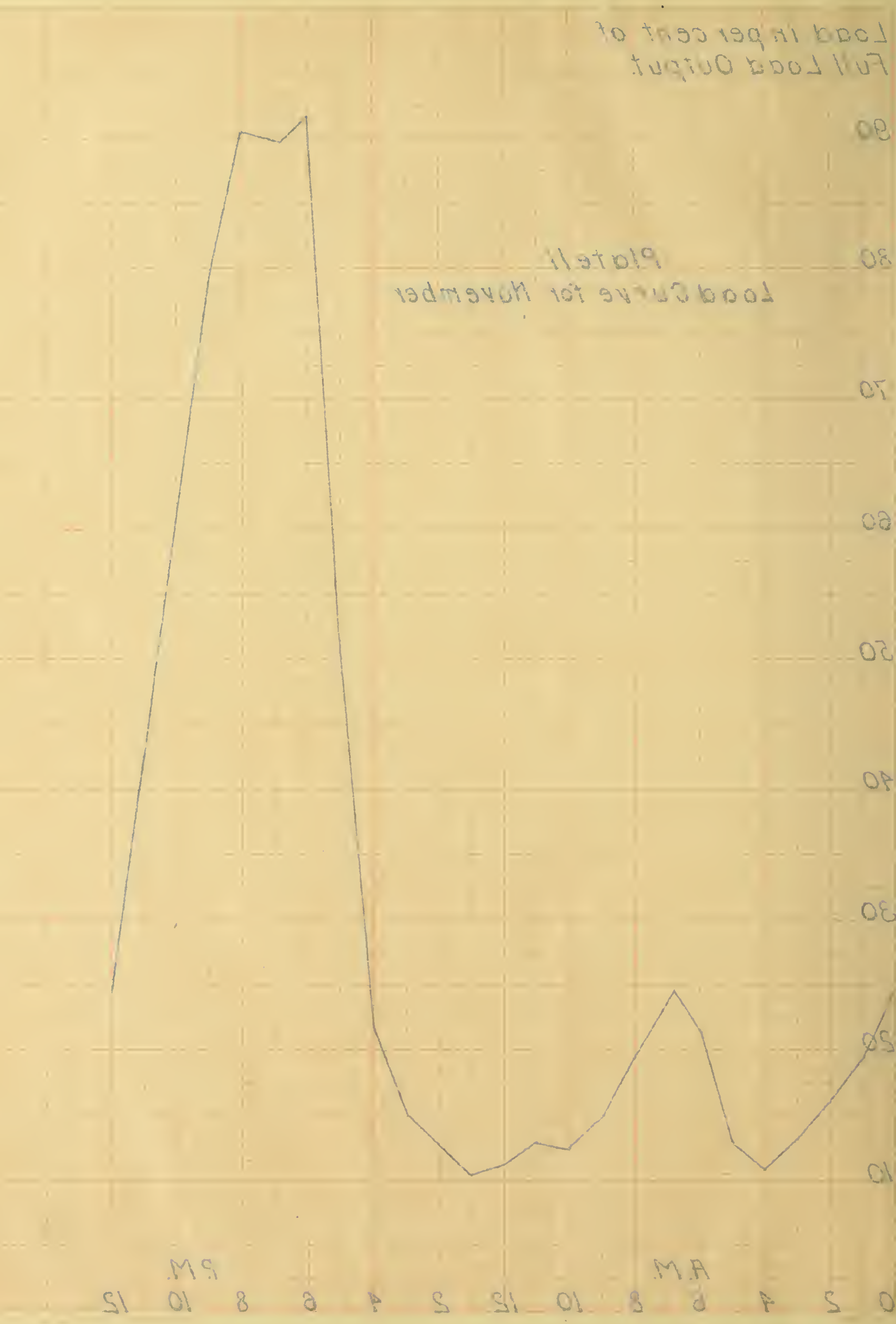
Plate 9
Load Curve for September


Load in percent of Full Load Output
Plate 9
Load Curve for September
90
80
70
60
50
40
30
20
10
A.M.
P.M.
6
2
4
6
8
10
12
2
4
6
8
10
12


Load in percent of
Full Load Output
90
80
70
60
50
40
30
20
10
Plate 10
Load Curve for October
A.M.
P.M.
0
2
4
6
8
10
12
2
4
6
8
10
12


Load in percent of Full Load Output
Plate 10
Load Curve for October
90
80
70
60
50
40
30
20
10
P.M.
A.M.
12 10 8 6 4 2 12 10 8 6 4 2 0

Load in per cent of
Full Load Output.
Plate II
Load Curve for November
90
80
70
60
50
40
30
20
10
A.M.
P.M.
0
2
4
6
8
10
12
2
4
6
8
10
12


Load in per cent of
Full Load Output
Plate II
Load Curve for November
90
80
70
60
50
40
30
20
10
P.M.
A.M.
12 10 8 6 4 2 12 10 8 6 4 2 0

