AN ECONOMIC JUSTIFICATION OF USING A SMALL TURBINE RATHER THAN PRESSURE REDUCING VALVES BETWEEN THE HIGH PRESSURE HEADER AND HIGH PRESSURE HEATING LINES OF V. P. I. POWER PLANT

by

Anil Kumar Chatterjee

Thesis submitted to the Graduate Faculty of the
Virginia Polytechnic Institute
in candidacy for the degree of
MASTER OF SCIENCE
in
Power and Fuel Engineering

APPROVED:

Director of Graduate Studies

Dean of (School)

APPROVED:

Head of Department

Supervisor or Major Professor

June 1953

Blacksburg, Virginia

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation and thanks to the following faculty members and personnel of the Virginia Polytechnic Institute:

, Utility Engineer, Virginia Polytechnic Institute, Heat and Power plant, for his untiring effort, guidance and encouragement throughout this investigation, right from the selection of the topic to the end of the work.

Professor H. S. Miles, Associate Professor, Mechanical Engineering Department, for his interest, co-operation and healthy suggestions and guidance to the best possible channel of investigation.

Professor C. H. Long, Associate Professor, Mechanical Engineering Department, Virginia Polytechnic Institute, for his able suggestions and helpful comments.

Professor J. B. Jones, Head of the Mechanical Engineering Department, for his rightful comments and encouragements and also serving as head of the author's thesis committee.

Professor W. A. Murray, Professor-in-charge, Electrical Engineering Department, Virginia Polytechnic Institute, for his advice and comments.

Professor O. G. Barnes, Professor of Electrical Engineering Department, Virginia Polytechnic Institute, for his valued interpretation and suggestion.

, Virginia Polytechnic Institute, Heat and Power plant, for his cordial relationship and encouragement.

Thanks are also due to the many unknown others who have helped in making this thesis possible.

INTRODUCTION

Generally it is believed that in a power station when there is a demand for process steam and also demand for heating, most of the auxiliaries of the plant should be arranged to be driven by steam rather than using electrical energy for them. This is, however, a general remark and a correct selection can be made only after a detailed study is made of all factors involved. The V. P. I. central heating and power plant works mainly as a heating station, generation of electrical energy, being a by-product. So this problem is completely different from the standpoint of a general power station. This station supplies heating steam to the college through two different pressure lines. One is the low pressure, and the other is the high pressure line. The low pressure heating load is largely met by the entire exhaust of Allis-Chalmers Back Pressure turbine. The low pressure heating line requires a pressure of three to six psig and the high pressure line requires 75 to 100 psig. The high pressure load is met by, first throttling the steam from 250 psig to 160 psig through a pressure reducing valve and then bringing it down to the required pressure by throttling further through a second set of pressure reducing valves. The boiler and the turbine are run according to the demand of the low pressure and high pressure heating loads and therefore, they are directly dependent on on the outside temperature. During the period investigated, the high pressure steam was supplied to Dining hall, Infirmary, Wood Research Laboratory, Dairy building, Girls Dormitory, Davidson Hall, Faculty Apartment, and Green house. Out of these only the Girls Dormitory and the Green house are heated by the high pressure steam. The rest is for process work or for the need of laboratory experiments.

This load picture shows that the load of the plant varies much in seasons and accordingly, the generation of steam is variable. Now looking back to the boiler feed-water pumping system, it is found that the feed water is being constantly supplied to the boiler by a pump being driven by an electric motor. To supply feed-water to number 5 and 6 boilers, there are three pumping units, two with the capacity of 100 gpm each and the third one being 120 gpm. One pump is driven by a Westinghouse constant speed 50 hp induction motor, the second one being driven by a Moore steam turbine and the last one by a Wheaton steam turbine.

According to observation of Mr. Fleming[1] in his thesis, for the Power and Fuel Engineering, the feed pump is generally driven by the electric motor and the steam units are kept as stand-by units. Now as the steam for the high pressure heating lines is supplied by throttling live steam of 250 psig to 75 psig, through the pressure reducing valves, consideration may therefore be given whether this amount of steam can usefully be utilized in a turbine and then exhausting to the high pressure heating lines. This would conserve available energy which is at present being wasted by the throttling. A turbine such as this, could be used to drive the boiler feed pump. The present system of throttling 75 psig steam from 250 psig by pressure reducing valves may however be retained to cope with emergency and for accommodating excess steam load that can not be handled by the turbine concerned.

---

1. Mr. D. A. Fleming's thesis: *A Study of the Electric and Steam Driven Feed Pump for No. 6 Boiler*, V. P. I. Publication, June 1951.

REVIEW OF LITERATURES

It is wise men's desire to extract as much work and heat as possible from the expanding steam and most all Utility concerns strive to achieve the best result. The Virginia Polytechnic Institute, heat and power station, is an excellent source of investigation on this field. There is a large demand of heating and process steam, and the demand of the electrical load is fairly great as it takes care of the campus and town of Blacksburg. Quoting Mr. Herbert Addison's remark in his book titled as Centrifugal and Rotodynamic Pumps, it is found that the most economical drive for the pump for feed-water, which is a part of an electrical generating plant, is by a direct coupled electric motor. In another place he has commented that in the demand of process steam, the consideration of steam driven units, have to be thought of. This part of the comment is favourable to our investigation, as V. P. I. heating and power plant is not primarily electric generating station, generation of electrical energy being a by-product. Mr. Terrel Croft states that selection of boiler feed pump drive depends upon local condition, facilities, initial cost, maintenance charges, and above all the operating cost. The entire factor of the selection of drive is so complicated that it is difficult to draw a clear cut line of demarcation.

Mr. D. A. Fleming in his thesis for Power and Fuel Engineering, proved that for the V. P. I. power plant, it is more economical to run the boiler feed pumps by electrical motor, than by turbine exhausting to the low pressure line, as steam can be used more efficiently in the main turbine. He commented, and subsequently admitted, that the facility of turbine driven pump is that the pump output can be readily and effectively controlled by the steam flow adjustment only. Another advantage marked by him in his thesis is that, a turbine adjusts itself to the fluctuation of power demand on it.

Mr. A. D. Some, in his paper at the fall 1951 meeting of ASME has commented about process steam turbine for industry and said where steam must be generated to serve the needs of the process, by-product power can be made by a process turbine at an additional fuel consumption of approximately 4250 btu per kw-hr., as compared with 11,500 btu per kw-hr for prime mover in an equivalent plant. In another place in the same discussion, he has commented that basically the turbine accommodates itself to the steam flow required by the process while extracting as much power as practicable. The flow through the turbine must exactly balance the process requirements.

Mr. Lawrance Mcrow in his paper, '<u>Prevent Steam Waste with Turbine Driven Refrigeration Units</u>' says;since many types of turbines are available, steam can be utilized at almost any initial and back pressure. First cost is higher than for motor driven units but operating expenses are usually substantially low. When a turbine is used as a reducing valve in the heat balance of a plant the cost of operations is extremely low.'

In another place Mr. C. M. Sieben while discussing the <u>Heat Balance of a Brewery</u> commented that if there is no additional labor cost which will offset any saving and if it would result in a lower cost per unit of production and while a good heat balance is definitely desireable, it can be expected that the use of an exhaust turbine for the process work will definitely offer a saving which again will justify a fair return on additional investment.

The comments of Mr. A. A. Cummins and Mr. H. N. Bernard in their discussion of the Rules for Revamping Small Plants, says, "Among small plant operators there is considerable loose thinking relative to the economy of by-product power generation. While in many cases it may be a profitable procedure, considerable care is necessary in selecting the proper size and character of the equipment. Where steam can be reduced from boiler pressure to heating header pressure by passing it through a turbine or engine instead of a reducing valves, mechanical or electrical power can be secured for approximately coal consumption of ½ pound per kwhr. If coal costs $5.00 per ton, the fuel cost would be 1¼ mills per kw-hr. There is however, the investment and operating cost of the engine or turbine to consider.

In another article of "The Engineer," March 6, 1942, it is found in a discussion titled as Turbo-Generator Installation in Brewery, that the author recommended to retain the existing pressure reducing valve as an alternate means of throttling the steam. The reducing valve, however should be provided with the means of adjustment of such a way that this path remains closed as long as the quantity of steam passing through the turbine is sufficient to cover the steam demand of the line. He suggested that the steam passing through the turbine should be regulated to give a uniform back pressure independent of the quantity of steam demand.

