DESIGN OF A SMALL STEAM-ELECTRIC POWER PLANT

by

James Holt, Jr.

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Bachelor of Science in
Mechanical Engineering

from the

Massachusetts Institute of Technology

1943

Signature redacted

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Acceptance:

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Instructor in Charge of Thesis ....

May 15, 1943

Cambridge, Mass.

May 15, 1943

Professor G. W. Swett
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Sir:

In accordance with the requirement for the degree of Bachelor of Science in Mechanical Engineering, I submit herewith a thesis entitled, "Design of a Small Steam-Electric Power Plant."

Respectfully submitted,

Signature redacted

James Holt, Jr.

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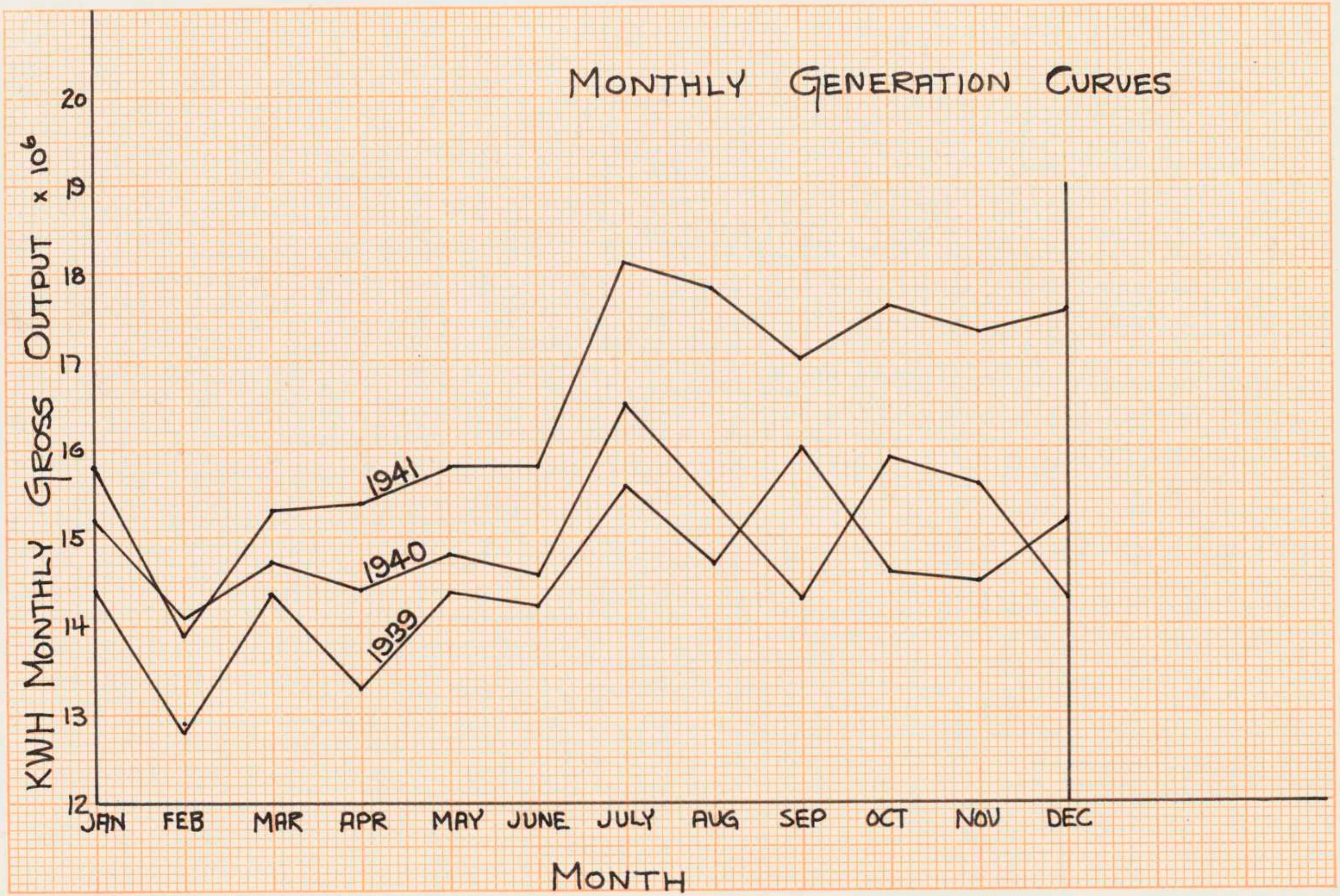
Part I

Introduction

Progressive growth of the electric load and depletion of existing equipment has necessitated the construction of an entirely new power plant at McPherson, Kansas. It is, however, supposed that the growth of the load will no longer be increased due to existing conditions within the area served.

From an examination of the average daily load curve, it can be seen that a firm capacity of 4000 kw. is necessary. The station is designed to operate at throttle conditions of 390 psi, and 675 degrees F. Steam for feedwater and building heating is obtained from the exhausts of the various pieces of equipment.

No attempt has been made to design the piping required in this station due to the required amount of work involved.



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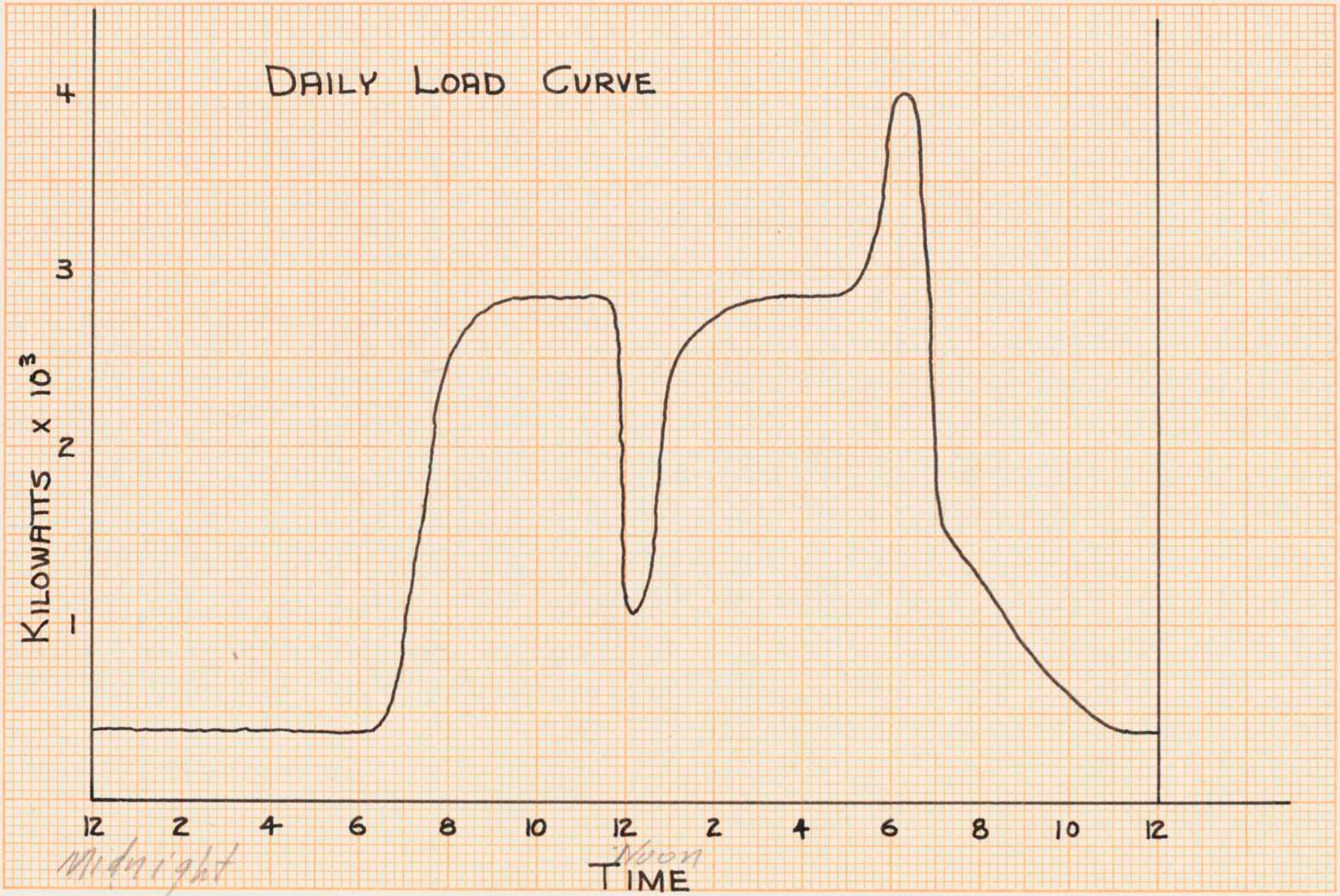
MARCH 8, 1943

LOAD GROWTH

Year	Annual Generation KW Hr.	Annual Demand KW.	Annual Load Factor %.	Percent Annual Increase	
				Generation	Demand
1936	9,476,000	2,100	50.0	15.4	16.7
1937	11,181,500	2,600	49.1	18.0	23.8
1938	15,365,600	3,200	54.6	37.5	23.1
1939	17,406,100	3,350	59.3	13.3	4.7
1940	17,947,200	3,300	62.0	3.3	-1.5



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Part II

Preliminary Plant Layout

A. Turbine Room

1. Size of Turbo-generators.

From an inspection of the average daily load curve several possible choices of equipment are indicated:

a. Four 1,500 kw. condensing turbines, and one 500 kw. condensing turbine.

b. Three 1,500 kw. condensing turbines, and two 500 kw. condensing turbines.

c. Two 3,000 kw. condensing turbines, and two 500 kw. condensing turbines.

d. Two 2,000 kw. condensing turbines, and two 1,000 kw. condensing turbines.