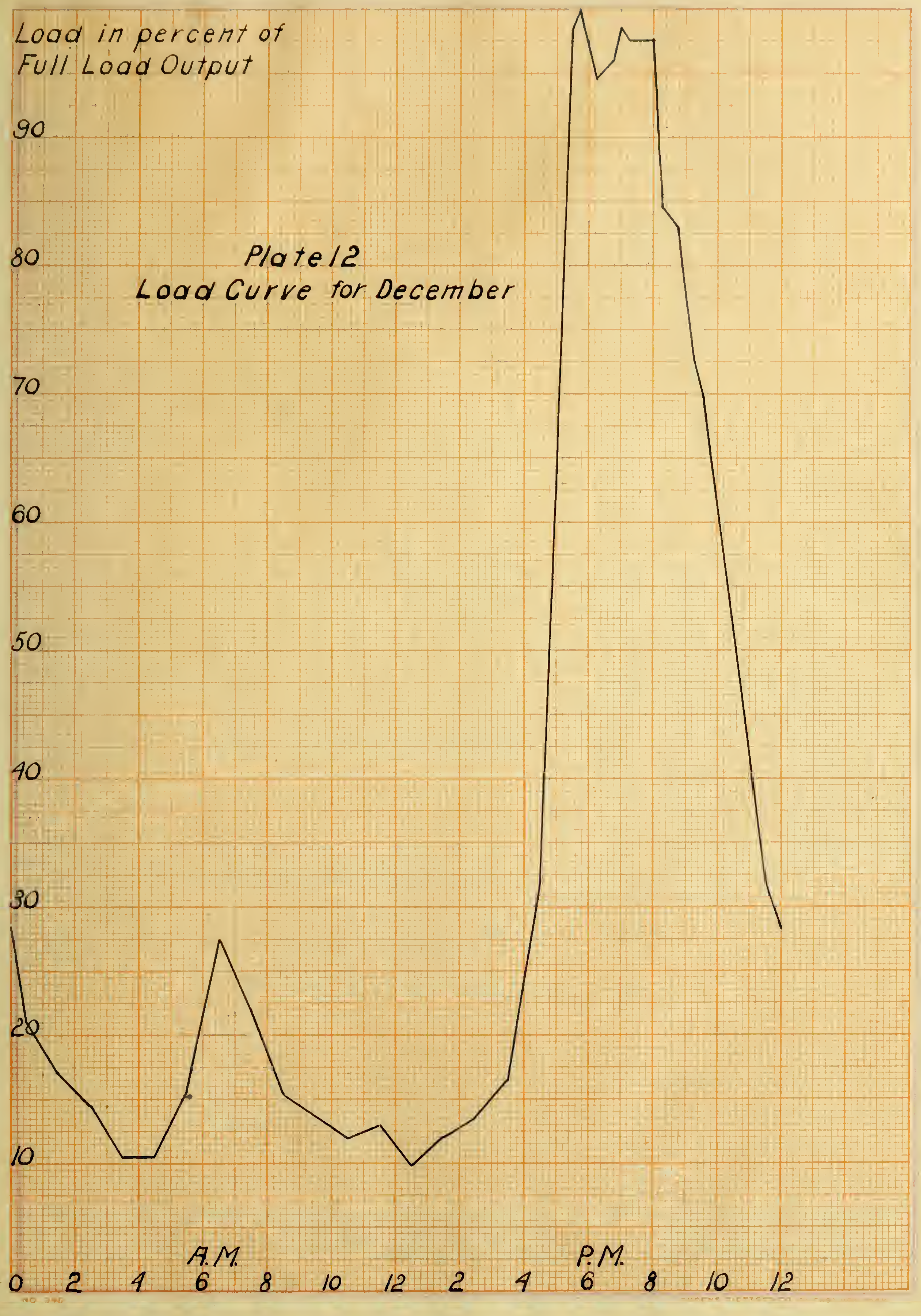