IV THE INVESTIGATION

A. OBJECT

B. METHOD OF PROCEDURE

    1. Plan

    2. Factors involved

    3. Procedure

C. SAMPLE CALCULATIONS

D. CURVES

THE INVESTIGATION

A. OBJECT

This investigation was carried out to study the economic justification of using a small turbine rather than a pressure reducing valve between the high pressure header and the high pressure heating lines of the V. P. I. Power Plant, so that the steam may be usefully utilized by expanding in the turbine and thus to have some amount of work out of it.

INVESTIGATION

B. METHOD OF PROCEDURE

1. PLAN

As the problem is to justify the use of a turbine to be worked as pressure reducing valves between the high pressure header and the high pressure heating lines by taking steam at 250 psig and exhausting at 75 psig to high pressure heating mains, the first job is to find out the high pressure heating load of the plant. This high pressure heating load is recorded by the recording meters on the plant. As the work output of the proposed turbine may be better utilized if it is given the work of taking the entire load of supplying power to drive, the feed water pump of the boiler, the next step is to determine the feed water pumping load of the plant. These data are also available from the recording meters readings of the plant. These heating load and the feed water pumping load data should be tabulated and shown through curves with an hourly duration basis. As the maximum load of heating steam and pumping will be recorded during the winter and the minimum in the summer, two groups of curves will be sufficient, if they are drawn with average values of six winter and summer months. Thus the average peak and minimum values on an average for the winter and summer months could be recorded from these two curves.

The above values of heating load will be required to find out the available steam to drive a turbine and a decision of the size of the turbine could be made by consulting the manufacturer's specifications. The power required to pump the necessary feed water can be had from the pump manufacturer's specification.

If the present pumping unit is retained, the energy consumption by the present induction motor driving the pump, can be found out from the observation of Mr. Fleming in his thesis.

Once the rating of the turbine and the pump drive, have been considered, the next step will be to find out from the turbine and pump manufacturers specifications (1) how much steam a turbine will be required to use to pump the desired amount of feed water and (2) how much steam will be available surplus that can be otherwise utilized and also (3) if the steam supply to the turbine is less than its demand, to cope with the demanded work of feed water pumping, by how much amount it will run short. To get these figures, it is necessary to subtract the horsepower required to pump the desired amount of water to the boiler, from the available horsepower generated by the turbine.

If the high pressure heating load is such that a turbine can develop enough horsepower which is more than the horsepower to be required for driving the feed water pump, consideration may then be given to transform the effort of the turbine into the generation of electrical energy through an induction motor, to be run as a generator. The reason behind this suggestion being that it is rather simple to transfer the total turbine output into electrical energy and then to utilize it through different motors, driving the plant auxiliaries or it may be used wholly to increase the station killowats output. The induction motor has also the advantage of being the initially low cost unit and also best suited for a work like this sort of situation, of generating by-product electrical energy.

The rating of this induction motor could be determined from the available output of the turbine during different periods of the year. After a definite decision has been reached as to the size of the units and their steam and heat rates, the economical aspect of this proposition has to be considered. In the exsisting system the feed water is being pumped by an induction motor, consuming electrical energy from the station. So the computation of this energy cost at different load periods has to be made from the observation of Mr. Fleming's thesis.

The amount of electrical energy generated by the turbine, the portion of it used for driving the pump, and the balance in excess have to be determined, to get the respective values to reach at a point of economic justification.

The cost of computation of the electrical energy should be done as per contract rate of the Appalachian Electric Company and as the cost of steam generation by the plant is known, the cost of this steam used up by the turbine from the point of heat value of steam can be determined.

INVESTIGATION

B. METHOD OF PROCEDURE

2. FACTORS INVOLVED

To work with the plan laid out in the previous chapter, it was found that the main factor is the evaluation and the taking of data for the high pressure heating load (75 psig) and load for the feed water pumping, from the best available sources. The plant log-sheet records, daily data of each such items as boiler evaporation, high pressure and low pressure steam used, steam used for the auxiliaries etc, with the details of daily running important information of the plant equipment. But as to get the true picture of these heating steam and feed water pumping load, it is required to get an hourly variation of these loads, these values were to be found out from the readings of the recording meters for that purpose. On looking to the recording charts for both heating and pumping load, it was found, that due to mechanical defects of the recorders, some of the recordings were irregular and in some cases they are incomplete. Thus it is difficult to compute an average monthly load on hourly duration basis, by dividing the sum of each days hourly characteristic load values per month by the number of days. In some cases, these recordings are incomplete and in some cases they are so irregular that they should not be considered as the true trend of load. This factor was faced for both heating steam load and also for pumping load of the feed water.

The next factor about the value of total heating steam load is that there is a meter which records the high pressure heating steam consumption of the V. P. I. infirmary, separately from the other consumption.

This particular meter is an integrating type, by which the hourly recording of demand can not be determined. Therefore, to complete this investigation from the best possible sources of information, the average value of this consumption per hour will have to satisfy our want. The third factor in the determination of the size of a turbine unit, is to find out the necessary details of steam rate of the unit and its load characteristic curves to show how much steam will be required to run at different load capacity of the unit. The only possible and easy way is to consult manufacturer's specification and quotation. The similar details in respect of feed water pump showing different power consumption at variant capacity of the pump will have to be found out from the pump manufacturer's commitments.

As the pumping load was computed from charts showing evaporation of the boiler, the value of blow down should be added to this value. From the consideration of the plant water treatment condition, a value of 3½% can be assumed which is a quite reasonable figure from the point of safe boiler feed water concentration.

This assumption was seconded by Mr. DeBusk, Utility Engineer of the V. P. I. heat and power plant, from his experience of previous investigation and data available for it.

THE INVESTIGATION

B. METHOD OF PROCEDURE

3. PROCEDURE

To draw a logical sequence of development in the chapter of procedure adopted to complete this investigation, is to look to the points as (a) the study of original data for both two main items of observation as the high pressure (75 psig) steam load and the feed water pumping load of the plant from the recording chart of the plant and to compute their hourly load values and then to (b) use the available values of steam load and pumping load to drive a turbine and to decide the economical size of the unit based on above figures. The next step is to evaluate the surplus energy after spending the necessary energy for pump or defeicit of the same and how to meet this problem. The investigation could be concluded with the observation of the economic justification of these arrangements.

Now, to follow step by step the above sequence, the high pressure steam load of the plant was calculated by taking three days a month's feasible and possible data of the recording meter of the plant. The spacing between these three days interval was tried to be kept within ten days. The V. P. I. infirmary load on the high pressure steam was found out by dividing the total daily reading of the integrating type of meter on this account by 24 hours a day, to get the average value per hour of the day. These hourly infirmary load of high pressure steam were added to the data received and computed from recording meters chart. The reason for adopting such a way of computation was discussed in the chapter under 'Factor involved'. However, the main point of defense on this step of evaluation of data is the effort to get the best possible data from the most suitable and available resources under this investigation. Moreover, this heating steam load remains fairly constant during each day of a month, unless there is unusual and sudden changes of outside temperature. For example, three days figures for the month of April 1952, for five different periods of a day, were quoted here.

Date	8 a.m.	11 a.m.	5 p.m.	3 a.m.	7 a.m.
April 11, 1952	7613 #/hr.	7863 #/hr.	7613 #/hr.	8113 #/hr.	7963 #/hr.
April 20, 1952	7330 #/hr.	7330 #/hr.	7330 #/hr.	7430 #/hr.	7330 #/hr.
April 30, 1952	7908 #/hr.	7658 #/hr.	7408 #/hr.	7408 #/hr.	7408 #/hr.

On examining the charts, it was found that this sort of change is very rare, and a liberal margin of capacity of the driven units, will be able to take this sudden increase in load. Now, as outlined in the chapter of the plan of this investigation, the observations were grouped into two terms as winter and summer. The winter term was assumed to begin with November 1951 till April 1952 while the summer term will include May and June 1952 with July 1951 to October 1951. The reason for considering the months of observation as such, from the middle of the year, beginning in July 1951 and ending June 1952, being that, a number of the campus lines on 75 psig heating load have been shifted to low pressure (3 to 6 psig) heating main before July 1951.