From a study of the Willans lines and the most economical system of operation, the third scheme of two 3,000 kw., and two 500 kw. turbines proves to be the best as far as steam requirement is concerned. However, the cost and maintenance of the machines is an important item to be considered. The fourth scheme is the cheapest, but its large steam consumption rules it out as the best choice. Next to be accounted for because of low cost is the second scheme, but here too it is ruled out in favor of the third scheme because of its large steam consumption, and requirement of an extra machine.

The third scheme is best also because it offers a higher total capacity as well as a lower steam consumption.

2. Condensers

Due to the poor quality of the condensing water, which make it unsuitable for use in the boilers, we must use surface type condensers. From the calculations for a 3,000 kw. turbine shown in the appendix, it can be seen that a two-pass type condenser of 910 ten foot length tubes is desirable. For the 500 kw. turbine it can be seen that a two-pass type condenser of 183 ten foot length tubes is desirable.

Then for the condensers in this station, Ross type "C" condensers nos. 40 and 20 shall be used for the 3,000 kw. and 500 kw. turbines respectively.

3. Air Removal

Since there is always some air in the exhaust steam from the turbines the ability of the condenser to produce high vacuums is materially impared. To remove this air Ross Standard Air Removal Equipment no. 806-6T shall be used with the 3,000 kw. turbines, and no. 804-6T shall be used with the 500 kw. turbines.

4. Circulating Pumps

Electrically driven circulating pumps of the propeller type shall be used because of their simple installation and small space requirements.

B. Boiler Room

1. Size of Boiler Units

Since boilers may be operated with a fair degree of efficiency over a wide range of output, they need only be designed for average loads. However, in this station it is assumed that one boiler shall always be out for inspection or repairs.

At the average load a BHP of 840 is needed and at the maximum peak load a BHP of 1890 is needed. For these specifications, three Babcock and Wilcox boilers of 509 BHP shall be used. Then since only two boilers would be "on the line" at any one time, they could operate at 186 per cent over nominal rating to take the peak load.

2. Type of Coal Burning Equipment

The availability of a good grade of soft coal naturally leads to underfeed stokers in a small power plant. Pulverized coal burning would not justify itself because of its high cost and the auxiliary equipment needed with its installation.

From the calculations for stoker in the appendix it can be seen that a multiple-retort stoker of 43.1 ft^2 of grate surface is needed. For this station Riley Underfeed Stokers of three retorts shall be used.

3. Draft Requirements

From the calculations shown in the appendix it is necessary to have a forced draft fan capable of handling 11,500 cu ft/min. at a static pressure of 7.5 inches of water. For this a no. 8 Cindervane Fan made by the B. F. Sturtevant Co. shall be used. The fans shall be driven with turbines of 10 horse power capacity.

For the induced draft requirements, calculations in the appendix prove that a chimney of 225 ft. height and 6 ft. diameter will handle the gases naturally.

4. Feedwater Heating

Since this station is one of small capacity, and simplicity of design and operation is desirable, an open type feedwater heater shall be used. From the calculations shown in the appendix, it can be seen that the heater must have a capacity of 60,000 pounds per hour.

5. Coal Bunker Design

Calculations for the bunker size are shown in the appendix. It is assumed that the bunker is to be of large enough capacity to hold a week's supply of coal.

The coal shall be lifted into the bunker by means of a bucket conveyor which is to be electrically operated.

6. Boiler Feed Pumps

Two steam turbine driven boiler feed pumps will service the three boilers. They shall be of capable of handling 7,000 gallons per hour. The driving turbine shall be of 55 horse power. For this station Bethlehem Weir turbo feed pumps type T.F.P. 7 shall be used.

7. Feedwater Pumps

The feedwater pumps for this station shall be electrically driven. They shall be capable of handling 7,000 gallons per hour under a suction of 29" Hg abs and a discharge head of 40 feet. For this station, Wheeler Centrifugal Pumps of 4 inch size shall be used. The motors shall be of 10 horse power size.

8. Superheaters

Since this station operates on superheated steam, a separate superheater must be installed to deliver the steam at the desired state. Calculations for the necessary size superheater are shown in the appendix. The surface necessary is 1,270 sq. ft.

For this station, the superheater shall be supplied by the Babcock Wilcox Company.

9. Economizer

The calculations for economizers shown in the appendix prove that they are not economical in this station. Therefore, they are not included in the design for this station.

Part III

List of Equipment

3 Babcox and Wilcox Boilers

Boiler to be integral furnace type; heating surface 5,090 sq. ft.; designed pressure 425 lb. per sq. in.; operating pressure 390 lb. per sq. in. at the superheater outlet; superheating surface designed to give 240^{o} F superheat; soot blowers to be provided.

Combustion Equipment

Riley 3 retort underfeed stoker of 45 sq. ft. grate surface. Stoker is to be motor driven.

Feedwater Heating

An open type of Cochrane heater is to be used. This heater is to have a capacity of 60,000 lbs. per hour.

3 Forced Draft Fans

Turbine driven Cindervane fans no. 8 made by the B. F. Sturtevant Company to be used.

2 Boiler Feed Pumps

Bethlehem Weir turbo feed pumps type T.F.P. 7 to be used. Driving turbines to be 55 horse power capacity.

2 Feedwater Pumps

Wheeler Centrifugal Pumps driven by 10 horse power, squirrel-cage motors to be used.

Coal Handling and Ash Handling Equipment

Coal handling equipment is to be of a bucket conveyor type electrically operated. Ash handling equipment is to be of a trolley type, hand or mechanically operated.

Main Power Units

2 General Electric turbo generators of 3,000 kw. capacity and 2 of 500 kw. capacity to be used. Units to operate at 3,600 RPM, 2,300 volts, 3-phase 60 cycles. 390 psi steam at 657°F to be used. Excitation produced by tow turbine driven exciters.

Condenser Equipment

Two Ross no. 40 surface condensers and two no. 20 surface condensers to be used. Effective tube length to be ten feet.

Four motor-driven circulating water pumps of the propeller type to be used; two having a capacity of 5,000 gallons per min. and two having a capacity of 1,000 gallons per min.

Ross Air Removal Equipment to be used. Two of no. 806-6T and two of no. 804-6T to be used with the 3,000 kw. and 500 kw. machines respectively.

