621.181.6-186.4:536.71

Experimental Results with a Supercritical Pressure Test Plant*

(1st Report)

By Tsutomu WATAMORI* and Shigeru MAEDA**

In view of the current tendencies in power requirements, it will become a necessity in the very near future to construct in Japan large-capacity supercritical pressure thermal power plants. In this paper, we outline the supercritical pressure test plant recently built by Hitachi Ltd., at the Hitachi Laboratory, and discuss some of its experimental results.

These plant facilities include a boiler with steam conditions of 350 kg/cm²g and 650°C and a steam flow rate of 2 t/hr, a 200 kW turbo-generator, as well as a complete set of plant equipment and a large variety of testing apparatus. Here a wide range of research activities are being conducted on heat transfer and flow characteristics of supercritical steam and water, control methods and operating methods of entire plants using once-through boilers, the water treatment of supercritical pressure plants, and heat-resisting materials for supercritical pressure plants. In this paper, we report on some of the results of this research.

1. Introduction

The present trend in Europe and America is towards the adoption of supercritical pressure steam in thermal power plants, in order to obtain larger capacities and higher efficiency. Everywhere fundamental investigations are being carried on using well-equipped research facilities, such as the Alliance plant of the American Babcock and Wilcox Ltd., the Carteret plant of the Foster Wheeler Co., and the Philo No. 6 test plant. These test plants have been steadily producing experimental results of great value^{(1)~(7)}.

It is inevitable that supercritical pressure thermal power plants will be built in Japan also in the near future. In order to obtain a speedy clarification of points which were not clear in the design, manufacture, and operation of such plants, it was found necessary to begin research activities immediately by means of supercritical pressure thermal power plants. Hitachi Ltd., has accordingly installed a test plant equipped with a 200 kW turbo-generator giving steam conditions of 350 kg/cm²g and 650°C and a steam flow rate of 2 t/hr. Research has already been commenced at this test plant, and in this paper we shall describe some of the experimental results obtained from these research activities.

2. Description of the test plant

In planning this test plant, the advantages and disadvantages of the various test plants constructed in various foreign countries were taken fully into consideration, and every effort was made to furnish the plant with as complete and perfect equipment as possible. It was decided to provide a full set of plant equipment which would make possible, not only research on the boiler but also on the plant as a whole, including the turbo-generator.

Fig. 1 is a schematic diagram of the test plant, while Table 1 gives the specifications of the main equipment. As shown in Fig. 1 (a), this plant is provided with a turbine, a generator, and all other necessary plant equipment. In this manner, it is possible to study the operating and control methods of entire plants using once-through boilers. It is also equipped with devices for the investigation of heat transfer and flow characteristics of supercritical steam and water, with devices for research on superalloys for supercritical pressure plants, for the investigation of water treatment, and for research on corrosion and scale adhesion in the boiler tubes. Fig. 2 shows the boiler, feed water pump, and demineralizer; Fig. 3 shows the turbine, generator, and pressure and temperature reducing equipment; and Fig. 4 shows the central control panel. The piping system inside the boiler was arranged as similar as possible to

* Assistant Manager, Hitachi Works, Hitachi Ltd., Hitachi.

** Chief of the 102th Research Room, Hitachi Laboratory, Hitachi Ltd.

Table 1 Specification of test plants

Boiler	Type	Benson
	Max. steam pressure (2ry super heater outlet)	350 kg/cm ² g
	Max. steam temperature (")	650°C
	Max. steam flow	2 t/hr
	Feed water temperature	120°C
	Firing method Draught	Oil burning Forced draught
Turbine	Type	DR
	Main steam pressure	37 kg/cm ² g
	Main steam temperature	400°C
	Max. output rpm	200 kW 595.9
Generator	Type	S-RD
	Terminal voltage	212.5 kVA
	rpm and frequency	3 300 V 1 500, 3φ/50~
Pressure & temperature reducing apparatus	1ry	Press. 350 kg/cm ² Temp. 650°C
	2ry	Press. 37 kg/cm ² Temp. 400°C