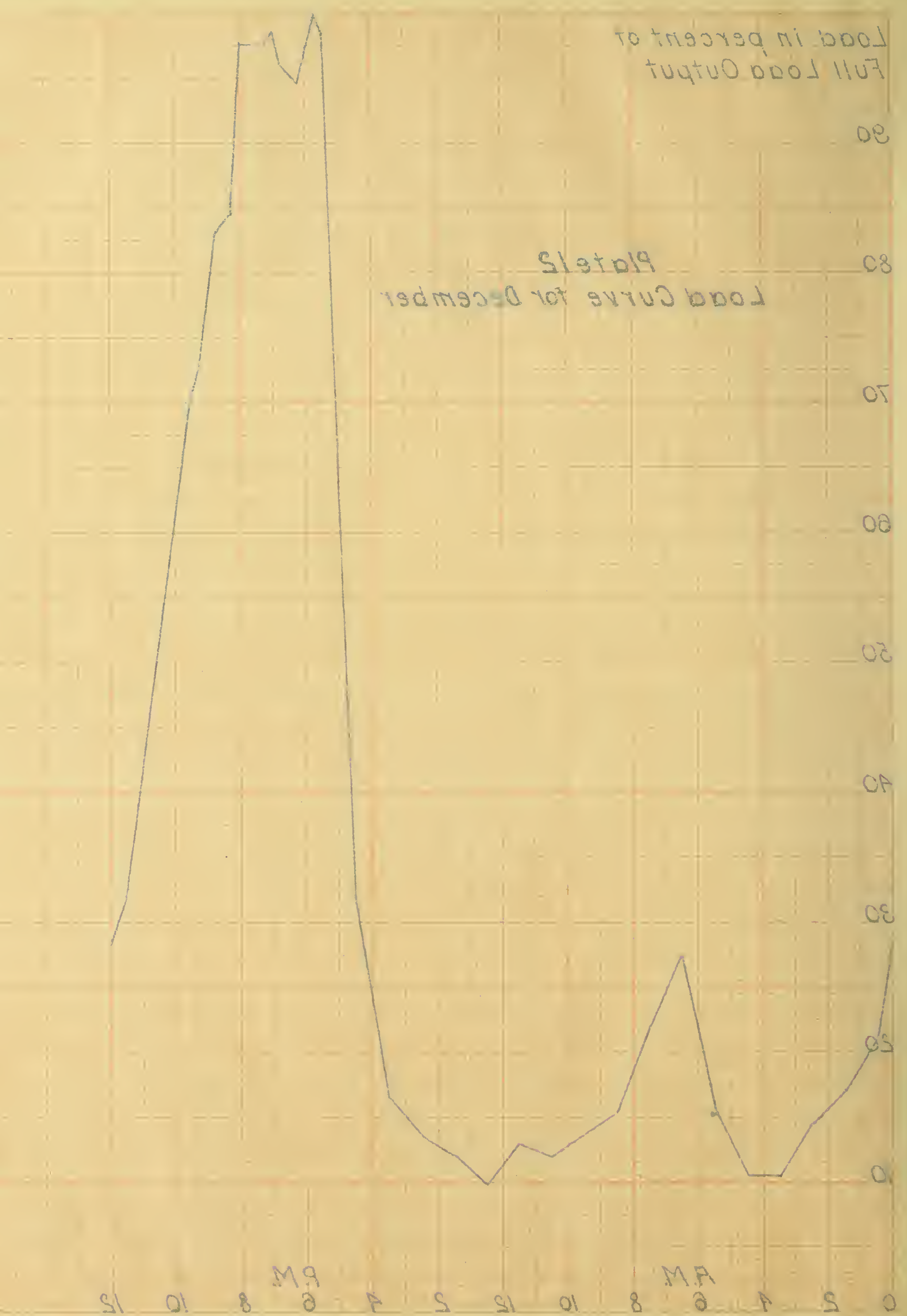