PART IV

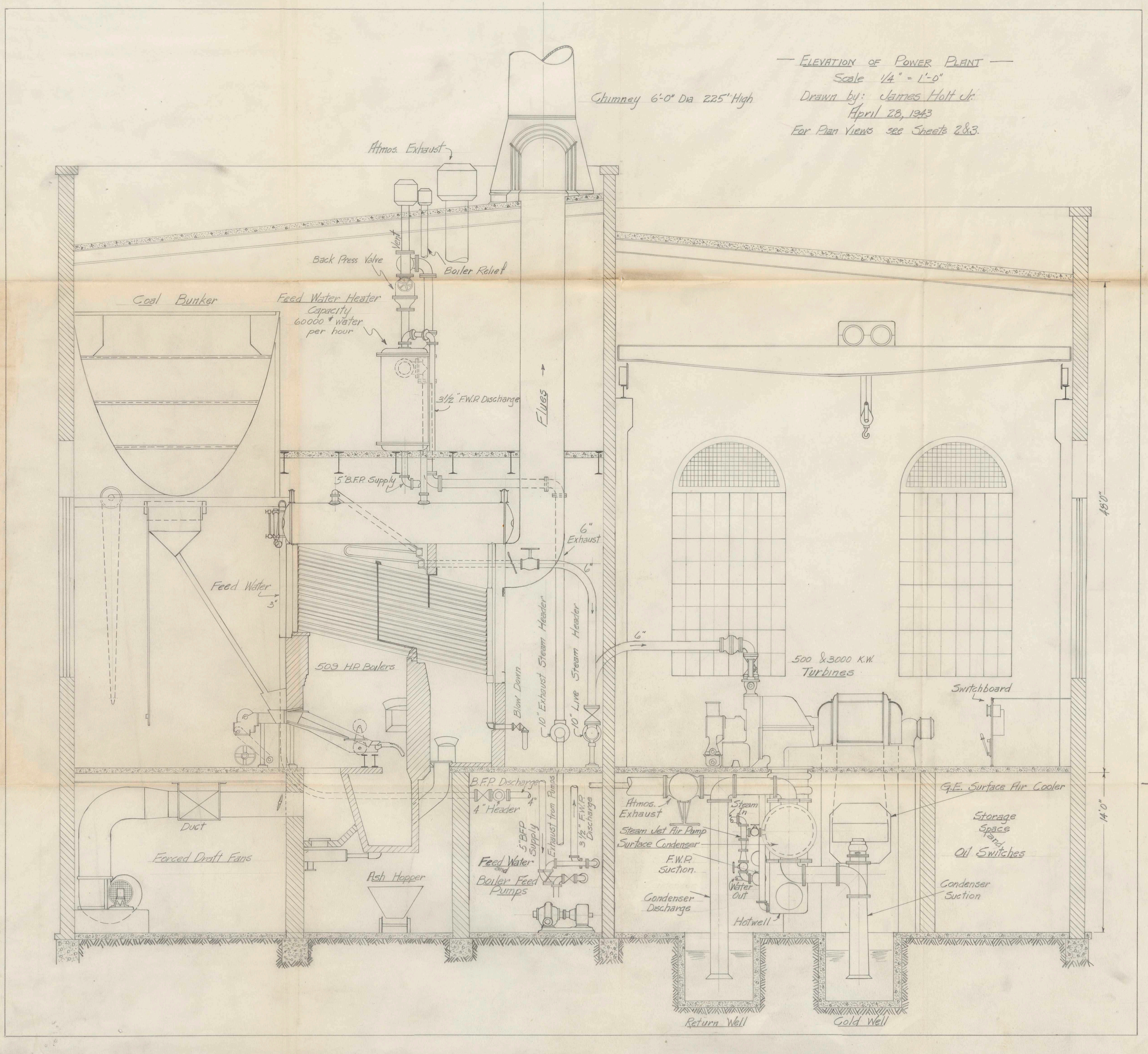
COST SHEETS

No.	Description	Unit Cost
1.	Foundations	$ 80,500
2.	Sidings, roadways, circulating water intake and discharge and buildings	$ 105,000
3.	Chimneys and flues	$ 24,500
	Building Total	$ 210,000
4.	Boilers installed	$ 105,000
5.	Superheater	$ 19,600
6.	Stokers	$ 100,000
7.	Coal conveyor and bunkers	$ 35,000
8.	Ash conveyor	$ 10,500
9.	Piping and pipe covering	$ 84,000
10.	Feed pumps	$ 7,000
11.	Feedwater heater	$ 7,000
12.	Turbine and generator and air piping	$ 170,000
13.	Condenser, surface type and circulating pump and dry vacuum pump	$ 77,000
14,	Exciters	$ 10,500
15,	Switchboard	$ 14,700
16.	Cables and conduits in power house, wiring	$ 42,000
17.	Incidentals	$ 28,000
	Machinery Total	$ 710,300
	Grand Total	$ 920,300
18.	Engineering supervation	$ 35,000

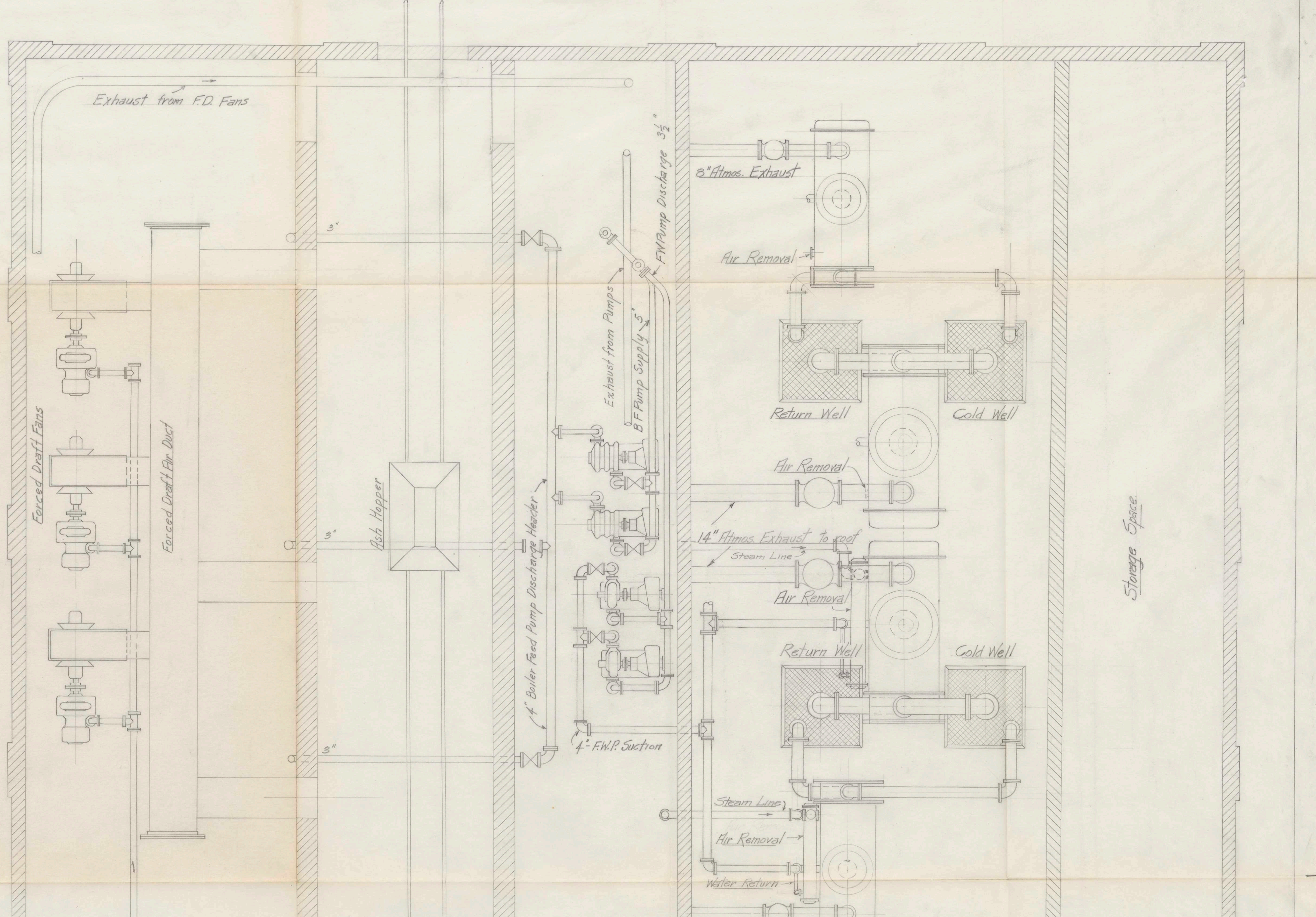
Total unit cost per KW -	$ 136.50
Fixed charges -	14 %
Total yearly generation -	17,947,200 KW
Fixed charges per KWH -	0.745 cents
Fuel economy -	0.70 # coal/KWH
Coal costs	$ 8.00 per ton
Fuel cost per KWH -	0.280 cents
Total cost per KWH -	1.035 cents