(a) Block diagram of supercritical pressure test plant

(b) Control system of test plants

Fig. 1

that of a central power station; the piping was divided into economizer, water walls, transient zone, radiant-superheater, and secondary-superheater, and the piping was formed of two parallel circuits on the right and on the left. The approximate position of each portion is shown in the left of Fig. 1 (a). The boiler control system is as shown in Fig. 1 (b), and the steam pressure, steam temperature, and steam flow rate are under automatic control. The plant output control is arranged so that comparisons can be made between both the conventional method and the direct energy balanced method of control. The research described below has been

performed in this comprehensive test plant.

3. Water treatment investigation

Although in a conventional drum boiler the corrosive particles in the cycle and the dissolved salt contained in the make-up water can be eliminated by the blowdown of the boiler water, no such method is applicable in a supercritical pressure once-through boiler, and much more exacting demands are made upon the boiler feed water. Accordingly, it is no exaggeration to state that the realization of the once-through boiler has been made possible thanks to the development of ultra-demineralizers. The make-up water for this plant is provided by first passing raw water through a coagulator; then it is demineralized in a cation exchanger and an anion exchanger. After this it is refined in a mixed bed ion exchanger and is fed into the make-up water tank. At the same time, all or some of the condensing water is passed together with the make-up water through an anthracite or leaf type prefilter and into the mixed bed ion exchanger. After passing through a cellulose filter, it is stored in an ultra-demineralized water tank. NH_3 is used for PH control, and N_2H_4 is injected as a degasser. In Table 2 we show the specifications of the boiler feed water of this plant as compared with those of supercritical pressure power plants overseas.

The quantities of SiO_2 , Fe, and Cu in the flow medium inside the cycle depend upon the pressure, temperature, and feed water flow, but their quantities tend to decrease in operation with the passage of time. An example

Left: Boiler
Center: Feed pump
Right: Demineralizer
Fig. 2

Left: Turbogenerator
Right: Pressure and temperature reducing equipment
Fig. 3

Fig. 4 Central control panel

Table 2 Specification of boiler feed water for test plant and foreign supercritical pressure plants

		Test plant	Philo No. 6	Avon No. 8	Hüls	Eddy-stone
Pressure	kg/cm ²	350	316	245	300	350
Temperature	°C	650	621	594	600	649
Total solid	ppm	0.05	0.5	0.05	E = 4~5 μ/cm ²	0.1
SiO ₂	ppm	0.01	0.02	0.02	0.015	
Fe	ppm	0.01	0.01	0.01	0.01	
Cu	ppm	0.01	0.01	0.01	0.01	
O ₂	ppm	0.005	0.005	0.007	0.007	0.005
PH		9.0~9.5	9.5~9.6	9.0~9.5	9.2	9.0~9.5

of this time variation during start-up is shown in Fig. 5. The graph shows that the amount of SiO_2 began to increase after about two hours, accompanying the temperature and pressure rise at the boiler outlet. After reaching its peak value, it returned to its original value 9 hours after the change in the operating conditions. When the feed water flow is increased, it displays a temporary rise with practically no time lag. There is also a slow rise in the Fe content as the feed water flow, pressure, and temperature are increased; it reaches its peak value after about 6 hours, and returns to its original value after 12 hours. As the test plant continues in operation, samples are taken from each part and are automatically analyzed and recorded; examples of these values are shown in Table 3. Twenty further places are provided in the plant where sampling can be carried out, and automatic analysis and recording is conducted whenever and wherever required.

Fig. 5 Analytical value of boiler outlet steam

4. Investigation of static characteristics

In order to design a once-through boiler it is essential to know the heat absorption, the pressure drop, and the unbalanced flow in each section; and it is only to be expected that the various factors should undergo changes in proportion to the changes in conditions of the supercritical pressure steam and water. However, since these points have not yet been fully clarified, experimental studies are being conducted on them.

