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U. S. NAVAL TECHNICAL MISSION TO JAPAN
CARE OF FLEET POST OFFICE
SAN FRANCISCO, CALIFORNIA

2 April 1946

RESTRICTED

From: Chief, Naval Technical Mission to Japan.
To : Chief of Naval Operations.

Subject: Target Report - Characteristics of Japanese Naval Vessels, Article 12 - Boilers and Machinery.

Reference: (a)"Intelligence Targets Japan" (DNI) of 4 Sept. 1945.

1. Subject report, covering boilers and machinery of the Japanese Navy outlined by Targets S-01 and S-05 of Fascicle S-1 and gas analysis instruments outlined by Target X-07 of Fascicle X-1 of reference (a), is submitted herewith.

2. The investigation of the targets and the target report were accomplished by Comdr. L. C. McCloskey, USNR, assisted by Lt. (jg) G. H. Sheeks, USNR, as interpreter and translator.

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CHARACTERISTICS OF JAPANESE NAVAL VESSELS
ARTICLE 12
BOILERS AND MACHINERY

"INTELLIGENCE TARGETS JAPAN" (DNI) OF 4 SEPT. 1945
FASCICLE S-1, TARGETS S-01 AND S-05

FASCICLE X-1 TARGET X-07

APRIL 1946

U.S. NAVAL TECHNICAL MISSION TO JAPAN

SUMMARY

SHIP AND RELATED TARGETS

CHARACTERISTICS OF JAPANESE NAVAL VESSELS ARTICLE 12-BOILERS AND MACHINERY

No new or positive information of the details of design and construction of boilers and machinery was developed by this investigation. The general status of Japanese boiler and machine design was on a rather low level. What was good appeared to have been copied from United States of British design - it was not Japanese. German design influence strangely seemed to be lacking.

There was an apparent lack of knowledge of furnace and steam drying design. Wasted furnace volume was the basic reason for Japanese ships having only half the shaft power of U.S. Navy ships of similar tonnage. Inability to design boilers for dry steam delivery to the superheaters caused excessive outage for boiler and machinery repairs.

Lack of application of fuel-economy principles sharply reduced the cruising radii of ships.

The use of high-resistance air-heaters, rather than economizers, seriously hampered flank-speed running.

Automactic control was seldom used.

The lack of fool-proof equipment suggested a reluctance to use such things.

The fine arts of oil-burning were nowhere in evidence.

Design elements very often appeared to be the work of designers unskilled in operation. Evidence of lack in dual training-theory and its application-seemed to crop up everywhere.

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The Report

LIST OF ENCLOSURES

LIST OF ILLUSTRATIONS

REFERENCES

Location of Target:

Navy Ministry, TOKYO
Naval Technical Research Institute, Meguro, TOKYO
Mitsubishi Shipyards, HIRO
Navy Yards at: YOKOHAMA,
SASEBO,
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INTRODUCTION

This report is based almost entirely on detailed studies of shop drawings and acceptance trial machinery data, complete sets of which were obtained, and inspections of equipment at Navy Yards and in ships. Observations of the machinery plant of DD HANETSUKI were made while under way. Technical personnel interviewed supplied very little information concerning design principles and many of them had only a limited operating background.

THE REPORT

Part I - BOILERS

A. FOREWORD

The Japanese Navy had standardized boiler design to a single shape and size.

The shape followed that of conventional three-drum express boilers, using air heaters in the uptakes. The boilers had superheaters in the banks and were symmetrical. They had suspended furnaces, double fronts, and were fired by 11 burners in three rows of two, four, and five. Decrease in depths was characteristic. The depth at the furnace was 14 feet. The depth at the superheater was about 10½ feet and frequently the depth at the air heater was 9½ feet. Large diameter outside down-takes also were characteristic.

The size was fairly well standardized. Mud drums were 24" I.D. and 16 feet apart. Steam drums were 54" I.D. and 11 feet above.

Performance was standardized to a consumption of 16,000 pounds of oil per hour maximum, to generate steam at 30 kg/cm^2 and 350°C from 95°C feed water.

B. GENERAL DETAILS

Details of design were radically different in many particulars from boilers of American or British manufacture. These differences will be pointed out in a descriptive analysis of the boilers of two of the best Japanese ships: BB YAMATO and DD AKITSUKI. Oil burners are discussed in Part II of this report.

C. CONSTRUCTION DETAILS OF BOILERS IN BB YAMATO

1. Foreword

This ship had 12 boilers and is reputed to have delivered 150,000 shaft horsepower. Japanese acceptance trial reports indicate a maximum of 138,000 total shaft horsepower, using 62.7 metric tons of fuel per hour when 12 boilers were being fired, each using nine burners.

2. Size

Each boiler was supported by three 21" pedestals under each mud drum. Mud drums were 16' 5" apart. The steam drum was 10' 10" above the mud drums. Drum shells were 15' 2½" long.

3. Shape

Boiler banks were 19 tubes deep. The first two rows were 45mm O.D. x 3.5mm thick on 75mm centers. The next five rows were 32 x 2.9 on 50mm centers. The last twelve rows were 29 x 2.6 on 45mm centers. All tubes were staggered and back pitched to give approximately equilateral spacing. The superheater gap was between the seventh and eighth rows.

Peculiar to the standard, or KAMPON, boiler was a necking down in length of the boiler bank between the furnace and the superheater. The center to center length of the first three tube rows was 4250mm. The reduction took place in the fourth to seventh rows so that at the superheater and beyond the gas passage was only 3263mm long, resulting in a reduction of

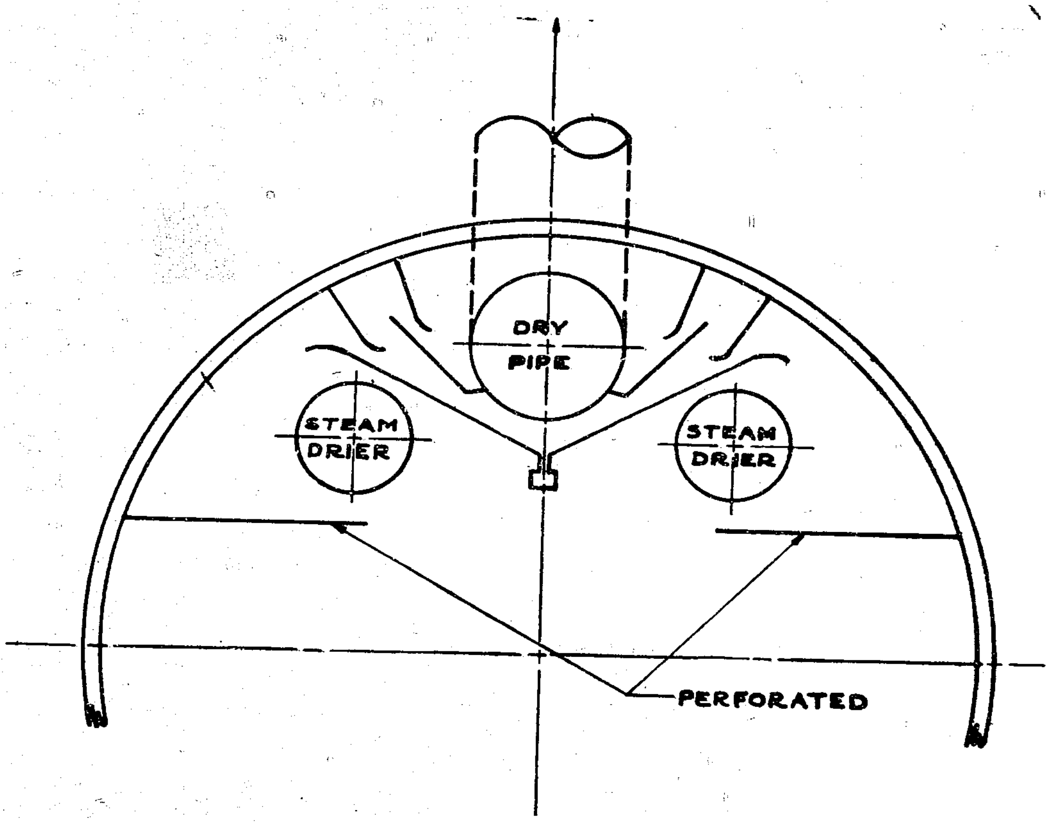


Figure 1
STEAM DRUM BAFFLES
BB YAMATO

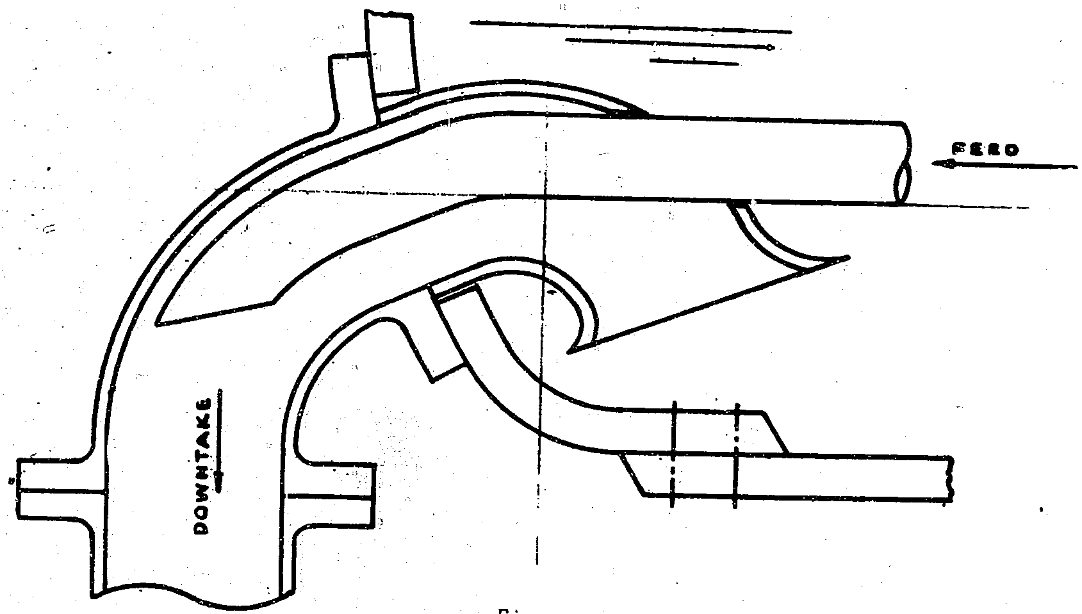


Figure 2
FEED WATER DELIVERY
BB YAMATO

nearly 25%. Some of the tubes in the transition rows were off-set against the tubes ahead to facilitate fairing of the casing, and to serve as a deflecting baffle.

A two-pass, four-loop superheater lay between the seventh and eighth rows.

Beyond the generating bank was a single pass air heater. The shape of the tubes in this air heater was peculiar. In the lower third of its height, the tubes were round, 75mm O.D., and on equilateral spacings of 110mm. Above them, the tubes were tear drop shaped, 101 x 43mm. Those on the furnace side were on 70mm side by 95 back pitch, while those away from the furnace side were on 75 by 95. The air heaters occupied an amount of space approximately equal to the space required for U.S. Navy economizers on three-drum express boilers.

The boilers were fired by 11 burners arranged in horizontal rows of two, four, and five. A smoke-maker nozzle was centered above the two upper burners.

4. Steam Drum

The steam drum had a forged steel (SF 44B) shell with pressed heads double riveted to it. Its internal diameter was 1400mm; thickness was 23mm except for the thickened tube sheet which was 60mm. There was but one manhole, this was of conventional size and in the front head, but it was set 100mm above the center line; shell length was 4648mm, about 400 longer than the distance between the tubes of the first two rows. Tubes did not enter the drum radially but were template-drilled in two gangs, the first seven rows in one gang drilling, the last twelve rows in another. Tube holes were partially counter-bored to take the tube flare. Taking an axial view of the drum, the depth of counter-bore was to the point where the center line of the tube row at the bottom of the flare intersected the inside of the shell. The normal water level was 140mm below the drum center line.

5. Mud Drums

Both mud drums had forged steel shells, 650mm I.D. and 15mm thick. The tube sheet was thickened to 45mm. There was a man-hole in the front head only. Tube holes were gang drilled in two clusters in the same manner as in the steam drum.

6. Steam Collector Pipe

The dry pipe was conventional in location but not in design. Its outlet was at one end. An effort was made to draw steam uniformly over the length of the drum by an arrangement of dry pipe holes in ten clusters, spaced equally, but having different total areas, and located in such a manner that the smallest cluster was nearest the outlet, while the largest was furthest from the outlet.

Cluster	No. Holes	Diam. mm	Area cm^2	Percent of Total Area
1	108	5	21	2.1
2	180	5	35	3.5
3	324	5	64	6.4
4	394	5	77	7.7
5	468	5	92	9.2
6	210	8	106	10.6
7	244	8	123	12.3
8	270	8	136	13.6
9	300	8	151	15.2
10	384	8	193	19.4
			998	100

At full power, steam velocity at the pipe exit was 1000 ft/min; through the holes it was 2000 ft/min.

7. Steam Drum Baffles

A rather elaborate but ineffectual system of labyrinth baffle plates was provided in the steam space to assist in the collection of dry steam. Ten plates caused the steam to make about nine right angle turns between the separating surface and the collector pipe. The two bottom plates alone were perforated. There were no submerged plates. Figure 1 shows the arrangement of baffles.

8. Steam Driers

This feature was unique. The steam outlet piping from each superheater passed through the side of the shell to run internally, the length of the steam drum. The two lines then merged and two pipe connections carried the steam through the side of the shell again, one to the main stop and the other to the safety valve. These two internal superheater lines were above the water level and so arranged that the flow of steam from separating surface to collector pipe was swept over them in its passage between the two principal baffle plates.

These internal pipes were relatively large (6¼" I.D.), and heavy (0.197" thick). They had several flanged joints near the water level. Thermal expansion probably caused a great deal of joint leakage, with attendent danger of shipping water into the steam main when the ship rolled.

Steam velocity, both inside and outside was of low magnitude and the overall heat transfer rate available for drying of saturated steam was therefore low.

This method of drying steam appears to have been a considerably greater liability than asset in the boiler design.

9. Superheater Supply Piping

Saturated steam left the drum through a single outlet on the top of the shell after coming from the collector pipe. This connection was a double outlet valve with a 9.05" I.D. supply and two 6.30" I.D. discharges. Each of these was connected to a 6.30 I.D. by 0.315 thick pipe which delivered saturated steam to the upper half of a two-pass superheater. The pipes were accordion pleated over about one half of their length, for flexibility. The valve permitted isolation of the superheater from the boiler. It also permitted isolation of the safety valve from the boiler.

10. Superheated Steam Piping

Superheated steam piping was the same in general design as the saturated steam piping. These pipes delivered steam from the lower pass of each superheater to fittings on the side of the steam drum for connection to the internal drier. The fittings were centered about two inches above the drum horizontal center line.

11. Superheaters

There was but one header for each superheater, and this was in the form of a baffled drum. The superheater was two-pass, with four hairpin loops.

a. Headers

Internal plate baffles formed the three necessary compartments. Drums were at the rear and were set to incline about 35 degrees.

The shell was a forged steel drum (SF 443). It was 500mm I.D. by 14 thick and 2021 long, with the tube sheet thickened to 36mm. Its top was a pressed head with round hand hole at the center. Its bottom was a machined forging of shell stock and had a 380 x 300mm manhole. Both top and bottom were double riveted to the shell. Tube holes were non-radial, and gang drilled with a single template. The header was set back from the gas passage in a recess so that the tube sheet was about six inches from the gas stream.

b. Tubes

The superheater tubes were 32mm O.D. by 3.2 thick, and were bent in conventional hair pin fashion. Tubes had a side pitch of 48mm and back pitch of 42. Loops were made on 60, 102, 144, and 186mm radii. The tube bends were recessed and the straight run in the gas path was 3263mm long. There were 51 tubes in the first pass, 57 in the second. All tubes inclined for drainage. Three plate supports were used.

The end tube centers of the superheater were 1516mm apart. The face to face distance of the steam and mud drums was 3010mm. The superheater tube bank occupied only one-half the height of the gap. By-passing of the gas around top and bottom was prevented by suitable baffles.

12. Internal Feed Piping

Feed entered through the front head, and below the water level. A thermal sleeve effect was attempted. A main and an auxiliary line entered; each 100mm I.D. They were merged by means of a Y fitting into a common 100mm pipe which ran on bracket supports into a branching Y fitting near the rear. The two legs of this were 68mm I.D. and discharged loosely but directly into two special elbow fittings riveted on the outside of the rear head. These elbows supplied large external downtakes. Special elbow-shaped bell-mouth fittings were on the inside of the head and secured to the external elbows. The bell-mouths were submerged. Their design was such that feed water was discharged directly into the downtakes and boiler water was siphoned in at the same time. No feed water was discharged into the water of the steam drum. All of it went directly to the mud drums along with the siphoned water from the steam drum. Siphon effect is illustrated in Figure 2.

13. Downtakes

a. Rear

There were two external downtakes outside of the casing at the rear of the boiler, one to each mud drum. They were of 180mm I.D. and 8mm wall thickness accordion-pleated pipe, flange-connected to elbows riveted to the drum heads.

b. Front

There were eight external downtakes at the front, four on each side These were located within the double front. Design and method of connecting were conventional in all respects. Tubing was 80mm O.D. with 5mm wall thickness.

14. Gas Baffles

Two gas control plates were used in each boiler bank. They were clipfastened to the back of the tubes immediately ahead of the superheater and served to close the gaps above and below the superheater tubes. They were of the filter type, with 75mm holes in 4.5mm plate, and extended from each drum cover to the nearest superheater tube. Trickle area was 10% of the plate area. Another baffle plate was hung, shoulder-fashion, on the back of each outside row of boiler tubes. These hung from the steam drum and extended approximately 25% of the length of the tubes. In construction they were similar to the other baffles.

The length of the shoulder baffle was such that gas entering the air heater was guided through the cluster of round tubes at the bottom.

15. Air Heaters

A single air pass and single gas pass air-heater were built into each uptake area. Each was composed of 40 round tubes and 235 teardrop tubes. Gas entered the air heaters through the cluster of round tubes at the bottom, and then flowed upward through the teardrop tubes. The round tubes were 75mm O.D. by 1.2mm thick. The other tubes, pressed out of the same stock, were ovoid 101 x 43mm. The tubes were drift-expanded and flared into 10mm thick plates which were 3355mm apart. The round tubes were on 110mm equilateral pitch, while the teardrop tubes were on 70mm side pitch near the furnace by 95mm back pitch. Away from the furnace, side pitch was increased to 75mm. About 2/3 of the tubes were on the 70mm side pitch. Two gaps in the teardrop section were provided for soot blowers.

The heating surface totaled about 4700 ft^2. Thicknesses of tubes and plate were roughly half those generally accepted as necessary in U.S. merchant practices, while the mass flow of gas and air was roughly 1.5 times as great. In other words, the weight was half, while the air horsepower was 2¼ times U.S. practice. The thicknesses used provided no corrosion factor, and the air-heater life must have been very short.

16. Water Columns

Each boiler had two water columns connected to the front head of the steam drum. These were direct copies of the double glass U.S. Navy type.

17. Safety Valves

There was no safety valve, whereby a simple and direct-acting device could prevent excess pressures. However, an automatic relieving gear was installed. In this, steam pressure was exposed under a simple spring-loaded pilot valve which on opening discharged into a closed chamber. This valve had a flat seat 1mm wide and 30mm I.D., with no attempt at blow-back control. Steam was supplied to it through a 13mm line. Steam discharged from it entered a steam cylinder to work against a spring-loaded piston, the rod of which operated a simple stop valve seating against boiler pressure. It thus permitted escape of steam to the atmosphere. The relieving valve had a flat seat 2.5mm wide and 90mm I.D. Superheated steam coming from the steam drier device inside of the drum, entered this relieving valve through a single 240mm inlet connection. There were two pilot valves and two relieving valves built integrally with the one escape fitting, making it possible to set the two in relay. Hand relieving gear was attached to open each of the relieving valves.

The automatic pressure relieving gear could relieve only the steam coming through the superheaters. There were no means for automatically relieving the drum steam if the superheater inlet valve was closed. For such a contingency, a quick-operating hand valve was provided.

18. Soot Blowers

Each side of the boiler was fitted with six soot blowers. Two of these were in the tear drop section of the air-heater tube clusters. Two were at the two top quarter points on the last row of generating tubes. The remaining two were in the cavities above and below the superheater. These had rotating elements, but no automatic controls or stops.

19. Bottom Blow Valve

The blow-down valve was rather primitive. It was formed by two simple glove stop valves, fastened together right and left handed so that one closed with the pressure while the other closed against it.

20. Feed Checks

Main and auxiliary feed water check valves were alike. They were conventionally designed 100mm checks with a tail piece which passed through the drum head. There was a recess on the end of the tail piece, to which a split flange was attached. The internal feed line was secured to this split flange.

21. Feed Stops

A stop valve of conventional design was set outside the main and the auxiliary check valves.

22. Main Stop

The main stop valve was a compound affair. It was connected through the drum shell to the internal steam drier and took superheated steam through a single 240mm supply connection. It had three outlets, one before the valve and a pair after the valve. This pair supplied two parallel 160mm steam lines and may be called the main stop. The other outlet was 140mm in diameter and supplied steam to the auxiliary stop valve for superheated steam. This auxiliary stop was bolted to the main stop.

23. Auxiliary Stop

A stop valve of conventional design at the front end of the boiler supplied the saturated auxiliary steam line.

24. Feed Water Regulator

An internal ball float actuating device for feed water control was used. The float rod transmitted mechanical motion to an external fitting at the top of the shell, where motion was converted to hydrostatic pressure.

25. Boiler Casing

The boiler casing was of conventional insulated panel construction. The casing was single except for the doubled front. Discharge from the air heaters was led down to the burners between an inner and an outer front casing.

26. Furnace Construction

Furnace construction, in some respects, was unique. There were no flat surfaces. From front to back, a center section showed the floor ends approaching catenary shape. From side to side, a center section showed walls of catenary section, as well as a curved bottom. It was almost as though a center flat of 50% length and 50% width had been hung by catenary supports; but this center flat ballooned slightly. Several vertical brick stays were used.

Brickwork was entirely of bolted flat tile. In size the floor and side tiles averaged about 9 x 9 x 3 inches. They were fastened to the casing by a single 5/8 inch carbon steel bolt. A 2 5/8 inch hole was sunk half-way through from the front face for the bolt head. After a small amount of plastic had been applied a fitted capping plug of tile was inserted to protect the bolt head. There was a profusion of special shapes.

Burner cones were of large tile sections. Burners were on equilateral spacings to simplify cone construction. Rear wall and lower front wall tile was 5¼ inches thick, upper front wall tile was four inches thick and cone tile was six inches thick.

Insulation of calcined diatomaceous earth 1½ inches thick was used under the thin floor and walls. None was used on the front or rear walls. A 3/4 inch layer of uncalcined diatomaceous earth was used on the outside, all over, except at the burner tile.

27. Fire Brick Standards

Fire brick standards are set forth in Enclosure (A).

D. CONSTRUCTION DETAILS OF BOILERS IN DD AKITSUKI

1. Foreword

The Japanese considered ships of AKITSUKI class as their best destroyers. They were 3000 ton, 52,000 horsepower ships; each ship had 3 boilers, all fitted with 11 burners of 850 kg/hr capacity.

In the following description of the AKITSUKI machinery plant comparisions are made with similar items of YAMATO.

2. Size

Each boiler had four rather than three pedestal supports under each mud drum. Mud drums were 17' -8" apart. The steam drum 10' -6" above the mud drums. Shells were 15' -10" long.

3. Shape

Boiler banks were 18 tubes deep: two of 45 x 3.2mm on 78mm side pitch, five of 32 x 2.6 on 52, and 11 of 29 x 2.3 on 47. All tubes were staggered. The superheater gap was between the seventh and eighth tube rows.

Center to center tube row length at the furnace was 4316mm. This necked down in the fifth, sixth, and seventh rows so that for the superheater and beyond it was 3008mm. There was an additional necking down for the air heater. In the last six rows of generating tubes, a further reduction to 2867 was made.

The superheater was essentially a duplicate, being two-pass and four loop, between G and H rows.

The air heater was essentially a duplicate except that tube length was shortened by additional necking down.

Oil burners were the same in number and arrangement as in YAMATO.

4. Steam Drum

The steam drum was not duplicated. Here it was riveted, doublebutt and triple riveted. Inside diameter was 1350mm; thickness was 30mm increasing to 60 at the tube sheet. Again there was only one manhole. This was set 50mm above drum center. Water level was 150 below center. Shell length was 4830mm, or 514 more than the furnace tube row length. Tubes were non-radial, gang drilled in four clusters in the steam drum, 7-4-4-3. Counterboring was duplicated.

5. Mud Drums

The mud drum shells were steel forgings 600mm I.D., 18 thick and 4690 long. They were thickened to 45 at the tube sheet. Tube holes were gang drilled in three clusters, 7-8-3. Tube holes were counter-bored.

6. Steam Collector Pipe

This was of duplicate design except for one added feature. The auxiliary saturated steam stop on the front head drew steam from a take-off on the end of the collector pipe.

7. Steam Drum Baffles

This was radically different from YAMATO. Plates perforated by 10mm holes on 20 x 20 centers were used in tiers of three. The upper baffle was approximately at the water level and ran the full length of the shell, ending near the front in a swash-plate effect. The lower baffle was a flat-vee extending to within about two feet of the shell ends. No labyrinth baffles in the steam space were used. The baffles are illustrated in Figure 3.

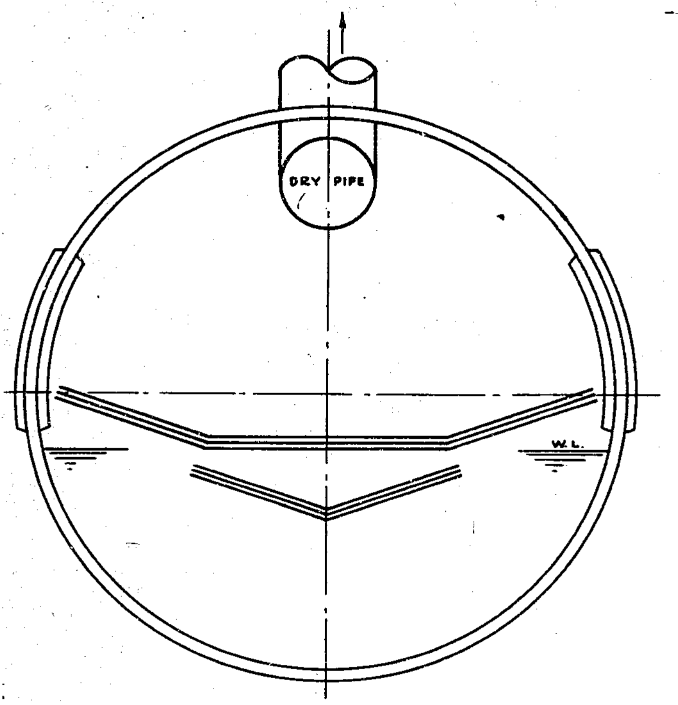


Figure 3
STEAM DRUM BAFFLES
DD AKITSUKI

8. Steam Drier

No steam drying by internal superheater piping was attempted.