PART V

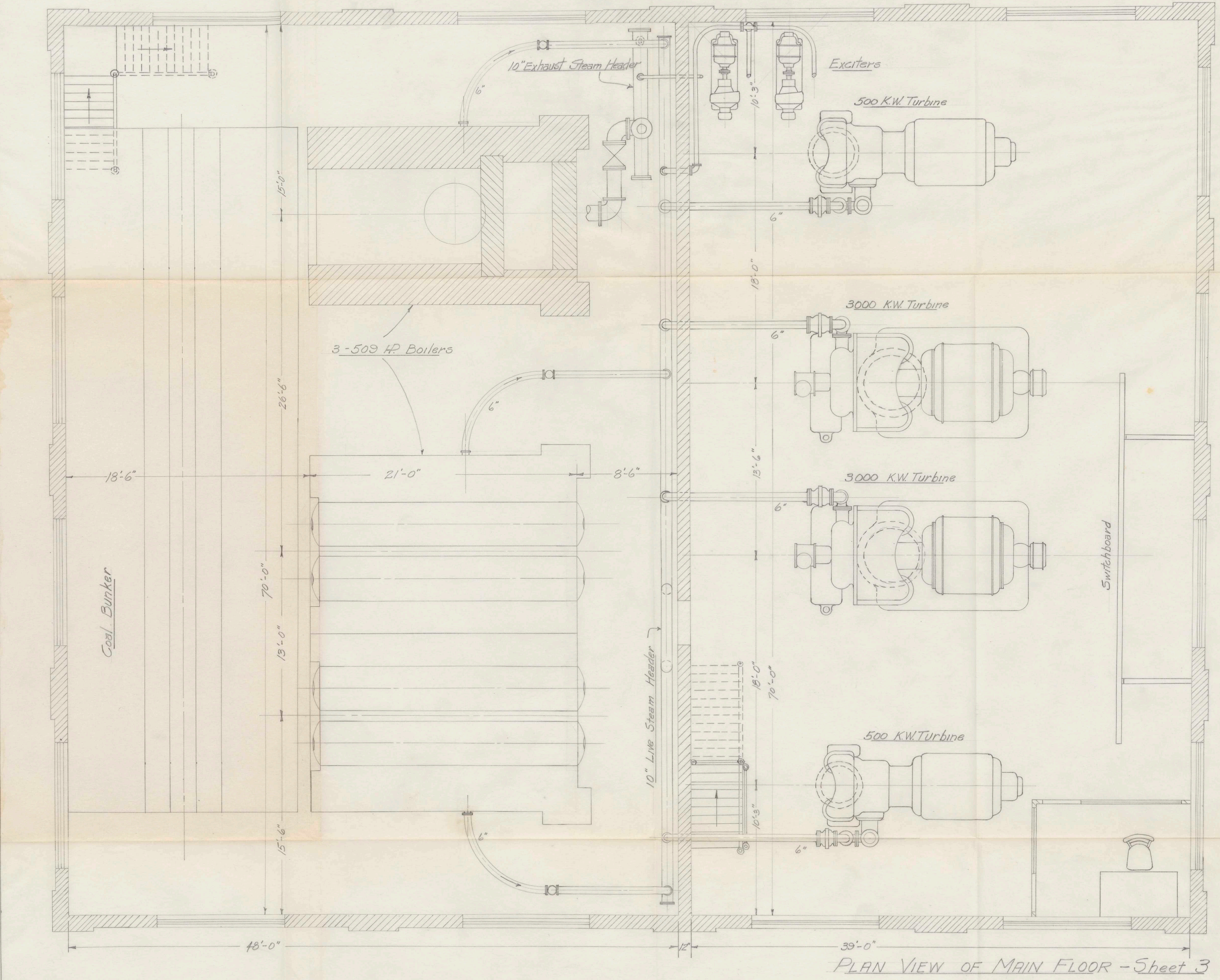
PLANT DRAWINGS



— Elevation of Power Plant —
Scale 1/4" = 1'-0"
Drawn by: James Holt Jr.
April 28, 1943
For Plan Views see Sheets 2&3.
Chimney 6'-0" Dia 225' High
Atmos. Exhaust
Vent
Back Press Valve
Boiler Relief
Coal Bunker
Feed Water Heater
Capacity
60000 # water
per hour
3 1/2" F.W.P. Discharge
Flues
5" B.F.P. Supply
6"
Exhaust
6"
Feed Water
3"
509 H.P. Boilers
Blow Down
10" Exhaust Steam Header
10" Live Steam Header
6"
500 & 3000 K.W.
Turbines
Switchboard
48'0"
14'0"
Duct
Forced Draft Fans
Ash Hopper
B.F.P. Discharge
4"
4" Header
5" BFP Supply
Exhaust from Pumps
3 1/2" F.W.P. Discharge
Feed Water and Boiler Feed Pumps
Atmos. Exhaust
Steam In
Steam Jet Air Pump
Surface Condenser
F.W.P. Suction.
Water Out
Condenser Discharge
Hotwell
G.E. Surface Air Cooler
Storage Space and Oil Switches
Condenser Suction
Return Well
Cold Well

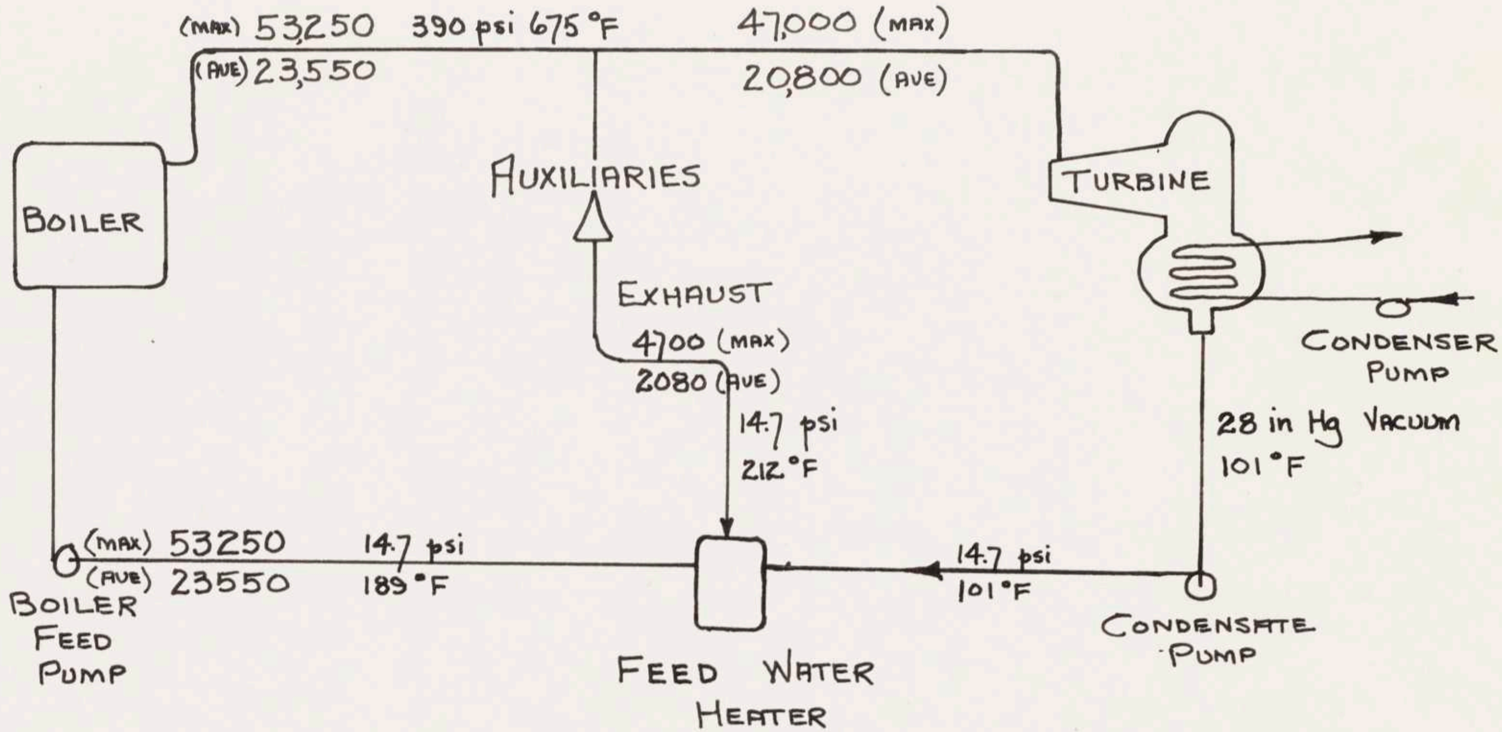


PLAN VIEW OF BASEMENT Sheet 2



PLAN VIEW OF MAIN FLOOR - Sheet 3

— FLOW DIAGRAM —



MAXIMUM PEAK LOAD = 53250 # STEAM/HOUR.

AVERAGE HOURLY LOAD = 23,550 # STEAM/HOUR.

PART VI

PART VII

APPENDIX

Hour	Average KW Generation	Steam Consumption Scheme 3	Steam Consumption Scheme 2	Steam Consumption Scheme 4
12-1	400	5,900	5,900	7,200
1-2	400	5,900	5,900	7,200
2-3	400	5,900	5,900	7,200
3-4	400	5,900	5,900	7,200
4-5	400	5,900	5,900	7,200
5-6	400	5,900	5,900	7,200
6-7	550	9,200	9,200	8,300
7-8	1,650	22,500	22,700	20,300
8-9	2,650	31,500	34,800	33,500
9-10	2,850	33,500	36,800	35,200
1o-11	2,850	33,500	36,800	35,200
11-12	2,800	33,000	36,400	35,000
12-1	1,500	21,300	19,500	18,500
1-2	2,600	31,000	34,400	33,300
2-3	2,800	33,000	36,400	35,000
3-4	2,850	33,500	36,800	35,200
4-5	2,850	33,500	36,800	35,200
5-6	3,100	38,000	41,400	42,400
6-7	3,800	47,000	50,400	48,400
7-8	1,500	21,300	19,500	18,500
8-9	1,050	17,000	14,800	15,000
9-10	750	11,400	11,400	10,700
10-11	500	7,000	7,000	8,200
11-12	400	5,900	5,900	7,200
	TOTAL	498,500	526,400	518,300

Estimated steam consumption of station auxiliaries to be 10 % of turbine throttle flow plus 3 % of total as waste.