Although the boiler is for test purposes, its heating surface was arranged as far as possible in the same manner as that of an actual boiler. At a boiler outlet steam pressure of 150~350 kg/cm²g and a steam temperature of 650°C, the transient point will coincide with the low gas temperature position, and the boiler can be operated safely even at a 30 per cent load.

The pressure drop in the boiler tube, ΔP , is:

$$\Delta P = \xi \frac{l}{d} \cdot \frac{W_f^2}{2gV} + \rho u \frac{W_f^2}{2gV}$$

where ξ is the friction factor, ρ is the resistance coefficient of the bends, l is the pipe length, d is the inside diameter, W_f is the mean velocity of the fluid, V is the specific volume of the fluid, and u is

Fig. 6 Pressure and temperature distribution in boiler

Table 3 Analytical results in test plants

		Deaerator out- let	Boiler outlet	Condensate pump outlet	Make up demineralizer outlet	Condensate demineralizer outlet
Specific resistance	10 ⁴ Ωcm	15	45	45	1 000	500
SiO_2	ppb	50	50	42	25	5
O_2	ppb	<5	<5			
NH_3	ppm	3	1	1		
PH		9.6	9.4	9.2	6~7	6~7
Fe	ppb	<2	<2	5	<2	<2
Cu	ppb	12~16	12	10	8	8

the number of stages. An equation for the heat transfer coefficient⁽¹⁰⁾ has been deduced for each section, and studies are being conducted on the basis of experimentally obtained values.

In Fig. 6 we show an example of such an experiment. The pressure drop in the boiler, the wall temperature, the fluid temperature, and the gas temperature were measured in conditions where the feed water was kept at a uniform 1.4 t/hr, the main steam pressure was kept at 300 kg/cm², and the main steam temperature was also kept at a uniform 650°C. This test boiler has been provided with an especially large number of measuring points for making detailed studies of the heat transfer and the wall temperature at the transient point. Studies are being conducted of each factor, varying the pressure, temperature, and flow. Especially detailed

Fig. 7 Friction factor versus enthalpy for several pressures

Fig. 8 Unbalance flow for change in oil flow

investigations are being made of the friction factor by means of a test section provided near the boiler outlet. The results of these studies are shown in Fig. 7. It is found that there is little changes in the friction factor as a result of changes in the steam pressure, and that it declines slightly together with an increase in the enthalpy. There is a rise in the Reynolds number as the enthalpy increases; consequently, an increase in enthalpy signifies a rise in the Reynolds number.

This test boiler is constructed to have two parallel circuits in order to make possible investigations of the unbalanced flow; tests of the unbalanced flow are conducted by adjusting the inlet valves. Examples of this are shown in Fig. 8 and Fig. 9. In Fig. 8 the fluid temperature in the parallel circuits is shown when the oil flow was changed with the feed water flow and the boiler pressure at uniform values. It can be concluded that the unbalanced flow increases proportionally to the increase in the oil flow, and there is also an increase in the fluid temperature difference. In Fig. 9 is shown the fluid temperature when the steam pressure was changed with the feed water flow and the oil flow at uniform values. There is a smaller temperature difference at a supercritical pressure than at a subcritical pressure; as a result, there is a smaller unbalanced flow. The unbalanced flow increases proportionally the lower the pressure is, and increases the higher the gas temperature is. It seems that this can be explained by the fact that the flow

Fig. 9 Unbalanced flow in pressure change

resistance in each of the parallel circuits is different at a subcritical pressure and there is a smaller feed water flow in whichever circuit has the larger flow resistance; as a result, the circuit has an increased heat absorption per feed water flow unit, evaporation occurs more rapidly, and the flow resistance is larger; for this reason, it is considered, there is an ever increasing amount of unbalanced flow. A separate parallel circuit test device has also been installed for performing fundamental investigations of unbalanced flow; it is being used chiefly for studies of the effects on unbalanced flow of flow resistance fluctuations of two-phase flows and studies of flow resistance in converging or separating flows.