Now as the demand of the high pressure steam and the pumping load are maximum during the winter term, where as, in the summer it is very low, maximum peak will be available from the winter term figure with a minimum available load from summer and which again will determine the rating of a turbine unit that is to be installed. As detailed this factor in the previous chapter, the computation of a suitable size of a steam turbine, to be driven from the available steam load, will be determined from the details furnished by THE TERRY STEAM TURBINE COMPANY'S representative, THE HAWKINS-HAMILTON COMPANY, and which was subsequently plotted to a curve shown with a title of "Performance curve for Terry turbine", in curve number "C". The average values for the steam and the pumping load was calculated for these two terms, which is in this case six. The rating of the turbine and generator units have been made from these average values. It was decided to run the turbine and the generator units always at 10% overload capacity when ever possible and especially in the winter term. As per plan detailed before, this proposed turbine will be given the work of pumping feed water to the boiler throughout the year. Therefore any excess surplus energy, if available, from the output of the turbine, after meeting the power required for pumping load, should be pushed back to the station bus-bar to increase the killowatt output of the station. On the other hand, if the available effort of the turbine is less than demanded effort of the pump, the motor driving the pump will be free to draw out the deficit energy from the station bus-bar.

Curves that were plotted from these data, have been grouped as showing the average winter and summer term 75 psig steam load through curve titled as "Feed water pumping demand" and was marked as "B". These two curves show the relation of pounds of high pressure heating steam demand or pounds of feed water demand of the boiler on an hourly load basis for a day of 24 hours. A curve was copied from the details of the load power performance of the Worthington Pump and Machinery Corporation's pump to show the relation of horsepower required against capacity of the pump in gallons per minute. This was marked as "D" curve. The fifth curve required in this investigation is the information found by Mr. Fleming in his thesis, to get the relation of boiler evaporation in pounds per hour with kilowatts required to drive the pump. This curve was a true copy of Mr. Fleming's work and was marked as curve "E".

Now coming to the justification of the economics of this proposition, the calculations have been conducted as (1) to find out the heat rate of the turbine per pound of steam used. The available steam rate of the turbine as received from Terry Steam Turbine Company, may be used to divide the heat equivalent of horsepower hour output of the turbine and again this result is divided by the efficiency of the turbine. This will give the work in BTU per pound of steam.

Computation of the cost of BTU used was found out by multiplying the ratio of BTU used by the turbine to BTU available per pound of steam at the initial supply condition of steam with the cost of steam as found out by the plant. The total cost of running the turbine per day based on this heat value of the steam was calculated by multiplying the total steam consumption for 24 hours a day with the cost of BTU per pound of steam. Then by finding out the average feed water pumping load for a day and from curve "E" the corresponding kilowatt consumption of the motor driving the pump was found out. The cost of this electrical energy at contract rate with Appalachian Electric Company was determined. When there is an excess of electrical energy available to the station bus-bar or whenever any deficit of electrical energy was drawn from the station output, their values were calculated in the similar way at the contract rate of the plant. The savings will be found out when the total running cost of the turbine, to develop the necessary power for driving feed water pump and to supply excess energy to the station output in kilowatts, will be deducted from the total sum of the cost of the electrical energy otherwise expended if the pump would have been driven by electric motor drawing current from the station bus-bar and the cost of the surplus electrical energy put to the station output. The same procedure will be adopted for computing the summer and winter term load condition and to find out respective prospect of economics.

SAMPLE OF CALCULATIONS

(WINTER TERM)

(1) Feed water pumping load in pounds per hour

$P_L = S_f + B_d$

$P_L = 68,332 + 2390$

$P_L = 70,722$ lbs per hour

Where: S_f = steam flow in lbs/hour as recorded by meter (68,332 lbs/hour is the average steam flow at 8 a.m. time for the month of November 1951.)

B_d = Blow down loss, assumed as 3 1/2% of steam flow in lbs/hour

Willians line data for curve number "C"

(2) Throttle flow in pounds per hour

T_f = S.R. x H.P.

$T_f = 69.5 \times 100$

$T_f = 6950$ lbs/hour

Where: S.R. = steam rate of the turbine from the Terry steam turbine company's details, in lbs/hp hour

H.P. = total horsepower output per hour

(3) Heat rate of turbine in BTU/lb of steam

$$h_r = \frac{H_e}{S.R.}$$

$$h_r = \frac{2545}{69.5} = 36.6 \text{ BTU/lb}$$

Where: H_e = heat equivalent of one horsepower hour in BTU

S.R. = Steam rate at rated capacity of a 100 horsepower from the Terry turbine company's details, in lbs/horsepower hour.

(4) Net BTU consumption by the turbine while considering losses

$$h_r = \frac{h_r}{1-L_b-L_r}$$

$$h_r = \frac{36.6}{1-.02-.02}$$

h_r = 38.12 BTU/lb

Where: L_b = losses as percent due to friction in bearing and windage etc., and assumed as 2%

L_r = losses in radiation which is assumed as 2%

(5) Net enthalpy added in boiler in BTU/lb of steam

$Q_n = (E_s - E_f)$

$Q_n = (1263 - 190)$

Q_n = 1073 BTU/lb of steam

Where: E_s = enthalpy of steam at the condition of inlet to turbine in BTU/lb

(250 psig at 100° superheat)

E_f = enthalpy of entering feed water in BTU/pound

(6) Cost of BTU used per pound of steam by the turbine in dollars

$$C_b = \frac{h_r}{Q_n} \times C_s$$

$$C_b = \frac{38.12}{1073} \times \frac{\$0.22}{1000}$$

C_b = \$0.0000078

Where: C_s = cost of one pound of steam in dollars

(7) Total cost of BTU used by the turbine at full load capacity per day in dollars

$C_t = P_s \times C_b \times t$

$C_t = 6950 \times 0.0000078 \times 24$

$C_t = \$1.296$

Where: P_s = pounds of steam used by the turbine per hour at the considered capacity

t = hours in a day

(8) Present cost of electrical energy for pumping feed water by electric motor per day

$P_c = K_w \times t \times C_{kw}$

$P_c = 45.6 \times 24 \times 0.008$

$P_c = \$8.8$ per day

Where: K_w = Kilowatts used by the motor to pump the average winter term feed water load of 61,423 lb/hour as per curve number "E".

C_{kw} = value of Kwhr. in dollars as per contract rate with the Appalachian Electric Company.

(9) Surplus electrical energy available in Kilowatts

$S_e = (E_g - E_p)$

$S_e = \left(\frac{74.6 \times 110}{100} \times 0.9 - 45.6\right)$

$S_e = 29.4$ Kilowatts

Where: E_g = electrical energy generated by the induction generator having an efficiency of 90% working with an overload capacity of 10%

E_p = electrical energy input to the motor for pumping feed water as per curve number "E".

(10) Value of surplus electrical energy at the contract rate with the Appalachian Electrical Company

$V_{se} = S_e \times 0.008 \times t_{av}$

$V_{se} = 29.4 \times 0.008 \times 24$

$V_{se} = \$5.65$ per day

Where: t_{av} = average period of run in a day

(11) Savings per day

$G_d = (P_c - C_t) + V_{se}$

$G_d = (\$8.8 - \$1.296) + \$5.65$

$G_d = (\$7.504 + \$5.65)$

$G_d = \$13.154$

(12) Gain for winter term of 6 months at the above rate

$T_g = G_d \times t_d$

$T_g = 13.154 \times 30 \times 6$

$T_g = \$2370$

Where: T_d = total number of days in winter term

(SUMMER TERM)

Available average heating steam during summer = 4607.5 lb/hour

Kilowatts generated from the above steam load from curve "C" =

$\frac{38.0}{1.34}$ = 28.4

Steam rate of turbine at the reduced capacity of the turbine in pounds per horsepower from curve "C" = 121.2 lb/horsepower hour