$$\overline{W}_{AD} = 498500 + 49850 = 548350 \text{ \#steam/day}$$

$$\overline{W}_{D} = 548350 + 0.03 \times 548350$$

$$= 548350 + 16450$$

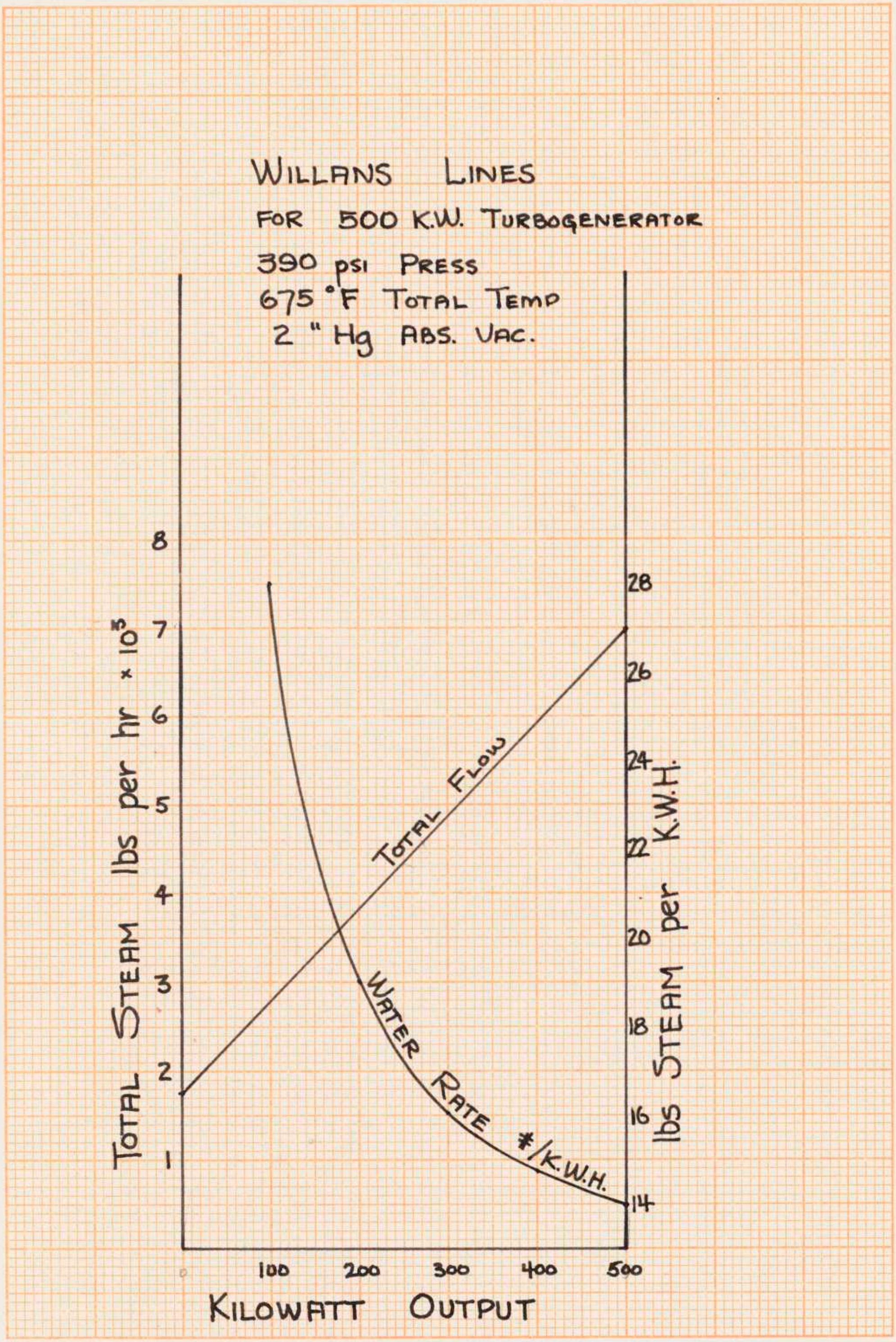
$$= 564{,}800 \text{ \# steam/day}$$

Average steam consumption per year

$$\overline{W}_{Y} = 564800 \times 365 = 206{,}000{,}000 \text{ \# steam/year.}$$

$$\overline{W}_{H} = \frac{564800 \times 365}{365 \times 24} = 23{,}550 \text{ \# steam/hour.}$$

Hour	Steam Consumption plus Auxiliaries & Waste	
12-1	6,685	
1-2	6,685	
2-3	6,685	
3-4	6,685	
4-5	6,685	
5-6	6,685	
6-7	10,424	
7-8	25,493	
8-9	35,690	
9-10	37,956	
10-11	37,956	
11-12	37,399	
12-1	24,133	
1-2	35,123	
2-3	37,399	
3-4	37,956	
4-5	37,956	
5-6	43,054	
6-7	53,251	← max load (peak)
7-8	24,133	
8-9	19,261	
9-10	12,916	
10-11	7,931	
11-12	6,685	
TOTAL	564,726	



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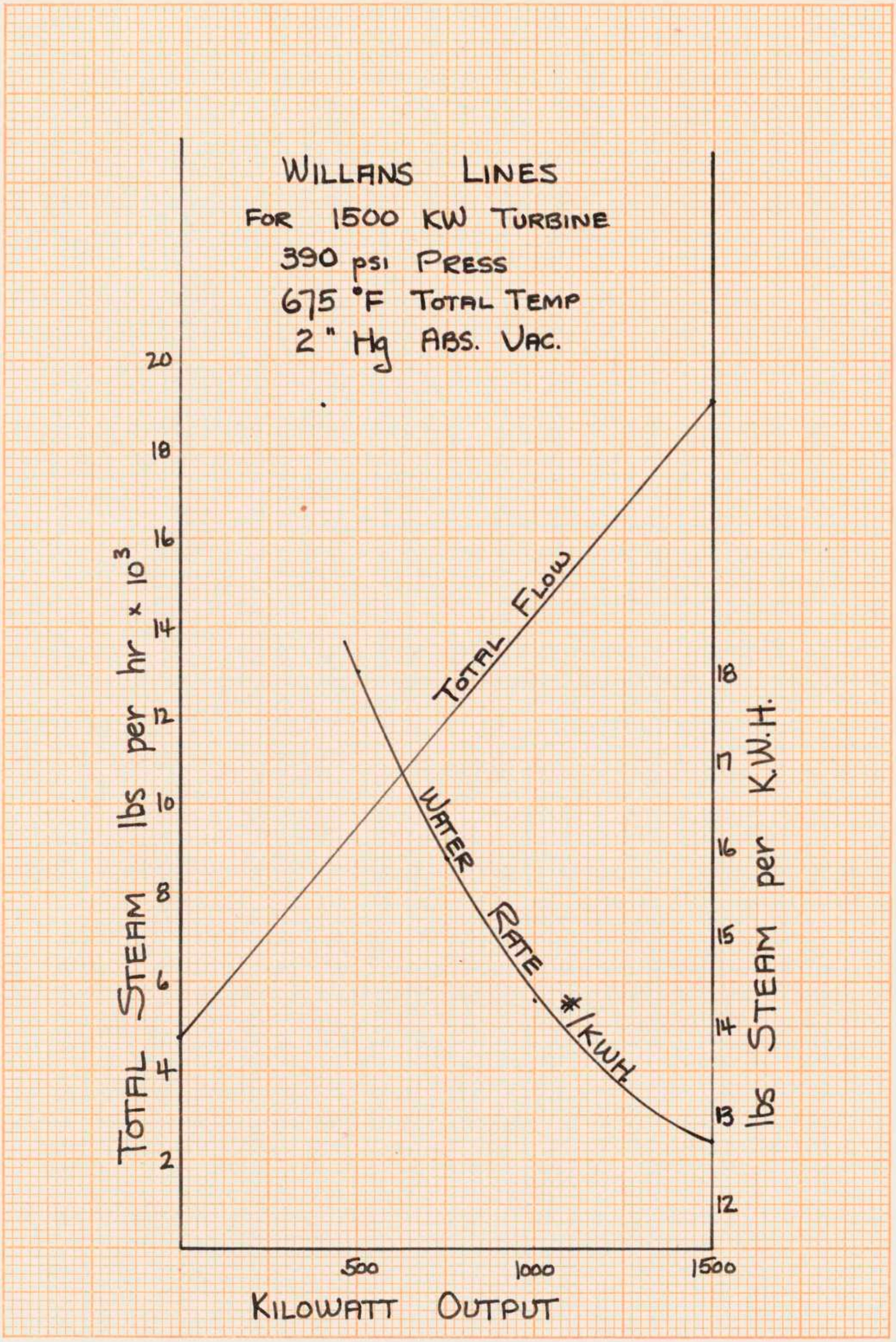
MARCH 8, 1943



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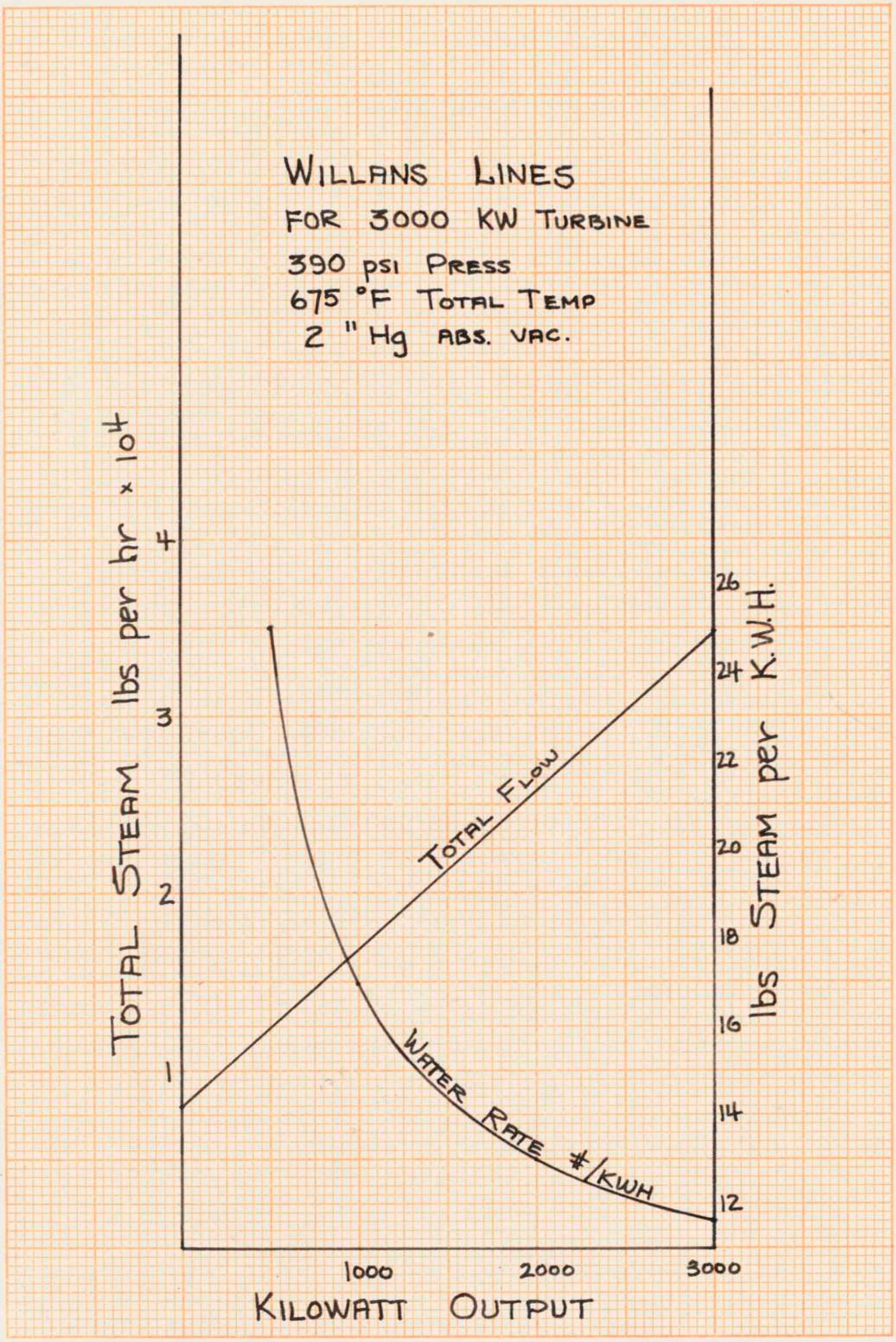