9. Superheater Supply Piping

The design was essentially duplicated. The valve on the drum had a single inlet 8.67 inches in diameter and two outlets of 6.30 inches each. Piping was similar in size and design.

10. Superheated Steam Piping

Piping was the same in design, but delivery was different, since no drier was used. Piping came up the back and over the roof to a sort of manifold secured to the top of the steam drum near the front. Flow was controlled by a single stop valve even though there was double entry and double exit.

11. Superheater

Header design was essentially duplicated throughout. The shell was 500mm I.D. by 13 thick and 2125 long. The tube sheet was thickened to 40mm.

Tube design was essentially duplicated. Tubes were 32 x 2.9 and on 48 x 42 pitch. Loops were on the same radius. Length of straight run in the gas passage was 3040. There were 57 tubes in the first pass and 70 in the second. By-pass of gas around the ends was prevented as in YAMATO's design.

12. Internal Feed Piping

Internal feed pipe design included all of YAMATO's particulars, but added one more. The straight section between the two Y fittings was enlarged and perforated, for partial discharge into the drum.

13. Downtakes

Design was duplicated both front and rear.

14. Gas Baffles

Design was duplicated.

15. Air Heater

Design was duplicated. There were 40 round and 251 tear drop tubes of the same size and on the same pitch. Length between tube sheets was 2900mm.

16. Water Columns

Design was duplicated.

17. Safety Valves

Design was duplicated.

18. Soot Blowers

Design, location, and number were duplicated.

19. Bottom Blow Valves

Design included an internal perforated pipe strainer before the valves.

20. Feed Checks

Design was duplicated.

21. Feed Stops

Design and location were duplicated.

22. Main Stop

This was a manifold fitting secured to the outside of the drum shell near the front. The valve was double inlet and double outlet. Before the valve was the take-off for an auxiliary steam stop valve.

23. Auxiliary Stop

Design was duplicated.

24. Boiler Casing

Essentially duplicated.

25. Furnace Construction

Essentially duplicated.

E. GENERAL CRITICISM OF BOILER DESIGN DETAIL DIFFERENCES.

1. Foreword

Analytical criticism of the construction details of standard Japanese naval boilers must include all items radically different from conventional U.S. Navy design. Outstanding items were the:

- Size
- Shape
- Steam collector pipe
- Steam drum baffles
- Steam driers
- Superheater supply piping
- Superheated steam piping
- Superheaters
- Internal feed piping
- Downtakes
- Gas baffles
- Air heaters
- Safety valves
- Soot blowers
- Bottom blow
- Main stop
- Furnace construction

These seventeen design details of the twenty-four previously considered were radically different.

2. Size

Weight and cube are of vital importance in naval boilers. Japanese furnaces had about half the heat release rate of U.S. Navy furnaces. This fact is significant in explaining why U.S. Navy shaft horsepower is so much greater for comparative ship weight. Furnace volume was large for two reasons: poor burners and poor circulation. A third reason which may have been involved was poor feed water.

a. Burners

Air mixture was patently poor, and furnace volume had to be increased to provide smokeless combustion. Boiler gas passages fouled readily with poor combustion. The two extra burners had to be provided so that increased gas resistance through the boilers could be compensated for by lower air resistance through an increased number of burners in use. Higher blower pressures with good burners easily could have decreased the number of burners required, since these had 20 inch throats and burned a maximum oil weight of only 1600 pounds per hour.

b. Circulation

Circulation in the Japanese standard boiler was poor because of an insufficient number of downtakes and ineffective protection of approach areas to the down-takes. Absorption rate by the furnace rows of tubes had to be held down to prevent burning within the bank.

c. Feed Water

Make-up feed averaged 5% or better on Japanese ships; large, single-effect high pressure evaporators were used constantly at sea to supply this. Boiler scale was a very serious problem. Fire-side tube heat absorption had to be kept down to reduce burning.

3. Shape

Boiler shape was not economical for the cubage required. The necking-back at the ends of the superheater screen rendered many of the screen tubes ineffective because they were removed from the high velocity part of the gas stream. Large voids above and below the superheater created wasted cubage. Necking down in the rear of the boiler bank to give a shorter air heater, also resulted in uneconomical use of space.

4. Steam Collector Pipe

Steam velocities through the holes of the collector pipe resulted in less than half of the pressure drop found most desirable in U.S. Navy ships. End exit was part of this. Proportioning of area to available head at each of the ten sections was a step in the right direction, but U.S. Navy research long ago showed this type of collector to be inadequate for the demands made on it. Interrogation developed that the quality of the steam was only 0.98 at full power, which bears out U.S. Navy findings. This caused extensive maintenance of superheaters, and resulted in high turbine water rates.

5. Steam Drum Baffles

Six different baffle arrangements were described and discussed during interrogations. The problem was a very serious one to the Japanese. It was obvious that even on TERUTSUKI class destroyers, where U.S. Navy design was in part copied, they did not find a satisfactory answer. Superheaters rarely lasted a year without requiring re-tubing.

6. Steam Drier

It is obvious that YAMATO's unit was both ineffective and dangerous. It was ineffective because overall convection transfer rate was too low for any practical use and dangerous because the 10 flanged joints gave constant trouble from leakage. There was a relatively large (2 inch) drain line paralleling the large pipes, and set six or eight inches below. When rolling, or heeling at turns, this drain line must have been submerged frequently. Any flange leakage readily would have created turbine hazard from water slugs. Loose sleeves to the shell fittings also might have caused by-passing and resulted in the burning of superheater tubes.

7. Superheater Supply Piping

The valve at the inlet to the superheater supply piping presented a serious hazard. Careless operation, in neglecting to have this open at all proper times, could have exposed the superheater to burning. Use of flexible piping appeared to offer many advantages.

8. Superheated Steam Piping

As in (7), flexible piping seemed advantageous for YAMATO. For destroyers it seemed beyond requirements. In both, the main stop was in a poor position. It might well have been placed closer to the superheaters.

9. Superheaters

Much more economical use of space would have obtained if header construction had been better. The large diameter header required useless space of itself and there were gaps above and below the cluster of superheater tubes. A two, or possible three loop superheater with smaller diameter headers would have reduced greatly the size of the superheater cavity in the tube bank. If the steam supplied had been of higher quality, the superheater could have been placed nearer the furnace. This would have given better performance with less heating surface.

10. Internal Feed Piping

Attempt to create a siphon nullified much or the effectiveness of the two rear downtakes by reducing their inlet areas. Air in feed water (open, direct contact heaters were used) was released in a dangerous area. Use of a perforated pipe submerged in the steam drum resulted in a longer length of life for boiler tubes.

11. Downtakes

Probable cavitation at supply due to lack of proper submerged baffles opens the question of effectiveness. It appeared that a copy of early U.S. Navy design had crept in here; design that had not matured and had been corrected later.

12. Gas Baffles

These were good, but were necessary only because of a faulty step is design as a whole. To perforate the shoulder baffle was wrong.

13. Air Heaters

The air heaters were designed for a very high velocity of both gas and air, half again more than in good U.S. marine practice. Without doubt, the air horsepower requirements fixed the limit of boiler capacity, since about six out of the eight inches of air pressure available would be consumed by the air heater alone. Tube thickness was about half of accepted U.S. practice, leaving little or no corrosion factor. It can be assumed that the length of life of air heater tubes was not more than a year or two.

14. Safety Valves

Nothing good can be said about this pressure relieving apparatus, nor for the placing of a valve between it and the drum.

15. Soot Blowers

Soot blowers were located in such a manner that a good job of cleaning could be done. However, the cost in terms of make-up water was very great. Steam control was by a hand-operated stop valve. The steam was delivered into a recessed chamber around an entry hole in the element. A direct hand wheel turned the element. Lack of cams and stops in the head made it wasteful of steam.

16. Bottom Blow Valve

Globe valves tended to plug rather easily when used for bottom-blows, and length of time required to open and close made them generally unsatisfactory. The strainer device in TERUTSUKI class destroyers indicated plugging difficulties.

17. Main Stop

The Japanese seemed reluctant to use large diameter pipe. Main steam lines often were composed of two, and sometimes three parallel lines of smaller diameter piping. This main stop valve was unnecessarily complicated by the extra outlets.

18. Furnace Construction

A furnace with light weight per unit area of envelope had been achieved. But this design never could have stood up in a furnace with high heat release rate. Neither tile nor brick-bolts could have survived. Heat loss through this type of casing would have been too high to make the conventional fire-room liveable. The fire-rooms were not conventional however, but were designed so that the operating force never needed to get to the rear or top of a boiler when steaming. The double fronts were a veritable maze of valve handwheels on the ends of reach rods. All operational valves were manipulated at the outer front casings.

19. Summation

Although more than half of the principal design features on Japanese naval boilers showed radical differences from U.S. Navy practice, it was felt that there were none which held any interest. Lack of fool-proof features seemed amazing. Waste of cubic requirements explains why the U.S. Navy can almost double the shaft horsepower on ships of similar tonage.

F. GENERAL STATUS OF BOILER RESEARCH AND INVESTIGATION

1. The Velox Boiler

The Japanese Navy investigated the design of the Velox boiler. Captain HASEGAWA, head of the engine department at Kure Navy Yard states that shore trials were conducted on a Velox boiler for use in submarine propulsion. These were conducted in the boiler laboratory at the Maizuru Navy Yard. When the war ended the unit had not reached the installation stage. No extensive use or plans for Velox boilers existed.

2. The Lamonte Boiler

The design of the Lamonte boiler was also investigated by the Japanese Navy. A 4500 S.H.P. AK, bought from Germany, was powered by Lamonte boilers and Brown-Boveri turbines. This was KASHINO, which was sunk on her third voyage three years ago. Apparently the Japanese experienced the same tube trouble as the U.S. Navy experienced with SATURN. Two standard Kampon boilers were added to the original plant almost as soon as the ship was received in Japan.

3. The Wagner Boiler

The Wagner boiler design also was investigated. A merchant vessel equipped with Wagner boilers was bought from German- and converted to a carrier but was lost shortly thereafter.

4. The Kampon Boiler

Although the Kampon boiler was the standard, it had been subjected to many variations, all of which evidenced serious dissatisfaction with certain features.

a. Steam Drum Baffles

Both steam and water side baffles were very poor. Many experimental changes in drum baffles were seen, none of which was good.

b. Superheater Tube Failures

Failures were common, apparently due to moisture in the supply. A readily accessible unit was required. Several superheaters with straight tubes were observed, with cast or forged headers flanged to provide open access to the tube sheets. In at least one instance a non-symmetrical three-drum express boiler, with superheater in one side only, was used.

c. The Air Heater

This was subjected to many modifications, apparently due to high air horsepower requirements.

5. High Pressure Boilers

These did not find much favor, although a few had been tried. Boiler scale was a major problem, because of poor evaporators, and therefore, naval design men were reluctant to use high pressures. An unsatisfactory design for 45 kg/cm^2 and 400°C on the PC#53 was made about 10 years ago. This was the highest observed on any combat vessels. DD SHIMIKAZE, built about three years ago, used 40 kg/cm^2 and 400°C steam.

6. Automatic Controls

Automatic operation was not favored. Manual operation of nearly all equipment was the rule.

7. Colloidal Fuel Furnaces

Combatant ships were not equipped with colloidal fuel furnaces.

Part II
OIL BURNERS

A. ATOMIZERS

1. Types

There was but one general type of atomizer for use in combatant ships. Its general features were common to those in use about thirty years ago in the United States and Great Britain. (See Figure 4.) Oil entered the atomizer through the cylindrical wall of the whirl chamber by means of three tangentially drilled holes. A cone-ended plug was inserted in the whirl chamber to assist in guiding the oil to the orifice.

This design was modified recently for new construction by adaption of return flow features. (See Figure 5.) The cone-ended plug was hollowed out and holes were drilled through the wall of the cone. A return line connection allowed oil to by-pass the orifice and escape through the center of the plug. Valve control of pressure in the return line determined the percentage of fuel by-passed.

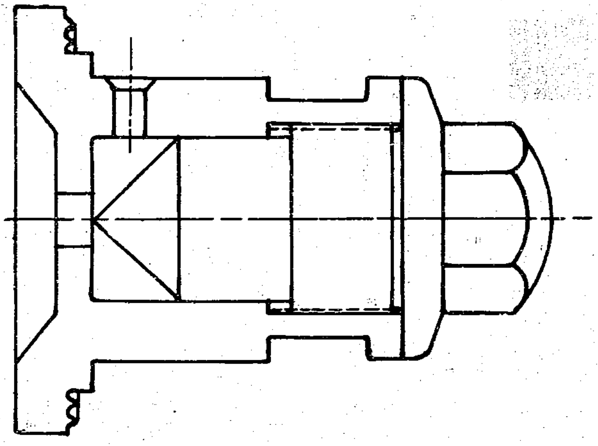


Figure 4
GENERAL TYPE ATOMIZER

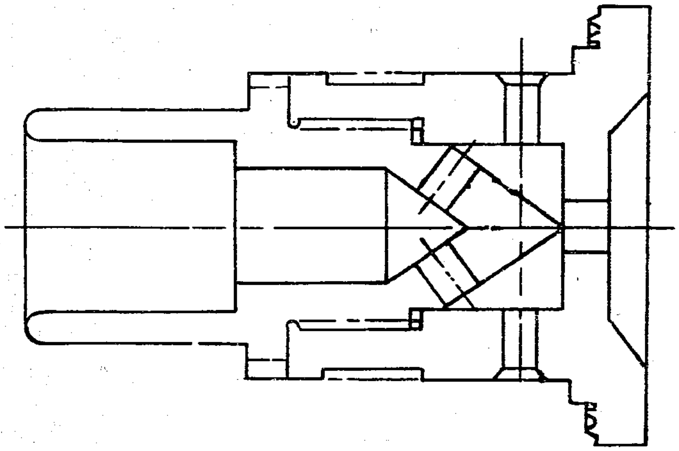


Figure 5
MODIFIED TYPE ATOMIZER

Table I
PRINCIPAL DIMENSIONS AND CAPACITIES OF ATOMIZERS

Type	Nominal Size	Oil Press (lbs/in.^{2})	Orifice Dia. (in.)	Tangential Tube Dia. (in.)	No. of Tangential Tubes	By-Pass Tube Dia. (in.)	No. of By-Pass Tubes	Capacity (lbs/hr)	Spray Angle (°)
Single Flow	20	228	.253	.104	3	-	-	2205	95
Return Flow	20	71 - 228	.239	.099	3	.118	6	660 - 2205	110 - 95
	11	71 - 199	.177	.091	3	.102	6	397 - 1210	110 - 95
	05	71 - 199	.126	.071	3	.068	6	176 - 550	110 - 95

2. Principal Dimensions and Capacities

Table I shows principal dimensions and capacities. Capacities are based on flow of water at 60°F.

3. Design Viscosity

The Japanese Navy used one single boiler fuel, "Bunker C". This was heated on all ships to 90-95°C. No variation in grade of fuel or in atomizing temperature was permitted.

4. Materials of Construction

Atomizers were constructed throughout from carbon steel.

B. AIR REGISTERS

1. Types

There was but one basic design of air register, with slight modifications. It was cylindrical with all air entering at the outer end. Burner throats were about 19 inches in diameter. An internal sleeve about 10 inches long was characteristic, it was affixed to and concentric with the register body so as to provide a cylindrical passage inside the sleeve for primary air, and an annular passage an inch and a half wide on the outside for secondary air. The sleeve extended to within 1¼ and 2½ inches of the refractory throat. The annular passage was bladed for rotation of air.

An early, but now superceded model used flat butterfly-type air doors. The standard and the latest registers used gear operated conical air doors.

2. Materials of Construction

Air registers were fabricated entirely from carbon steel. The latest model showed dip-calorizing of all parts within six inches of the refractory throat.

C. IMPELLER PLATES

The difference in oil burners was primarily a difference in impeller plates.

1. Superceded Impeller

The standard impeller on older ships consisted of a truncated, rather than of a full cone. (See Figure 6.) Its setting was inverted from the conventional one. It was secured inside of, and to the outside end of the sleeve. The smaller diameter showed clearance of an inch from the oil cone. Interrogation developed that 7 or 8% CO_2, along with considerable pulsation, was common for this arrangement.

2. Standard Impeller

The common impeller was of approximately the same design throughout, as that made for the U.S. Navy today by B&W or Todd. (See Figure 7.) It was placed outside the sleeve and about two inches from the outer end. Interrogation developed that CO_2 had increased to 9 or 10%, and that pulsation had decreased.

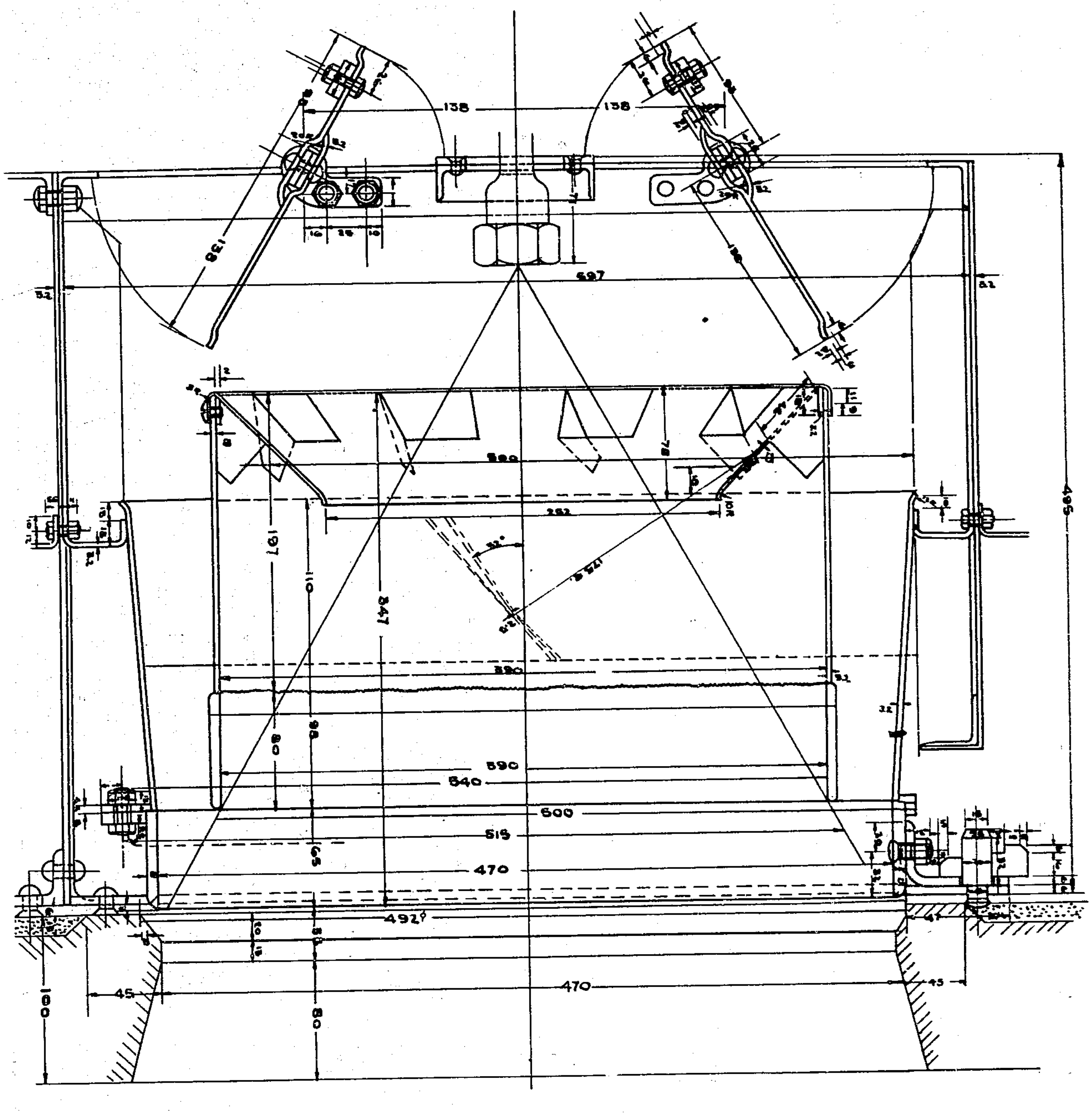


Figure 6
SUPERCEDED IMPELLER

3. Latest Impeller

The standard impeller apparently had proven inadequate and had been modified on recent new construction so as to have a much sharper cone angle. (See Figure 8.) While the standard cone angle was about 140°, the newest was 90°. In addition, it was longer, projecting into the sleeve by two inches. Annular width of clearance between impeller and sleeve was just under two inches. Blading in the secondary-air annulus was modified to give better stream-lining when this latest impeller was used. Interrogation indicated CO_2 of 10 to 13%.

An additional feature used with this impeller was a system of right-and-left-hand burners. An attempt was made to have counter-rotation of the air stream from adjacent burners.

D. BURNER CLEARANCES

Permissible setting dimensions of burners appeared to be as follows:

28 inches - burner center line to floor
36 inches - burner center line to generating tubes
25 inches - burner center line to burner, horizontally
22¼inches - burner center line to burner, vertically

These dimensions are for the latest burner, which had a 19½ inch refractory throat and a 24½ inch body.

E. BURNER OPERATION

Uptake air heaters on both sides of the boiler were standard. Air at 300°F was brought down from the top into a rather ample double-front. A six inch glass peep-hole served each burner. Flexible hose connections from a box type manifold supplied each burner. Burners were cut in without the use of torches, and in accordance with a standard of sequence.

Air pressures ranged up to eight inches maximum.

Oil pressures ranged up to 230 pounds maximum.

Oil supplied always was "Bunker C" and always was heated to 90-95°C.

No split-plate firing was possible. A single size of steaming plate was supplied to the ship.

The number of burners on the double front invariably was two more than were needed for flank. Further, even when operating with two idle burners, about 20-25% oil in excess of flank requirements could be supplied.

Cold starting was accomplished by use of a fuel heating coil set into one of the registers. It was an Elesco-type return bend tube large enough to carry the supply to that one burner, and it projected about five inches into the furnace.

Recirculation of oil as far as the manifold box was provided.

Flushing-out connections were provided.

Burner barrels could be withdrawn from the registers, but no quick-detachable gear was supplied. Change of sprayer plates upon change of speed was not practiced.