Plate 12
Load Curve for December



Load in percent of Full Load Output
Plate 12
Load Curve for December
90
80
70
60
50
40
30
20
10
0
A.M.
P.M.
0 2 4 6 8 10 12 2 4 6 8 10 12

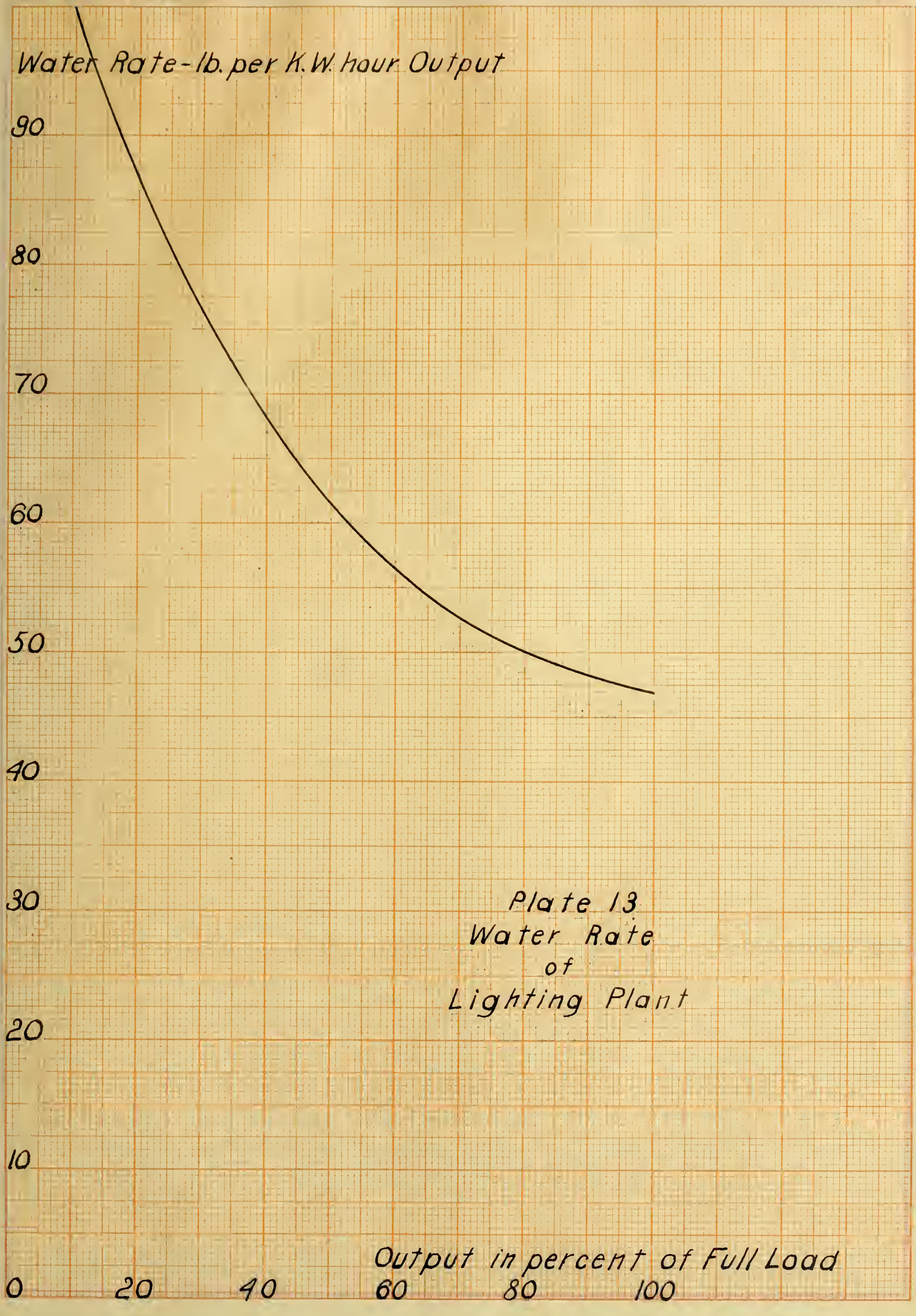


Plate 13
Water Rate
of
Lighting Plant

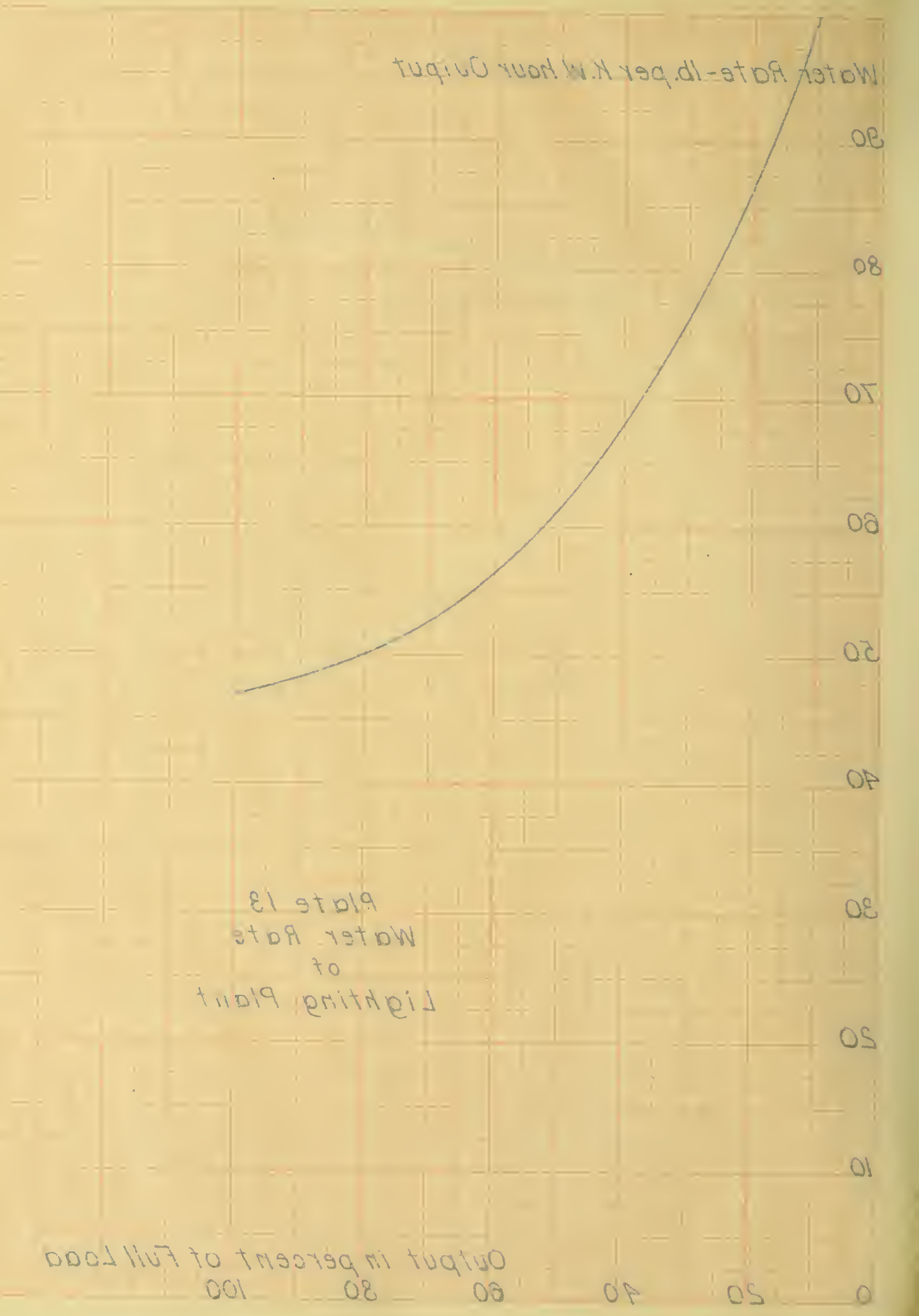