5. Research on dynamic behavior

One of the primary objectives of this test plant is to clarify the dynamic behavior of once-through boilers, to study the plant controllability, and to explore suitable control systems. A number of monographs have already been published on the subcritical analysis of once-through boilers^{(11),(12)} but there is a dearth of literature dealing with supercritical pressure. The fundamental equation of the once-through boiler was analyzed to obtain the dynamic equation⁽¹³⁾, and the results were applied to the test boiler. The dynamic behavior was determined by means of an analogue computer, and it was compared with the experimental results obtained from this test boiler.

5.1 Analysis of dynamic behavior

The analysis was divided into several parts: the preheating part, the transient zone, and the superheated part. The following conditions were imposed upon each part.

1. The pressure response and the temperature response are to be handled separately, since there is a considerable difference between them.

2. The heat transfer coefficient from the pipe wall to the medium is to be uniform.

3. The heat transmission intensity is to be uniform for all parts.

4. Heat transfer is to be identical in the radial direction of the pipe, and there is to be no movement of heat in the longitudinal direction of the pipe.

5. The medium is to be in an identical condition in the radial direction of the pipe.

6. Each part is to satisfy the equation $PV = aI + b$.

Under the above conditions, we obtain the following fundamental equations.

Heat transmission of combustion gas to the pipe wall:

$$R_2 - R_1 = C \frac{\partial \theta'}{\partial t}$$

Heat transmission from the pipe wall to the flow medium: $R_1 = H(\theta' - \theta)$

$$\text{Energy of the medium: } R_1 = Q \frac{\partial I}{\partial L} + \frac{F}{V} \cdot \frac{\partial I}{\partial t}$$

$$\text{Continuity of flow: } \frac{\partial Q}{\partial L} = \frac{F}{V^2} \cdot \frac{\partial V}{\partial t}$$

$$\text{Pressure drop: } \frac{\partial P}{\partial L} = -KQ^2V$$

By the process of linear differentiation of the above fundamental equations within the range of small changes from a steady state with respect to each of the three parts, we obtain the following equations for dynamic behavior.

(1) Preheating part

$$\begin{aligned} \text{Temperature: } \theta_{p0} = & \frac{R_{p0}}{\theta_{p0} H_{p0}} \frac{1}{(T_1 + T_2 + T_1 T_2 s)} \left\{ 1 - e^{-C_2 \frac{H_{p0}}{R_{p0}} \frac{(T_1 + T_2 + T_1 T_2 s)s}{1 + T_2 s}} \right\} \\ & \times \left(\frac{\gamma}{1 + T_{FS}} - q_{pi} \right) + \frac{\theta_{pi0}}{\theta_{p0}} e^{-C_2 \frac{H_{p0}}{R_{p0}} \frac{(T_1 + T_2 + T_1 T_2 s)s}{1 + T_2 s}} \theta_{pi} \end{aligned}$$

(2) Transient part

$$\begin{aligned} \text{Enthalpy: } i_{t0} = & \frac{I_{t0}}{I_{t00}} \frac{1 - K_v' e^{-K_v T_3 s}}{1 - T_3 s} i_{ti} - \frac{R_{t0} T_3 T_s}{F I_{t00}} \frac{V_{t00} e^{-K_v T_3 s} - V_{t0}}{1 - T_3 s} s \theta_{t0} \\ & + \frac{R_{t0} T_3}{F I_{t00}} \frac{V_{t00} e^{-K_v T_3 s} - V_{t0}}{1 - T_3 s} \left(\frac{\gamma_0}{1 + T_{FS}} - q_{ti} \right) \\ & + \frac{R_{t0} T_4}{F I_{t00}} \frac{V_{t00} - (V_{t00} - V_{t0}) T_3 - V_{t00} e^{-K_v T_3 s}}{1 - T_3 s} P_{t0} \end{aligned}$$