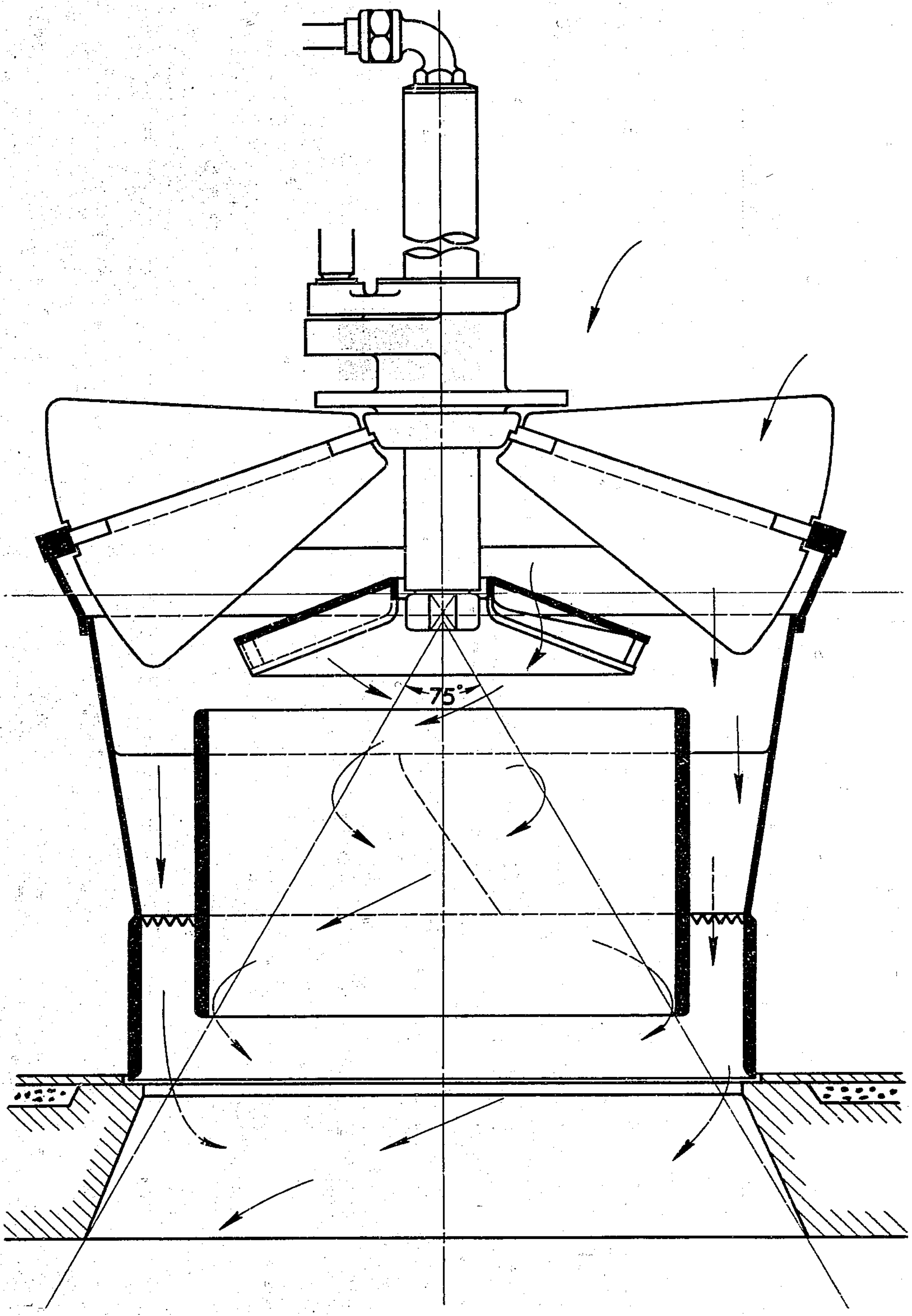


Figure 7
STANDARD IMPELLER

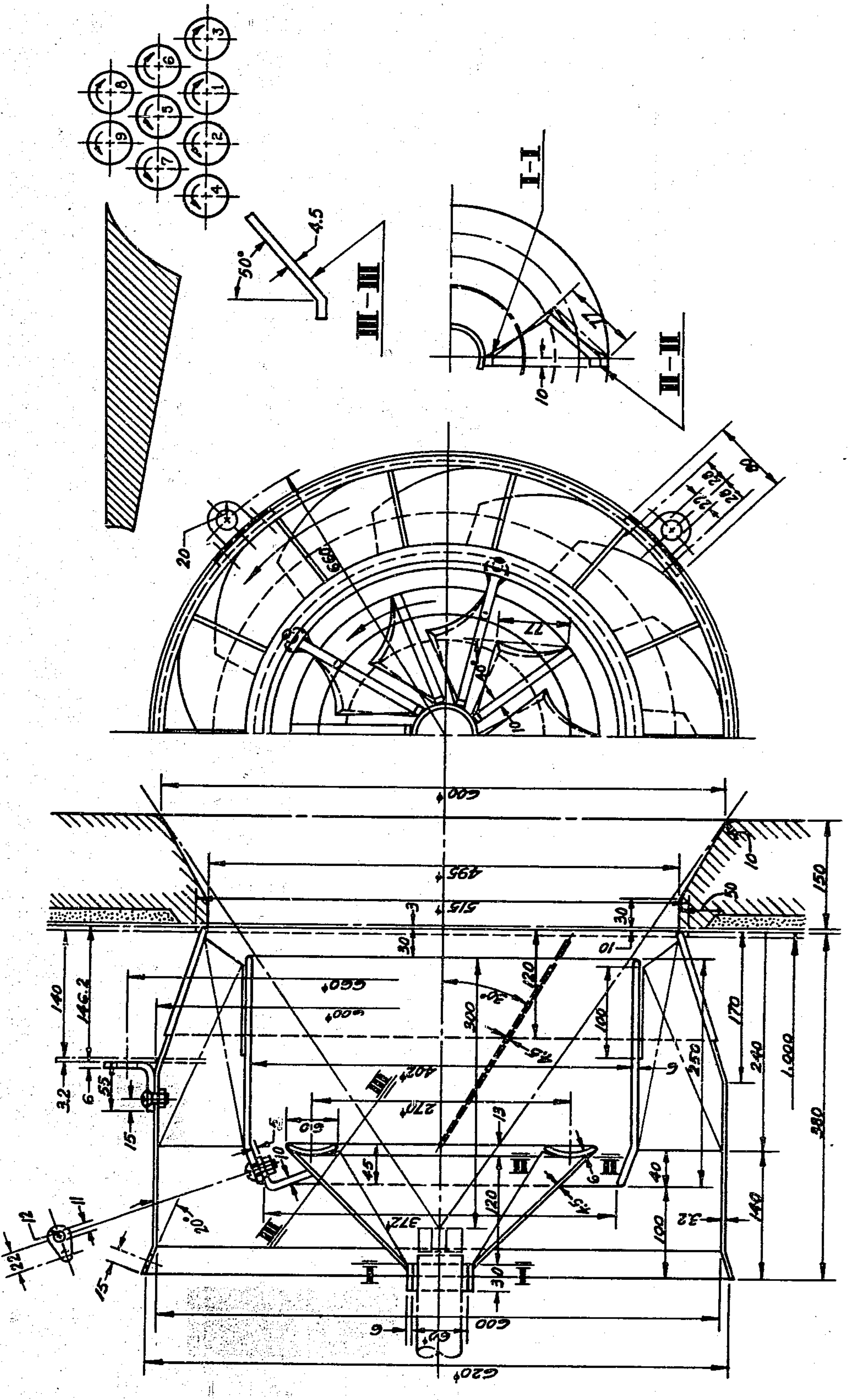


Figure 8
LATEST IMPELLER

Fuel oil pressure gauges were calibrated in kg/cm^2, the normal range being 10 to 14 in ½ kg divisions. Scales extended beyond 10-14 to 6 and 16, these extensions being in 1 kg divisions.

Operation was by telegraph to the boiler front from a boiler control room, which signaled for the number of burners and fuel supply pressure.

F. SUMMATION

The art of oil burning was in a rather primitive state, offering nothing of value to U.S. Navy designers.

The battleship YAMATO, of very recent design, ran her flank acceptance runs with two idle burners in each boiler. Interrogation of the Engineer Officer, indicated that all burners in all boilers were used frequently thereafter when in service, "After the efficiency of the plant fell off". Nebulous fundamental concepts or design principles proved to be a rather serious barrier to satisfactory interrogation. It is believed that poor combustion rapidly fouled the boiler banks to a point where increased resistance to gas flow had to be counter-balanced by decreased burner resistance which resulted when standby burners were cut in. Tachometer speeds of blowers, rather than wind-box pressures were taken. Tank soundings of fuel were taken, but neither oil-flow meters nor capacity curves were available to tell the operators anything about instantaneous values of fuel rate. The Engineer Officer in YAMATO was a Technical Captain. Similar testimony of "decreased plant efficiency, leaks at flanges, gland seals, etc., together with worn turbines", came from other technical officers.

The reason for installing 11 burners when only nine would have carried flank load plus 20% in excess, is unknown. Interrogation failed to develop a satisfactory explanation.

Part III
FEED WATER TREATMENT

Boiler scale presented a very serious problem to the Japanese Navy. Its boilers, in comparison with U.S. Navy boilers had to be turbined and cleaned at frequent intervals.

A rather elaborate boiler-water testing scheme was developed, data being taken after a half hour steaming period to get uniform distribution after adding compound.

Lack of vent condensers on air ejectors and elsewhere caused a loss of roughly 5% of all steam made. A large evaporator system had to be integrated into plant design. High pressure, single effect evaporators run on live saturated steam were made standard, and exhaust steam which might have been used with low-pressure evaporators was put to less efficient use. This type of evaporator delivered rather low grade water especially when test tanks were eliminated. In reality the feed was poor although the Japanese thought they had good feed.

Enclosure (B) is a Japanese Navy treatise on feed water treatment. Apparatus and methods for testing boiler water are described in detail.

One probable cause of scale trouble arose from the type of evaporator used. This design would prime and carry over salt very easily if operation was careless. Because of this, good procedure demanded that all distillate be sent to a check-tank before entering the storage system. Japanese procedure eliminated the check-tank. Accidental and undetected carry-over was very probable in Japanese ships.

Part IV
MATERIAL SPECIFICATIONS

A. FOREWORD

The Japanese Navy used a very wide variety of metal stock in the construction of boilers and machinery. In fact, the effort to use at all times the most desirable material from a metallurgical stand-point seems the work of acadimician rather than an engineer.

B. NOMENCLATURE OF METALS

The system of nomenclature is foreign to Japan, and evidently was developed from the notebook of someone who had studied metallurgy in the United States. It has considerable merit.

In general, the first letter indicates the principal metal, the second represents the means of forming it, the two digits represent tensile strength in kg/cm^2, and the last letter represents the grade. The final A, B, C, and D sometimes means grade but at other times A means acid (acid steel), B means basic (basic steel), and N means Navy standard. The following is a comprehensive list of metals in common use:

Name	Grade	Symbol
Steel Boiler Plate	1	SB 39
	2	SB 44
	3	SB 34
	4	SB 41
Steel Bar Stock	1	SB 41
	2	SB 44
Cast Steel	1	SC 41A
	2	SC 45
	3	SC 47
	4	SC 60
Hex. Drawn Steel Bar	1	SDBH —
	2	SDBH41
	3	SDBH44
Forged Steel	1	SF 34B
	2	SF 39B
	3	SF 44B
	4	SF 49B
	5	SF 54
Soft Steel Plate	1	SM 41N
	2	SM 44N
Soft Steel Rivet Stock	1	SMR 39N
	2	SMR 41N
Nickel Steel	1	SN 65B
	4	SN 70D

Name	Grade	Symbol
Ni-Cr Steel	2	SNC 80B
	3	SNC 90B
Seamless Steel Pipe	1	ST 48
	2	ST 44
	3	ST 38A
	4	ST 30A
	5	ST 38B
	6	ST 30B
Boiler Tubes (hot drawn)		STS 41 STS 43
Boiler Tubes (cold drawn)		STW 41N
Steel Pipe (cold drawn)		STG 34
Carbon Moly Steel		Mo SC
Si-Mn-Ni-Cast Steel		NiCb SC
Aluminum Plate	soft	AeP 8
	semi hard	AeP 11
	hard	AeP 15
	very hard	AeP 18N
Bronze Castings		B 17 B 18 B 22B B 22C BcPb (15)
Brass Castings	1	BsC 17
	2	BsC 20
	3	BsC 26
	4	BsC 28
Brass Bar (naval)		BsNB
Brass Plate	1 (soft	BsP 70A
	1 (semi-hard	BsP 70B
	1 (hard	BsP 70C
	2 (soft	BsP 67A
	2 (semi-hard	BsP 67B
	2 (hard	BsP 67C
	3 (soft	BsP 60A
	3 (semi-hard	BsP 60B
	3 (hard	BsP 60C
Condenser Tube	1	BsTC AN
Seamless Brass Pipe	2	BsTC BN
Copper Plate	soft	CuP 22
	semi-hard	CuP 25
	hard	CuP 28
Seamless Copper Tube		CuT

Table II
MATERIAL SPECIFICATIONS FOR BOILERS AND TURBINES, BB YAMATO

			Material		Composition of Material %									Heat Treatment			Mechanical Test								
Part		Use	Name	Mark	C	Si	Mn	Cu	Cr	Mo	P	S	Ni	Normalizing	Hardening	Tempering	Yield Point kg/cm²	Tensile strength	Elongation		Impact 1200	Charpy	Hardness Brinell	Bending Test	
																			mm	%				RAD mm	Degree°
Turbine	Rotor	Main Engine	Material of Turbine Rotor No. 2	STbWB					<0.5		< 0.055	< 0.050	0.5 -1.5	83° -87° AC	83° -87° OC	65° -70° AC	> 28	>54		> 20	>3	>4		16	150
		Aux Engine	Ni Cr Steel No 3-2	SNC90B	0.25 -0.40	0.35	0.35 -0.65	-	0.5 -1.0	-	< 0.035	<0.035	0.3 -0.4		82° 87° OC	55° 65°	> 75	>90		>15	>6	> 9	>260		
	Blade	Main Engine	Stainless Steel No. 2 for Turbine Blade	STbBA	0.20 -0.40	0.60	<0.50	-	11 -15	-	< 0.035	< 0.035	<2.0		95° OC	75° AOC	> 40	> 60		> 25	> 9	>13	170 -230		
		Aux Engine	Stainless Steel No. 2 for Turbine Blade	STbBA	0.20 -0.40	0.60		-	11 -15			< 0.035	<2.0		95° OC	75° AOC	> 40	> 60		> 25	>9	> 13	170 -230		
Gear	Wheel	Main Engine*	Forged Steel No. 5 Forged Steel No. 4-2	SF54 SF49B							< 0.055	< 0.050						54-60 49-55	Tensile Strength 1.5x Elongation 90					16 10	180
		Aux Engine	Ni Cr Steel No. 2-1	SNC70D	0.25 -0.40	0.35	0.35 -0.65	-	0.3 -0.9	-	<0.035	< 0.035	2.5 -3.5		82° 87° OC	55° 65° OC	> 50	> 70		>20	> 3.5	> 5	-		
	Pinion	Main Engine	Material of Pinion	STbPA	0.22 -0.35	0.35	0.30 -0.80	-	-	-	< 0.035	<0.035	3.5 -4.5	83° 85° FC	83° 85° OC	60° 65° OC	> 50	> 90		> 20	>5	> 7	> 200		180
		Aux Engine	Material of Pinion	STbPB	0.25 -0.40	0.35	0.5 -0.65	-	0.5 -1.0	-	< 0.035	<0.035	3.0 -4.0		82° 87° OC	55° -65° Q	> 75	> 90		>15	>6	> 9	> 280		180
Boiler		Shell	Forged Steel No. 3-2	SF 44B	0.2 -0.24						< 0.04	<0.04													
		End Plate	Steel Plate for Boiler No. 2	SB4IN							< 0.04	<0.04						41 -50		> 23				1.5t	180
		Tube	Solid Drawn Tubes**	STW4IN	0.1 -0.18	0.03	0.3 -0.5	<0.18	-	-	<0.035	<0.035						>41		>35				t 4, 1.5t, t 4, 2.0t	80
			Special Boiler Tube No. 1#	HCK	0.1 - .02	0.15 -0.25	0.35 -0.5	<0.18	-	0.03 -0.1	< 0.03	<0.03						38 -50		> 25					
Steam Pipe			Special Boiler Tube No. 2#	HCM	0.1 -0.2	0.25	0.25 -0.5	<0.18	0.8 -1.5	0.2 -0.5	<0.03	<0.03						.44 -60		>25					
			Seamless Tube ##	STG34														34 -46		>35				1.5t	180

*For shaft and boss for rim
**Steel tube for water tube boiler and oil heater

#For inside two rows of the combustion chamber and high pressure boiler and super heater
##For live steam

AC Air Cooling
OC Oil Cooling

FC Furnace Cooling
Q Quenching

Name	Grade	Symbol
Cast Iron	1	FC 10
	2	FC 14N
White Metal	1	Wm A
	2	Wm B
	3	Wm C
Zinc		Zn
Lead		Pb
Stainless Steel		Eb

C. MATERIAL SPECIFICATIONS - YAMATO MACHINERY

Table II shows materials used in the construction of boilers and turbines of YAMATO. Symbol, composition, treatment, and physical properties are included.

Part V
FUEL OIL SPECIFICATIONS

A. HEAVY OILS AND GAS OIL

See Table III.

Table III

		#1	#2	#2 Mod.	#3	Bunker
Sp. Gr.		0.95 Max.	0.85 Min.	0.915	1.1 Max	0.96 Max
Flash Point(°C)		above ~~80~~	65 Max.	65 Min.	65 Min.	80 Min.
Pour Point		-	-5°C Max.	-5°C Max.	15°C Max.	-
Viscosity	(Seconds Redwood)	500 Max @ 0°C	30 Min @ 30°C	30 Min@ 30°C	-	2000 Max @ 0°C
Cetane No.		-	45 Min.	38 Min.	-	-
S.	Max in Percent	0.5	1.0	1.0	3.0	3.0
Conradson C		5.0	0.5	2.0	-	-
Ash		0.05	0.01	0.05	-	-
Sediment		0.05	0.01	0.05	-	-
Water		0.5	0.1	0.2	1.0	0.5
Calprific Value Min.		-	10,000	10,000	-	-

#1 - diesel oil for single acting diesel engine
#2 - diesel oil for double acting diesel engine
#2 Mod.-diesel oil for double acting diesel engine
#3 - Bunker fuel oil. moderate climate
Bunker - Bunker fuel oil, general purpose

Note: Reaction for all types was neutral.

Part VI
GAS ANALYSIS ON SHIPBOARD

A. FOREWORD

Refinements in operation by the Japanese Navy were few and far between. Gas analysis on shipboard was given little attention.

1. Boiler Gases

Gases from oil fuel burned under boilers or in internal combustion engines were analyzed in the conventional way with an Orsat for CO_2, O_2, and CO. Interrogation of technical officers indicated that a special test crew did this, and only at one time - during acceptance tests. Ships did not normally carry Orsats, nor did they make any regular reports on CO_2. Boiler laboratories analyzed flue gases with Orsats only. The Orsat gave both qualitative and quantitative analysis. No quantitative analysis equipment in the form of CO_2 indicators was in use.

2. Powder Storage Area, Gases

Gas or vapors in explosive areas were not analyzed by any regular or standardized method. On shipboard, temperature checks alone were made.

3. Fuel Tank Cofferdam Gases

Chemical or mechanical gas detection methods were non-existant.

4. Gasoline Spillage Vapors

A pollution indicator, capable of measuring quantity of pollution of air, was designed and placed in production toward the end of the war. It was to have been issued to carriers and ships carrying gasoline. In reality, this instrument was an interferometer, which measured optically the interference produced in a light ray by diluent gases in an air chamber. It had no use as a qualitative measuring device.

5. Fuel Tank Gas-Free Tests

The Japanese Navy paid little or no attention to such tests. Before permitting workers to enter the area it was ventilated to the satisfaction of the repair officer in charge. Personal judgement alone was involved. Candles were in use while workers remained in fuel tank areas, and the appearance of the candle flames was their only index of gas-free conditions.

6. Gas Warfare Tests on Shipboard

Interrogation of the officer in the Navy Ministry who headed the gas warfare program indicated that no test equipment was standard for ships. The human senses were used for detection. All analytical testing was by chemical reaction.

7. Other Gases

Mine-damp instruments (such as the Platinum-Black ignition and other similar devices made in particular by "Mine Appliance" in the United States) were known but were not adopted for any general use by Japanese Naval forces.

8. Summation

It may be stated safely that the Japanese Navy used no gas analysis instruments based on physical rather than chemical principles.

Part VII
AUXILIARY MACHINERY

A. FOREWORD

Convenience and comfort of crews meant little in Japanese Naval design. Cooking, ventilation, sanitation, etc., were handled with a minimum expenditure of weight and space. Auxiliary machinery therefore differed from that in U.S. Navy vessels.

In the main, all machinery integral to the propulsion plant was turbine drive. Pumps etc., not propulsion equipment, were reciprocating.

Turbine drive for auxiliary machinery was standardized. Curtis, single stage wheels drove rotary machinery through single reduction gearing. Turbine wheels were much alike and were built in four sizes only, but permitted a range in horsepowers available of 30 to 360. The design of these is covered in NavTechJap Report, "Characteristics of Japanese Naval Vessels, Article II - Main and Auxiliary Machinery", Index No. S-01-11.

Generally speaking, the design of pumps, generators, and other such equipment did not vary from standard marine practice.

B. INDIVIDUAL UNITS

1. Generators

At sea, turbo-generators carried the load. In port, diesel generators were used.

2. Feed Pumps

Main feed pumps were turbo-drive. Auxiliary pumps were Worthington or Weir.

3. Auxiliary Pumps

Bilge, ballast, transfer, sanitary, fresh water, fire pumps, etc., were mostly Worthington-Simplex, or Weir-Duplex.

4. Main Pumps

Feed, condensate, circulating pumps, etc., were turbo-drive rotary pumps.

5. Oil Pumps

Heavy oil commonly was handled with gear pumps. Light oils commonly were handled with screw pumps. The pump ends were IMO or other standard designs.

6. Refrigeration

Refrigeration systems were conventional - CO_2 was disappearing and ammonia had almost totally disappeared. New designs used modern refrigerants.

7. Motor Drives

Small-auxiliary drives were by motor.

C. BATTLE DAMAGE

The repair and replacement problem for small turbines became critical in the closing days of the war. Motor drives were hurriedly installed.

D. SUMMATION

There was little of interest in auxiliary machinery, except the small turbine design details which are covered in the NavTechJap report referred to above (Index No. S-01-11).

Part VIII
MACHINERY ACCEPTANCE TRIAL TEST DATA

Machinery acceptance trial test reports were obtained for ships in almost all principal ship classes. They were voluminous and beyond the scope of satisfactory field analysis and therefore were forwarded to the Bureau of Ships for study. (See Endlosure (C) NavTechJap Documents No. ND50-1952.1 through ND50-1952.71.)

Part IX
BOILER DESIGN DRAWINGS

Drawings supplementing descriptions of design detail of machinery in BB YAMATO and DD AKITSUKI were obtained and forwarded to the Bureau of Ships. (See Enclosure (C) NavTechJap Documents No. ND50-1950.1 through ND50-1950.20 and ND50-1951.1 through ND50-1951.84.)

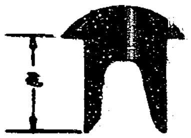
ENCLOSURE (A)

FIRE BRICK STANDARDS

1. <u>Kinds of Brick</u>

		Types										
		Ordinary	Naval						Formed	Plugs		
	Sizes (mm)	230x 114x 65	230x 230x 40	230x 230x 50	230x 230x 70	230x 230x 100	230x 230x 135	230x 230x 150	Specially Formed	Length of neck 30	40	45*
Ordinary Fire Brick	#1	01	A1	B1	C1	D1	E1	F1	S1	K1	L1	M1
	#2	02	A2	B2	C2	D2	E2	F2	S2	K2	L2	M2
	#3	03	A3	B3	C3	D3	E3	F3	S3	K3	L3	M3
Special Fire Brick	Light	04	A4	B4	C4	D4	E4	F4	S4			
	Warmth Keeping	05	A5	B5	C5	D5	E5	F5	S5			

* Length <u>a</u> in the following sketch

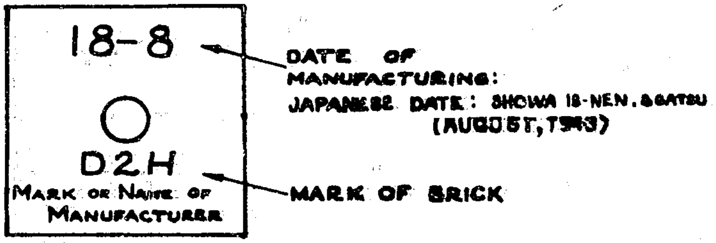


<u>Notes</u>

(1) The first letter of each mark indicates the size, and the second, the kind.

(2) The letter H added shows that the same brick has a bolt-hole in the centre (for example: C4H, D3H.)

(3) Meaning of marks stamped on brick surface:



ENCLOSURE (A), continued

2. Standard

HEAT TREATMENT OF MATERIAL CLAY

Kinds	Heating Temp. (°C)	Heating Time (ARS)
#1	16 SK*	10
#2	14 SK	10
#3	10 SK	10
Light	--	--
Warmth Keeping	--	--

* SK: Seger cone No.

Note

(1) Each brick is to include more than 80% of treated clay by weight.

HEATING TEST

Kinds	Testing Temp. (°C)
#1	> 36 SK
#2	> 34 SK
#3	> 26 SK
Light	> 28 SK
Warmth Keeping	1150

ENCLOSURE (A), continued

Notes

(1) Material is to be crushed to pass through a sieve of 400 holes/cm2 (the diameter of wire to be 0.16mm). However, the grain should not be made too small.
(2) The test cone is to be made from the above material and formed after the shape of the small Seger cone.
(3) Heating rate: 10°C/min., above 800°C.

GLOWING TEST - I STANDARD

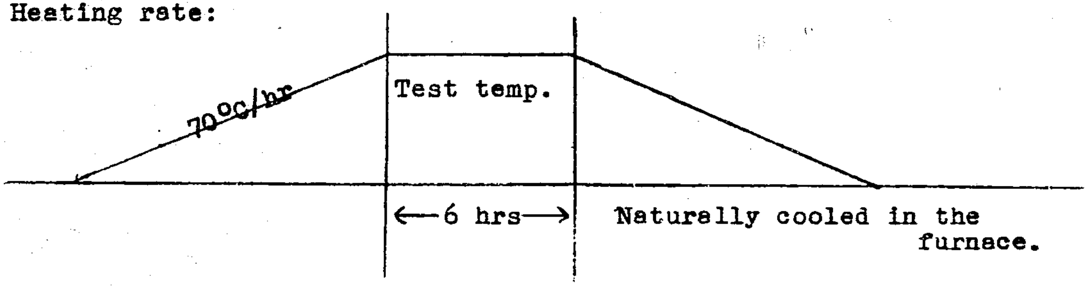
Kinds	Glowing Temp. (°C)	Weight Decrease	Shrinkage
#1	34 SK	< 2.5%	< 3.0%
#2	31 SK	< 2.0%	< 2.5%
#3	-	-	-
Light	> 20 SK	< 2.5%	< 3.0%
Warmth Keeping	1000	< 2.5%	< 3.0%

Notes

(1) The dimension of test brick is the standard size, 230mm x 230mm x (40 ~ 100)mm.
(2) Glowing time: 6 hrs.
(3) Neither deformation nor crack is allowed.
(4) No expansion allowed.

GLOWING TEST - II STANDARD

(1) The dimension of test brick: 225mm x 40mm^{2}.
(2) The test brick should be supported with two edges, the interval of which is 175mm.
(3) Heating rate:



ENCLOSURE (A), continued

(4) Testing Temperature

Kinds	Glowing Temp. (°C)
#1	34 SK
#2	31 SK
#3	-
Light	-
Warmth Keeping	-

(5) No crack is allowed.
(6) The angle of bend of the heated brick should be within 10°.

WEIGHT STANDARD

Kinds	Specific Weight Limit
#1	< 2.5
#2	< 2.15
#3	< 2.15
Light	< 1.5
Warmth Keeping	< 0.8

ENCLOSURE (B)

OFFICIAL IMPERIAL JAPANESE NAVY TREATISE ON FEED WATER TREATMENT

(Translation)

Note: These discussions are based on Maizuru Naval Base Intelligence Report No. 0238, of the "Research and Experiment Report." published at the Maizuru Naval Arsenal Experimental Engineering Section, 15 November 1942. Further, the same discussions are in Part 3 of the Maizuru Naval Arsenal Report No. 9780 of March 1943, No. 48 of Classification 26 of the Fifth Section collection.

TABLE OF CONTENTS

ENCLOSURE (B), continued

GENERAL DISCUSSION

This report is the result of actual tests conducted as reported in Secret Navy Secretariat Memorandum 2770 of 21 April 1940. In addition, new methods for handling sodium phosphate type treatment compounds used in boilers adapted only for distilled water, and the water supply for same, are reported here. Further, the handling of apparatus for determining the quantity of phosphoric acid to be used in treating feed water along with the handling of sodium carbonate type compounds for feed water are herein discussed. In addition there has also been set down in detail the necessary chemical information for handling feed water treatment compounds. This report has been written principally for the instruction of those who handle this problem aboard warships.

Section I

VARIOUS USES OF BOILER FEED WATER

A classification for boiler feed water was set out in Routine Order No. 215 of 8 October 1940. Little difference will be found in the feed waters suitable for boilers on land as compared to those in warships.