(13) Heat rate in BTU/lb of steam

$$h_r = \frac{H_e}{S.R.} = \frac{2545}{121.2}$$

$$h_r = 21.5 \text{ BTU/pound}$$

(14) Net heat rate in BTU/lb when considering losses (as in winter term)

$$h_n = \frac{h_r}{1-0.02-0.02}$$

$$h_n = \frac{21.5}{0.96}$$

$$h_n = 22.4 \text{ BTU/lb}$$

(15) Total cost of this BTU of steam for 24 hours of run at the prevailing throttling flow of steam

$$T_B = \frac{h_n \times \$0.22 \times 24 \times P_s}{Q_n \times 1000}$$

$$T_B = \frac{22.4 \times \$.22 \times 24 \times 4607.5}{1073 \times 1000}$$

$$T_B = \$0.507$$

Average pumping load per day in summer term from data sheet

27,233 lb/hour

Power required to pump this amount of water from curve number "E" is 41.6 kilowatts per hour

Where: P_s = available steam flow for the summer term on the average in lb/hour

(16) Cost of this kilowatts per day of 24 hours

$C_k = 41.6 \times 24 \times 0.008$

$C_k = \$8.00$ per day

(17) Electrical energy running short from the induction generator to supply the motor of the pump

$E_{sh} = E_q - E_a$

$E_{sh} = 41.6 - 28.4$

$E_{sh} = 13.2$ Kilowatts

Where: E_q = kilowatts energy required to pump the demanded quantity of feed water

E_a = kilowatts available from the generation of electrical energy in the turbine

(18) Kilowatts short per day of 24 hours running

$13.2 \times 24 = 316$ kilowatts per day

(19) Cost of electrical energy lying short of generation and that has to be met from the station bus-bar

$316 \times 0.008 = \$2.52$ per day

(20) Net cost of driving the motor for feed water

$N_t = C_{sh} + C_{bt}$

$N_t = \$2.52 + \$0.507$

$N_t = \$3.027$

Where: C_{sh} = Cost of electrical energy running short of generation from the induction generator in dollars

C_{bt} = Cost of BTU used by the turbine to develop the required energy in dollars

(21) Savings in dollars per day of summer

$S = C_k - N_t$

$S = \$8.00 - \$3.027$

$S = \$4.973$

(22) Savings for the whole summer term of six months

$S_s = \$4.973 \times 30 \times 6$

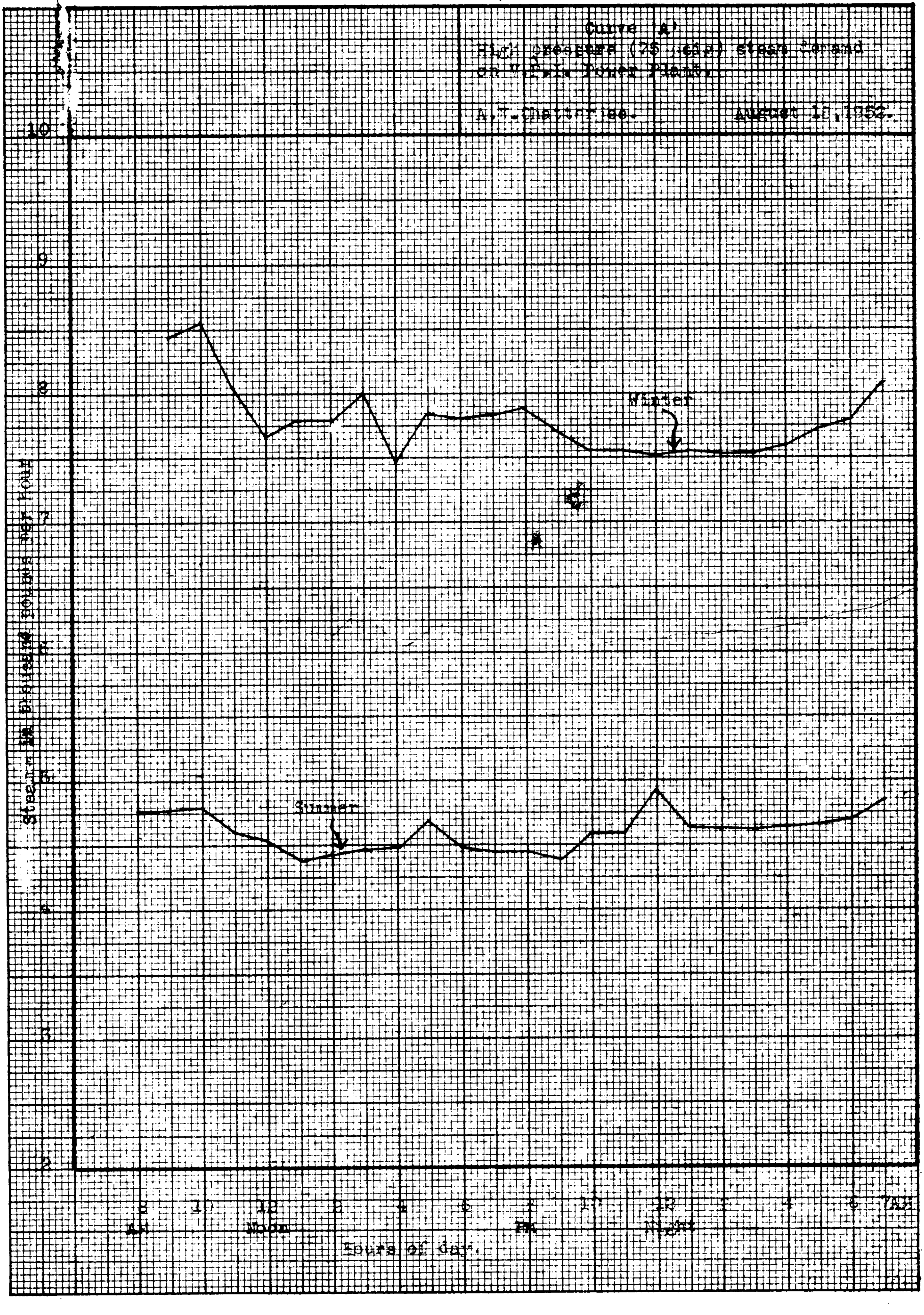
$S_s = \$895$

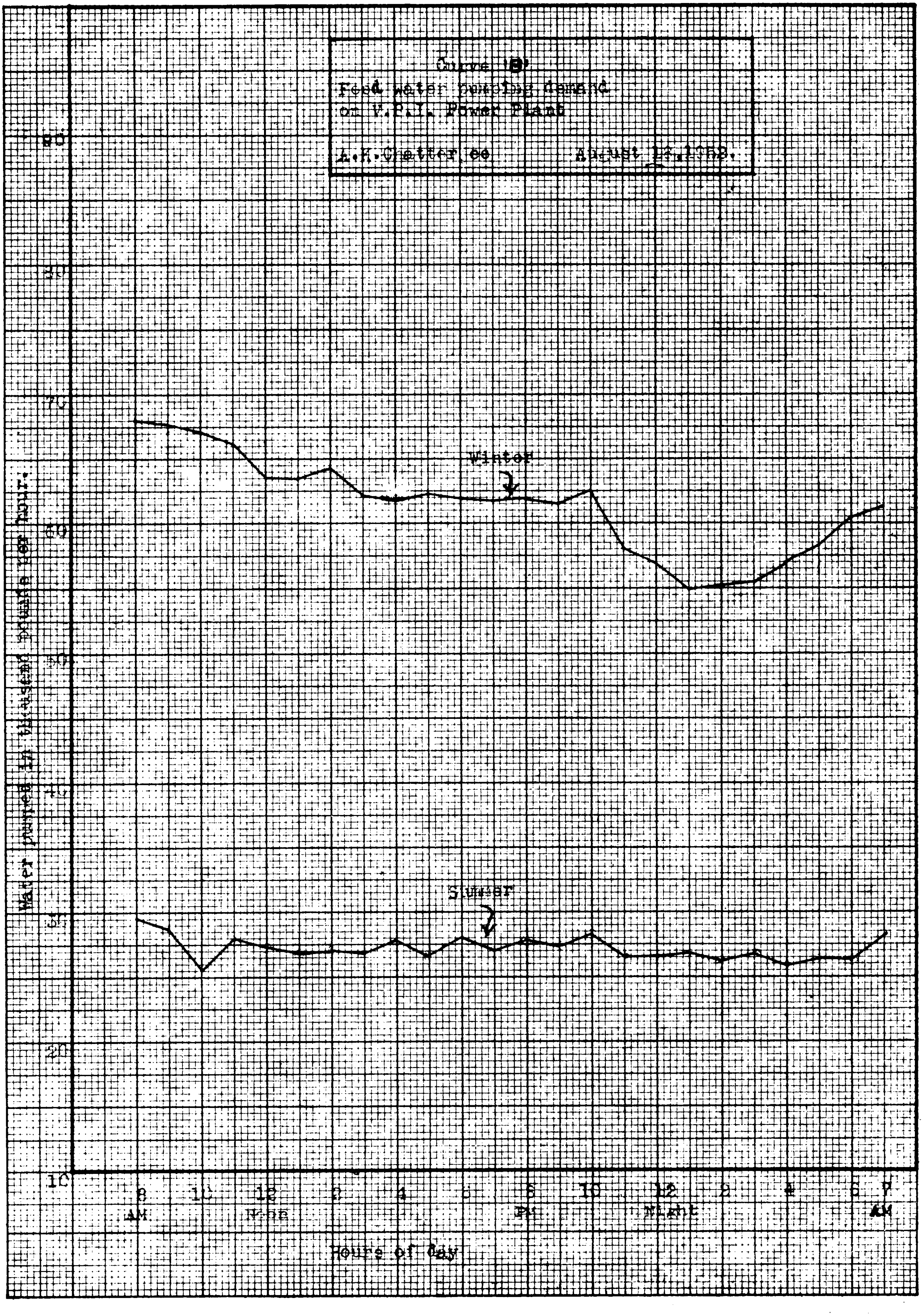
(23) Savings for both term (winter and summer)