Plate 13
Water Rate
of
Lighting Plant

Monthly Ice Sales in percent of Average Sales

Plate 14

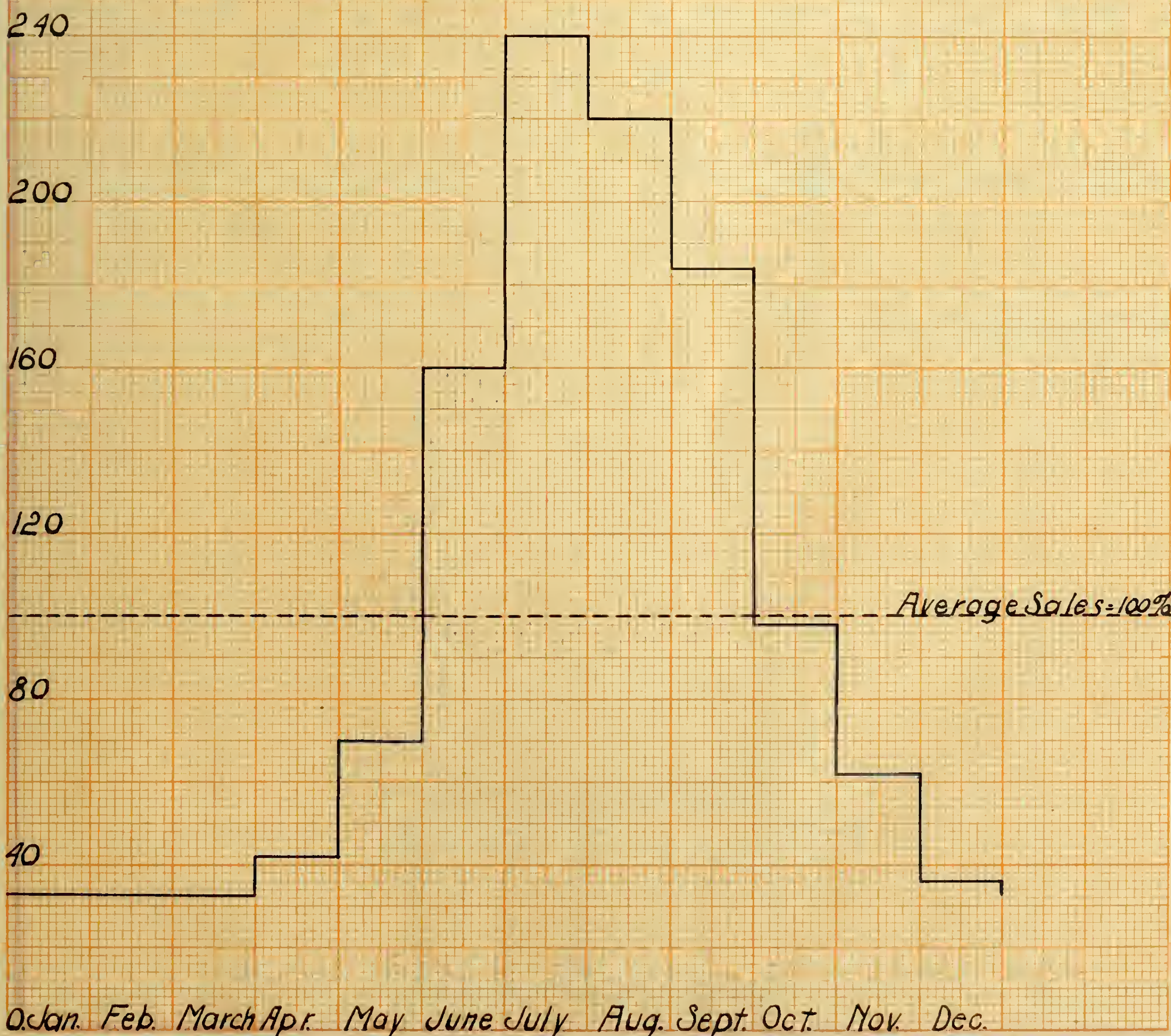



Plate 14
Monthly Ice Sales in percent of Average Sales
240
200
160
120
Average Sales=100%
80
40
Jan Feb March Apr. May June July Aug. Sept Oct Nov Dec.