TABLE I(B)

Type of boiler	Uses
Marine Type Water Tube	1. More than half of the boilers mentioned in the following paragraphs, particularly those on warships, although built to use distilled water, can use tap water of good quality in emergency. a. Boilers which burn coal exclusively. b. Boilers which burn mixed fuels and generate a pressure of less than 20 kg/cm^2.
	2. Ships which are not equipped with evaporating machinery make use of good quality tap water.
	3. Other ships use distilled water exclusively. However, at time of commissioning, overhaul, or completion of construction, as well as in a limited number of ships where there were no facilities for storing distilled water, it was possible to adapt a small number of boilers to the use of tap water of good quality.
Other Than Marine Type	In general, based on the same considerations which govern marine type water tube boilers, tap water permissible for use in boilers should conform to the analysis shown below:

ENCLOSURE (B), continued

Other Than Marine Type (cont.)	Grams per metric ton:
	SiO_2 .... less than 15 CaO .... less than 25 MgO .... less than 10 SO_3 .... less than 15 Cl .... less than 20 Impurities remaining after evaporation, less than 150.

Section II

PROCEDURES FOR USE OF FEED WATER COMPOUNDS

In Memorandum No. 367 of 29 November 1941, the procedures to be followed in the use of feed water compounds were fixed as follows: (In reference to this, Memorandum 368 in the Navy Engineering Handbook was also amended).

A. General Regulations.

After reference to physical classification, these regulations were set for the composition, special uses, and standards for feed water compounds used on warships.

B. Classification and Composition.

The two types considered are sodium phosphate and sodium carbonate compounds.

For the sodium carbonate type compounds, soda ash is used.

For the sodium phosphate type compounds, tertiary sodium phosphate and sodium hydroxide are used.

C. Classification by Use.

Ships which use tap water exclusively as feed water, and those which use distilled plus tap water employ sodium carbonate type compounds.

Ships which use distilled water exclusively in their boilers employ sodium phosphate type compounds.

D. Standards for Use.

With respect to degree of alkalinity, the weight of soda ash plus sodium hydroxide should be confined within the limits of 130 and 250 parts per million, but while getting up steam it should in general be kept to less than 200. While boilers are steaming or while laid up full of water, the limit can be held at over 200 parts per million.

Section III

SODIUM PHOSPHATE TYPE COMPOUNDS

A. Composition.

The basic compounds consist essentially of the two reagents outlined below.

ENCLOSURE (B), continued

Tri-sodium phosphate ($Na_3PO_4 \cdot 12H_2O$)
Sodium hydroxide (NaOH)

Further, the chemical composition of these reagents, depending on the amount or scale of purchase, should be as outlined below.

Composition of Tri-sodium Phosphate

Pure tri-sodium phosphate ($Na_3PO_4 \cdot 12H_2O$) .... 98% or more
Impuritles:
Chlorides (Cl) .... 1.0% or less
Sulphurous acid (SO_3) .... 0.5% or less
Others .... Negligible amounts

Composition of Sodium Hydroxide

Pure sodium hydroxide (NaOH) .... 90% or more
Impurities:
Chlorides (Cl) .... 1.5% or less
Sulphurous acid (SO_3) ...... 1.0% or less
Others .... Negligible amounts

B. Methods for Manufacturing.

1. Tri-sodium phosphate: Start with a solution of phosphoric acid, and neutralize with soda ash. Di-sodium phosphate will be formed. Neutralize this with sodium hydroxide. Evaporate the result until separation of tri-sodium phosphate takes place by crystallization.

$$H_3PO_4 + Na_2CO_3 = Na_2HPO_4 + CO_2 + H_2O$$

$$Na_2HPO_4 + NaOH = Na_3PO_4 + H_2O$$

2. Sodium hydroxide: There are many methods of preparation. Electrolysis of sodium chloride with subsequent concentration through evaporation to solid NaOH is the process in most common use.

$$2NaCl = 2Na + Cl_2$$

$$2Na + 2H_2O = 2NaOH + H_2$$

C. General Characteristics.

1. Tri-sodium phosphate: This is a colorless, transparent crystal with 12 molecules of water attached. In pulverized state it is a white powder with a specific gravity of 1.63. The melting point is 77°C. Solubility at 15°C is 9.51 (with water 100). When the temperature is raised to 160°C, water of crystallization is released with no other change. At ordinary temperatures there is no deliquescence or efflorescence. On long exposure to air it absorbs carbon dioxide from the atmosphere, and is decomposed as follows:

$$Na_3PO_4 + CO_2 + H_2O = Na_2HPO_4 + NaHCO_3$$

Water solutions display a rather strong alkaline reaction, and possess the property of absorbing atmospheric carbon dioxide.

2. Sodium hydroxide: Sodium hydroxide comes in a white, granular form, in stick form, or in large lumps. When crushed, the surface

of the particles is crystal-like. Specific gravity is 2.13, melting point is 322°C. It has a strong corrosive effect on organic substances, and strong tendencies toward deliquescence. It dissolves easily in warm water.

A solution in water is strongly alkaline. When in solid form, or in a concentrated solution, it readily absorbs atmospheric carbon dioxide.

$$2NaOH + CO_2 = Na_2CO_3 + H_2O$$

D. Process for Treating Feed Water.

These water treating compounds, both tri-sodium phosphate and sodium hydroxide, are used to prevent corrosion of the boiler interior and attachment of oily substances or hard foreign matter.

Generally speaking, the tri-sodium phosphate eliminates calcium and magnesium from the boiler water by precipitation as soft sludge, and prevents formation of hard scale, while the sodium hydroxide, by maintaining a suitable alkalinity in the water prevents corrosion of the boiler surfaces.

The present-day methods for treatment are described clearly in detail as follows:

1. Tri-sodium phosphate:

a. This substance is an extremely effective water-softening chemical. The various compounds of calcium and magnesium carried into the boiler by feed water are precipitated as soft, muddy phosphates which have very low solubility, and as sludge, preclude any formation into hard scale. Even under high pressure and high temperature they will not decompose to go into solution, exhibiting this characteristic in a highly adequate degree in respect to practical operation.

$$3CaSO_4 + 2Na_3PO_4 = Ca_3(PO_4)_2 + 3Na_2SO_4$$

$$3CaCO_3 + 2Na_3PO_4 = Ca_3(PO_4)_2 + 3Na_2CO_3$$

$$3CaCl_2 + 2Na_3PO_4 = Ca_3(PO_4)_2 + 6NaCl$$

$$3MgSO_4 + 2Na_3PO_4 = Mg_3(PO_4)_2 + 3Na_2SO_4$$

$$3MgCO_3 + 2Na_3PO_4 = Mg_3(PO_4)_2 + 3Na_2CO_3$$

$$3MgCl_2 + 2Na_3PO_4 = Mg_3(PO_4)_2 + 6NaCl$$

b. When using this substance, the resulting solutions of calcium phosphate and magnesium phosphate will be found to exhibit some colloidal characteristics. Since to some degree this will tend to cause precipitation by a matting-together of any oil particles carried in the water, there is a possibility that its use will aid in the prevention of oil scale or deposits.

c. Under high temperatures and high pressures, these compounds act on still surfaces, to form a red, rust-colored scale thereon. It is important, therefore, that measures be taken to rust proof internal surfaces coming in contact with the water.

Further, this coating quickly forms on newly exposed iron surfaces of the boiler. However, if a particular density of phosphates and a fixed degree of alkalinity is maintained, it will form only slowly while getting up steam. Since the thickness of this coating does not increase more than 0.002cm at the most, there is no adverse effect on heat transfer.

d. According to Strobe and Bradbury, this is effective in preventing weak alkalinity and priming, but as yet this is not generally accepted.

2. Sodium hydroxide:

a. When a solution of this substance is made, ionization takes place, with formation of a preponderance of (OH^-) or hydroxyl ions. The concentration of hydrogen ions, which have the characteristic of dissolving the iron, will be greatly decreased. Consequently, there arises a method by which corrosion of iron metal is prevented. However, the limit of corrosion prevention by sodium hydroxide solutions is at about a pH of 11.5 (phenolphthalein 130 gms/kg) at ordinary temperatures when exposed to the atmosphere. At pH's greater than 11.5 the original solution of sodium hydroxide can maintain conditions in which polished iron surfaces remain bright for a considerable length of time.

b. Any silicates carried in by feed water are combined with the alkali of the foregoing paragraph. Since it is dissolved in the water as sodium silicate, it cannot be deposited as scale on the internal surfaces.

c. This substance, by virtue of its alkaline properties, saponifies the oil particles, to make them soluble. The oil no longer floats on the surface, but is mixed into the water. This property increases greatly the possibility of oil adhering to the calcium phosphate which is in colloidal state and is being precipitated with it.

d. This compound is carried into the boiler, and, by neutralizing the acidity which has arisen there, arrests the progress of corrosion.

e. This compound combines with calcium bicarbonates and the bicarbonates, sulphates, chlorides, and nitrates of magnesium to form calcium carbonate and magnesium hydroxides, both of which have a low degree of solubility. This softens the water.

$$Ca(HCO_3)_2 + 2NaOH = CaCO_3 + Na_2CO_3 + 2H_2O$$

$$Mg(HCO_3)_2 + 4NaOH = Mg(OH)_2 + 2Na_2CO_3 + 2H_2O$$

$$MgSO_4 + 2NaOH = Mg(OH)_2 + Na_2SO_4$$

$$MgCl_2 + 2NaOH = Mg(OH)_2 + 2NaCl$$

$$Mg(NO_3)_2 + 2NaOH = Mg(OH)_2 + 2NaNO_3$$

Further, if there are large quantities of bicarbonates present, the resulting sodium carbonate which will be formed will cause further precipitation of sulphates, chlorides, and nitrates of calcium in the less soluble form of calcium carbonate.

ENCLOSURE (B), continued

$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$$

$$CaCl_2 + Na_2CO_3 = CaCO_3 + 2NaCl$$

$$Ca(NO_3)_2 + Na_2CO_3 = CaCO_3 + 2NaNO_3$$

f. This substance through its alkaline properties can cause further precipitation since it decreases the solubility of calcium phosphate and magnesium phosphate.

E. Procedure for Use.

Procedure for use of the sodium phosphate type of treatment is described as follows:

1. As reagents, tri-sodium phosphate and sodium hydroxide are used.

2. The amount of sodium hydroxide to be used is determined by the following standards for alkalinity in the boiler water:

   a. In any case the degree of alkalinity is to be maintained between the limits of 130-250 parts per million (130-250 gms NaOH to 1000 kgs boiler water). In general it is to be maintained at a value of less than 200 ppm while warming-up, and at a value of over 200 when in a cold-laid-up-full condition or when in normal service.

   b. At the time of extinguishing the fires, alkalinity should be increased to above 200. While idle there is no objection to having the alkalinity at this value if the boilers are cold; however, steps should be devised to lower the degree of alkalinity as quickly as possible to the proper value when the boilers are getting up steam.

   c. For high temperatures, the alkalinity should be high and for low temperatures the alkalinity should be low; therefore, one should ordinarily decide on a suitable value of alkalinity by making comparisons of the temperatures at the time samples are withdrawn. It is difficult to say in particular, but in general, the following rules are adequate for alkalinity:

High temperature	170-200
Med. temperature	150-180
Low temperature	130-160

3. The amount of tri-sodium phosphate is generally maintained between 10-30 ppm in the boiler water.

4. In general, the preparation of sodium hydroxide and tri-sodium phosphate, in a quantitative way, is as follows:

   a. While getting up steam, 6 gm NaOH to one metric ton of boiler water are used per 10 ppm deficiency, and the water is kept lower than the water level recorded in the log book for the boilers. However, when the boilers are not in use or when the water level is to be kept at full, the amounts should be in the ratio of 10 gm NaOH per metric ton of boiler water.

   b. To remedy a phosphate deficiency of 10 ppm, tri-sodium phosphate should be added in the proportion of 35 gm per metric ton

ENCLOSURE (B), continued

boiler water, and is added in sufficient amount to fill it up to the water line recorded in the boiler log. However, in case the boilers are not operating or are filled to capacity, 55 gm tri-sodium phosphate should be added for each metric ton. Further, should hard scale have formed previously on the boiler, it is necessary to add the above frequently.

c. In case the boiler water is changed, water with 80 gm NaOH, 100 gm Na_3PO_4 per metric ton boiler water should be added in sufficient amounts to bring the level to just below that given in the boiler log book. Then a pre-heating of the boilers is carried out as quickly as possible for at least 30 minutes at working pressure. However, there is no objection to omitting the test firing (pre-heat) if the firing is scheduled within 24 hours.

d. When the boiler water is changed and brought to full, the water with 170 gm NaOH, 120 gm Na_3PO_4 is added according to the boiler log. As soon as possible thereafter a 30 minute (or more) firing test is carried out (with water level at the center of the gauge) and the feed water treatment is regulated during the test so that the alkalinity is about 300, with phosphate about 30. After the fires are extinguished and the boiler pressure reaches zero, fresh (distilled) water is added to bring it to full condition.

e. Even though only tri-sodium phosphate be added, the alkalinity rises considerable and so immediately after addition it is necessary to take pains in correcting the alkalinity.

f. Care must be taken in this respect because there are many examples of unusual conditions arising in the relationship between the amounts of tri-sodium phosphate, phosphate concentration, and the correct degree of alkalinity in cases where much scale has attached itself to the boiler surfaces, also when ordinary tap water is used, and where there is a considerable chloride concentration in the boiler.

g. The method of injecting treatment compounds into the boiler is carried out according to boiler type. Both sodium hydroxide and tri-sodium phosphate are added through a special device. For each injection the method is to first dissolve the compound in about ten times its weight of water. The solution is then added through the special device for boiler compound. If there is no injection apparatus installed, it is added through the steam drum man hole or the air vent valve, etc. It is never pumped in from the main tank.

5. Alkalinity values are obtained by the water test kit. The phosphate content value is obtained from phosphate test kit.

6. The proper time interval between tests for phosphate and alkalinity value is as follows:

a. The procedure for sampling should be previously set up for determination once every twelve hours; during the interval when water treatment compound is being added; just before the bottom blow is to be used, and immediately after the bottom blow has been used.

ENCLOSURE (B), continued

b. Measurements should be made once a week when the boilers are not in operation or once a month when the boilers are laid-up-full. However, immediately after test firing when the boilers have cooled, measurements should always be taken.

7. When boiler compound is used to excess, there is a tendency to prime. When the boiler pressure is high, or when the salt content is high, or when too little is used, or when the use is not proportionate to the need, there is insufficient prevention against corrosion and scale formation. It is important that constant and close attention be given to these points.

8. A large amount of sludge forms when boiler compound is used. Boilers should therefore be blown down thoroughly in accordance with the following:

a. Once every twelve hours, or while getting up steam, the bottom valve is opened with the water column at 2cm. The boiler is blown several times dropping 2cm in the column each time.

b. Before boilers are put on the line, they should be blown down by the same amount.

c. A comparatively large amount is blown out when the fires are cut off.

If the important points as described above were expressed in outline form, they would appear as in Tables II(B) to VI(B).

The relation between phosphates and alkalinity to be maintained in the boiler water when using sodium phosphate-type treating compound is shown in Table II(B).

TABLE II(B)

	Getting up steam		Steaming or laid-up-full	Notes
Alkalinity	Usually less than 200	Low temp: 130-160 Med. temp: 150-180 High temp: 170-200	Usually over 200	In any case between 130-250
Amount of Phosphates	10-30			
Remarks	Units are expressed in ppm. (gms per metric ton water)			

ENCLOSURE (B), continued

Quantities of sodium phosphate type of compound to be added in filling boilers are given in Table III(B).

TABLE III(B)

	In case the operating level of water is changed upon changing boiler water		In case the boiler is full and the water is changed	
$NaOH$	70 (water below water line)	Over 30 parts at operating pressure when lighting off. In case ignition occurs within 24 hours this can be omitted.	170 (boiler full)	Above 30 parts at firing-operating pressure. (While test firing alkalinity is 300, phosphate 30). After extinguishing, boiler pressure drops to zero and then refill.
Tri-sodium phosphate	100 (water below water line)		120 (boiler full)	

Remarks: Quantity of cleaning compound is in gms per metric ton boiler water.

Quantities of sodium phosphate type cleaning compound used to supply full boilers are shown in Table IV(B).

TABLE IV(B)

	To remedy deficiency in alkalinity by 10		To remedy deficiency in Na_3PO_4 by 10	
	Getting up steam	Steaming or laid-up-full	Getting up steam	Steaming or laid-up-full
$NaOH$	6 (water below water line)	10 (boiler water)		
Na_3PO_4			35 (amount of water less than water line)	55 (amount of boiler water)

Remarks: Amounts of purifying compound are given as number of gms per metric ton of boiler water.

ENCLOSURE (B), continued

The standard time interval between tests for phosphate and alkalinity when sodium phosphate type of compound is used is shown in Table V(B).

TABLE V(B)

	Frequency of measurement	Notes
When getting up steam	Once every 12 hours	Boiler compound should be replenished immediately after blowing down boiler when necessary.
When boilers are cold	Once a week	As quickly as possible immediately following test firing, or if boilers are cold, once in each case.
When boilers are operating	Once a month	

Frequency schedule for blowing out boilers using sodium phosphate type cleaning compounds is shown in Table VI(B).

TABLE VI(B)

	Frequency	Degree	Summary
When getting up steam	Once every 12 hours	Water column 2cm	Blowers opened several times during each short period
Simultaneous with firing of boilers	Once before simultaneous use		
When boilers are being shut down	Once immediately before shutting down boilers	Comparatively large amount	

ENCLOSURE (B), continued

F. <u>Precautions for Use of Above Tables</u>.

1. Boiler feed water compounds are intended for use with distilled water only, and this should be adhered to. However, when distilled water is not available, tap water may be used. In such cases, give scrupulous attention to using as few boilers and auxiliary tanks as possible. In addition, keep the length of period of their use at a minimum. Further, as soon as it becomes no longer necessary to feed with tap water, clean out the boiler without fail before again using distilled water.

2. It is imperative that close attention be given to strict observance of procedures as outlined, because when use of boiler compounds is not suitable, the following difficulties are likely to arise:

a. Corrosion of boiler surfaces.

b. Decreased heat transfer due to formation of hard scale and oil sediment on heating surfaces, interference with circulation of boiler water, decreased boiler efficiency, and overheating damage in the form of bent and swollen tubes.

c. Decrease in steam quality due to foaming and priming. Accompanying this will be a decrease in steam temperature and a soiling of boiler accessories such as the turbine, etc.

d. Damage to boiler materials by caustic embrittlement.

3. When feed water treatment is first used, or if at any time later on hard scale attaches itself to the boiler, the rate of consumption of phosphate will be great, (consumed in the formation of iron phosphate when softening the scale). In this event shorten the interval between tests, and if necessary, increase somewhat the fixed amount of tri-sodium phosphate added.

4. Injection of water treatment compounds should be accomplished only when completely in solution. In case the material is slow to dissolve, apply heat to the mixture.

5. It is not necessary to be especially careful in handling sodium phosphate, but the caustic properties of sodium hydroxide make its corrosive effect very strong. It is capable of staining and damaging skin or clothing. For that reason if it should come in contact with the skin or with clothes, immediately wash it off with fresh water. If some should by chance get into the eye, immediately wash the eye thoroughly with fresh water, and to be safe, thereafter apply a solution of boracic acid.

6. Sodium hydroxide tends strongly toward deliquescence, absorbing water from the atmosphere, and thus becomes difficult to handle. Keep it in a moisture-proof all-steel container, and after use, be sure to seal it tightly.

7. There is good reason to fear that corrosion will make progress in boilers, not so much while being forced, but rather while idle. Therefore, there is special need to see that the degree of alkalinity in idle boilers does not decrease.

ENCLOSURE (B), continued

8. It is very difficult to regulate the alkalinity of treated water drawn out of boilers during recirculation at warming up. At this time it is pumped back into the reserve tanks, and re-fed back into the boilers getting up steam. Once the boiler is warmed up, it is better to throw this water out. Pump all water in the reserve tanks overboard.

Section IV

WATER TREATMENT COMPOUNDS OF THE SODIUM CARBONATE TYPE

A. Composition.

In this type of treatment only one chemical, anhydrous sodium carbonate (called soda ash) is used. Its chemical composition, for specification purposes and purchase, is shown in the following table:

Composition of Anhydrous Sodium Carbonate

Pure anhydrous soda carbonate (Na_2CO_3)	98% or more
Impurities:	
Chlorides (Cl)	1.0% or less
Sulphites (SO_3)	0.5% or less
Others	Trace

B. Method of Manufacture.

There are many methods, but the most common at present is the ammonia-soda method of Sorbe. In this method, ammonia gas is passed into a saturated sodium chloride solution until saturation is reached, then carbon dioxide gas is passed on until saturation is reached. Reaction takes place which produces ammonium chloride and sodium bicarbonate, as follows:

$$NaCl + NH_3 + CO_2 + H_2O = NH_4Cl + NaHCO_3$$

Ammonium chloride remains soluble during the process, but sodium bicarbonate is less soluble and precipitates out. It is then filtered out and washed with water. The washed sodium carbonate is next heated, and the following reaction takes place:

$$2NaHCO_3 = Na_2CO_3 + CO_2 + H_2O$$

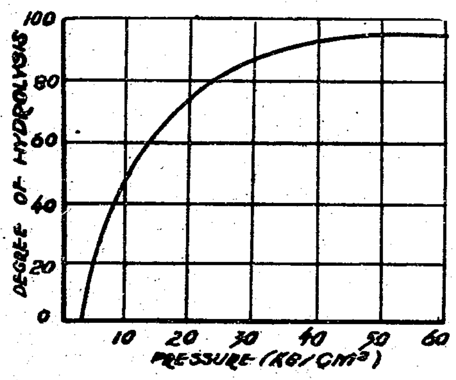


Figure 1(B)

DEGREE OF HYDROLYSIS

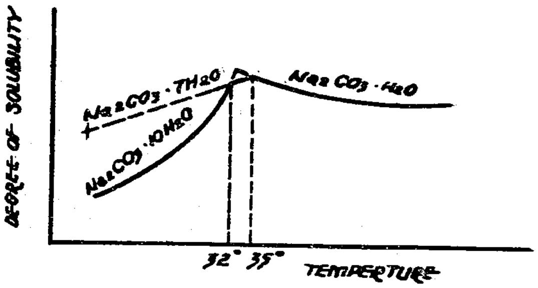


Figure 2(B)

DEGREE OF SOLUBILITY

ENCLOSURE (B), continued

C. General Characteristics.

It is a white powder with a specific gravity of 2.5, deliquescent properties, and a melting point of 852°C. On heating in atmosphere above 700°C, carbon dioxide gas is liberated. If a water solution is boiled for a considerable length of time or subjected to high temperatures and pressure, hydrolysis takes place, carbon dioxide gas is liberated, and sodium hydroxide results. Figure 1(B) shows that the rate of hydrolysis increases rapidly with increase of pressure.

$$Na_2CO_3 + H_2O = 2NaOH + CO_2$$

On the other hand, in solid form or cold solution, sodium carbonate has the characteristic of absorbing CO_2 from the atmosphere.

It is readily soluble in water. At 35.2°C solubility of 33.8% is reached. At higher temperatures the rate of increase of solubility diminishes (assymptotically levels off).

Figure 2(B) shows transition points of $Na_2CO_3 \cdot 10H_2O$ to $Na_2CO_3 \cdot 7H_2O$ at 31.9°C, $Na_2CO_3 \cdot 7H_2O$ to $Na_2CO_3 \cdot H_2O$ at 35.2°C.

D. Feed Water Treating Process.

This compound can prevent formation of scale, oil, sedimentation, and corrosion within the boiler. Details are as follows:

1. The various chlorides of calcium and magnesium which are carried into the boiler with feed water will be precipitated as carbonates of calcium and magnesium which are low in solubility and settle out as sludge. Soda ash, therefore, prevents formation of hard and harmful scale. However, under high temperatures and pressures, with resulting increase in rate of hydrolysis, its efficacy decreases. Unless the system operates at under 20 kilograms/cm², soda ash cannot be expected to give satisfactory results.

$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$$

$$CaCl_2 + Na_2CO_3 = CaCO_3 + 2NaCl$$

$$Ca(NO_3)_2 + Na_2CO_3 = CaCO_3 + 2NaNO_3$$

$$MgSO_4 + Na_2CO_3 = MgCO_3 + Na_2SO_4$$

$$MgCl_2 + Na_2CO_3 = MgCO_3 + 2NaCl$$

$$Mg(NO_3)_2 + Na_2CO_3 = MgCO_3 + 2NaNO_3$$

2. By dissociation this substance forms a considerable quantity of hydroxyl ions (OH), and displays a rather strong alkaline nature. Any silicates which may be carried in by feed water are attacked by the alkali and become sodium silicate. This is relatively soluble and by remaining in solution reduces the tendency for scale to form.

3. The aforementioned alkalinity results in a decreased concentration of hydrogen ions, which have the ability to bring iron into solution by displacement. Therefore, a strong inhibition to corrosion exists, that is, if the pH is not above 11.5. Where there is exposure to the air, this is not completely effective.

4. This agent is capable of preventing corrosion by neutralizing any acidity formed at high temperatures and pressures within the boiler or any that is carried into the boiler by feed water.

$$2HCl + Na_2CO_3 = 2NaCl + CO_2 + H_2O$$

$$H_2SO_4 + Na_2CO_3 = Na_2SO_4 + CO_2 + H_2O$$

5. Because this agent endows oil particles with hydrophilic qualities through its alkaline property and emulsifies them, it will not only make the oil float on the surface, but also causes it to be mixed largely with the boiler water. Thus it increases the likelihood of its precipitation along with the sludge. Consequently, it becomes possible to clear out the boiler from the outside by using the bottom blow valve and thus prevent adherence of the oil dregs to a certain extent.

E. Method of Use.

The methods for use with water treatment compounds of sodium carbonate type are as follows:

1. Use soda ash as the cleaning compound.

2. The quantities of soda ash to be used in obtaining various degrees of alkalinity in the boiler water should be determined by use of the following established standards:

    a. The alkalinity in any case should be between 130-250 parts per million (number of grains of NaOH to one metric ton of boiler water) and should not vary outside those limits. Alkalinity should generally be less than 200 while getting up steam, and more than 200 if the boilers are operating or laid-up-full.

    b. At the time that boilers are being shut down, alkalinity should exceed 200. When lighting boilers, there is no objection to utilizing the same alkalinity as was present when the boilers were idle. However, when getting up steam, methods should be devised to lower the alkalinity so fixed, within as short a period as possible.

    c. With high temperatures, the degree of alkalinity should be high and usually alkalinity is determined when boiler water is sampled and then compared to the boiler temperature. No general rule can be given, but the following values appear satisfactory:

High temperatures	170-200
Medium temperatures	150-180
Low temperatures	130-160

3. The soda ash required is to be supplied by injection. The method of injection generally is as follows:

    a. While getting up steam, soda ash in the proportion of 10 grams of soda ash per metric ton of boiler water is to be added to bring the alkalinity to 10 ppm. It is added according to the water level determined by the boiler log.