$= T_g + S_s$

$= \$2370 + \$895$

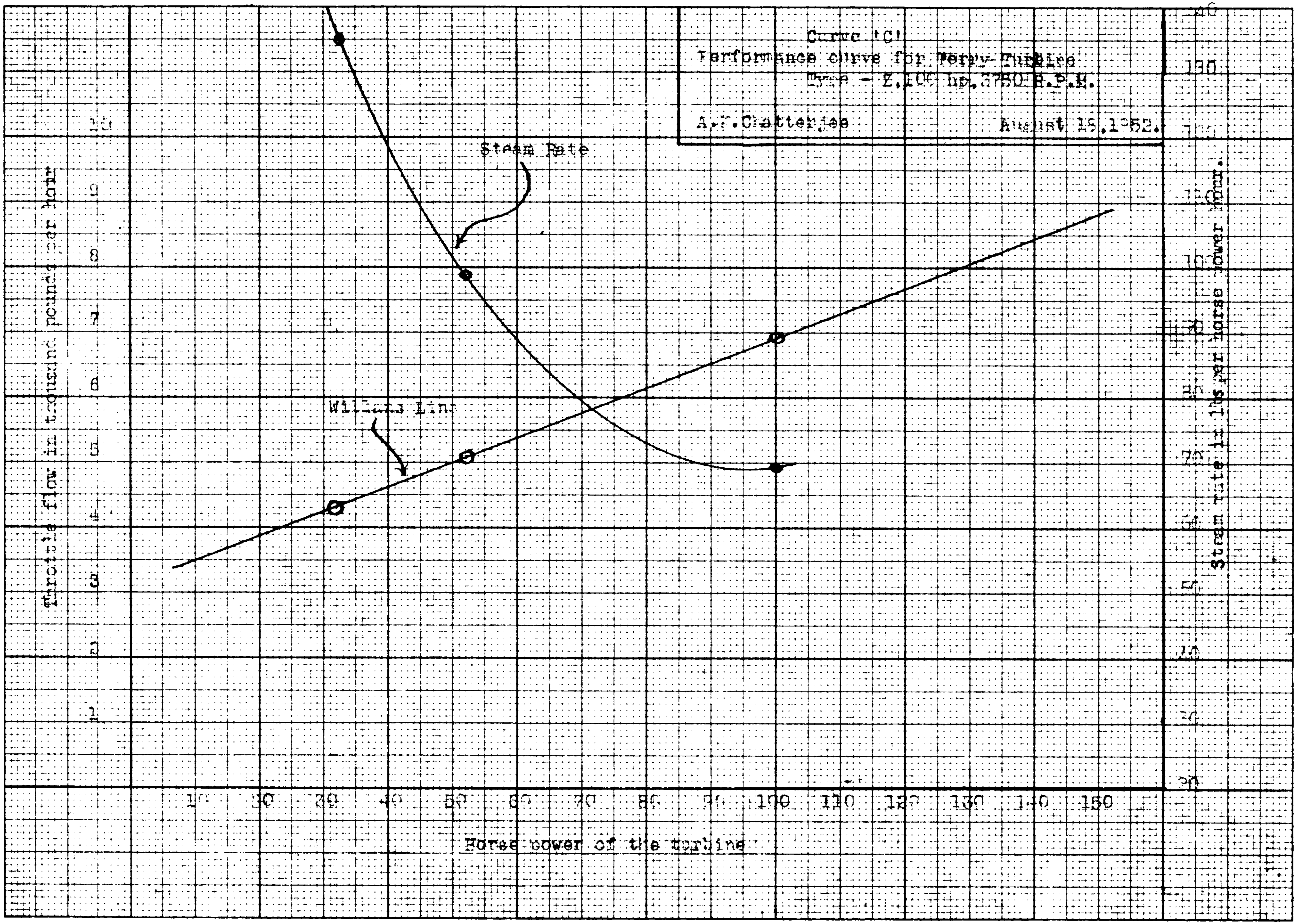
$= \$3265$


Curve A'
High pressure (75 psig) steam demand
on V.P.I. Power Plant.
A.T. Chatterjee.
August 18, 1952.
Steam in thousand pounds per hour
10
9
8
7
6
5
4
3
2
Winter
Summer
8
10
12
2
4
6
8
10
12
2
4
6
7AM
AM
Noon
PM
Night
Hours of day.



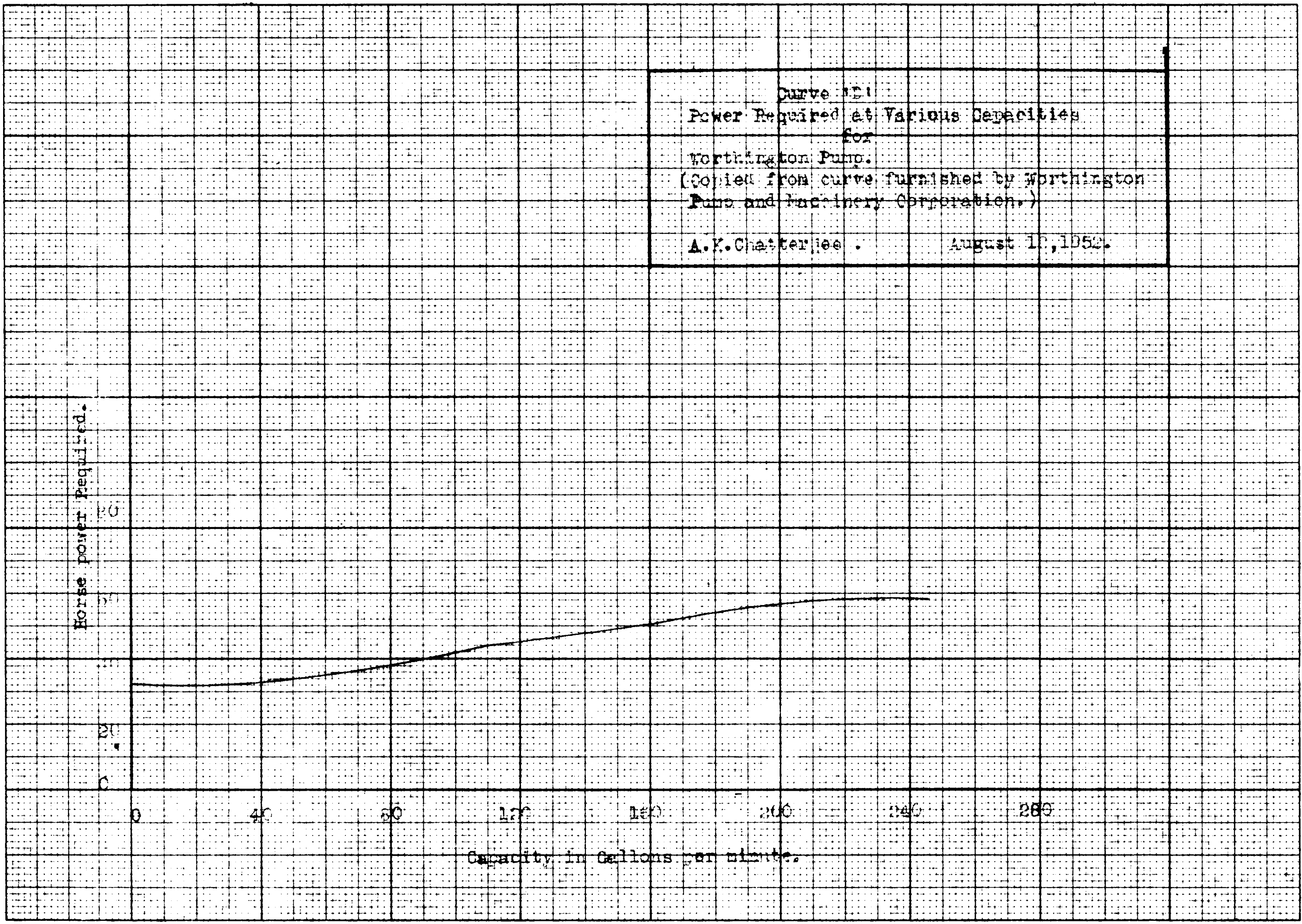
Curve 'B'
Feed water pumping demand
on V.P.I. Power Plant