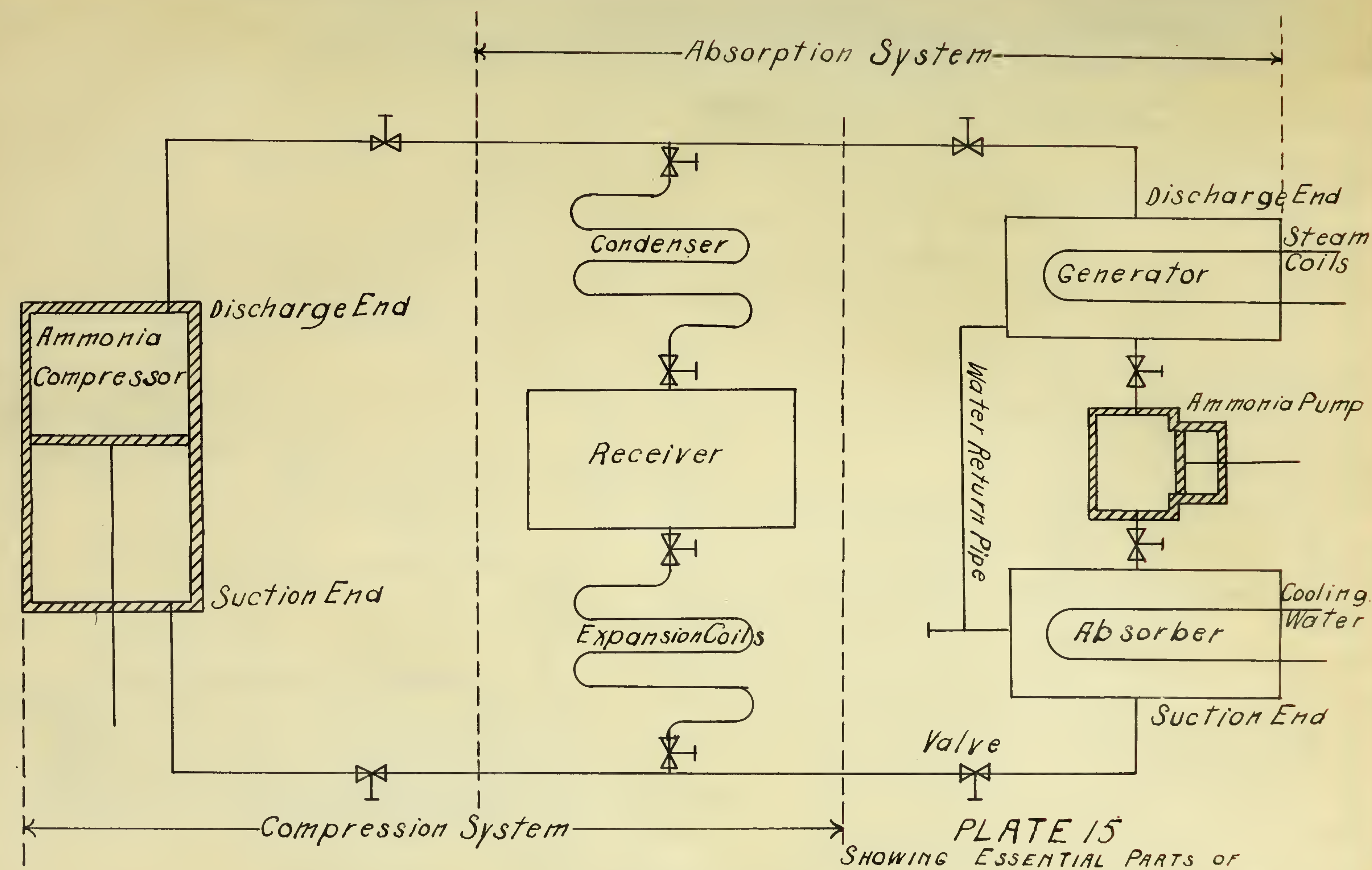


PLATE 15
SHOWING ESSENTIAL PARTS OF ABSORPTION AND COMPRESSION