ENCLOSURE (B), continued

b. When the boiler water is changed, water is added to the log book value in the proportion of 300 grams soda ash per metric ton of boiler water, and the test firing must be done as quickly as possible in 30 minutes at working pressure. However, there is no objection to omitting the test firing in case the ignition schedule is within 24 hours after the water change.

c. In case the level is maintained at full upon changing the water, the filling water is added according to the boiler log in the proportion of 300 grams soda ash per one metric ton boiler water. The test firing is done as quickly as possible for over 30 minutes (water level gauge at center) and during the test firing alkalinity is regulated to about 300. During the cooling period the filling water conditions are determined

d. The supply and injection of soda ash is done with a solution of approximately 10 parts water to one part soda ash. Each boiler is separately treated by the cleaning compound injection equipment. If unavoidable, it may be done through the steam drum manhole or the water-filling valve, but it may not be injected from the main feed water tank.

4. The proper amount of alkalinity shall be determined by the water test kit.

5. Intervals between tests on alkalinity will be as follows:

a. While getting up steam. Once every four hours. Chlorides shall be tested at the same time.

b. While boilers are not in operation, once a week.

c. While boilers are kept at idle-full, once a month. However, during said periods, whenever purifying compounds are added, or the boiler bottom-blow is used, a test should be made immediately thereafter.

6. If the cleaning compounds are used over and over again when steam is being produced at high power; or the chlorides content is high, in addition to there being present a strong tendency to foam, especially if the amount used is too small or the method of handling inappropriate, its power to prevent formation of scale and corrosion of the boiler surfaces will be insufficient. Therefore, it is important that extremely close attention be paid these points.

7. Since a considerable amount of sludge results from using this cleaning agent, always carry out the blowing-down of the boiler water in strict accordance with the following paragraphs:

a. While much depends on the extent to which a particular boiler is being used, if run at an economical rate of combustion, generally speaking, it should be blown out every 12 hours until the water gauge shows about 5cm, and the blow-down valve should be opened and closed several times at each of these intervals.

b. In using boilers simultaneously and during continuous firing, before using them together, they should be blown down to about the same degree.

ENCLOSURE (B), continued

c. When shutting down, blow down the boilers comparatively often.

If the aforementioned points were to be extracted and expressed in outline form, they would be shown as in Tables VII(B) to XI(B).

Maintenance of alkalinity by use of compounds of sodium carbonate type is shown in Table VII(B).

TABLE VII(B)

		While Raising Steam	Boilers in full use or at full
Alkalinity	Generally below 200	Low temperatures 130-160	
		Med. temperatures 150-180	Generally above 200
		High temperatures 170-200	

Quantities of sodium carbonate type cleaning compound added are shown in Table VIII(B).

TABLE VIII(B)

	In cases where water changed up to operating level		When full boiler of water is changed	
Soda ash	300 (Quantity of water below water line)	At test-firing pressure more than 30 parts. However, if within 24 hours firing is scheduled, it can be ommitted.	300 (full quantity of water)	At pressure used in test firing, over 30 parts (alkalinity about 300 during test firing). Fill after shutting down boilers and pressure has fallen to zero in boiler

Note: Quantities of cleaning compound shown as grams per metric ton.

Amounts of sodium carbonate type cleaning compound to be replenished are shown in Table IX(B).

TABLE IX(B)

To Remedy Deficiency of 10 in Alkalinity

	While raising steam	While keeping full boiler or with boiler not operating
Soda ash	10 (Amount of water below water line)	16 (Amount of boiler water)

ENCLOSURE (B), continued

Time intervals for sampling when using sodium carbonate type cleaning compounds are shown in Table X(B).

TABLE X(B)

	Frequency of Testing	Notes
While raising steam	Once every 4 hours	Immediately after adding cleaning compound or blowing down, test once as required.
When boilers not in use	Once a week	
When maintaining idle full boiler	Once a month	Immediately after test firing and when the boiler cools, test once quickly each time.

Frequency of blowing down boilers when sodium carbonate type cleaning compounds are used is shown in Table XI(B).

TABLE XI(B)

	Frequency	Degree	Summary
When getting up steam	Once every two hours	Water column about 5cm	Blowers opened several times during each short period of time
Simultaneous firing of boilers	Once before simultaneous use		
Boilers shut down	Once immediately before shutting down boilers	Comparatively great	

F. Cautions in Use of Above Methods.

1. The boiler cleaning compound is primarily for use with boilers which utilize tap water. It is also used in ships that use distilled and tap water, as well as ships which use tap water exclusively.

2. No matter how suitable the use of the cleaning compound is, if the quality of supply is bad, it cannot produce good results, so the tap water must be of as good quality as possible. However, the tap

ENCLOSURE (B), continued

water from each of the following places is recognized as of good quality from the results of analytical tests made in 1940, and therefore, there are no objections to its use.

However, in cases where it is recognized as being necessary, further exhaustive analyses and tests can be carried out. It would be advisable therefore, to ascertain whether or not the following sources still conform to the "specifications fixed for classification of water for use in boilers of naval vessels."

YOKOSUKA
HIROSHIMA
TOKUYAMA
SUKIMO
MOJI
ODOMARI
NANKING
SHIMONOSEKI
KURE
KOBE
SAEKI
YOKKAICHI
OTARU
GENZAN
HANKOW
SHIBUSHI
SASEBO
OSAKA
CHINKAI
FUSAN
KAGOSHIMA
HAKODATE
KEELUNG
AMOY
MAIZURU
NAGASAKI
URAGA
KOMATSUJIMA
MURORAN
CANTON

In the following places, as a result of analyses in 1940 it was found that the water was impure and unsatisfactory. Therefore, its use should be avoided as much as possible.

TAKAO
SHANGHAI
BAKO
AOSHIMA
PORT ARTHUR
WAKKANAI
DAIREN

3. If the methods of application of the purifying compounds are not appropiate, the following kinds of breakdowns or difficulties are likely to arise, so observe the regulations strictly, and pay closest attention to them:

a. Corrosion of boiler surfaces.

b. Injurious effect on circulation of boiler water and on heat transfer due to adhesion of hard oil residue and scale; together with, and accompanying the above, lowering of boiler efficiency and bent, swollen, and burst boiler tubes, etc.

c. Foaming and priming, causing lowering of quality of steam, and accompanying this, a drop in steam temperature, staining of and damage to boiler accessory equipment such as turbines, etc.

d. Caustic embrittlement.

4. Although corrosion of boiler surfaces takes place primarily while steam is being raised, it progresses even more rapidly when the boilers are not in operation. Special attention therefore should be paid to regulation of the alkalinity during such periods.

5. Once cleaning compounds have been added to boiler water, and this water recirculated to the reserve tanks, it is very difficult to regulate the degree of alkalinity in the boiler. It is better to discard all such treated water.

ENCLOSURE (B), continued.

Section V

APPARATUS FOR TESTING BOILER WATER

A. Fundamental Principles.

This boiler water testing apparatus measures scientifically the chlorides and degree of alkalinity in boiler water. To make its carrying and handling convenient, the alkalinity test equipment, the chloride equipment, and other such measuring equipment necessary, should be able to fit into one box, with a special boiler water disposition device attached. The fundamental principles are as follows:

1. Principle for measuring alkalinity: If phenolphthalein indicator is dropped into the sample of boiler water, and alkali is present, the solution becomes pink in color. When this is titrated against sulfuric acid, the alkalinity is gradually neutralized. Finally, when the end point is reached, the pink color disappears. That is to say, one can easily calculate the amount of alkalinity in boiler water by the amount of sulfuric acid of known concentration consumed in titration. With this apparatus, one reads directly the weight of consumed sulfuric acid on the burette and immediately knows the number of grams of NaOH per metric ton of boiler water, since both the calibrations and concentration of sulfuric acid have been proportioned for this.

2. Principle for measuring chlorides: When a potassium chromate indicator is dropped into the sample of boiler water, the solution turns yellow-orange. When this is titrated with a silver nitrate solution, the chlorides in the boiler water are gradually precipitated as white silver chloride. Finally, after the chlorides have been completely precipitated, the silver combines with potassium chromate and silver chromate precipitates. The solution at this time becomes muddied, with a reddish-brown color. By this, one can easily calculate the quantity of chlorides in the sample of boiler water, from the spent amount of a silver nitrate solution of known concentration. By taking readings on the burette of the quantity of spent silver nitrate solution, one immediately knows the number of grams of Cl in one metric ton of boiler water, as both the concentration of silver nitrate and the calibrations of the tube are properly proportioned.

B. Apparatus.

This equipment is a scientific measuring apparatus which can be housed in one box. It includes the alkalinity and chlorinity apparatus and other necessary apparatus. Details are as shown in Figure 3(B) and as follows:

1. Alkalinity measuring apparatus:

   a. Reagent flask (capacity about 500cc) 1
   This is a transparent bottle made of tough glass, has the shape shown in Figure 3(B)(1), and is filled with the 1/16 N standard sulphuric acid solution.

   b. Indicator reagent bottle (capacity about 50cc) 1
   This has the shape shown in Figure 3(B)(2), is made of colorless glass, and is filled with the 1% phenolphthalein solution. However, the stopper is a rubber medicine dropper.

ENCLOSURE (B), continued

c. Calibrated burette. The three cubic centimeter glass tube is marked into 60 divisions as shown in Figure 3(B)(3) and is made of hard transparent glass. On the upper part "NaOH gms/kg" is inscribed. It is attached to the mouth of the reagent bottle. Thus, one can measure the alkalinity from the amount of sulfuric acid used.

d. Rubber bulb. It has the shape shown in Figure 3(B)(4). By pressing the rubber bulb, one can raise the solution in the reaction flask (1) into the burette.

e. In place of this device a small pump can also be used.

2. Chloride measuring apparatus.

a. Reagent flask (500cc capacity) 1
It is a dark brown colored bottle of hard glass having the shape shown in Figure 3(B)(5) and is filled with silver nitrate solution of 11.98 gm/l.

b. Indicator reagent bottle (50cc capacity) 1
Of hard, colorless glass, it has the shape shown in Figure 3(B)(6) and contains 20% potassium chromate solution. Again, inserted in the top is a rubber-bulbed medicine dropper.

c. The 3cc burette is marked (0-300 gm/kg) with 60 divisions, as shown in Figure 3(B)(7) and is a dark-brown colored glass tube. On the upper portion, Cl in gm/kg is inscribed. Attachment is made in the reagent bottle's mouth. One can read the chloride content directly, from the quantity of silver nitrate used.

d. Rubber bulb 1
It has the shape as shown in Figure 3(B)(8). By exerting pressure on the bulb, the solution in the reaction bottle (5) can be raised into the glass burette (7). In place of this device, a small pump can also be used.

3. Titration apparatus, etc.

a. Glass graduate (25cc capacity) 1
This has the shape shown in Figure 3(B)(9), and is made as a colorless hard glass cylinder, measuring 0-25cc. It is used to measure the amount of water sample to be tested.

b. Erlenmeyer flask (100cc capacity) 2
It is a flask of hard, colorless glass having the shape shown in Figure 3(B)(10) and is utilized in the titration procedure.

c. Funnel 1
The funnel is made of hard, colorless glass of the shape shown in Figure 3(B)(11) and is utilized in filtering the boiler water.

d. Washing (cleaning) brush 2
It has the shape shown in Figure 3(B)(12) and is used in the cleaning of glass equipment.

e. Filter paper (diameter 11cm) .... 100 sheets.
Used in filtering test samples of boiler water and kept in the drawer.

ENCLOSURE (B), continued

f. Portable case 1
The case, Figure 3(B)(14), holds all of the above apparatus. The outside is lacquered, and the inside is painted with an enamel to withstand acids and bases.

C. Testing the Boiler Water.

1. Taking of the test sample: When boiler water is drawn off in taking the sample, it should be done so as not to allow the slightest amount of atmospheric air to come in contact with the 500cc sample of boiler water in the sampling bottle, (as CO_2 in the atmosphere will react with the NaOH). While waiting for it to cool down to room temperature, the funnel is placed in the top of the graduated cylinder, and the solution is filtered through filter paper, 25cc of the filtered solution being placed in the Erlenmeyer flask to be tested. In case the test sample is clear, filtering is unnecessary.

2. Titration method for determining alkalinity:

a. First, one or two drops of phenolphthalein indicator are dropped into the sample in the Erlenmeyer flask, giving it a red color. (When it does not show red, it indicates that the test sample is not alkaline, and that it is necessary to replenish the boiler cleaning compound immediately).

b. When gradually opening the glass stopcock, Figure 3(B)(15), exert pressure on the rubber bulb (4) (or operate the pump) so that the 1/16 N sulfuric acid solution in the burette (3) is raised to 0. Close the glass cock (15) and stop the fall of the reagent.

c. The cock (16) used in titration is opened, and drop by drop the reagent in the burette (3) is dropped into the sample in the Erlenmeyer flask (10). During this procedure, rotate the flask, to stir up the solution. When the sample loses its reddish color, close the titration cock (16). Read the level of the reagent in the burette (3). This measures the alkalinity of the sample of boiler water in grams/metric ton of sodium hydroxide (NaOH) or ppm, as shown with phenolphthalein as indicator.

3 Chloride titration analysis:

a. After titration for alkalinity, add one or two drops of potassium chromate indicator to the neutralized sample in the Erlenmeyer flask Figure 3(B)(10), which should then display a lemon-yellow color.

b. Press the rubber bulb (8) (or operate the pump) and by gradually opening the glass cock (17), raise the 11.98 g/liter silver nitrate solution up to 0 on the brown-colored glass burette (7). Then close glass cock (17), shutting off the flow of reagent.

c. The titration cock (18) should be opened to let the reagent fall into the sample drop by drop. At this time, rotate the solution in the triangular flask (10) to stir it. When the lemon-yellow color of the sample has turned slightly brown, close titration cock (18) and read the value indicated where

ENCLOSURE (B), continued

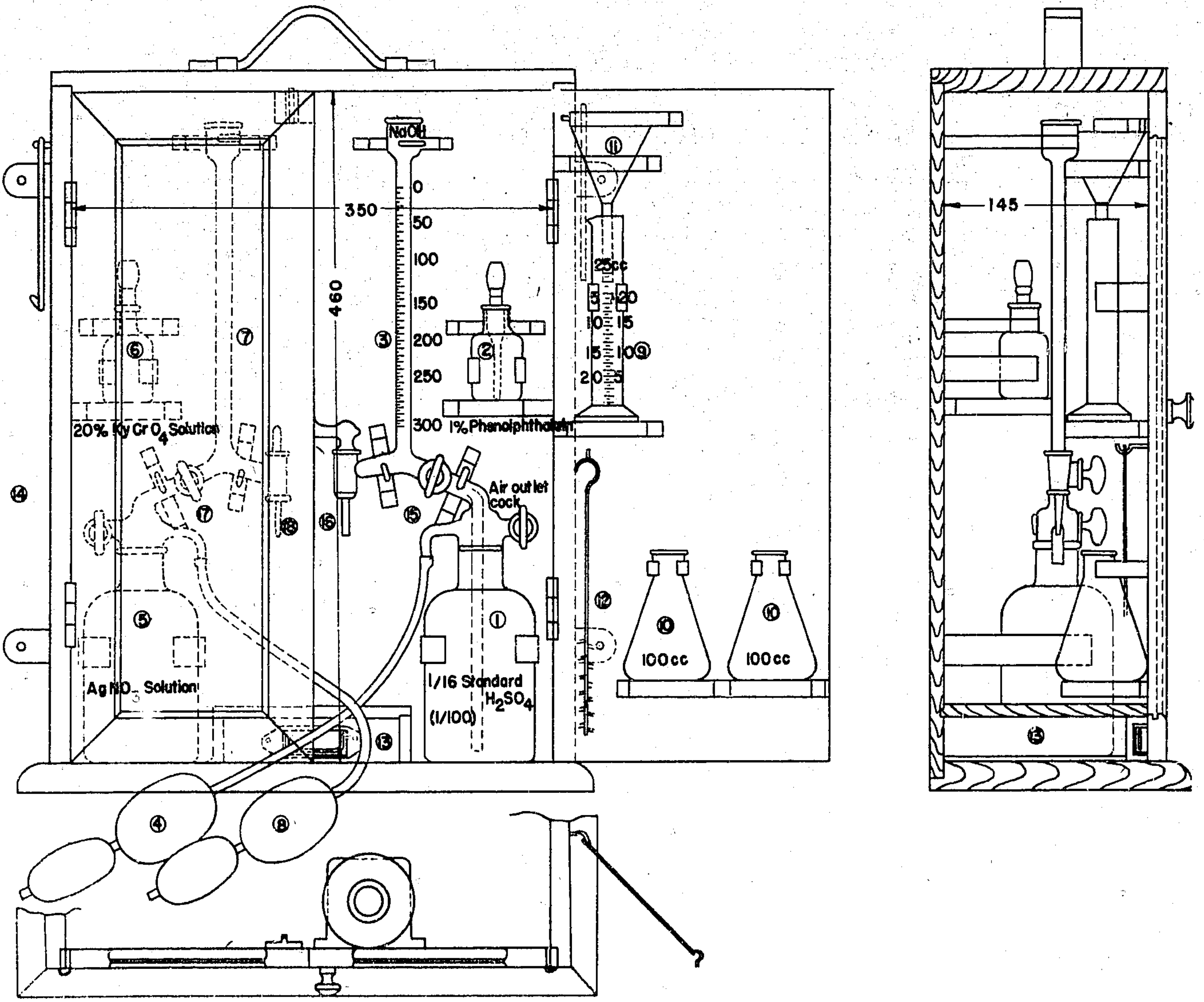


Figure 3(B)

APPARATUS FOR TESTING BOILING WATER

ENCLOSURE (B), continued

the surface of the reagent shows on glass burette (7). This measures the gram/metric ton chloride concentration (unit of one part per million).

4. Disposition after testing: When the boiler water test is completed, the reagents remaining in the burettes Figure 3(B)(7) and (3) should be returned to bottles (1) and (5), and every cock should be fully secured. Further, the triangular flask (10), the graduated cylinder (9), and the filter (11) should be carefully washed with fresh water and put back into the case.

D. Points to be Observed in Above Measurements.

1. Ordinarily the boiler water sample is taken from the salinometer cock on the water drums. However, when the occasion arises, try also to compare it with a sample taken from the steam drum. Also, test the condition of the boiler cleaning compound mixture.

2. In order to prevent air from coming in contact with the sample at the time of sampling, one must fill the sampling bottle to the brim with the boiler water and immediately cap the bottle while the water is overflowing. Be very careful not to allow atmospheric air to penetrate into the sampler bottle.

3. In the event that the boiler water is filtered and there is still an off-color to it, put into another flask an equal quantity of boiler water as a color standard. If titration is conducted while comparing the two, there is no difficulty in determining the end point.

4. During titration, if the temperature of the sample is high, errors are likely to arise, and so, titration ought to be conducted at approximately room temperature. Further, if the sample has to be cooled quickly, the sample bottle is to be taken outside of the case and cold water poured over it so that the excess water flows downward.

5. When titrating a sample with very low chloride content such as distilled water or condenser water, the volume of one drop is subtracted from the volumetric reading to give the final reading. Silver nitrate solution containing 1.198 gm/l (1/10N, or ordinary standard) is used.

6. Rinsing the funnel, flasks, and graduated cylinders two or three times with a small quantity of the sample is sufficient.

7. Separate flasks should be used for boiler water, condenser water, and feed water.

8. Titration should be made at a well lighted place. Direct sunlight, however, is to be avoided.

9. It is more expeditious to use a metal dipper for sampling. This also eliminates chances of broken sample bottles.

E. Cautions Regarding Handling.

1. This testing apparatus must be handled with great care since it is a complicated maze of fine glassware and breaks at the slightest impact.

ENCLOSURE (B), continued

2. Glassware should be washed several times with sodium carbonate or soap solution and should be thoroughly cleaned (especially inside) before storage. Black spots left by silver nitrate are removed by dilute nitric acid or potassium cyanide. The glass should then be wiped with a clean cloth that has been rinsed in distilled water.

3. Glass cocks are very likely to freeze, and such surfaces should be coated frequently with grease or vaseline. If the apparatus is not to be used for some time, the ground surfaces should be coated with grease or vaseline and a strip of paper inserted between them. If a cock should be frozen, the rubber washer is first removed, and then the cock is gently tapped with a piece of wood from the small side taking care not to impart any other force to the glass. This will usually accomplish the purpose.

Section VI

PHOSPHATE TESTING EQUIPMENT

A. Fundamental Principles.

1. This apparatus is used to determine the phosphate content of boiler water in which sodium phosphate boiler compound has been added. The principles of operation are as follows:

Phospho-molybdic acid has the property of forming a beautiful blue color when it reacts with any reducing agent. The intensity of color, up to a certain point, is directly proportional to the phosphate concentration. The apparatus is an application of this principle in which colored solutions are compared with standard color solutions; thus, phosphate content is determined.

$$6H_3PO_4 + 72(NH_4)_2\ MoO_4 + 63H_2SO_4 = 6(NH_4)_3PO\cdot 12MoO_3 + 63(NH_4)_2SO_4 + 72H_2O$$

(Blue becomes deeper as reduction progresses).

B. Equipment.

This is a chemical instrument which consists of volumetric apparatus utilizing the hydroquinone method for determining phosphate, and all the necessary reagents. These are contained in a wooden case to expedite handling. Details are given in the following paragraphs and Figures 4(B) and 5(B).

1. Reagent bottle for No. 1 Solution (500cc) 1
This has the shape shown in Figure 4(B)(1) and is a brown glass bottle with cover.

2. Reagent bottle for No. 2 Solution (250cc) 1
This has the shape shown in Figure 4(B)(2) and is a brown glass bottle with cover.

3. Reagent bottle for No. 3 Solution (500cc) 1
This has the shape shown in Figure 4(B)(3) and is a brown glass bottle with cover.

4. Distilled water bottle (250cc) 1
This has the shape shown in Figure 4(B)(4) and is a colorless glass bottle with stopper.

ENCLOSURE (B), continued

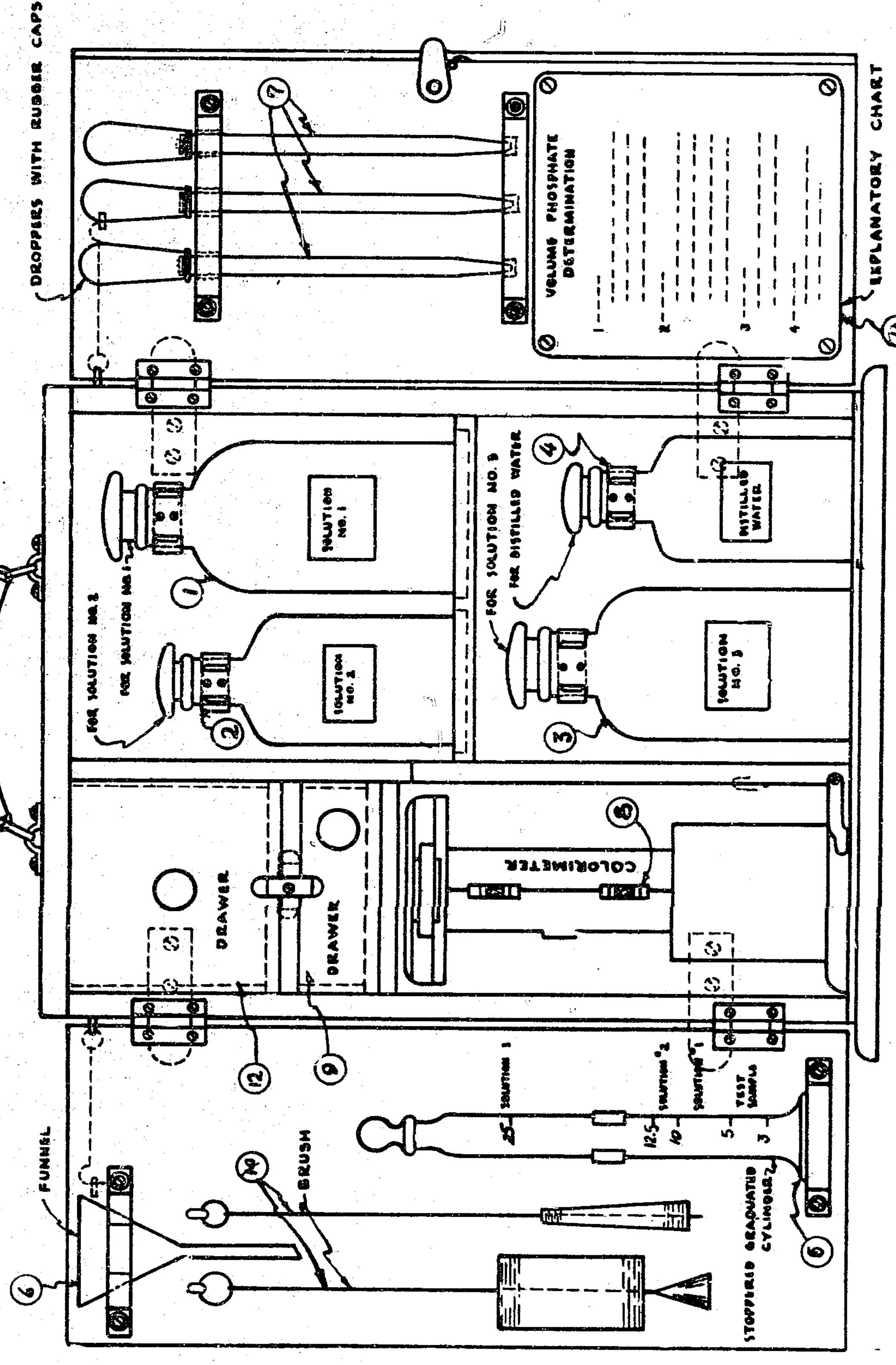


Figure 4(B)
APPARATUS FOR PHOSPHATE DETECTION

ENCLOSURE (B), continued

5. Cylinder Graduate with stopper (25cc) 1
This has the shape shown in Figure 4(B)(5) and is a colorless glass cylinder. It is marked at 3cc (to measure Reagent No. 2), at 5 (for test sample), at 10 (for Solution No. 1), at 12.5 (for Solution No. 2), and at 25 (for Solution No. 3). The reactions are conducted in this vessel.

6. Funnel (diameter 60mm). This has the shape shown in Figure 4 (B)(6) and is a colorless glass funnel used to filter the sample.

7. Medicine dropper with rubber cap. (3cc) 3
These have the shape drawn in Figure 4(B)(7) and are glass droppers with rubber caps. They are used to add amounts of each solution separately.