$$\begin{aligned} \text{Flow rate: } q_{t0} = & \frac{a_3 I_{t00}}{P_{t00}} \left\{ \frac{1}{V_{t00}} e^{-K_v T_3 s} - \frac{1}{V_{t00}} \right\} \frac{T_3 s}{1 - T_3 s} i_{ti} \\ & + \frac{T_3}{T_4} \left\{ \frac{1}{K_v'} \frac{T_3 s}{1 - T_3 s} + e^{-K_v T_3 s} \frac{1}{1 + T_3 s} + 1 \right\} \frac{1}{1 + T_{FS}} \gamma_0 \\ & + \left\{ \frac{-1}{K_v'} \frac{T_3 s}{1 - T_3 s} + e^{-K_v T_3 s} \frac{1}{1 - T_3 s} + T_3 s + 1 \right\} P_{t0} \end{aligned}$$

$$+ \left\{ e^{-KvT_3s} \frac{1}{1-T_3s} - \frac{1}{Kv'} \frac{T_3s}{1-T_3s} - 1 \right\} T_3s\theta_{t0}$$

$$+ \left\{ e^{-KvT_3s} \frac{T_3}{T_4(1-T_3s)} - \frac{1}{Kv'} \frac{T_3^2s}{T_4(1-T_3s)} + 1 - \frac{T_3}{T_4} \right\} q_{ti}$$

(3) Superheated part

$$\text{Temperature: } \theta_{so} = \frac{R_{so}}{\theta_{so0}H_{so}} \frac{1}{(T_6+T_7+T_6T_7s)s} \left\{ 1 - e^{-C_4 \frac{H_{so}}{R_{so}} \frac{(T_6+T_7+T_6T_7s)s}{1+T_7s}} \right\}$$

$$\times \left(\frac{\gamma_0}{1+T_{FS}} - q_{so} \right) + \frac{\theta_{si0}}{\theta_{so0}} e^{-C_4 \frac{H_{so}}{R_{so}} \frac{(T_6+T_7+T_6T_7s)s}{1+T_7s}} \theta_{si}$$

$$\text{Pressure: } P_{so} = \frac{a_1\theta_{so0}}{k_4P_{so0}V_{so0}} \cdot \theta_{so} + \frac{1}{T_3s} (q_{si} - q_{so})$$

$$\text{Flow: } q_{so} = f - \frac{a_1\theta_{so0}}{2k_4P_{so0}V_{so0}} \theta_{so} + P_{so}$$

Most of the symbols in the equations given above are those which are commonly used in the field of thermal dynamics. The capital letters are the values at the steady state, while the small letters are the changing rates in transient response based on the values at the steady state. Here C : heat capacity in unit length of pipe; F : section area of flow path; H : heat transfer in unit length of pipe; L : length of pipe; R : heat removal quantity in unit length of pipe; and Q : fluid temperature. The following symbols represent definite quantities:

$$Kv' = V_{t00}/V_{ti0}$$

$$C_2 = \theta_{p00} - \theta_{pi0}$$

$$C_4 = \theta_{so0} - \theta_{si0}$$

$$k_4 = \theta_{so0}/I_{so0}$$

The suffixes have the following meanings:

i : inlet

o : outlet

p : preheated part

t : transient part

s : superheated part

o : stable state

The various time constants are represented by the following equations:

$$T_1 = F/k_1 H_{p0} V_{p0}$$

$$T_2 = C/H_{p0}$$

$$T_3 = FL_i/Q_{t0}(V_{t00} - V_{t0i})$$

$$T_4 = P_{t0}F/a_3 P_{t0}$$

$$T_5 = C\theta_{t0}$$

$$T_6 = F/k_4 H_{so} V_{so}$$

$$T_7 = C/H_{so}$$

$$T_8 = FL_s/V_{so} Q_{so}$$

$$T_F = \text{Time constant of flue}$$

5.2 Experiments on dynamic behavior

In order to measure the dynamic behavior of the test boiler alone, all of the steam coming from the boiler was passed through the turbine bypass and discharged into the atmosphere, and the transient responses with regard to sudden changes in oil

flow, feed water flow, and control valve lift were studied. In the following we give examples of the results.