ICE MACHINES

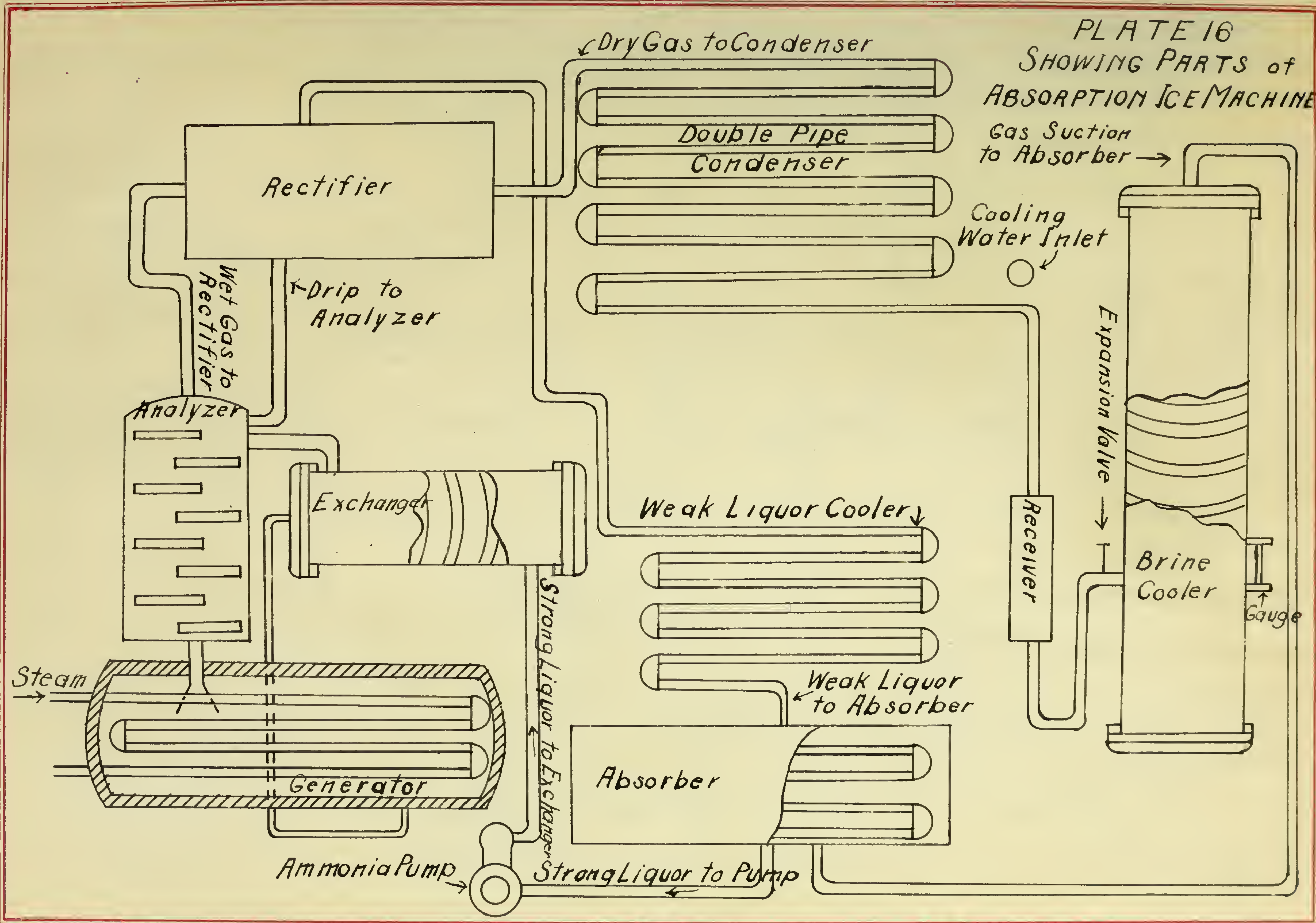
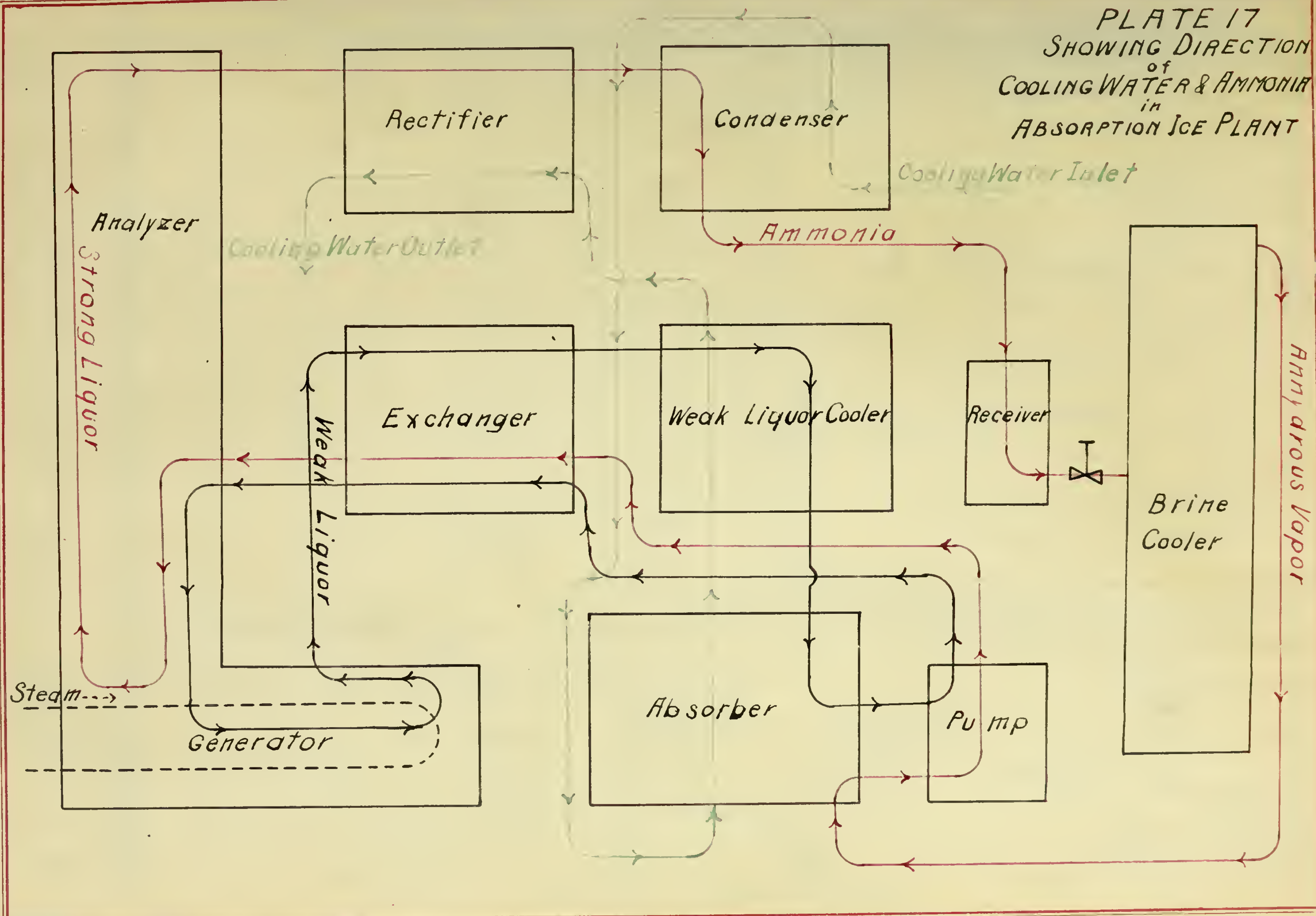