8. Colormeter. This has the shape shown in Figure 4(B)(8) and separately in Figure 5(B). It is a black colored compound color meter. It has two color cups Figure 5(B)(1), rotating standard color plate Figure 5(B)(2), and reflector Figure 5(B)(3). The color of the test solution which has previously been treated to give off this color is compared with that of the standard color plate. From this comparison, phosphate content is determined.

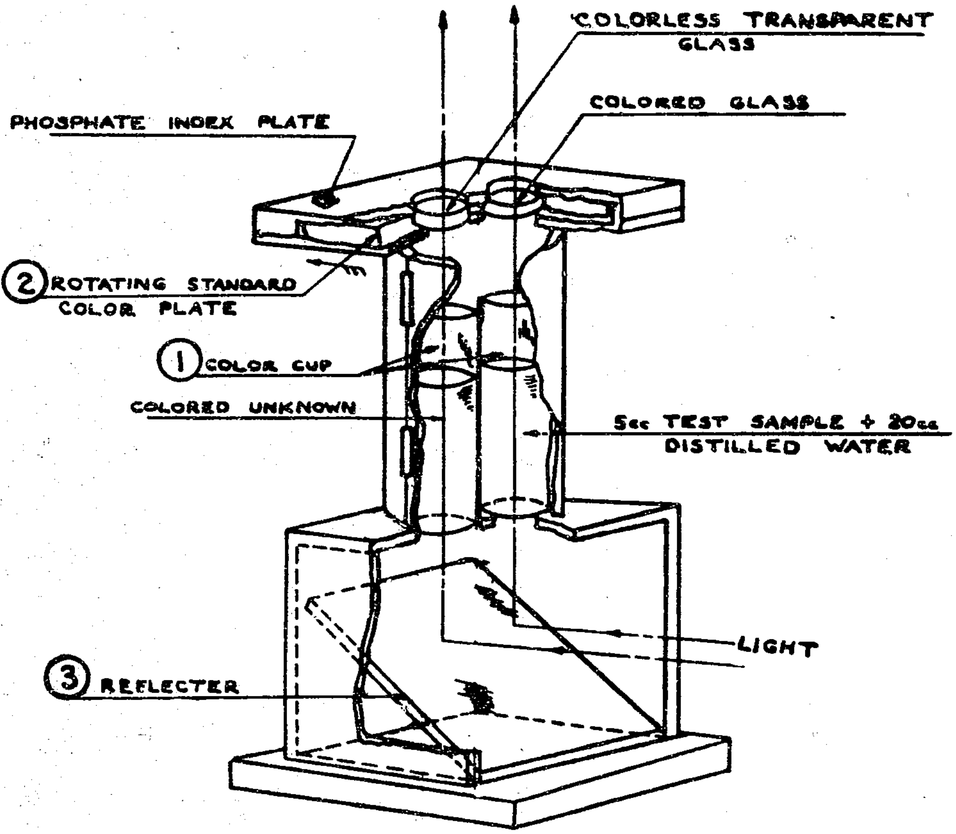


Figure 5(B)
COLOR METER

ENCLOSURE (B), continued

9. Drawer 1
This has the shape shown in Figure 4(B)(9). It is a drawer in which about 100 sheets of filter paper of 90mm diameter are placed.

10. Brush (one large, one small) 2
These have the shapes shown in Figure 4(B)(10) and are cleaning brushes. They are used to clean the reagent bottles, stoppered cylinder graduate, funnel, droppers, and color cups.

11. Instruction chart on phosphate determination 1
Mounted in celluloid case at position shown in Figure 4(B)(11).

12. Drawer 1
This has the shape shown in Figure 4(B)(12). This drawer contains additional reagents and miscellaneous articles.

13. Outer case 1
This is the case shown in Figure 4(B) and contains all the items listed above.

14. Sample bottles. There are two of these 50cc colorless stoppered bottles for each case. These are used to hold samples to be tested.

C. Quantitative Method.

1. Sampling procedure: Boiler water (50cc) is placed in the sample bottles, cooled to room temperature, and filtered into the graduated cylinder. This filtrate in 5cc lots is used for test samples.

Cold water may be poured over the sample bottles when it is desired to cool samples quickly.

The sample should be filtered even though it may appear to be clear; otherwise any calcium or magnesium phosphates that may be present will enter into the reaction and cause errors.

2. Preparing color solution: To the above mentioned 5cc samples in the graduated cylinder, there are added in order with the droppers, the No. 1 and No. 2 Solutions. The mixture is thoroughly shaken and after three minutes No. 3 Solution is added in the same manner. The cylinder is then stoppered and shaken thoroughly until color appears.

3. Color measurement: The colored solution is now transferred in its entirety to one of the color cups and the cup is placed directly under the colorless glass plate side of the color meter; 5cc of sample and 20cc of distilled water are put into the other color cup and this cup is placed on the standard color plate side of the color meter. The colors are then compared and the color plate rotated until the same shade is obtained, when the corresponding scale reading is taken. This gives the number of grams of phosphate in the boiler water (expressed as ppm). When the color of the test solution is between two standard colors, one uses his judgment to interpolate the value.

D. Preparation of Solutions.

The solutions used in this process are prepared in the following manner.

ENCLOSURE (B), continued

1. Solution No. 1. Two hundred and fifty cubic centimeters of reagent A for No. 1 solution (dilute sulfuric acid) are placed in the reagent bottle and into this is poured and dissolved the entire amount of reagent B for No. 1 solution (10 gm ammonium molybdate). Distilled water is added to make volume up to 500cc.

2. Solution No. 2. The entire amount of reagent for No. 2 solution (5 gm hydroquinone) is put into reagent bottle and dissolved in 250cc of distilled water; 3cc of reagent A for solution No. 1 are then added.

3. Solution No. 3. Prescribed amount of reagent A, solution No. 3 (15 gm sodium sulfite) is dissolved in about 400cc of distilled water. Reagent B, solution No. 3 (100 gm sodium carbonate) is dissolved into this and volume made up to 500cc with distilled water.

E. Cautions.

1. Since most of this equipment is glassware, it should be handled very carefully to avoid breakage.

2. To prevent decomposition and deterioration of solutions, reagent bottles should be tightly stoppered after use and stored in cool, dark places.

3. Only samples which have been allowed to cool to room temperature should be used.

4. Samples always should be filtered even though apparently clear.

5. Separate dropper should be used for each solution and there should be no mixing of the droppers.

6. Best results are usually obtained when the color readings are made about five minutes after color appears.

7. Since this color meter utilizes beams reflected by a white reflector placed near the base, it should be used at some brightly lighted location.

8. All parts should be cleaned after use and dried in preparation for the next determination.

Section VII

INFORMATION PERTINENT TO BOILER WATER CONTROL

A. Items Concerning Water to be Tested.

1. Physical properties of water: Pure water (H_2O) is a tasteless and odorless liquid at ordinary temperatures. It is colorless if contained in shallow depths and takes on a bluish color as depth increases. Its physical constants are as follows:

Density, water	0°	0.99987
	4°	1.
	100°	0.95838
ice	0°	0.9167
Boiling point	100°	(760mm)

ENCLOSURE (B), continued

Melting Point (freezing point) .... 0°
Specific heat .... 1°
Heat of fusion .... 79 calories
Heat of vaporization ..... 539 calories (100°)

Water exists in three states: solid, liquid, or gaseous, according to the temperature it is subjected to.

Although liquid water contracts with decreasing temperature, it has maximum contraction with resultant maximum density at 4°C. (1cc = 1 gm). As temperature is further reduced, specific volume increases conversely. This is a phenomenon other substances do not exhibit. One hundred cubic centimeters of water at 0° form about 110cc of ice at the same temperature. When water is heated to 100°C at one atmosphere pressure, it turns to steam. In this process, 1cc of water forms about 1650cc of steam. Water vapor can be formed from water or ice at temperatures below 100°C.

The heat which ice absorbs when it melts is called heat of fusion and the heat which water absorbs when it vaporizes is heat of vaporization. This heat is conversely given off when water freezes to ice or when steam condenses to water. The boiling point of water rises as atmospheric pressure on the water surface is increased. The relative rise is as follows:

Pressure (atm.)	B.P.°C.	Pressure	B.P.
1	100	50	265
10	181	60	277
20	213	70	287
30	235	80	295
40	251	100	312

2. Chemical properties of water: Water has a very great solvent power on all substances (especially inorganic). Being a solvent, it dissolves solutes to form solutions. Solutes of acid, base, or salt ionize in solution. Water not only acts as the solvent medium for chemical reactions, but is itself also easily decomposed or changed into its basic elements or other compounds. For example:

$2H_2O + 2Na = 2NaOH + H2$
water + sodium = sodium hydroxide + hydrogen

$H_2O + CaO = Ca(OH)2$
water + calcium oxide = calcium hydroxide

Even at high temperatures water very seldom decomposes, except at temperatures over 1000°C when there is a slight degree of decomposition ($2H_2O = 2H_2 + O_2$):

Temp. (°C)	Decomposition (at atmospheric pressure)
1200	0.02%
1730	0.6%
2000	1.80%
2650	11.00%

As temperature is increased, degree of decomposition increases, and as temperature is decreased there is a reversible reaction and water is re-formed.

ENCLOSURE (B), continued

3. Ionization properties of water: Although the degree of dissociation is very minute, water does partially dissociate to give positive and negative charged ions.

$$H_2O = H^+ + OH^-$$

Water = Hydrogen ion + Hydroxyl ion

If we should express this relation of the hydrogen ion, hydroxyl ion, and water concentrations, the following relation is derived:

$$\frac{(H^+) \quad (OH^-)}{(H_2O)} = K$$

Since the concentration of the undissociated water is very great compared to the dissociated ions, it may be considered constant. In the above relation (H^+) and (OH^-) may be assumed to be constant. If we designate this constant as "Kw", then:

$$(H^+) + (OH^-) = K(H_2O) = Kw$$

This Kw usually is called the electrolytic dissociation constant or ionization value of water. It always is constant at a given temperature. If the temperature is increased, however, there is a slight increase:

°C	Kw	°C	Kw
0	0.12×10^{-14}	60	0.93×10^{-13}
10	0.30×10^{-14}	70	2.1×10^{-13}
18	0.59×10^{-14}	80	2.3×10^{-13}
25	1.00×10^{-14}	90	3.6×10^{-13}
30	1.5×10^{-14}	100	5.1×10^{-13}
50	5.5×10^{-14}		

At about 250°C Kw is 10^{-14}. In pure water, moreover, the H^+ and the OH^- concentrations are the same; therefore, $(H^+) = (OH^-)$. That is to say the concentration of such ions is about 10^{-7}.

$$(H) = (OH) = \sqrt{10^{-14}} = 10^{-7}$$

We call water of this concentration neutral water.

Furthermore, if (H^+) (hydrogen ion concentration) is greater than 10^{-7}, that is to say, the (OH^-) (hydroxyl ion concentration) is less than 10^{-7}, this solution is acid. When (OH^-) is greater and (H^+) is less than 10^{-7}, then the solution is basic.

In order to express this hydrogen ion concentration, a hydrogen ion index is often used. This index is the logarithm of the reciprocal of the hydrogen ion concentration and is usually called pH.

$$pH = \log \frac{1}{(H^+)}$$

With neutral solutions

$$pH = \log \frac{1}{10^{-7}} = \log 10^{-7} = 7$$

ENCLOSURE (B), continued

This value, however, only holds for solutions at 25°C. When temperature is increased, the neutral pH value decreases as shown in Figure 6(B). That is to say, dissociation increases with rise in temperature and reaches a maximum at about 200°C.

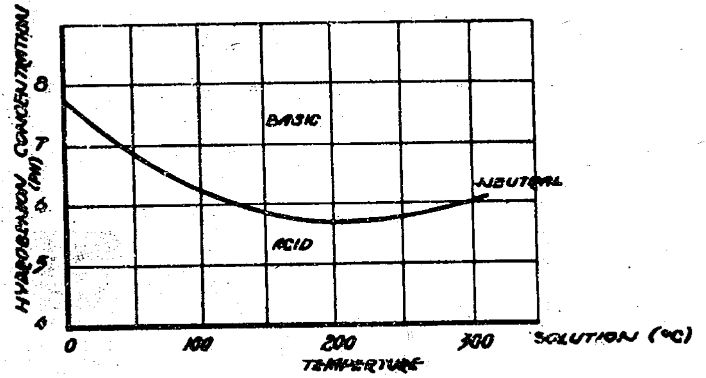


Figure 6(B)

HYDROGEN ION CONCENTRATION (pH)

4. <u>Characteristics of feed water</u>:

a. Feed water impurities.

(1) <u>Natural water</u>. This may be roughly divided into rain water, underground water, and surface water. In any case the water holds in solution air and carbon dioxide as a result of contact with the atmosphere.

Rain water is sometimes called natural distilled water, yet it contains chlorides from sea water, or picks up sulfates, ammonia, nitrates, nitrites, dust particles, microorganisms, etc., on its descent.

As water seeps through the earth it comes into contact with and dissolves various soluble materials from the earth's crust. These are mainly:

$NaCl$	Sodium chloride or table salt
KCl	Potassium chloride
$CaCl_2$	Calcium chloride
$MgCl_2$	Magnesium chloride
Na_2SO_4	Sodium sulfate
$MgSO_4$	Magnesium sulfate
K_2SO_4	Potassium sulfate
$Ca(HCO_3)_2$	Calcium bicarbonate
$Mg(HCO_3)_2$	Magnesium bicarbonate
Na_2CO_3	Sodium carbonate
$NaHCO_3$	Sodium bicarbonate
$CaCO_3$	Calcium carbonate
H_2SiO_3	Silicic acid
$MgCO_3$	Magnesium carbonate

Besides, there may be included organic, sulfate, nitrite, ammonium, etc., compounds of iron, aluminum, manganese, etc., which are products of decomposition of plant and animal origin. Surface water, moreover, may include all the aforementioned plus other products of decomposition of organic materials, nitrates, nitrites, chlorides, suspended material, microorganisms, etc.

(2) Distilled water. Water distilled artificially contains small amounts of impurities from the original distilled stock, besides fairly considerable amounts of air, carbon dioxide, and the like. It is very difficult to obtain truly pure distilled water.

b. Hardness of water. The lime and magnesia contained in water are responsible for the so-called hardness of water. The representation of hardness differs according to countries, but we generally use the German scale in which one milligram of lime (CaO) per liter of water is equivalent to one degree of hardness. In the case of magnesia, it is figured as a multiple of CaO.

$$MgO = 40, \quad CaO = 56$$
$$CaO = \frac{56}{40} MgO = 1.4\ MgO$$

By multiplying the magnesia value by 1.4, its equivalent in terms of lime is obtained.

The bicarbonates of calcium and magnesium are very soluble in water. By boiling these solutions, insoluble carbonates may be precipitated out.

$$\underset{\text{calcium bicarbonate}}{Ca(HCO_3)_2} = \underset{\text{calcium carbonate}}{CaCO_3} + \underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O}$$

$$\underset{\text{Magnesium bicarbonate}}{Mg(HCO_3)_2} = \underset{\text{Magnesium carbonate}}{MgCO_3} + \underset{\text{carbon dioxide}}{CO_2} + \underset{\text{water}}{H_2O}$$

In this manner, hardness due to the bicarbonates of calcium or magnesium can be removed simply by boiling; this is therefore called temporary or carbonate hardness. On the other hand, hardness due to the sulfates of calcium or magnesium cannot be removed by boiling and is called permanent or sulfate hardness. The sum of both hardness values is called total or overall hardness.

Temporary + permanent = Total hardness

Water from Japan is relatively soft in comparison with water from European sources, but water from Manchuria, North China, South Formosa, etc., is relatively hard.

c. Scale found in distilled water. If distilled water used on ships is analyzed, it always contains salts and residues of sulfates, silicates, etc., of calcium, magnesium, etc., which were present in the original water that was distilled, regardless of whether said water was from the sea, river, or pipeline.

The so-called natural distilled water, or pure rain water, and distilled water prepared in laboratories do not contain these scale forming substances. There is, therefore, no alternative but to accept the fact that in the process of distillation aboard ship, some of the impurities in the original water are carried over.

ENCLOSURE (B), continued

(1) Sea water. Sea water is said to contain about 3.5% (35 gm per kilogram) of salts. The relative amounts of the different salts are (unit %):

$NaCl$	77.7
$MgCl_2$	10.9
$MgSO_4$	4.8
$CaSO_4$	3.8
K_2SO_4	2.4
$CaCO_3$	0.3

Analyses of samples of water distilled from sea water are as follows (unit Mg/l):

Sample	1	2	3
SiO_2	0.40	0.60	0.43
CaO	0.42	0.31	0.49
MgO	0.63	0.46	0.61
SO_3	0.29	0.42	0.67
Cl	0.5	0.6	1.2
pH	5.3	5.6	5.9

Evaluation of these data can lead to but one conclusion, that the impurities found in the distillate must have come from the original sea water. It is also apparent why there are so many sulfates that are responsible for hardness. It is also thought apparent that whenever there is priming in the evaporator, it has a considerable effect on the amount of residue in the distillate even though there is no appreciable rise in salt content of the portion being distilled; therefore, priming should be avoided as much as possible.

(2) Piped water. Recently made analyses of water from water mains in different localities are given in Table XII(B).

Summing this up, it can be said that water from mains contains many more scale forming substances than distilled water. If compared with sea water, however, this amount is relatively less. Therefore, water from mains is better suited for boiler use as compared to sea water even though such water does contain some amount of scale forming substances.

d. Dissolved gases. Generally speaking, solubility of gases is inverse, decreasing with increasing temperature and increasing with increasing pressure. Air by volume is normally 20.96% oxygen, 79.01% nitrogen, and 0.03% carbon dioxide; therefore, air at one atmosphere pressure is the sum of 0.2096 atm. due to oxygen, 0.7901 atm. due to nitrogen, and 0.0003 atm. due to carbon dioxide. Also, the amount dissolved in water is proportional to the partial pressure of the gas in question, as clearly enunciated by Dalton's law of partial pressures. On the other hand, each gas has its own absorption coefficient. Therefore, at 0°C and 760mm the solubility of the gases in question in a unit volume of water is:

ENCLOSURE (B), continued

TABLE XII(B)

Place	SiO_2	CaO	MgO	SO_3	Cl	pH
YOKOSUKA	12.78	9.01	2.64	2.80	5.40	7.1
KURE	15.17	17.92	1.85	7.97	5.00	7.3
SASEBO	17.52	27.43	5.66	8.05	9.65	7.0
MAIZURU	4.60	9.17	3.60	10.02	12.05	7.1
ODOMARI	8.51	20.52	1.44	2.89	7.16	6.2
#WAKKANAI	21.19	8.01	1.93	5.28	34.00	5.9
OTARU	4.61	18.61	7.45	8.09	10.46	6.6
MURORAN	7.40	17.21	4.81	0.68	9.75	7.0
#HAKODATE	11.59	20.01	1.19	18.34	9.22	6.0
YOKKAICHI	18.79	18.01	8.02	0.41	10.46	6.5
#KOMATSUJIMA	5.99	22.01	1.44	7.47	11.35	6.5
#SUKUMO	7.70	33.32	1.48	5.48	8.51	6.8
#SHIMONOSEKI	10.40	26.81	4.06	0.55	13.83	7.1
#MOJI	7.60	34.41	2.76	0.28	11.70	6.9
#KAGOSHIMA	14.00	22.81	7.13	1.44	10.11	6.7
#SHIBUSHI	5.80	16.02	2.88	2.95	15.25	6.8
GENZAN	3.41	25.21	1.44	2.19	5.67	7.0
FUZAN	4.00	19.22	4.08	7.06	8.51	6.5
*DAIREN	10.40	36.02	2.41	34.01	158.90	7.2
*RYOJUN	11.19	30.04	1.93	16.39	119.30	7.1
*AOJIMA	9.20	38.02	10.40	1.03	30.85	6.5
*SHANGHAI	3.21	36.43	1.44	18.65	76.06	6.9
*NANKING	12.80	30.81	1.44	14.93	7.09	7.0
#HANKOW	3.60	22.01	1.44	16.45	9.04	7.3
HONGKONG	7.19	10.01	1.20	0.82	6.03	6.7
KIIRUN	4.19	10.40	1.44	0.27	14.18	6.4
*MAKO	15.60	24.01	2.91	19.52	165.58	7.6
*TAKAO	15.32	74.03	24.45	52.10	7.09	7.5
CANTON	3.21	24.01	1.45	6.51	8.86	6.9

Notes

1. Values other than pH values are expressed in mg/l.

2. Those marked "*" are considered unsuitable for boiler use; those marked "#", more or less unsuitable. With piped water, however, it must be expected that there will be a considerable variation in salt content even from a single source according to the time and place of sampling.

ENCLOSURE (B), continued

	Absorption Coefficient	x	Partial Pressure	=	Absorbed Amount
O_2	0.0489		0.2096		0.01024
N_2	0.0235		0.7901		0.01855
CO_2	1.713		0.0003		0.00051

From this it can be inferred that at 0°C and one atm. pressure, 100 parts of dissolved air will theoretically be composed of 34.96 parts O_2, 63.28 parts N_2, and 1.75 parts of CO_2. The variation in the dissolved components of a saturated solution at one atm. pressure with increasing temperature is given in Table XIII(B).

TABLE XIII(B)

	Temp.	0	20	40	60	80	100
O_2	cc/l	10.19	6.35	4.48	3.28	1.97	0
	mg/l	14.56	9.08	6.40	4.68	2.87	0
N_2	cc/l	18.44	11.90	8.67	6.49	4.03	0
	mg/l	23.06	14.88	10.84	8.11	5.03	0

These are, however, theoretical values. Actual values are usually greater. In order to get the actual values to approach the theoretical, mechanical operations such as stirring, agitation, or heating are necessary. Dissolved oxygen is expended in oxidation reactions.

e. Dissolved oxygen. (TN: Next two sentences illegible).

When an air-tight water filler is not used.

Within feed tank .... 3.5 - 4.5 mg/l.
Outlet of feed water heater 2.5 - 3.5 mg/l.

When an air-tight water filler is used.

At condenser pump outlet .. 0.1 - 0.3 mg/l.
At outlet of feed water heater 0.05 - 0.1 mg/l.

Furthermore, under optimum high pressure power conditions with an air-tight filter, there have been cases when this value has dropped to as low as 0.03 mg/l at the outlet of the feed water heater.

f. Dissolved carbon dioxide. At room temperature, one liter of pure water dissolves about 30 mgs of calcium carbonate and 800 mgs of magnesium carbonate. If carbonic acid is present in solution, however, the carbonates are changed to bicarbonates with a resultant increase in carbonates (actually bicarbonates) in solution; therefore, it may be said that the carbonic acid content of water increases hardness of water and plays a great role in the corrosion of metals.

ENCLOSURE (B), continued

g. Solubility of salt mixtures. The presence of other salts in solution has a very great influence on the solubility of a substance. For example, the solubility of calcium sulfate is 2.69 gm per liter at 40°C, but this solubility is greater in the presence of ammonium salts or sodium chloride.

B. Items Concerning Boiler Corrosion.

1. Principles of corrosion: The decomposition of solids by water is called corrosion. This is a chemical or electrochemical surface phenomenon. As a result of corrosion, parts of machines which are in contact with water become weakened or riddled with holes, resulting in a rather hazardous condition. This is called spot-corrosion (TN Literal). Besides this, corrosion by very small spots, called macula corrosion, (TN Literal) and by grooves, called groove corrosion (TN Literal) occur. Continued use of a substance which has started to corrode results in increased oxidation and formation of rust and further exposure to water makes corrosion even more effective. What could be the cause of corrosion? Dunstan has formulated the following theory. The primary cause of corrosion is the action of a thin film of water on a part. This is so, no matter how thin this film of water may be. This corrosion does not occur just because the metal comes in contact with oxygen. Thus it is that water is responsible for the initial phases of corrosion and this initial phase makes way for the second, third, etc. phases.

2. Cause of boiler corrosion: It is extremely difficult to explain the theory of boiler corrosion and even today there is no one theory which everybody accepts. This is because boiler corrosion is complicated by a number of factors, types of material used, shape of materials used, treatment of materials, method of feeding water, method of handling, etc., and it is not possible to account for all these factors so simply. Leaving purely chemical speculation aside, it may be thought that boiler corrosion is a result of electrochemical action. The boiler becomes a sort of battery. The iron oxide on the surfaces of the boiler and the impurities contained within the iron itself acquire a negative charge on contact with water while the iron itself acquires a positive charge. Thus, there is a potential difference resulting in a flow of current and gradual disintegration of the metal itself. It is thought that this theory is most acceptable to explain corrosion.

The following discussion is an attempt to explain in a simple manner the problems of corrosion from an electrochemical standpoint.

a. Normal electrode potentials. It is well accepted by electrochemical people that when a metal is immersed in water, potential is set up. This potential is usually figured by the following formula:

$$E = \frac{0.000198T}{n} \times \log \frac{P}{p}$$

When P = Solution (electrode) potential of metal in question.
p = Osmotic pressure of metallic ion in solution.
T = Absolute temperature of solution.
n = Valence of metallic ion.

According to this formula, P is constant for any one metal but p will depend on concentration of solution. If solutions of different metals are held at the same concentration, that is, that p is made constant, we get a measure of the relative values of P by determining the magnitude of E in each case because P will be the only independent variable.

The value of E determined under the above given conditions is known as normal electrode potential. Furthermore, this potential is an index of the ionization tendency of any metal. Standard potentials for some of the more commonly used metals are:

Metal	Ion	Potential (volts)	Metal	Ion	Potential (volts)
Gold	Au^{++}	+1.50	Cadmium	Cd^{++}	-0.40
Platinum	Pt^{++}	+0.86	Iron	Fe^{++}	-0.43
Silver	Ag^{++}	+0.80	Chromium	Cr^{++}	-0.60
Copper	Cu^{++}	+0.34	Zinc	Zn^{++}	-0.76
Hydrogen	H^{+}	0	Manganese	Mn^{+++}	-1.00
Lead	Pb^{++}	-0.13	Aluminum	Al^{+++}	-1.27
Tin	Sn^{++}	-0.14	Magnesium	Mg^{++}	-1.80
Nickel	Ni^{++}	-0.22	Sodium	Na^{++}	-2.72
Cobalt	Co^{++}	-0.29	Potassium	K^{++}	-2.92

The values given in this table are relative values with respect to a single hydrogen potential taken as zero. Those metals with positive potentials are displaced by hydrogen, in other words those metals will cause hydrogen to go into solution as ions. Those with negative potentials unite with oxygen to displace hydrogen. As the arithmetic value increases, this tendency to displace increases.

b. <u>Corrosion of iron</u>. It has already been mentioned that water of any purity dissociates into hydrogen and hydroxyl ions as shown in the following equation:

$$H_2O \rightleftharpoons H^{+} + OH^{-}$$

If iron is placed in this system, the following reaction results, releasing free hydrogen and forming ferrous ions.

$$Fe + 2H^{+} + OH^{-} \rightleftharpoons Fe^{++} + 2H + 2OH^{-}$$

This is to say, hydrogen with a low ionization tendency is deprived of its charge by iron which has a greater ionization tendency and collects on the surface of the iron as atomic or molecular hydrogen. If this reaction continues to the extent that the iron surface is enveloped by free hydrogen, the iron can no longer ionize and an equilibrium is established.