A.K. Chatterjee August 14,1958.



Curve 'C'
Performance curve for Terry-Turbine
Type - Z,100 hp,3750 R.P.M.

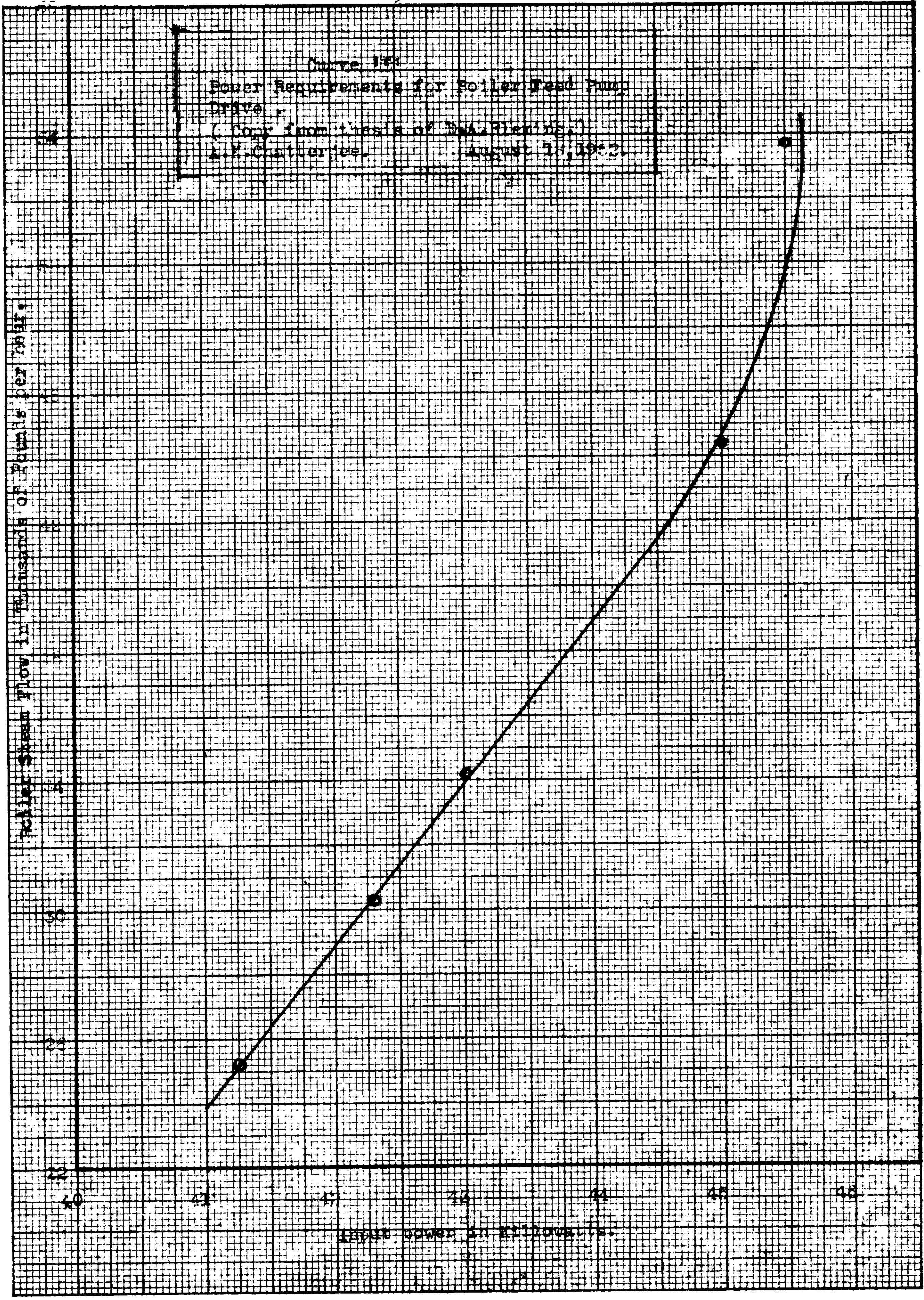
A.K.Chatterjee August 15,1952.



Curve "D"

Power Required at Various Capacities
for
Worthington Pump.
(Copied from curve furnished by Worthington Pump and Machinery Corporation.)

A.K.Chatterjee . August 18,1952.



Curve 1[illegible]
Power Requirements for Boiler Feed Pump
Drive .
(Copy from thesis of D.A.Fleming.)
A.K.Chatterjee. August 1[illegible],1952.

DISCUSSION OF RESULTS

This chapter of discussion may be grouped under (1) determination of the size of a turbine and generator units and (2) economics of their introduction.

To decide the size of the above units the only data helpful in this case is the high pressure heating load of the plant. From the data sheet, it is found that the value of the average winter term steam load is 7827 lb per hour while in the summer it drops down to 4607.5 lb per hour. Now checking the curve "C", it was found that the maximum steam consumption by a 100 horsepower unit is 6950 lb per hour, which in the summer term will be able to develop only 38 horsepower. As regards peak demand of this steam at 8 a.m., it was 8502 lb per hour for winter and 4778 lb per hour in summer.

The question that arises out of these figures is that a bigger size unit is quite befitting for a winter load but considering the loss in efficiency that will occur in the summer term, when the whole unit will run at a much lower capacity, it may be decided that a turbine with a 100 horsepower capacity is just a judicious selection. The heavy increase on steam rate at low load surely baffles the idea of the consideration of a bigger unit.

Now to handle the full demand of steam load, when this turbine will be able to accommodate only 6950 lb per hour, the excess steam may be throttled by the present system of passing through the pressure reducing valves.

The size of the induction generator should be therefore also of the same size of the turbine. It may safely be assumed that both of these units may be able to be run at 10% overload all the time in the winter term or whenever steam load will be befitting.

As the electrical energy running short in the summer term is by 13.2 kilowatts an hour it is better to keep the present setup of driving the feed pump by electrical motor and let the proposed units of the turbine and the induction generator be installed separately in any other convenient place. As the induction generator has to be hooked up with the station bus-bar to get the magnetising current, let the motor driving the feed pump be hooked up with the induction generator terminals. Thus in the winter term this motor driving the feed water pump will draw its current from the induction generator and in the summer term when there will be a deficit of power from this terminal of the induction generator, the motor will also be able to draw its driving current from the station bus-bar.

Discussing the feasibility of coupling the feed pump with the turbine and the induction generator, on the same shaft with each other, it is found that much complication of mechanical coupling the three units and their problem of drawing a relation in driving with respect to each others characteristic demand, comes up, which can safely be avoided if the above suggested setup is followed.