Fig. 10 shows the changes in the steam pressure at boiler inlet and outlet, the steam temperature at boiler outlet and in the steam flow at boiler outlet, when the oil flow was suddenly increased from 135 l/hr to 158 l/hr and the air flow was also suddenly increased (maintaining a uniform fuel-air ratio), keeping the steam pressure at the boiler outlet at 250 kg/cm², the temperature at 550°C, the feed water flow at 1.4 t/hr, and the control valve lift at a uniform setting. Fig. 11 shows the temperature changes in the fluid at each part of the boiler. Although the dead time is relatively small, there is

Fig. 10 Transient response for change in heat input

a long settling time. This is because of the construction of the furnace, which was given a rather large furnace capacity in order to stabilize the combustion. The steam temperature at the boiler outlet does not undergo rapid changes, but the steam pressure and the steam flow at the boiler outlet do undergo rather rapid changes; the steam flow

reaches its maximum at about 2 minutes, thereafter gradually decreasing until it finally returns to its original value. In Fig. 12 and Fig. 13, the steam pressure at the boiler outlet was kept at 250 kg/cm², the temperature at 575°C, and the oil flow, the air flow, and the valve lift of the boiler outlet at uniform values; the figures show the changes in the

Fig. 11 Transient response for change in heat input

Fig. 13 Transient response for change in water flow

Fig. 12 Transient response for change in feed water

Fig. 14 Transient response for change in valve lift

steam pressure, steam temperature, and steam flow at the boiler outlet when the feed water flow was suddenly reduced from 1.4 t/hr to 1.31 t/hr. Sudden and intense changes appeared in the steam pressure and the steam flow, and the response in the fluid temperature was delayed, although a temporary reverse response occurred. This is attributed to the advance of the transient point because of the reduction in the feed water flow, which is believed to cause the reverse response in the steam flow. About 20 minutes are required before the steam flow, the steam pressure, and the steam temperature become completely settled. Fig. 14 and Fig. 15 show the changes in steam pressure and steam flow at the boiler outlet, as well as the changes in temperature at each part when the control valve lift was suddenly changed (from 12.2 mm to 11.5 mm), with the steam pressure at the boiler outlet at 255 kg/cm², the temperature at 575°C, the feed water flow at 1.4 t/hr, and the oil flow, the air flow, and the feed water flow remaining at uniform values. The pressure undergoes a rapid change, becoming practically settled within about 4 minutes. The steam flow also undergoes a sudden change, but regains its original value after about 4 minutes. The temperature changes occur at a smaller rate than the pressure and flow rates, but in this case require a longer time to become settled. From the above examples, we can easily understand that while pressure and flow have a quick response, the steam temperature response is slow. As mentioned

Fig. 15 Transient response for change in valve lift

before, the settling time depends on the construction of the furnace. In this test boiler, the furnace wall area was made rather large in order to increase the stability of combustion; therefore, it has a relatively long settling time for a once-through boiler. As for the temperature in various parts of the boiler, the water wall part (inside the furnace) has a quick response, and the response becomes gradually slower the farther ahead of the flue one goes. These tendencies remain valid even when the operating conditions of the boiler and the quantitative changes are varied.

The above-mentioned dynamic behavior equations were used with respect to the same operating conditions and quantitative changes as in the above experiments, and the results obtained by means of an analogue computer are shown with broken lines in Fig. 10, Fig. 12, and Fig. 14. They display in the main the identical tendencies as the experimental results. It was concluded that it is possible to obtain the tendency by means of the dynamic behavior equations, but there was a certain discrepancy in the settling value, and further studies are now being devoted to this point.