Taking the above equilibrium at 18°C and substituting:

$$-0.43 + \frac{0.000198 \times 291}{2} \log (Fe^{++}) = \frac{0.000198}{2} \times 291 \log (H^{+})^2 - 0.18$$

where $(Fe^{++}) = 4.6 \times 10^8 \times (H^{+})^2$

The -0.18 volts represents the over voltage that must be put in to liberate hydrogen gas, assuming there is no oxygen in solution.

When this system is in equilibrium, the Fe^{++} ion concentration is 4.6×10^{8} times the square of the H^{+} ion concentration. In other words, iron goes into solution until this concentration is attained. Therefore, in a solution when the H^{+} ion concentration is high, there is a corresponding enormous corrosion of iron. As previously noted, however, the H^{+} ion concentration of pure water is so very small, about 10^{-7} at 22°C, that as long as there is no oxygen in solution, there is only a very small amount of corrosion. Therefore, the statement that "Pure water that contains no dissolved oxygen does not corrode iron" is not absolutely wrong. Of course, this is not always so in practical application and there is also a change in conditions with increasing temperature. It is not always wrong to say "Water in all forms has corrosive action on iron."

c. Relation of dissolved oxygen to corrosion. The foregoing theoretical discussions were made on the assumption that there was no dissolved oxygen. In reality, however, there is a certain amount of oxygen in solution which has a marked effect on the rate and amount of corrosion.

(1) Corrosion resulting from oxidation of hydrogen. As previously noted, corrosion of iron is determined by the H^{+} ion concentration. When dissolved oxygen is present, there is the added reaction as given below when iron is being converted to its ion and hydrogen is oxidized.

$$\underset{\text{iron}}{Fe} + \underset{\substack{\text{hydrogen}\\\text{ion}}}{2H^{+}} + \underset{\substack{\text{hydroxyl}\\\text{ion}}}{2OH^{-}} = \underset{\substack{\text{iron}\\\text{ion}}}{Fe^{++}} + \underset{\text{hydrogen}}{2H} + \underset{\substack{\text{hydroxyl}\\\text{ion}}}{2OH^{-}}$$

$$\underset{\text{hydrogen}}{2H} + \underset{\text{oxygen}}{\tfrac{1}{2}O_2} = \underset{\text{water}}{H_2O}$$

Thus, the hydrogen turns to water, and the overvoltage (-0.18 volts) required to liberate hydrogen gas is not needed. Then there is not equilibrium and the trend shifts so that there is an abnormal production of Fe ions. In other words, formation of Fe ion is hastened with a resultant increase in rate of corrosion.

(2) Corrosion resulting from oxidation of ferrous ions. Simultaneously with the above reaction, oxygen oxidizes the Fe^{++} (ferrous) ion to Fe^{+++} (ferric) ion. As shown in the preceding equation, a solution of Fe causes increase of OH^{-} ions. These ions combine with the dissolved ion to form ferrous hydroxide, $Fe(OH)_2$. If there is oxygen in solution, this ferrous hydroxide is oxidized to ferric hydroxide, $Fe(OH)_3$, which precipitates out as rust.

$$\underset{\substack{\text{ferrous}\\\text{hydroxide}}}{4Fe(OH)_2} + \underset{\text{oxygen}}{O_2} + \underset{\text{water}}{2H_2O} \longrightarrow \underset{\substack{\text{ferric}\\\text{hydroxide}}}{4Fe(OH)_3}$$

Thus, iron precipitates out and as the Fe^{++} ion concentration decreases, more iron goes into solution and this reaction continues indefinitely as long as there is oxygen in solution.

ENCLOSURE (B), continued

(3) <u>The Evans Hypothesis</u>. Evans has experimentally checked the relation of dissolved oxygen to corrosion and made the following statement. In brief, "When iron is immersed in water and one part is subjected to an excess of oxygen in solution, there is a potential difference set up between that part with the excess (−) and the part with low (+) oxygen. Thus a local circuit is formed and the part with low oxygen is subjected to corrosion."

(4) <u>Relation between amount of dissolved oxygen and rate of corrosion</u>. According to experiments conducted up to the present, it can be shown that the intensity of corrosion is roughly proportional to the amount of dissolved hydrogen. Figures 7(B) and 8(B) show some experimental results which clearly indicate this relation.

A certain German engine manufacturing firm has made the following statements which are of interest:

"When the oxygen content of boiler feed water was at least 0.5 mg/l, spot corrosion of 0.1 - 0.2mm in the boiler was observed after two months and about 0.6mm after six months.

"When oxygen content was maintained at 0.2 - 0.3 mg/l, degree of corrosion was negligible and the boiler tubes were considered suitable for long use.

"In high pressure, high temperature boilers, it is necessary to cut down the oxygen content as much as possible and a maximum content of 0.1 mg/l is considered ideal.

"A special gas bleeder should be installed. This should be able to cut down oxygen content to at least 0.05 mg/l. Other literature strongly recommends use of feed water with maximum oxygen content at 0.03 mg/l in boilers operating at 40 kg/cm^2 pressure or more."

The above discussion on the relation of dissolved oxygen to corrosion may be summarized as follows:

(a) In water that has been completely freed of dissolved oxygen, a very small amount of iron goes into solution as soluble ferrous hydroxide. Since there is no oxidation to insoluble ferric hydroxide, no rust is formed. The solution of iron also stops as the solubility limit is reached.

(b) Even if the water does contain oxygen, if this supply is limited, rust will be formed, but a limit at which solution of iron stops is finally approached with the depletion of dissolved iron.

(c) In water with a limitless source of oxygen, there is a continuous production of rust and corrosion which continues until all the iron is dissolved.

d. <u>Relation of dissolved carbon dioxide to corrosion</u>. Any factor which tends to change the H^+ ion concentration has an effect on rate of corrosion. This seems apparent from the discussion up till now. If we accept this statement, it is all

ENCLOSURE (B), continued

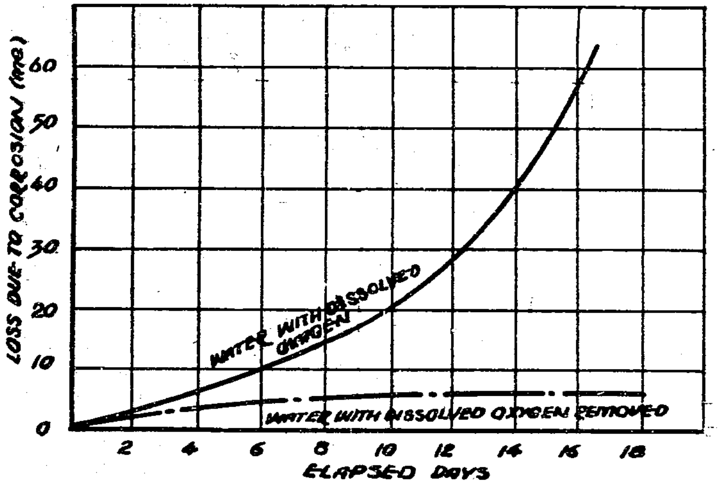


Figure 7(B)
RELATION BETWEEN AMOUNT OF DISSOLVED OXYGEN
AND RATE OF CORROSION

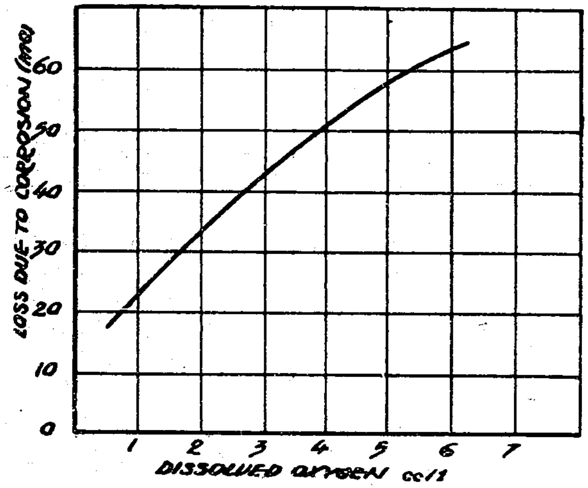


Figure 8(B)
RELATION BETWEEN AMOUNT OF DISSOLVED OXYGEN
AND RATE OF CORROSION

too apparent that dissolved carbon dioxide affects corrosion. This is because the solution of carbon dioxide increases hydrogen ion concentration in the following manner. Going into a more detailed discussion:

When carbon dioxide is dissolved in water, carbonic acid is formed. This acid partially dissociates giving H^+ ion and HCO_3^- (bicarbonate) ions. Thus, H^+ ion concentration of the solution is increased.

$$\underset{\text{water}}{H_2O} + \underset{\text{carbon dioxide}}{CO_2} = \underset{\text{carbonic acid}}{H_2CO_3}$$

$$H_2CO_3 = \underset{\text{hydrogen ion}}{H^+} + \underset{\text{bicarbonate ion}}{HCO_3^-} \text{ (ionization)}$$

Thus the corrosion of iron is hastened.

Dissolved carbon dioxide exerts still another bad influence. As corrosion takes place, the carbonic acid neutralizes the ferrous hydroxide that is formed giving rise to an unstable condition. (Since ferrous hydroxide is alkaline, its presence prohibits corrosion.) Again, carbonic acid decomposes under high temperatures and pressure and produces carbon dioxide gas. This gas acidifies the steam and causes corrosion of the superheater, steam pipes, turbines, etc.

$$\underset{\text{carbonic acid}}{H2CO3} = \underset{\text{water}}{H2O} + \underset{\text{carbon dioxide}}{CO2}$$

Summing it all, it may be said without reservation that dissolved carbon dioxide increases rate of corrosion. Also, the presence of both oxygen and carbon dioxide in solution has added destructive effects.

e. Effect of dissolved salts on corrosion. Most dissolved salts directly affect corrosion. A scanning of chemical literature gives the words of Hay (TN: Phonetic) and Bauell (TN: Phonetic) who conducted a series of corrosion experiments at constant temperature in the presence of air (TN: Probably dissolved air) and classified salts in two general classes:

(1) Corrosion is hastened with increasing concentration of certain salts in solution until a certain limit past which rate of corrosion becomes inversely proportional to concentration. The chlorides and sulfates of sodium, calcium, and magnesium have this property.

(2) Certain salts cause corrosion up to a certain limit, past which they have no effect on corrosion. This is what is called a critical concentration. Many alkaline compounds such as sodium carbonate, sodium hydroxide, and trisodium phosphate possess this property. In brief, salts in general have a marked effect on corrosion in almost all concentrations.

f. Effect of salt in feed water. The chloride content expresses the corresponding salt content of feed water and its function is almost identical with what is noted above. It should be remembered that, generally speaking, increase in salt

ENCLOSURE (B), continued

content increases conductivity of solution and corrosion is naturally affected proportionately. There are also certain salts like magnesium chloride which on dissociation form a complex ion causing an increase in hydrogen ion concentration and, therefore, an increase in rate of corrosion.

The alkalinity of the boiler compound now in use is capable of checking corrosion at constant high temperature and pressure, but even this cannot be too effective when salt content increases.

The following experimental results bear out this point:

(1) A newly polished boiler plate exposed to constant temperature and pressure, alkaline content of 130 gm/kg., and no salt content, did not rust. When salt content of 5 gm/kg was added, rusty spots were noticed after five hours.

(2) Even though alkaline content was increased to 250 and to 400 gm/kg, salt content of 75 gm/kg caused spot corrosion after six hours.

(3) When alkaline content was increased to 1000 gm/kg, salt content of 250 gm/kg caused spot corrosion after five hours.

This can be summed up in the statement that the effect on corrosion of salt contained in feed water is much greater than we had supposed.

Figures 9(B) and 10(B) show the relation of salt content to corrosion.

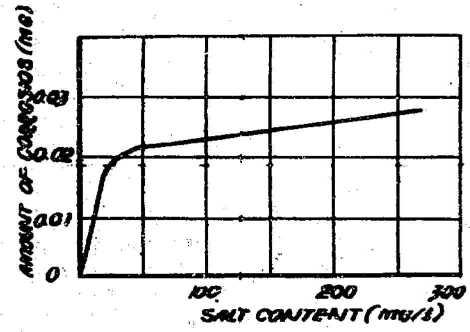


Figure 9(B)

RELATION OF SALT CONTENT TO CORROSION

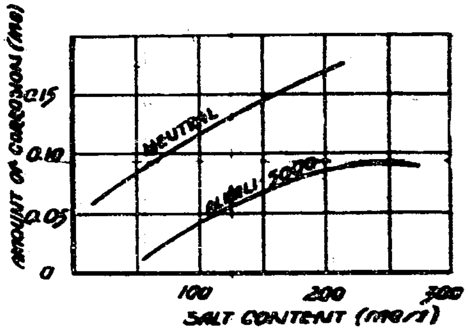


Figure 10(B)

RELATION OF SALT CONTENT TO CORROSION

ENCLOSURE (B), continued

These tests were made with pieces of boiler plate 50cm^2 in area which were immersed 50 hours in tap water of varying salt concentrations.

g. Relation of material to corrosion. No matter how carefully a metal is processed, its finish is not homogeneous, a point which is of great importance in these discussions.

Boiler materials differ in thickness, treatment, or composition according to the requirements of the part in question. When these different parts are bonded by contact with water, potential differences are set up and local batteries are formed resulting in flow of current. Any piece that becomes positive goes into solution, a basic factor of corrosion. The other factors work on this spot where corrosion has begun and enhance the damage.

3. Methods of preventing corrosion within boiler: How can we prevent boiler corrosion? This can be answered very simply. The best way would be to select materials which would resist corrosion under all conditions. This is, however, not very easily done because of technical, economic, or other considerations. In our work, therefore, we carefully follow the method described previously, using boiler compounds, and try to limit to a minimum the factors which were discussed in theory.

a. Keep feed water intake system in good working order. Keep air out as much as possible, thereby limiting dissolved oxygen and carbon dioxide content to a minimum.

b. Constantly check performance of condenser and keep in good working order. Keept salt content of feed water at a minimum.

c. Maintain alkali content within boiler at specified level to prevent increase in hydrogen ion concentration or decrease in pH value.

d. Use sodium phosphate as soon as possible to form a protective layer of iron phosphate and see that this layer is not destroyed.

e. Blow-down at appropriate intervals to prevent rise in salt content.

C. Scale.

1. Composition of scale: As mentioned previously this consists of non-volatile solutes together with insoluble material, dust, and other small particles suspended in the water. The main constituents are usually lime, magnesia, and silicic acid. The lime and magnesia are commonly found in sulphate and carbonate compound form, and sometimes as silicates.

There are two types of scale: hard and soft. The composition of these types is usually as follows:

Main composition of hard scale: sulphate salts of lime and magnesia ($CaSO_4$, $MgSO_4$).

ENCLOSURE (B), continued

Main composition of soft scale: carbonate salts of lime and magnesia: ($CaCO_3$, $MgCO_3$); hydroxides of lime and magnesia ($Ca(OH)_2$, $Mg(OH)_2$); non-crystalline silicates of lime and magnesia ($CaSiO_3 \cdot xH_2O$, $MgSiO_3 \cdot xH_2O$); non-crystalline free silicic acid (H_2SiO_3).

From comparing the results of tests of the composition of scale deposited in boilers in actual use, the following is deduced.

a. Scale deposited in the boiler tubes of boilers on land, using tap water supply:

TABLE XIV(B)

	Boiler Compound Tested (%)			
Scale Composition	1		2	
	Inner	Outer	Inner	Outer
$CaSO_4$	24.45	3.86	29.75	1.68
CaO	2.09	5.83	2.38	5.17
MgO	19.45	26.84	19.38	24.32
Al_2O_3	0.48	0.88	0.57	0.32
Fe_2O_3	6.08	9.71	4.02	9.86
SiO_2	29.77	33.44	25.67	38.11
Amount of heat reduction	13.70	17.12	12.58	16.98

Scale indicated in this table is that deposited on tubes inside boilers used on land and supplied with tap water. "Inner" and "Outer" indicate respectively, the side of the boiler next to the fire and the opposite side. The water used was Maizuru Navy-use water, and boiler cleaning chemicals (TN: Chemicals to prevent corrosion) were not used.

As is clearly shown in this table, it is known that when tap water is used for feed water, an extremely large amount of hard scale ($CaSO_4$) will form. Moreover, it should be carefully kept in mind that the calcium sulphate ($CaSO_4$) which constitutes hard scale, is chiefly deposited in large quantities on the "fire" side, i.e. the side toward the furnace.

The same type of scale was deposited in another boiler. The scale deposited on the side toward the fire was extremely hard. It was almost impossible to remove, even using tube cleaning tools or boiling with boiler cleaning chemicals.

b. Scale deposited inside tubes of marine boiler, using distilled water for feed:

ENCLOSURE (B), continued

TABLE XV(B)

Scale Composition	Boiler Compound Tested (%)		
	1	2	3
$CaSO_4$	0.18	0.11	0.31
CaO	1.22	1.09	1.34
MgO	3.48	10.23	2.81
Al_2O_3	0.05		0.03
Fe_2O_3	55.28	53.73	58.87
SiO_2	5.98	13.27	5.80

The scale indicated in this table was that deposited in a marine boiler using distilled water. The disposition of the deposit was uniform, with no marked difference between the side toward the furnace and the opposite side.

Detailed information on the distilled water is unknown, but most of the scale was iron rust, with very little hard scale.

c. Scale deposited in steam drum of high pressure super-heating boiler, using mixed equal parts of distilled water and tap water for feed:

TABLE XVI(B)

Scale Composition	Boiler Comp. Tested (%)	
	1	2
Amount of heat reduction	10.88	12.00
Oil	2.54	1.02
SiO_2	7.05	21.56
CaO	3.37	1.40
MgO	0.91	0.86
SO_3	0.56	0.33
Fe_2O_3	40.01	45.36
Al_2O_3	0.57	0.38

Scale indicated in this table is that deposited in steam drum of 40 kg/cm^2 pressure, 400°C super-heating boiler, using feed water composed of distilled water and tap water mixed in equal parts. It is soft scale with few sulphates. Moreover, in regard to the boiler water, when No. 3 sodium phosphate was used as a boiler cleaning chemical, and a degree of alkalinity of about pH 11.0 was maintained, almost nothing resembling scale was deposited in the boiler tubes.

Results of tests of feed water and boiler water used in this case are shown in Table XVII(B):

ENCLOSURE (B), continued

TABLE XVII(B)

	Feed Water (mg/l)	Boiler Water (mg/l)
SiO_2	2.0	13.6
Fe_2O_3	0.8	1.4
Al_2O_3	3.6	6.5
MgO	7.5	1.8
CaO	3.3	Traces
Cl	7.7	120.5
SO_3	1.3	21.2
P_2O_5		Traces
pH		11.1

Degree of hardness of water, 0.5

We may deduce the following from the results of this test:

(1) Since carbon and magnesia in the boiler water are reduced to about 1/15 of the amount in the feed water, they are almost eliminated. They are believed to be precipitated in the form of phosphate salts as a result of the action of the boiler cleaning chemicals.

(2) The fact that most of the silicic acid remains in the boiler water is believed to be a result of the fact that it is left in the boiler water in the form of sodium silicate, because of the high degree of alkalinity.

(3) Most of the sulfuric acid is left in the boiler water, probably as the result of the fact that calcium sulphate, which constitutes hard scale, was not precipitated.

In view of the results of the foregoing tests, we can make the following statements:

(1) If plain tap water is used, the deposit of hard scale will be extremely heavy.

(2) If distilled water is used, the deposit of hard scale will be light.

(3) If suitable boiler cleaning chemicals are skillfully used, it is possible to eliminate hard scale almost completely.

(4) Hard scale is deposited mainly on parts having high temperatures, soft scale on parts having comparatively low temperatures.

(5) If hard scale is once deposited, it is very difficult to remove completely by any method whatsoever.

In the above-mentioned tests, the results with the boiler which used distilled water and the one which used boiler-cleaning compound differed radically from those in the boiler which used tap water. It appears that in the former, the amount of rust was extremely large. However, in these, the amount of scale was very small, whereas in the latter, because of the large

ENCLOSURE (B), continued

amount of scale its ratio was increased. It has no connection with the total amount of rust.

2. Opportunities for formation of scale: In regard to the questions of how the scale producing materials which enter the boiler in feed water form scale, and how this scale is deposited, we now present the results of various experiments made by famous scientists. The conclusions which these men have reached are not to be regarded as absolutely perfect, but there is considerable truth in them, and we agree with them although not completely.

In the following we present first, the general theory of scale formation, and then attempt to set forth the theory which these men developed, adding a simple explanation.

a. General theory. As the various dissolved substances which constitute scale forming material in feed water have different degrees of solubility, and even the same substance has different degrees of solubility depending on temperature and pressure, it is very difficult to know accurately the actual condition of these materials in the boiler; however, in general it is believed that scale formation takes place in the following manner.

The scale forming materials which were fed into the boiler along with the feed water are left in the boiler in increasing concentration as steam is given off from the boiler. Whenever their degree of solubility reaches the saturation point, they are precipitated and deposited as solids, and form scale.

This explanation is greatly simplified, but basically we always return to it.

b. Hall theory. In regard to the relation of degree of solubility and temperature, for water containing dissolved materials, there are some substances whose degree of solubility increases and some whose degree of solubility decreases, as the temperature rises. Mr. Hall, on the basis of this fact, explains the process of the formation of scale as follows:

In the substances dissolved in feed water are some for which the relation between temperature and degree of solubility is positive (+) and some for which it is negative (-), i.e., if degree of solubility at temperature T is S, there are substances for which the gradient of the solubility curve dS/dT will be (+) and some for which it will be (-). Now when the feed water containing solutes passes through the boiler tubes the temperature rises, heating greatly the part of the water directly in contact with the inner walls of the tubes. As a result, substances whose dS/dT is (-) such as calcium sulphate ($CaSO_4$), are brought directly to saturation in this section, and are deposited as crystals on the walls of the tubes. When the base point of crystallization is thus reached, a condition of saturation will always exist in this section, and the formation of crystals will continue as long as heat is not withdrawn. Thus, hard scale is formed in the tubes. In contrast to this, substances whose dS/dT is (+), such as calcium carbonate ($CaCO_3$), will always be in a situation of non-saturation in hot places. Therefore, they will not form scale in these parts, but on the other hand will reach a condition of saturation or super-saturation in cool places, such as the inside surface of boiler drums, and will be ~~deposited~~ as solids ~~there~~.

ENCLOSURE (B), continued

This is to say that hard scale will be formed in high temperature sections because of solutes in the feed water whose dS/dT is (-), while soft scale will be formed in low temperature sections because of solutes whose dS/dT is (+). Comparison with the tables of composition of scale presented earlier reveals that this agrees with the facts.

However, there are cases where scale composed chiefly of $CaCO_3$ is deposited in high temperature sections, so that sometimes this theory alone is insufficient.

c. Stumpel's (TN: Kana spelling "Sutsumuperu") theory. In regard to the formation of hard scale, composed mainly of calcium sulphate ($CaSO_4$), Mr. Stumpel has a three-step explanation, as follows:

(1) When feed water comes into contact with the surface of tubes which have been heated to a high temperature, calcium sulphate in the feed water comes directly to a condition of saturation and is precipitated directly on the hot surface. Furthermore, its crystals gradually increase at right angles to the heated surface.

(2) The fine grains of anhydrous calcium sulphate which were formed in the feed water absorb water of crystallization and are changed to hydrous calcium sulphate ($CaSO_4 \cdot 2H_2O$). As a result, the fine crystals start to precipitate and form a solid on top of the calcium sulphate crystals formed according to the preceding process.

(3) When sulphate ions (SO_4^{--}) in the boiler water reach a sufficient concentration to form calcium sulphate, they gradually change calcium carbonate ($CaCO_3$), which had been forming in the boiler as soft scale, to stable calcium sulphate.

d. Partridge's theory. Partridge explains the formation of scale as follows:

When boiler water comes into contact with evaporation surfaces heated to a high temperature, the degree of solubility of gases contained in the water decreases, and gas bubbles are formed on the evaporation surface. Furthermore, the water, by evaporation, forms steam bubbles on the evaporation surfaces. Thus, as shown in Figure 11(B), there is on the evaporation surface a circular line AB where three strata, steam (or gas) bubbles, water, and solid (tube walls) are in contact at the same time.

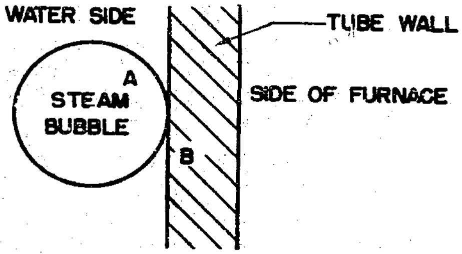


Figure 11(B)
THREE STRATA IN CONTACT ON EVAPORATION SURFACE

ENCLOSURE (B), continued

However, the heat conductivity of the steam bubble is very low in comparison with that of the water, so that the evaporation surface in direct contact with the steam bubble (Circle AB) suddenly becomes super-heated.

Therefore, the boiler water in the ring AB where all three strata are in contact will suddenly increase in temperature and start to evaporate. Solutes will be brought directly to a condition of super-saturation. Accordingly, substances whose dS/dT is (-), such as calcium sulphate, will be directly deposited as crystals. (In actual experience its form is usually ring-shaped.) Moreover, as this process continues for a long time, in a boiler in actual use, this scale which is deposited in ring form gradually spreads until it covers the whole surface of the tube walls.

This method of reasoning applies whether dS/dT is (+) or (-). If dS/dT is (+), the boiler water in AB in the diagram reaches an extremely high temperature and the degree of solubility increases. However, as the evaporation of boiler water nearby will at this time be very rapid, the limit of solubility will be reached immediately, and likewise crystals will be deposited. At the time the steam escapes, crystals which have once been formed may again be dissolved by the non-saturated boiler water nearby, and the process described above repeated by escaping steam, so that crystals are again deposited.