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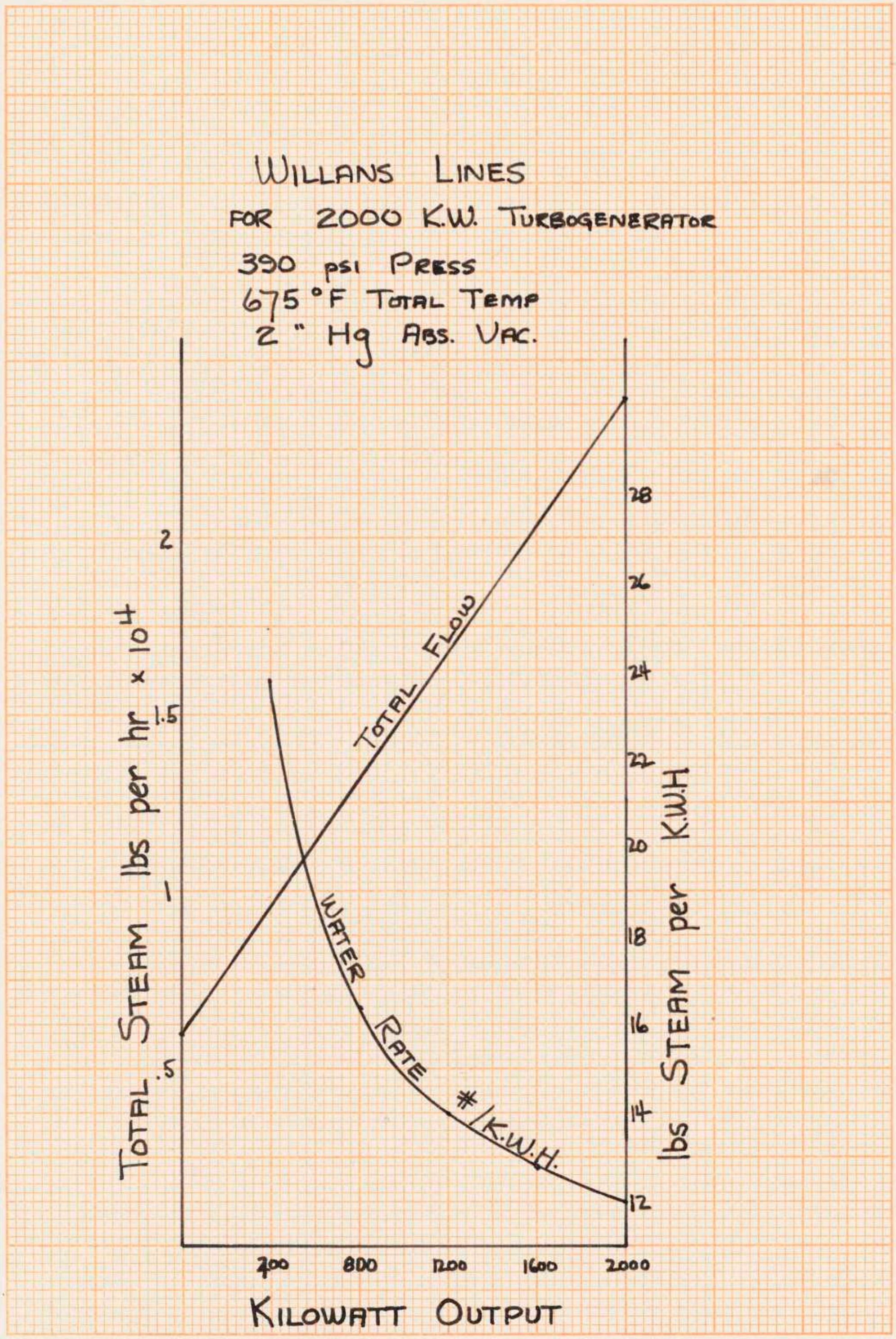

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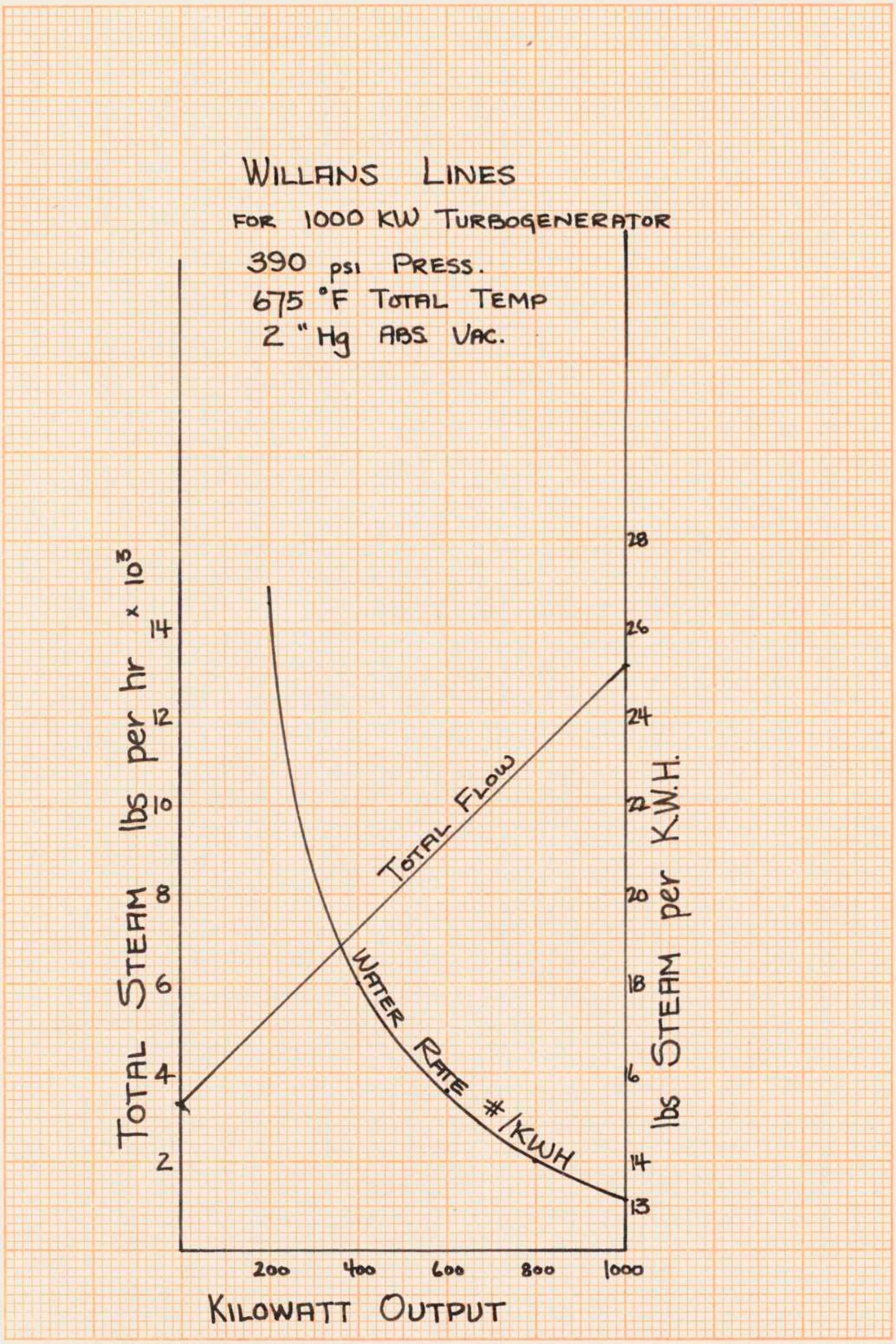

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COST COMPARISON OF SCHEMES

Scheme	Turbo-generators	Condensers	Total Equipment Cost	Total Installed Cost
1	$ 188,000	$ 52,900	$ 240,900	$ 250,900
2	$ 166,000	$ 48,300	$ 214,300	$ 224,300
3	$ 178,000	$ 49,800	$ 227,800	$ 227,800
4	$ 170,000	$ 46,200	$ 216,200	$ 216,200

Cost Installed per Turbogenerator

500 KW - 40 x 500 - $ 20,000

1000 KW - 33 x 1000 - $ 33,000

1500 KW - 28 x 1500 - $ 42,000

2000 KW - 26 x 2000 - $ 52,000

3000 KW - 23 x 3000 - $ 69,000

Cost of Condensers and Equipment

500 KW - $ 6,900

1000 KW - $ 9,100

1500 KW - $ 11,500

2000 KW - $ 14,000

3000 KW - $ 18,000

Condenser Design (3000 K.W. Mach)

H = Heat to be abstracted from steam in BTU/hr.