From the results shown in the curves and data sheets, it is defended as only the necessary figures that are actually required to draw up conclusion, in plotting curves and in calculating economics of this proposition, have been brought in. All other data and curves, which have very little bearing on above, have been eliminated. This will help to get the objectives of this thesis easily subjected to comment and also to grasp the idea behind it.

Now looking to the details of the problem of economics, it was found from the attached data sheet that the average feed water pumping load for the winter term is 61,423 lb per hour whereas in the summer, it is 27,233 lb per hour. The electrical energy that has to be spent up for these pumping loads was recorded by Mr. Fleming in his thesis and found to be 45.6 kw for the winter and 41.6 kw for the summer time load. So the first advantage of this proposition is found out when the present setup will be able to relieve the cost of this electrical energy at a much less cost. The cost for the present feed water pumping system is $8.8 per day in the winter term and it can be accomplished by a cost of $1.296, thus showing a saving of about $7.54 per day in the winter term, when in the summer term there will be some deficit of electrical energy and as it was shown in the sample of calculation that it is still a prospective proposition, by showing a profit of about $4.973 per day.

CONCLUSION

In drawing the conclusion of this investigation, it may be commented here that the present proposition shows a definite sign of profit by a return of about $3265 per year. Considering the initial cost of the turbine and the induction motor, they are found to be about $1613 and $1000 respectively. If a more than 25% cost be taken into consideration on the account of installation of these units, still the whole cost shows to be realzed within a year of running of the unit.

Thus, it can be recommended here that a 100 horse power back pressure turbine and a 100 HP induction motor to be worked as a generator may be installed to work as a pressure reducing valve between the high pressure header and the high pressure heating main. The turbine will take steam at 250 psig and at 100° superheat and exhaust at 75 psig. This exhaust steam will be led to the present 75 psig heating lines, which are now being supplied with the steam of the above pressure by throttling the steam through the pressure reducing valves. When the demand of steam will be such that the entire exhaust of the turbine will be insufficient to cope with, the pressure reducing valves should be operated to supply the extra steam at the required pressure.

The induction generator terminal should be connected to the station bus-bar and motor driving the pump be hooked up with the generator terminal.

Further investigation on this project is needed and may be followed as per tabled in the chapter of recommendation.

RECOMENDATIONS

1. A study may be extended to find out how much more steam in the future will be passed to the high pressure heating lines, to cope with the demand of the heat units requirements for the lines.

2. Also to find out if it is economical to use more live steam for this purpose, when the heat value of the exhausting steam from the turbine is less than the live steam from the boiler.

3. The study may be extended to know if it is economical to use enough live steam to run the turbine at full load at all times and even in summer when steam demand is very low.

4. The above study may also be directed to find out the economical feasibility of using a synchronous generator with a d.c. exciter than an induction motor.

IX APPENDICES

A. SUMMARY

B. DATA SHEET

C. BIBLIOGRAPHY

D. VITA

SUMMARY

At present the high pressure (75 psig) steam is supplied to the need of the campuss need of process work, as in the Dinning Hall, Infirmary, Green House, etc., from the V. P. I. central heat and power station, first by throttling the live steam at 250 to 160 psig and then to 75 psig through pressure reducing valves. Thus the whole amount of steam that is under this pressure reducing valve suffering a reduction in pressure, is doing no useful work and there may be a possibility of extracting some amount of work from this steam.

Thus the object of this investigation was directed to find how much available energy that can be extracted from the otherwise waste heat of the steam while under throttling through pressure reducing valves. To extract as much work as possible it was desired to install a back pressure turbine to work as a pressure reducing valve between the high pressure header of the boiler and the high pressure heating lines.

At the beginning of this investigation, it was decided to divide the whole year of investigation into two terms, as winter and summer term. The winter term was supposed to begin from the month of November and end in April, while the summer term ranges from May to October. The period under consideration in this thesis was from the month of July 1951 to June 1952. The reason being that many high pressure heating lines have been put to low pressure (3 to 6 psig) heating mains before this period.

While computing the data, it was found that there is enough high pressure heating load demand for the whole winter term to run a 100 hp turbine, while in the summer term also it will be able to serve the purpose it will be put in. To utilize the work output of this turbine, it was thought, to employ it in the feed water, pumping job of the boiler, which is now being done by a 50 hp induction motor, consuming electrical energy from the line. While studying the steam rate of this turbine from the manufacturer's quotation, and the pump load characteristic of the Worthington pump and Machinery Corporation, it was found that the turbine will not only be able to develop power enough to do the entire feed water pumping job during the winter, but also be able to supply a fair amount of electrical energy, if an induction motor be employed to generate the electrical energy. The result obtained is an encouraging one, as the whole cost of units (turbine and generator) with a 25% more on installation charge will be recouped with a year's saving. It is therefore concluded that a 100 hp turbine with an induction generator of 74.6 KW capacity may be installed and this will surely justify the proposition.

As the demand of high pressure steam during the winter term is more than the turbine of 100 hp can handle, it may be recommended to retain the present pressure reducing valves working, so that any time the demand is more, than the turbine can handle it will be passed through the pressure reducing valves. The induction generator will do the whole job of electrical generation and will supply electrical energy to the motor, now driving the pump of the feed water supply, and will push extra electrical energy to the line bus-bar for the increase of total kw output of the station.

The investigation shows a sign of savings of $3265. per year which will be able to compensate the initial and layout cost of this recommended proposition.

WINTER TERM 75 psig STEAM LOAD IN POUNDS PER HOUR

Time	Nov. 1951	Dec. 1951	Jan. 1952	Feb. 1952	Mar. 1952	Apr. 1952	Average Winter Term
8 a.m.	5,368	9,017	10,183	9,446	9,386	7,617	8,502
9 a.m.	5,114	8,851	10,016	9,645	9,303	7,700	8,444
10 a.m.	5,184	9,267	10,183	8,896	8,969	7,850	8,561
11 a.m.	5,001	8,434	9,516	8,562	9,136	7,617	8,044
12 noon	4,867	7,817	9,266	8,062	8,386	7,667	7,677
1 p.m.	5,044	8,101	9,516	8,062	8,553	7,483	7,793
2 p.m.	4,601	8,351	9,683	8,062	8,469	7,684	7,810
3 p.m.	4,951	8,684	9,899	8,296	8,553	7,817	8,033
4 p.m.	4,617	8,551	9,949	8,112	8,319	7,550	7,416
5 p.m.	4,368	8,467	10,183	8,396	8,219	7,450	7,847
6 p.m.	4,201	8,424	10,149	8,312	8,636	7,734	7,812
7 p.m.	4,268	8,184	10,266	8,462	8,503	7,417	7,846
8 p.m.	4,334	8,101	9,933	8,479	8,386	7,934	7,883
9 p.m.	3,868	7,851	9,849	8,696	8,386	7,584	7,705
10 p.m.	3,534	7,934	9,683	8,729	8,219	7,384	7,552
11 p.m.	3,451	7,767	9,516	8,562	8,303	7,717	7,552
12 p.m.	3,368	7,767	9,433	8,479	8,553	7,617	7,536
1 a.m.	3,534	8,184	9,233	8,462	8,386	7,584	7,563
2 a.m.	3,284	7,851	9,266	8,629	8,469	7,701	7,535
3 a.m.	3,601	7,901	9,016	8,646	8,803	7,651	7,547
4 a.m.	3,451	8,184	8,433	8,813	8,803	7,867	7,591
5 a.m.	3,868	8,351	8,516	8,812	9,136	7,701	7,730
6 a.m.	4,034	8,351	8,850	8,979	8,719	7,784	7,800
7 a.m.	4,334	8,767	9,683	8,896	9,219	7,701	8,072

Average daily steam load (75 psig) for winter term = 7,827 #/hr.