PLATE 16
SHOWING PARTS of
ABSORPTION ICE MACHINE
Dry Gas to Condenser
Double Pipe
Condenser
Gas Suction
to Absorber
Cooling
Water Inlet
Rectifier
Drip to
Analyzer
Wet Gas to
Rectifier
Analyzer
Exchanger
Weak Liquor Cooler
Expansion Valve
Receiver
Brine
Cooler
Gauge
Strong Liquor to Exchanger
Weak Liquor
to Absorber
Steam
Generator
Absorber
Ammonia Pump
Strong Liquor to Pump

PLATE 17
SHOWING DIRECTION
of
COOLING WATER & AMMONIA
in
ABSORPTION ICE PLANT



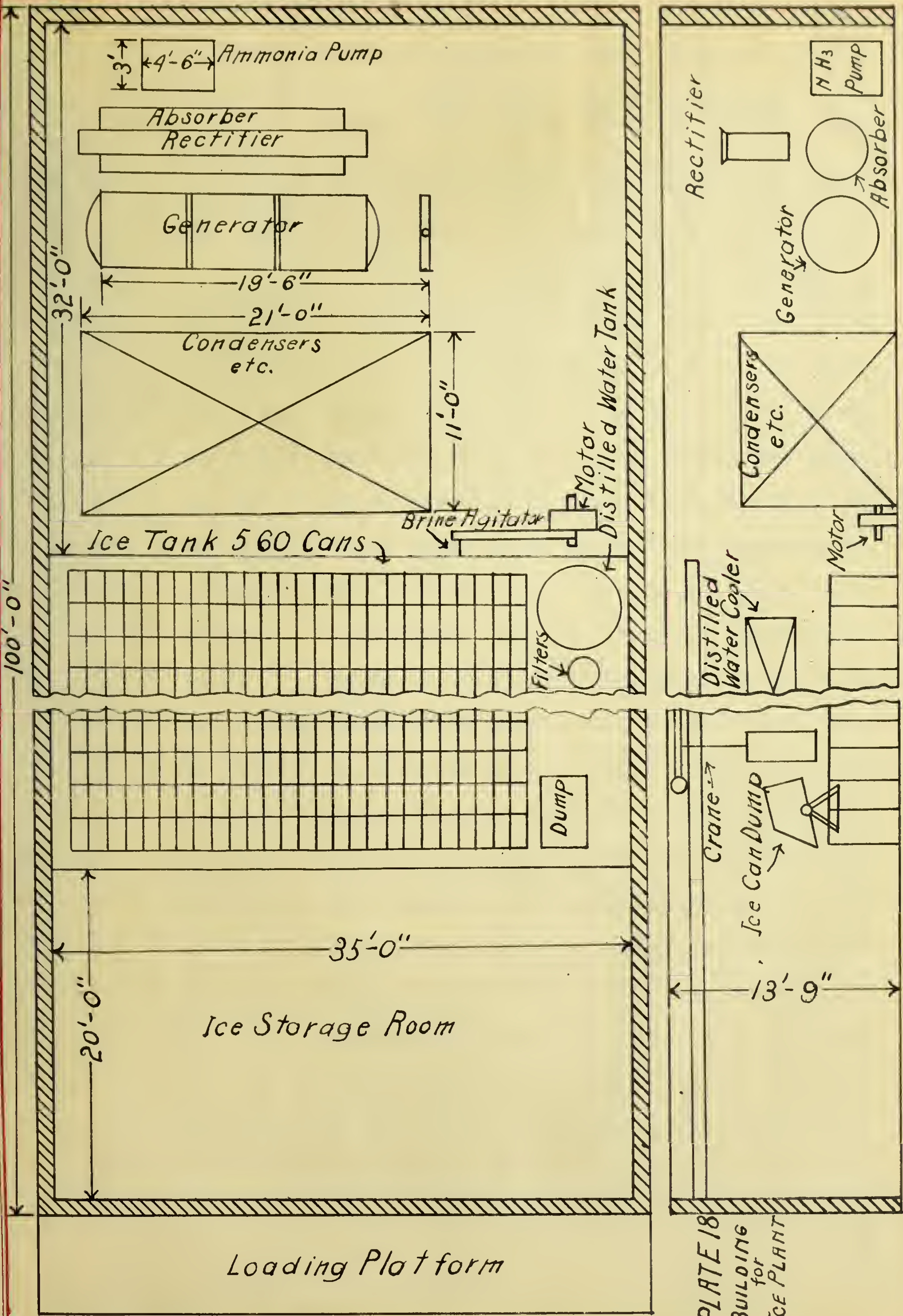


PLATE 18
BUILDING for ICE PLANT

Average K.W. Output in percent of full load.

	Dec.	Jan. Nov.	Feb. Oct.	Mar. Sept.	Apr. Oct.	May July	June
From 12 to 1 A.M.	22.25	21.15	18.75	16.50	14.75	12.75	10.75
" 1 A.M. to 2 A.M.	17.25	17.00	15.25	13.50	11.50	9.75	8.00
" 2 " " to 3 " "	12.75	14.00	12.75	11.50	10.00	8.75	7.75
" 3 " " to 4 " "	11.50	11.25	10.75	9.75	9.00	7.75	7.75
" 4 " " to 5 " "	11.75	11.25	11.25	10.25	9.75	9.25	8.75
" 5 " " to 6 " "	16.25	16.75	17.00	15.50	14.00	12.50	11.00
" 6 " " to 7 " "	25.25	23.25	20.75	19.50	16.50	14.50	12.00
" 7 " " to 8 " "	21.50	21.00	18.50	19.25	16.00	13.75	11.25
" 8 " " to 9 " "	16.00	16.25	17.50	15.00	13.50	12.00	10.00
" 9 " " to 10 " "	13.75	12.50	16.50	11.50	10.75	10.25	9.75
" 10 " " to 11 " "	12.35	12.00	12.75	11.25	10.75	10.50	10.00
" 11 " " to 12	12.50	12.00	11.25	11.75	10.50	10.00	9.75
" 12 " " to 1 P.M.	10.45	11.50	10.25	10.25	10.00	9.50	9.50
" 1 P.M. to 2 " "	12.00	12.00	11.00	10.75	10.50	10.00	9.75
" 2 " " to 3 " "	14.00	13.50	13.00	12.00	11.50	10.50	10.00
" 3 " " to 4 " "	18.10	18.25	16.75	14.00	13.50	11.75	10.50
" 4 " " to 5 " "	38.10	32.50	32.50	23.75	29.75	16.75	11.75
" 5 " " to 6 " "	93.00	72.25	58.00	43.75	37.00	28.00	19.00
" 6 " " to 7 " "	96.00	90.00	60.60	65.50	55.50	45.00	21.75
" 7 " " to 8 " "	98.00	89.50	83.00	75.50	69.00	61.00	39.00
" 8 " " to 9 " "	85.10	84.00	80.00	73.50	67.00	66.00	57.75
" 9 "" to 10 " "	69.50	69.00	67.75	66.00	62.00	62.50	60.00
" 10 " " to 11 " "	51.50	50.50	50.00	50.00	48.50	47.50	47.00
" 11 " " to 12 " "	33.60	32.50	30.50	27.50	27.50	26.00	25.00

Month	Total daily K.W. Hours per K.W. Output Capacity.
December	8.12450
January and November	7.64000
February and October	6.96350
March and September	6.36750
April and August	5.69750
May and July	5.25250
June	4.37750

Minimun Load Factor = 18.2% (June)

Maximum Load Factor = 33.8% (December)

Average Load Factor = 26.1%