S = Square feet of surface in condenser.

U = Coefficient of heat transfer

D = Mean temp. diff. between steam and circ. water.

G = Amount of circulating water required.

$h_e = 1349.7 - (1349.7 - 909) \times 0.71 = 1349.7 - 313 = 1036.7 \ \frac{BTU}{\#}$

$W = 1036.7 - 69.7 = 967$ BTU/#

$H = WP = 967 \times 34{,}800$ BTU/hr.

$$D = T_s - \frac{T_1 + T_2}{2} = 101 - \frac{70 + 84}{2} = 101 - 77 = 24F^o.$$

$U = 400$

$$S = \frac{H}{DU} = \frac{967 \times 348}{400 \times 24} = 3500 \text{ ft.}^2$$

$$G = \frac{H}{498(T_2 - T_1)} = \frac{967 \times 34800}{498 \times 14} = 4830 \text{ gallons/min.}$$

use 3/4 inch tubes at 5 ft/sec. velocity

$$N = \frac{G}{g} = \frac{4830}{5.3} = 910 \text{ tubes per pass.}$$

determination of tube length assuming single pass.

$$L = \frac{3500}{0.196 \times 910} = 19.6 \text{ ft.}$$

Assuming double pass.

L 9.8 ft or say 10 ft.

friction loss with single pass F_s

$$F_s \quad \frac{22.4 \times 20}{100} \quad 4.5 \text{ ft.}$$

friction loss with double pass F_D

$$F_D = \frac{22.4 \times 20}{100} + 2 = 6.5 \text{ ft.}$$

then assuming a 10 ft. additional head and pump eff of 75% the required to drive the pumps is and respectively showing a loss of only BHP, with use of the short 2 pass condenser.

Condenser Design (500 K.W. Machine)

$$S = \frac{H}{DU} = \frac{967 \times 70000}{400 \times 24} = 706 \text{ ft.}^2$$

$$G = \frac{H}{498 \times 14} = \frac{967 \times 7000}{498 \times 14} = 970 \text{ gallons/min.}$$

Use 3/4 inch tubes at 5 ft/sec velocity.

$$n = \frac{G}{g} = \frac{970}{5.3} = 183 \text{ tubes per pass.}$$

tube length assuming single pass

$$L = \frac{706}{0.196 \times 183} = 19.6 \text{ ft.}$$

tube length assuming double pass

$L = 9.8$ ft. or 10 ft.

Sizes of Circulating Pumps

3000 K.W. machine

must handle 5000 gallons/min against a 20 ft suction lift.

500 K W machine

must handle 1000 gallons/min against a 20 ft. suction lift.

Size of Air Pumps (3000 K W machine)

34800 pounds of steam /hr

28 inches vacuum

90° F temp at air pump suction

Pressure of air at 90° = Total pressure - Pressure of atmospheric vapor at 90°

$P_{air} = (30-28)\ 0.491 - 0.696$

$= 0.982 - 0.696 = 0.286\ \#/in^2$

Volume per pound = $\frac{RT_a}{P_a} = \frac{53.35 \times 550}{0.286 \times 144} = 712$ cu ft.

Taking pounds air per pound condensate as 0.0008 then the volume of air per pound condensate = 0.0008 x 712 = 0.570 cuft at 90°

Total = 0.570 x 34800 = 19,800 cu ft per hour to be handled by air pump. Assuming volumetric efficiency of 85% the air pump displacement necessary is $\frac{19800}{0.85}$ = 23,300 cu ft/hr.

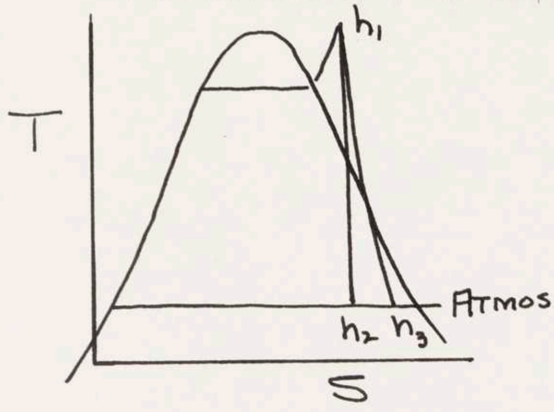
Size of Air Pumps (500 K W machine)

7000 pounds of steam/hour

Using same design as with the 3000 K W machine we have. Total = 0.570 x 7000 = 3990 cu ft/hr. to be handled by air pump. Assuming volumetric efficiency of 85% the air pump displacement necessary is

$$\frac{3990}{0.85} = 4700 \text{ cu ft/hr}$$

CALCULATIONS FOR OPEN FEED-WATER HEATERS



$$n_T = \frac{h_1 - h_3}{h_1 - h_2} = 0.50$$

$h_1 = 1350$

$h_2 = \underline{1064}$

286

$0.50 \times 286 = h_1 - h_3 = 143$ BTU/#

$h_3 = 1207$ BTU /#

assuming 10% loss in pipes

$Dh_3 = 120$

$h_3 = 1087$ BTU/#

Energy balance

$4700 \times 1087 + 47000 \times 69 = 53250\ h$

$5110000 + 3240000 = 53250\ h$

$$h = \frac{8340000}{53250} = 157 \text{ BTU/\#}$$

Temp of water leaving heater = 189°F

BOILERS

$$\text{BHP needed} = \frac{53250 \times 1193}{33500} = 1890$$

For this load 3 Babcock & Wilcox boilers of 509 BHP could be used. Assuming only two boilers were on the line at any time they could be operated at 186% over nominal rating.

Analysis of Coal (14724 BTU/#)

West Virginia Semi-Bituminuous Pocahontas.

Proximate Analysis		Ultimate Analysis (moisture included)	
Moisture	3.10	Sulphur	0.55
Volatile	17.91	Hydrogen	4.50
Fixed Carbon	75.26	Carbon	84.02
Ash	3.73	Nitrogen	1.17
		Oxygen	6.03
		Ash	3.73

Theoretical air required

$= 11.6\ C + 34.5\ (H - \frac{O}{8}) + 4.35\ S$

$= 11.6 \times 0.8402 + 34.5\ (0.045 - \frac{0.0603}{8}) + 4.35 \times 0.0055$

$= 9.75 + 1.29 + 0.024$

$= 11.06$ # air/#coal

Assuming 50% excess

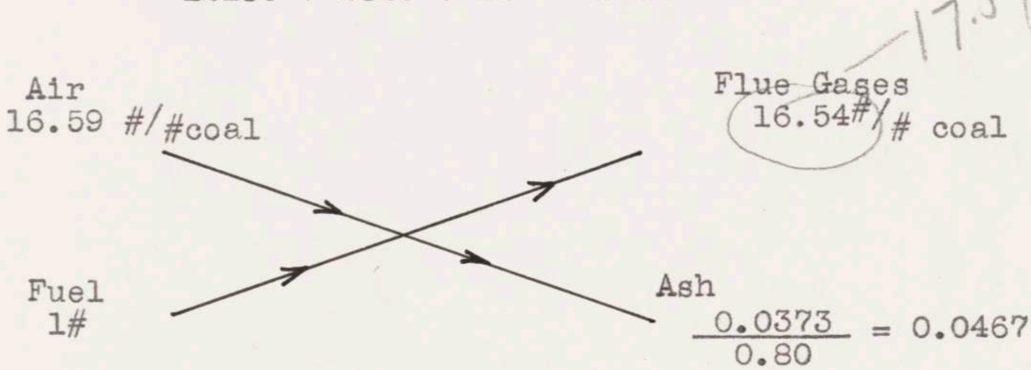
Air required = 16.59 #/# coal

Assuming 20% combustible in ash

H.H.V. $= 14500\ C + 62000\ (H - \frac{O}{8}) + 4000S$

$= 14500 \times 0.84 + 62000 \times 0.0375 + 4000 \times 0.0055$

$= 12180 + 2325 + 22 = 14527$



Ash $\frac{0.0373}{0.80} = 0.0467$ #/# coal

BTU/ # coal realized = 14724 - 0.0094 x14500 = 14588

Calculation of Economizer

Assuming a boiler efficiency of 70%

Weight of coal = $\frac{11780 \times 1193}{14588 \times 0.70}$ = 1375 #/hr

17.54

Weight of flue gas = 1375 x 16.54 = 22.800 #/hr.