6. Investigations of super alloys

Conventional Cr-Mo low alloy steel or 18Cr8Ni stainless steel cannot withstand use under such steam conditions as 650°C and 350 kg/cm²g. Therefore, some other pipe material is needed which will have a superior strength at elevated temperatures, which is weldable, and which is furthermore economical from the business viewpoint. In the selection of a pipe material, the cooperation of the Sumitomo Metal Industries Ltd., a steel pipe manufacturer, was obtained, and the following materials were chosen as prospective ones: 15-15N, AN31, 17-14CuMo, G-18B, and LCN-155. These were tested for their strength at elevated temperatures and weldability, and their economical properties and workability were also taken duly into consideration. The following three were selected as the pipe material: 15-15N, AN-31, and G-18B. This was the first time that high alloy steel pipes of this type had ever been produced in Japan, and there was a complete lack of previous experience. Nevertheless, thanks to the efforts of the manufacturer, excellent pipes were obtained. Their typical

Table 4 Typical composition of high alloy steel pipe (%)

Material	C	Ni	Cr	Mo	W	Co	Cb	V	N ₂
15-15N	<0.15	15	16.5	1.5	1.5	—	1	—	<0.15
AN-31	<0.10	13.5	16.5	1.3	—	—	0.75	0.7	0.10~0.15
G-18B	0.40	13	13	2	2.5	10	3	—	0.10~0.16

Fig. 16 Creep rupture strength of several super alloy

composition is as shown in Table 4. There are numerous problems involved in the welding of high alloy steel pipes of this type, but flaw-free, satisfactory welding was possible by the heliarc welding method. With regard to the strength at elevated temperatures of the welded parts, detailed experiments were conducted using separately sampled test pieces, and it was ascertained that with respect to strength the pipes were thoroughly reliable. In Fig. 16 we show the results of tests of their high temperature creep. Furthermore, in order to study the property and structural changes when actual supercritical pressure steam is passed through them, there is a test section in the test plant using especially thin pipes of these three types of materials at a location where a high stress will be applied. Research is going on at present about their properties, and we shall be able to report at a later date on the results which will have been obtained.

7. Conclusion

In the preceding sections we have described the supercritical test plant and some of the experimental results obtained to date. Research work is still going on at the present time, not only on water treatment, but also on the capacity of the condensate demineralizer, on heat transfer at high pressures, on plant controllability, on control systems, on methods of operation, on the properties of materials, etc. These many-faceted research and experimental activities are at the present being conducted with this test plant, and we shall be able to report later on the test results.

References

- (1) W.H. Rowand: *Power*, Vol. 98, (1954), p. 73.
- (2) E. Daman: *ASME Paper*, No. 58-SA-17 (1958).
- (3) S.N. Fiala: *ASME Paper*, No. 55-A-137 (1957).
- (4) W.H. Rowand: *ASME Paper*, No. 55-A-135 (1957).
- (5) J.H. Harlow: *ASME Paper*, No. 58-A-165, (1957).
- (6) T. T. Frankenbery: *Proc. Amer. Power Conf.*, Vol. 20, (1958), p. 144.
- (7) G. Noetzline et al.: *VGB*, Vol. 55 (1958), p. 230.
- (8) Y. Yamazaki: *Tech. Rep. of the Central Research Inst. of Elect. Power Industry*, (1959).
- (9) G.A. Orrok: *Trans. ASME*, Vol. 47, (1925), p. 1148.
- (10) M.P. Vukalovitch: *Thermodynamic Properties and Steam* (1958), VEB Verly Technik.
- (11) H. Terano: *Report of Transportation Tech. Research Inst.* Vol. 7, No. 10 (1957), p. 207.
- (12) S. Ishigaya: *Trans. Japan Soc. Mech. Engrs.*, Vol. 27, No. 173 (1961), p. 153.
- (13) Y. Nakano and K. Kawatake: *Hitachi Hyōron*, Vol. 44, No. 9.