SUMMER TERM 75 psig STEAM LOAD IN POUNDS PER HOUR

Time	May 1952	June 1952	July 1951	Aug. 1951	Sept. 1951	Oct. 1951	Average Summer Term
8 a.m.	7,109	5,619	4,746	3,474	2,753	4,868	4,778
9 a.m.	7,112	5,621	4,748	3,575	2,754	4,869	4,780
10 a.m.	7,156	5,655	4,777	3,595	2,771	4,900	4,795
11 a.m.	6,764	5,346	4,516	3,401	2,619	4,632	4,613
12 noon	6,760	5,343	4,513	3,398	2,618	4,629	4,544
1 p.m.	6,540	5,169	4,366	3,288	2,532	4,476	4,395
2 p.m.	6,578	5,199	4,391	3,307	2,547	4,504	4,421
3 p.m.	6,650	5,255	4,439	3,343	2,575	4,553	4,469
4 p.m.	6,658	5,255	4,445	3,347	2,578	4,559	4,473
5 p.m.	6,985	5,520	4,663	3,511	2,704	4,782	4,694
6 p.m.	6,676	5,277	4,457	3,356	2,585	4,571	4,487
7 p.m.	6,627	5,237	4,424	3,331	2,566	4,534	4,453
8 p.m.	6,624	5,236	4,420	3,330	2,565	4,535	4,451
9 p.m.	6,538	5,167	4,365	3,287	2,531	4,477	4,394
10 p.m.	6,448	5,097	4,304	3,241	2,496	4,415	4,581
11 p.m.	6,423	5,076	4,288	3,229	2,487	4,398	4,580
12 p.m.	6,416	5,071	4,284	3,226	2,484	4,393	4,940
1 a.m.	6,920	5,470	4,620	3,479	2,680	4,739	4,622
2 a.m.	6,476	5,118	4,323	3,261	2,507	4,434	4,622
3 a.m.	6,487	5,127	4,331	3,256	2,512	4,442	4,624
4 a.m.	6,476	5,119	4,324	3,284	2,508	4,455	4,635
5 a.m.	6,536	5,166	4,363	3,317	2,531	4,475	4,665
6 a.m.	6,598	5,215	4,405	3,420	2,555	4,518	4,709
7 a.m.	6,803	5,377	4,541	3,456	2,634	4,658	4,855

Average daily steam load (75 psig) for summer term = 4,607.5 #/hr.

WINTER TERM PUMPING LOAD IN POUNDS PER HOUR

Time	Nov. 1951	Dec. 1951	Jan. 1951	Feb. 1951	Mar. 1951	Apr. 1951	Average Winter Term
8 a.m.	70,722	62,962	63,826	60,370	75,760	74,520	68,027
9 a.m.	67,966	64,346	61,761	61,756	76,180	74,520	67,750
10 a.m.	67,380	63,326	63,124	62,442	74,520	71,420	67,019
11 a.m.	66,240	61,580	59,342	63,472	74,520	72,450	66,267
12 noon	60,372	61,407	58,131	59,686	73,280	68,993	63,643
1 p.m.	62,100	59,342	58,480	61,412	71,620	68,310	63,534
2 p.m.	61,916	61,751	60,272	60,372	73,900	68,310	64,425
3 p.m.	59,342	60,206	59,676	59,337	70,380	63,804	62,127
4 p.m.	60,030	58,810	58,126	59,100	70,585	65,550	61,727
5 p.m.	58,302	60,352	62,100	60,030	71,420	61,402	62,276
6 p.m.	59,000	58,480	60,550	59,680	70,890	62,776	61,878
7 p.m.	59,000	55,207	62,964	60,372	69,140	63,472	61,691
8 p.m.	59,342	57,960	61,060	57,262	70,380	61,756	61,950
9 p.m.	59,171	56,056	61,402	60,030	71,210	61,756	61,521
10 p.m.	59,171	59,166	61,756	60,372	68,720	66,240	62,570
11 p.m.	56,051	55,370	59,337	55,890	60,030	62,100	58,131
12 p.m.	56,676	55,546	60,366	55,182	59,820	63,472	56,830
1 a.m.	54,506	53,820	52,096	51,052	56,930	62,100	55,082
2 a.m.	53,132	53,122	52,446	53,820	55,060	64,170	55,291
3 a.m.	51,926	52,436	52,446	52,441	57,135	66,240	55,432
4 a.m.	52,780	57,960	48,834	54,506	59,620	68,310	57,000
5 a.m.	59,520	58,131	51,057	52,270	62,100	66,926	58,330
6 a.m.	59,520	58,296	52,048	56,232	65,410	71,066	60,432
7 a.m.	63,140	59,840	54,162	55,370	65,240	68,652	61,235

Average daily pumping load for winter term = 61,423 # /hr.

SUMMER TERM PUMPING LOAD IN POUNDS PER HOUR

Time	May 1952	June 1952	July 1951	Aug. 1951	Sept. 1951	Oct. 1951	Average Summer Term
8 a.m.	30,020	25,183	23,805	24,840	26,910	46,913	29,602
9 a.m.	29,323	24,491	24,323	24,491	27,426	42,263	28,719
10 a.m.	31,716	25,526	23,633	25,356	27,079	43,970	25,614
11 a.m.	28,288	24,840	23,456	24,840	27,079	40,191	28,116
12 noon	27,253	24,148	23,113	24,323	25,875	38,981	27,280
1 p.m.	27,253	23,805	23,113	24,666	26,390	36,568	26,965
2 p.m.	27,773	24,313	22,936	25,702	25,526	36,740	27,169
3 p.m.	27,253	23,636	23,296	24,666	26,045	36,396	26,880
4 p.m.	27,945	23,636	23,805	24,496	27,845	38,981	27,801
5 p.m.	27,253	23,457	23,113	24,323	25,526	36,396	26,677
6 p.m.	28,980	23,491	23,456	25,183	27,426	38,981	28,088
7 p.m.	27,699	24,330	23,113	24,491	25,875	36,396	27,139
8 p.m.	28,980	24,491	23,456	25,357	27,253	38,299	27,967
9 p.m.	28,460	23,975	23,113	24,667	25,457	37,780	27,225
10 p.m.	28,636	24,672	23,456	25,707	26,910	40,016	28,228
11 p.m.	26,561	23,456	23,456	23,975	25,457	36,740	26,591
12 p.m.	27,253	23,805	21,735	23,936	26,218	37,260	26,591
1 a.m.	27,945	23,805	21,735	23,456	25,526	38,295	26,792
2 a.m.	27,593	23,805	21,735	23,286	23,805	37,946	26,364
3 a.m.	27,596	23,805	22,252	23,456	25,875	37,775	26,792
4 a.m.	24,481	22,770	21,735	22,936	25,183	38,466	25,931
5 a.m.	26,516	22,770	21,735	22,936	23,456	41,566	26,420
6 a.m.	26,910	22,770	22,422	22,769	23,805	44,848	26,219
7 a.m.	28,283	22,770	22,422	23,436	25,703	48,645	28,446

Average daily pumping load for summer term = 27,233 # / hr.

BIBLOGRAPHY

1. Addison, H. A., Centrifugal and Other Rotodynamic Pumps. London: Chapman and Hall Ltd., 1948
2. Croft, Terrell, Steam Power Plant Auxiliaries and Accessories. New York: McGraw-Hill Book Company, Inc., 1922
3. "The Engineer", Magazine, March 1942, page 201, Turbo-Generator Installation in a Brewery
4. Fleming D. A., Thesis, A Study of the Electric and Steam Driven Boiler Feed Pumps for No. 6 Boiler, V. P. I. Publication, 1951. F 597
5. Gaffert, G. A., Steam Power Station, New York, McGraw-Hill Book Company Inc., 1946
6. "Industry and Power", Magazine, Vol. 44, April 1943, Page 48, Prevent Steam Waste with Turbine Driven Refrigeration Units
7. Morse, F. T., Power Plant Engineering and Design, D. Van Nostran Company Inc.
8. Marks, L. S., Mechanical Engineering Handbook, New York, McGraw-Hill Book Company
9. "Power Plant Engineering", Magazine, Vol 46, January, 1942, Page 70, Rules for Revamping Small Plants.
10. "Refrigeration Engineering", Magazine, Vol 45, June 1943, Page 458, Heat Balance in a Brewery
11. Somes A. D., Development of Process Steam Turbine for Industry, April 1952, Mechanical Engineering Magazine.
12. Bulletins of Messrs, The Terry Steam Turbine Company, Hartford, Connecticut, from Messrs, The Hawkins-Hamilton Company, Richmond,

Virginia

13. *Bulletin*, Worthington Pump and Machinery Corporation, Harrison, New Jersey