$P = \frac{11780 \times 1}{22800 \times 0.24} = 2.15$

$T_1 = 470^oF$

$T_2 = 400^oF$

$t_1 = 189^oF$

$t_2 = t_1 + \frac{T_1 + T_2}{P} = 189 + \frac{70}{215} = 189 + 32.5 = 221.5^oF$

$S = \frac{W_1 \quad C}{U(P-1)} \quad ln \quad \frac{T_1 - t_2}{T_2 - t_1}$

$= \frac{11780}{4 \times 1.15} \quad ln \quad \frac{248}{211}$

$= 2560 \times 0.16127$

$= 412$ sq. ft.

Economizer operating at max load

Weight of coal = $\frac{26630 \times 1193}{14588 \times 0.70}$ = 3110 #/hr.

Weight of flue gas = 3110 x 16.54 = 51400 #/ hr.

$P = \frac{26630}{51400 \times 0.24} = 2.15$

$T_1 = 560\ ^oF$

$t_1 = 189^oF$

$n = \frac{SU\ (P-1)}{2.3\ W_1C_1} = \frac{412 \times 4 \times 1.15}{2.3 \times 26630} = 0.0309$

$t_2 = \frac{T_1 - t}{P + \frac{1-P}{1-10}} + t1 = \frac{371}{2.15 + \frac{-1.15}{-0.074}} + 189$

$= \frac{3.71}{17.70} + 189 = 21 + 189 = 210\ ^oF$

$T_2 = T_1 - P\ (t_2 - t_1)$

$= 560 - 2.15 \times 21$

$= 560 - 45$

$= 515^oF$

Assuming a boiler efficiency of 70%

we must burn without using economizers

$$\frac{11780\ \overset{1193}{(1350 - 157)}}{14588 \times 0.70} = 1375\ \#coal/_{hr}$$

And we must burn using economizers

$$\frac{11780 \times \overset{1160}{(1350 - 190)}}{14588 \times 0.70} = 1340\ \#\ coal/_{hr}$$

we save 35 # coal/$_{hr}$ using economizers

$$\frac{35 \times 24 \times 365}{2000} = 153.5\ \text{tons coal saved}/_{year}$$

Calculations for Stoker

Assuming a boiler efficiency of 70%

$$\text{Weight of coal} = \frac{11780 \times 1193}{14588 \times 0.70} = 1375\ \#/_{hr}$$

at an average rate of combustion of

$40\#/_{hr}$ - ft^2 GS We need a

$$GS = \frac{1375}{40} = 34.4\ ft^2$$

$$\text{Depth} = 9\ \text{ft.} \quad \text{Width} = \frac{34.4}{9} = 3.83\ \text{ft.} = 3\ \text{ft. } 10\ \text{in.}$$

Must use a 3 retort stoker with

a width of 4.8 ft.

$$G.S. = 4.8 \times 9 = 43.1\ ft^2$$

$$\text{At average load } C = \frac{1375}{43.1} = 320\ \#/_{hr}\ ft^2\ GS.$$

$$\text{At maximum load } C = \frac{3110}{43.1} = 72.3\ \#/_{hr}\ ft^2\ G.S.$$

Combustion volume needed assuming

We need 3.5 cu $ft/_{sq.ft.}$ GS.

$$V_c = 3.5 \times 43.1 = 150\ \text{cu ft.}$$

Furnace draft required from this stoker taken from curves pg 39 "Notes on Power Plant Design"

$$\text{Percent solid} = \frac{0.8775}{1} \times 100 = 88\%$$

At average load Wind Box Pressure in inches of water = 2.5 in H_2O

At maximum load Wind Box Pressure in inches of water = 7.5 in H_2O

Draft loss through boiler

stoker burns semi-bituminuous coal of H.V. 14588 BTU/$_{\#coal}$

Boiler efficiency 70%.

16.54 #air/$_{\#}$ coal.

$$\frac{33500}{14588 \times 0.70} = 3.26 \text{ \# coal}/_{\text{H.P. hr}}$$

$$3.26 \times 16.54 = 54.0 \text{ \#air}/_{\text{HP-hr.}}$$

$$= 0.900 \text{ \# air-}/_{\text{HP-min}}$$

$$V = \frac{MRT}{P} = \frac{0.900 \times 53.35 \times 492}{14.7 \times 144} = 11.15 \text{ cu ft. air}/_{\text{min.}}$$

Draft loss when operating at rating = 0.37" water.

and when operating at 200% rating = 0.8" water.

Draft loss in flues.

Longest flue is about 65 ft. long

Draft loss = 0.07 inches of water.

Calculations of Stack

Theoretical air = 11.06 # air/# coal

Excess air = 11.06 x .50 = 5.53 # (1.28 # O_2 & 4.25 N_2)

Total N = 11.06 x 0.768 + 4.25 + 0.012 = 12.76 #/# coal

CO_2 formed - 3.05 #

H_2O = 0.405 #

Dry products of combustion = 12.76 + 1.28 + 3.05 = 17.09#

Wet. products of combustion - 1.405#

Density of dry products must be increased to $\frac{17.495}{17.09}$ - 102.3%

	CO_2	O_2	N_2	TOTAL
Density at 32°	0.123	0.089	0.078	
Density at 500°	0.063	0.046	0.040	
Products per # coal	3.05	1.28	12.76	
Weight / Density @ 500°	48.4	27.8	319	395

Average density of dry flue gas = $\frac{17.09}{395}$ = 0.0433 #/ft.^{3}

Flue gas density - 102.3 % x 0.0433 = 0.0443 #/ft.^{3}

Total chimney flow = 2 x 395 x $\frac{3110}{3600}$ = 682 cu ft / sec.

Required draft at base of stack = vacuum over fuel bed + boiler friction loss + loss in flue and bends + velocity head loss.

Assuming a velocity of 30 ft/sec $h = \frac{30^2}{64.4} = 14$ ft.

Specific gravity of gas = $\frac{0.0443}{62.5}$ = 0.0007

D_1 = 14 x 0.0007 x 12 = 0.12 inch water

Required draft = 0.12 + 0.10 + 0.80 + 0.07 = 1.10 inches

This is a brick chimney, therefore,

$$90\% \times 0.192 \times H\,(d_a - d_c) = 1.10 + \text{chimney friction loss}$$

$d_a @ 70 = 0.075$

$d_c - -.0443$

$$H = \frac{1.10}{0.00536} + \frac{\text{chimney friction}}{0.00536} = 205 + \frac{\text{chimney friction}}{0.00536}$$

$$A = \frac{\text{total flow}}{V} = \frac{682}{30} = 22.7 \text{ sq. ft.}$$

$$R = \frac{A}{-} = 7.23 = 2.7 \text{ ft.}$$

$$H = 205 + 0.0685\,\frac{30^2}{27} = 225 \text{ ft.}$$

<u>Size of F. D. Fan</u>

Air required = 16. 59 #/# coal.

Max. capacity per each boiler = 16. 59 x 3110 - 51,700 $\#/_{hr}$

at 70^{o}F, d_a= 0.075 $\#/_{ft^3}$

$$\text{Max. capacity} = \frac{51,700}{0.075} = 690,000 \text{ cu. ft./ jr.}$$

$$- 11,500 \text{ cu. ft.}/_{min.}$$

Fan must handle 11,500 cu. ft./$_{min.}$ at a static pressure of 7.5 inches of water.

$$HP - \frac{0.000158 \times 1.1500 \times 7.5}{0.30} = 4.54$$

Calculations for Superheater

$$T_s = \frac{q}{W_s C_p} - \frac{UA\Theta m}{W_s C_p}$$

$$A = \frac{tsWsCp}{U\ \Theta m} = \frac{(675-442) \times 11780 \times 0.46}{10 \times 100}$$

$= 1270$ sq. ft. surface

Flues

Max. total flow - 682 cu. ft./sec. at 30 ft./sec.

$A = \frac{682}{30} = 22.8 \text{ ft.}^2$

height = 5 ft. 9 in.

width = 4 ft.

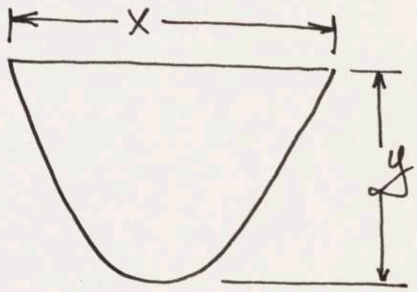
Bunker Design

Assume 1 week's supply is to be kept on hand

$$T = \frac{2750 \times 24 \times 7}{2000} = 232 \text{ tons}$$

$$V = 40 \times 232 = 9280 \text{ cu. ft.}$$

$$A = \frac{V}{L} = \frac{9280}{50} = 186 \text{ ft.}^2$$



$$A = \frac{2}{3}\, x\, y = 186$$

$$xy = 279$$

$$x = 18 \text{ ft.}$$

$$y = 15.5 \text{ ft.}$$

BIBLIOGRAPHY

1. Barnard, Ellenwood, & Hirshfeld, Heat-Power Engineering. Volumes II & III.

2. Morse, Power Plant Engineering and Design.

3. Gaffert, Steam Power Plants.

4. Miller & Holt, Notes on Power Plant Design.