Moreover, it is believed that the force depositing crystals by production of bubbles is generally stronger than that dissolving them. This is proved by the fact that calcium carbonate crystals are sometimes deposited in the boiler evaporation tubes.

In other words, the disposition of deposits varies depending on whether the solubility coefficient dS/dT of materials in the feed water is (+) or (-). It is believed that the former are deposited under conditions of low temperature, and form a comparatively coarse sediment. The latter are deposited under conditions of high temperature and form comparatively fine crystal scale.

As an explanation of the formation of scale in high temperature sections, this view is a very interesting theory. However, Hall's theory is more widely held.

However, if we accept this theory that the formation of scale is caused by the production of bubbles, in something like the Benson boiler, which is used at critical pressures, scale should not be formed, but it is authoritatively reported that even the Benson boiler is considerably troubled by the deposition of scale.

e. Chemical theories. Let us take a look at chemical aspects of the formation of scale.

(1) Calcium carbonate and magnesium carbonate. As indicated above, the calcium carbonate in natural water is ordinarily acid calcium carbonate, $Ca(HCO_3)_2$. This is generally unstable, so that when a solution of it is boiled, it readily gives off carbon dioxide gas (CO_2), and the normal salt of calcium carbonate, $CaCO_3$, which has a low solubility, is precipitated.

Thus, when water including calcium carbonate is fed into the boiler, CO_2 is immediately driven out, and a non-viscous scale of precipitated calcium carbonate results. However, in water which at the same time contains calcium sulphate, part may be attracted by this and enter into hard scale.

Magnesium carbonate precipitates a soft material in exactly the same way, but at times it is further broken down by heat, unites with calcium sulphate, and forms an extremely bad, hard scale.

(2) Scale formed by magnesium sulphate. Since magnesium sulphate has a far higher degree of solubility than calcium sulphate, the chances of its forming scale are comparatively slight. However, when calcium carbonate is present, the following reaction may take place at high temperatures, and a bad scale, composed of the compounds calcium sulphate and magnesium hydroxide, result.

$$MgSO_4 + CaCO_3 + H_2O = CaSO_4 + Mg(OH)_2 + CO_2$$

(3) Scale formed by magnesium chloride. The degree of solubility of magnesium chloride is extremely great, so by itself it will not form scale. However, at high temperature and pressure it often forms scale by the following reaction:

$$MgCl_2 + 2H_2O = Mg(OH)_2 + 2HCl$$

(4) Scale formed by floating matter. Floating matter is ordinarily precipitated as soft scale, but at times it is oxidized and included in other scale to form hard scale.

In other words, the process of scale formation is extremely complicated, and many processes are believed to exist. However, in the end they all come down to solutes in the feed water and other physical and chemical processes. As a result, the first positive problem in the prevention of scale is the elimination, as much as is possible, of impurities in the feed water.

3. Characteristics of scale and its elements.

a. General characteristics.

(1) Calcium sulphate, $CaSO_4$. Calcium sulphate is extremely hard and fine-grained, and scales in which it is the chief element are very difficult to remove. Once this scale has been deposited, not only can it absolutely not be removed by ordinary cleaning equipment, etc., but even if boiling with boiler cleaning chemicals is carried out it will hardly accomplish more than a softening of part of the surface. Furthermore, since dS/dT ~~of the degree of~~ solubility of calcium sulphate is (-), it is generally deposited in parts receiving intense heat, i.e., the inside of the boiler tubes nearest the fire. Therefore, it is the cause of many boiler explosions.

ENCLOSURE (B), continued

(2) Magnesium silicate ($MgSiO_3$), calcium silicate ($CaSiO_3$). Scale composed chiefly of these is hard and rocklike, and has the characteristic of not absorbing water. Therefore, even though the amount deposited is small, it is extremely bad, just like calcium sulphate.

The dS/dT of the degree of solubility of these compounds is (-), so that they are deposited chiefly on hot parts. However, when actually deposited as scale, they often become soft, non-crystalline SiO_2, so that the danger is not as great as that from calcium sulphate.

(3) Calcium carbonate ($CaCO_3$), magnesium carbonate ($MgCO_3$). These usually form soft and porous scale, so that elimination and removal of them is comparatively easy. Moreover, the dS/dT of their degree of solubility is (+), so that the places where they are deposited are as a rule low temperature parts i.e., inside the boiler drum, etc. They are also deposited in quantity when the boiler is cooled. The above presents the chief individual characteristics of the main elements of scale. However, actual scale is extremely complicated, with these elements intercombined, or with floating matter or oil particles included. Although some have dS/dT (-), like calcium silicate, the majority are precipitated as soft non-crystalline sediment.

b. Heat conductivity of scale. The main elements of scale produced and deposited in boilers may be divided generally into sulphates and carbonates, depending on whether the scale is hard or soft. However, as was clearly shown in the tables of test results, the percentages of principal composition and other composition differs radically depending on the water used, the use of boiler cleaning chemicals, etc. Therefore, it is practically impossible to determine the heat conductivity of various scales. Even if this were determined, it would not be of much value for practical use.

If we know the general value for the principal types of scale that is sufficient for practical purposes. The heat conductivity of principal types of scale, tested by the author, is as follows:

Type of Scale	Heat Conductivity (K Cal/mhC)
Chiefly calcium sulphate	0.5 - 2.0
Chiefly silicate salts	0.2 - 0.5
Chiefly carbonate salts	0.4 - 0.6

This is to say, calcium sulphate, which is bad as scale, has comparatively good conductivity.

Carbonate salts at times form extremely coarse porous scale. At these times its conductivity may reach 0.07. When it is deposited lightly, or when it is deposited in the boiler tubes, it seldom causes tube explosions.

Furthermore, for reference we have investigated the heat conductivity of materials related to scale. They are as follows:

ENCLOSURE (B), continued

Soft steel	50 - 60
Soot	0.06 - 0.1
Oil film	0.1

c. <u>Solubility of boiler scale formation compounds</u>. It has been previously stated that among the boiler scale formation compounds there are those whose solubilities rise with temperature increase and others whose solubilities fall. To be more specific, the solubility rises until a certain temperature is reached and once that temperature is passed, it falls. In other words, there are compounds whose solubility curves have extremely high values.

The general relationships between temperature and solubility can be classified into the following three groups:

(1) Compounds whose solubilities rise with temperature increase.

(2) Compounds whose solubilities fall with temperature increase.

(3) Compounds whose solubilities rise with temperature increase, but which fall after reaching a critical temperature.

In each case, it is a common fact that the solubilities of the scale formation compounds, compared to those of other salts, are extremely low.

It can easily be seen, however, that there will be some variance in these solubilities due to factors beside temperature, such as pressure and other salts.

Figure 12(B) shows the temperature-solubility relationship for the principal scale formation compounds, calcium sulphate and calcium carbonate.

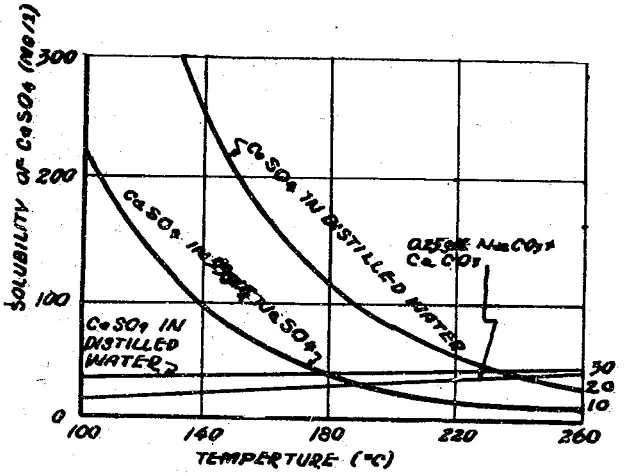


Figure 12(B)

TEMPERATURE-SOLUBILITY RELATIONSHIP FOR THE PRINCIPAL SCALE FORMATION COMPOUNDS

ENCLOSURE (B), continued

It can be seen that the solubility of calcium sulphate falls rapidly with increase in temperature, while the solubility of calcium carbonate rises only slightly with temperature increase.

In Table XVIII(B) is given the approximate specific solubilities of the different scale formation compounds. In this table, solubilities near normal temperature are given under the column on low temperatures and high solubility are given in the high temperature column.

TABLE XVIII(B)

Scale	Amount of Solubility (mg/l)		
	Low Temp.	Medium Temp.	High Temp.
$CaCO_3$	12.5(24)	-	20.0(100)
$Ca(OH)_2$	1650(20)	-	110(190)
CaO	1230(20)	-	80(190)
$CaSO_4$	2085(25)	2.100 (45)	61(200)
$MgCO_3$	22,100(18)	-	9500 (50)
$MgSO_4$	26,200(20)	364,000 (75)	14,000(200)
$Mg(OH)_2$	9.1(18)	-	0.4(100)
MgO	2.14(29)	-	-

<u>Note</u>

( ) indicate temp. in °C

We are able to learn the following facts from this table:

(1) The value of dS/dT for solubility is negative for the sulphate and carbonate salts of magnesium, but at high and low temperatures their solubilities are much greater than for other salts. Consequently, there is little opportunity for these compounds to form salts.

(2) The solubility of calcium sulphate is very great at normal temperatures (actually 38°), but at the temperatures we use, its solubility decreases sharply with temperature increase.

(3) The dS/dT value of calcium carbonate is positive, but since the solubility increase with temperature increase is small, the amount of solubility is small.

(4) Both calcium hydroxide and magnesium hydroxide have negative values of dS/dT. The actual amount of solubility for the former at normal temperature is 1600 mg/l, and at high temperatures (190°C) is 110 mg/l. On the other hand the amount of solubility for the latter is less than 1/100 of these values.

4. <u>Effect of scale on the boiler</u>: As mentioned previously, scale reduces the heat conducting efficiency of the boiler (with soft iron 1/50 - 1/100). Its occurrence not only decreases boiler efficiency, but also causes bends and swellings in the boiler tubes and may often, in very extreme cases, cause ruptures. Summing up the damage to boilers resulting from scale:

ENCLOSURE (B), continued

Scale causes overheating of boiler tubes resulting in bent, swollen, or ruptured tubes.

Scale decreases the heat absorbing capacity of boiler water with resultant decrease of boiler efficiency. In other words, fuel need is increased. Relative to ships, this means a decrease in cruising range.

Since all this is true, everyone who works with boilers should guard very closely against the formation of scale.

a. Overheating of boiler tubes as a result of scale formation.

It is not very difficult to see how formation of scale in the boiler tubes will prevent conduction of heat and cause overheating on boiler tube surfaces. There have been many actual cases where the inner steam tubes have burst because of scale formation inside.

Let us now try to figure the degree of overheating in boiler tubes resulting from scale formation. This increment is usually represented by the following formula:

$$d\theta = \frac{Q\ Ds}{2Ks} \log R$$

(Refer to Figure 13(B).)

$d\theta$ = Amount of overheating of surface of boiler tubes
Q = Thermal conductivity (K cal/hm^2)
Ds = Outer diameter of scale (m)
ds = Inner diameter of scale (m)
Ks = Coefficient of thermal conductivity (K cal/hm°C)
R = Difference of inner and outer diameters of scale

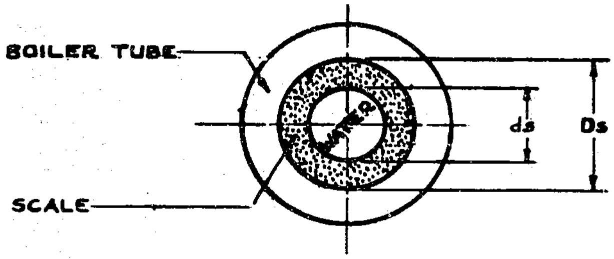


Figure 13(B)

DIAGRAM FOR COMPUTING DEGREE OF OVERHEATING IN BOILER TUBES

If we now apply this formula to the inner steam tubes (first row diameter 32mm) of a boiler operating at 50 kg/cm^2 water pressure with the following assumed constants, we get the results given below:

Constants: Q .... 478,500 K cal/hm^2
Ks ...... 1.5 K cal/hm°C.

ENCLOSURE (B), continued

Thickness of scale (mm)	0.2	0.6	0.8	1.0	1.5	2.0
Temperature increase (°C)	60	180	250	300	420	590

Temperatures within the boiler are:

Boiler water temperature .... 262°C.

Difference from temperature of water film directly adjacent to tubes (assumed) ..... 30°C.

Difference from temperature of tube wall (estimated) .... 38°C.

Using the above figures, we get these values:

Thickness of scale	0.2	0.6	0.8	1.0	1.5	2.0
Temperature at surface of boiler tube	390	510	580	630	750	920

All this goes to show that as thickness of scale increases, there is an extraordinary rise in tube wall temperature. Furthermore, we can apply the certified working temperature limit of the boiler tube and estimate the maximum allowable thickness of boiler scale.

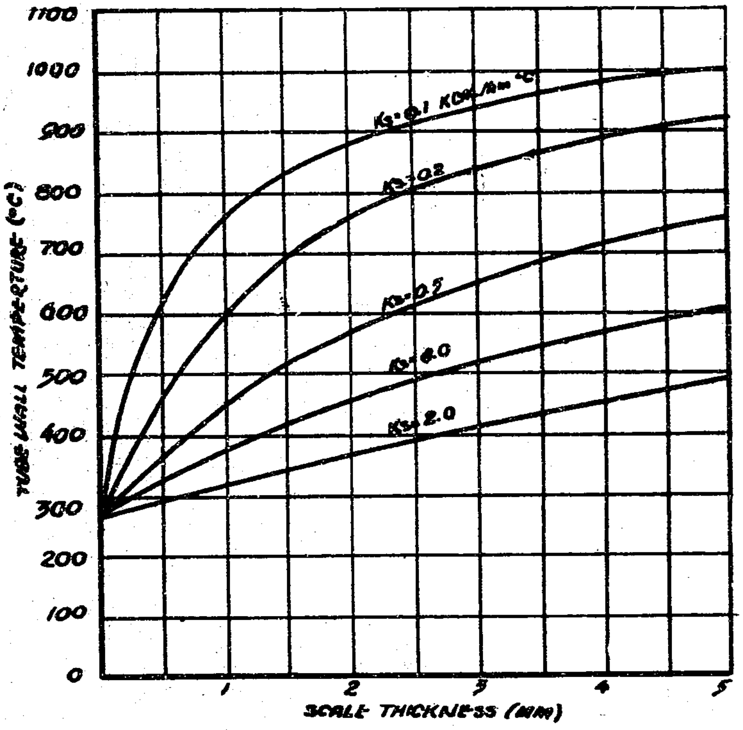


Figure 14(B)

RELATION OF SCALE THICKNESS TO TUBE WALL TEMPERATURES AT WATER PRESSURE OF 15 kg/cm^2

ENCLOSURE (B), continued

For example, when ordinary seamless steel tubes (soft steel) are used, boiler scale thickness of 0.8mm or more is very dangerous. We have thus far assumed in these computations that thermal conductivity remains constant, independent of scale thickness, but actually if scale thickness should exceed one mm, thermal conductivity decreases and so decreases the efficiency of the boiler itself. The work of Stumpel, who studied the relation of scale thickness to tube wall temperatures at water pressure of 15 kg/cm^2 and expressed the relation in terms of coefficient of thermal conductivity, is shown in Figure 14(B).

This is to show that as coefficient of thermal conductivity decreases, there is an abnormal rise in tube wall temperature.

b. Losses resulting from scale formation. As mentioned previously, scale formation decreases boiler efficiency and increases the amount of fuel required. The following data show the increased need of fuel, together with heat loss, relative to incidence of boiler scale.

TABLE XIX(B)

Scale Thickness (mm)	Increase in Fuel (%)	Scale Thickness (mm)	Heat Loss (%)
0.5	5	0.5	3-6
1.0	10	1.3	11
1.6	15	2.5	15
3.2	30	6.4	20
6.5	60	13.0	100-150
13.0	150		

Heat loss classified by composition of scale is as follows:

TABLE XX(B)

Scale Thickness (mm)	Type of Scale	Main Components	Heat Loss (%)
0.51	hard	carbonates	5.4
0.79	hard	carbonates	8.5
1.59	hard	carbonates	12.4
0.79	soft	carbonates	7.2
1.02	soft	carbonates	8.0
1.59	soft	carbonates	11.0
1.02	hard	sulphates	9.3
1.59	hard	sulphates	11.1
1.54	soft	sulphates	10.8
2.63	hard	sulphates	15.9

As shown above, boiler scale has a marked effect on boiler efficiency; therefore, we should exert every effort to prevent boiler scale formation.

5. Methods of preventing boiler scale: The use of chemically pure distilled water will satisfactorily prevent scale formation, but this is impractical at present. As we have already mentioned, when tap water or even so-called distilled water is used as feed water, it is

ENCLOSURE (B), continued

unavoidable that there will be an eventual scale formation with resultant undesirable influences. It behooves us, therefore, to conceive methods to prevent scale formation, or accepting the fact that scale formation is unavoidable, to conceive methods to neutralize the effects of this formation. This is all the more important when the boiler in question is a high temperature and pressure type. All our methods to prevent scale formation are summed up in the two following paragraphs.

a. Pass water through some suitable treatment before its entry into the boiler to remove scale forming components (method of extra-boiler treatment.)

(1) Distillation method. This is the practice followed by our ships. It need not be repeated that all efforts should be made to utilize maximum performance of evaporator and condenser to obtain product of maximum purity.

(2) Heating combined with lime treatment. This method is used principally with water possessing temporary hardness.

b. Use a boiler compound in some convenient method to precipitate in insoluble form and remove those compounds that are responsible for the formation of hard scale. (Method of internal boiler treatment). The following should be closely adhered to in the execution of this method.

(1) Maintain phosphate concentration constantly at specified level.

(2) Periodically use the bottom-blow to clean out the boiler to prevent increase in salt concentration of the water itself, and remove the soft scale compounds formed by the reaction of boiler compound.

D. Other Related Items.

1. Method of expressing concentration of boiler water: There are various methods in use and the methods most widely used are briefly explained below.

a. gm/ton or g/t. This expresses concentration of salts in grams per metric ton of water.

gm/ton = gm/1,000,000 gm

In other words this is expressed as parts per million.

b. mgm/l = milligrams per liter. This gives milligrams of salt per liter of water.

mgm/l = mgm/1,000,000 mgm

This also is equivalent to parts per million.

c. 1/1,000,000 or ppm. This is number of parts of salt per million parts of water and is actually a boiling down of (1) and (2). Parts per million is abbreviated to ppm.

ENCLOSURE (B), continued

d. 1/100,000. This gives concentration per 100,000 parts of water. This is equivalent to a multiple or 10 ppm.

e. Grains/gallon. This is in terms of grains of salt per gallon of water.

$$1 \text{ gr/gal} = 0.0638 \text{ gm}/4.546 \text{ liters} = 0.0638 \text{ gm}/4,456 \text{ gm} = 63.8 \text{ gm}/4.546 \text{ kg} = 14.5 \text{ gm/t}.$$

In other words:

$$14.5 \text{ gm/t} = 1 \text{ gr/gal}.$$

The above mentioned methods may be equated as follows;

$$\text{gm/t} = \text{mgm/l} = 1/1,000,000 = 1 \text{ ppm} = \frac{0.1}{100,000} = 0.069 \text{ gr/gal}.$$

2. Significance of boiler water concentration:

a. Degree of alkalinity. The alkalinity of boiler water is the so-called phenolphthalein alkalinity determined by titration with phenolphthalein as indicator and the value is expressed in grams of sodium hydroxide per ton of water. Besides this, there is methyl orange alkalinity using methyl orange as indicator, but at the present time the Navy does not use this method.

b. Salt content. Salt content refers to the grams of chlorine (Cl) per ton of boiler water (or feed water, condenser water, etc.). Since it is fairly safe to assume that actual salt content is proportional to chloride content, this method is a simple way of expressing salt content. As salt (NaCl) content increases, content of other salts may be assumed to increase accordingly. Also, most chlorides are very soluble and insoluble chlorides are rather scarce. We can thus estimate the relative concentration of salts from feed to boiler water. For example: Salt content of feed water 5 gm/t; salt content of boiler water 45 gm/t; then 5/45 = 1/9. This means that the boiler water has been concentrated to 1/9 of its original volume.

c. Phosphate concentration. Phosphate concentration is the number of grams of anhydrous phosphorous pentoxide (P_2O_5) per ton of water. There are certain substances which are combinations of two or more separate elements which act like single distinct elements. For example, the ammonium chloride molecule consists of the ammonium (NH_4) grouping and the chloride atom. In the case of phosphoric acid or phosphates the PO_4 grouping acts as a distinct atom and combines with hydrogen or metallic elements. The nitrate and sulphate groupings also belong to this category. These groupings are called radicals. The phosphate radical refers to the PO_4 grouping. These radicals exist as ions in solution but do not exist in the free state; therefore, P_2O_5 is used to express phosphate content. P_2O_5 is anhydrous phospheric acid and is derived by the following formula:

$$2H_3PO_4 - 3H_2O = P_2O_5$$

d. Titration value (titre) true and concentration density. When water from a boiler that is being fired is tested with the now used boiler water tester and the phosphate analyzer, there

ENCLOSURE (B), continued

is a certain difference in alkalinity, salt content, phosphate content, etc. between the titration values (titres) and true values for the following reasons.

(1) When a sample is being extracted from the boiler a portion of the water naturally is lost by evaporation, making the remaining solution slightly more concentrated. The value obtained from a titre of this solution is, therefore, slightly greater than the true value. This concentration due to evaporation is theoretically about 22, 26, and 30% for boiler pressures of 20, 30, and 40 kg/cm^2 respectively.

(2) Within the boiler itself the amount of dissolved gases varies with the amount of heat applied and the true alkalinity necessarily varies with the amount of gases in solution. Although it is difficult to estimate this amount accurately, using the half-fired boiler water as standard, there is approximately 10 - 20% left when fully fired.

3. Permissible salt content of boiler water: As previously mentioned, the greater the salt content the greater the damage wrought and the less the salt content the better for boiler use. The question now arises what is the permissible limit of salt content. We refer to the Naval Engineering Manual for the following specifications.

Kampon type tube boiler (fuel oil with air preheater)	150 ppm
Kampon type tube boiler (fuel oil)	200 ppm
Kampon type tube boiler (mixed firing, coal)	400 ppm
Tube boilers other than Kampon type	700 ppm
Cylindrical boiler	1000 ppm

It must be remembered, however, that these figures are excessive from the standpoint of corrosion.

4. Alkalinity and pH: *Alkalinity is determined by titration and is* a measure of the total alkalinity regardless of whether or not the substance dissociates on solution; pH, however, expresses only the concentration of the dissociated portion (in relation to substances which are alkaline with respect to water). It depends upon the substance itself, therefore, whether or not the total alkalinity coincides with pH value.

Sodium hydroxide, for example, is assumed to be totally ionized in very dilute solutions; therefore, its total alkalinity and pH value run close together and each can be calculated in terms of the other. With sodium phosphate and similar compounds, the degree of ionization is small and alkalinity and pH cannot be easily correlated.

On the other hand, the sodium phosphate now being used as boiler compound may be thought to owe its entire alkalinity to sodium hydroxide and may therefore, be computed in terms of its pH value. Sodium carbonate may also be thought of as ionized sodium hydroxide; therefore, its total alkalinity may be considered on terms of pH. The relation between alkalinity and pH of sodium hydroxide is given in Figure 15(B).

ENCLOSURE (B), continued

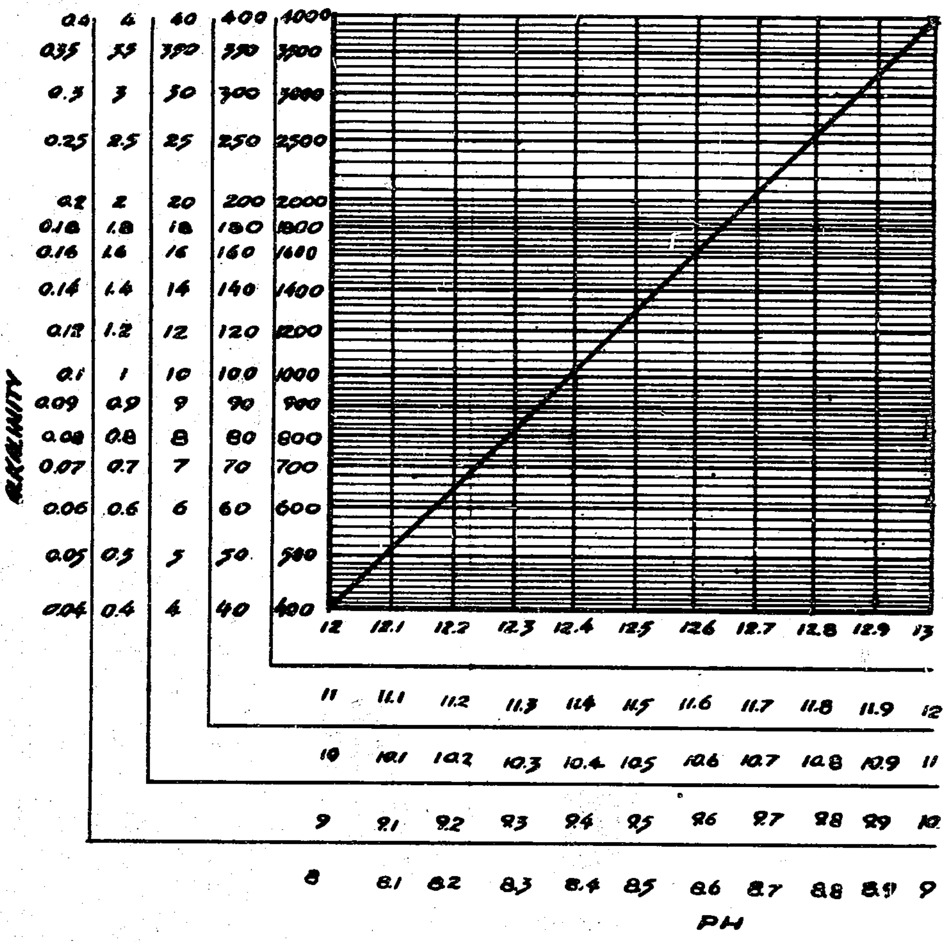


Figure 15(B)

RELATION BETWEEN ALKALINITY AND pH OF SODIUM HYDROXIDE

5. Weakening by effect of alkali (caustic embrittlement): This problem and its remedies are being studied by investigators in all countries, but as yet no suitable answer is in sight. In fact there are some who dispute whether there is any weakening effect caused by alkali.

a. Limits at which weakening occurs. This weakening becomes apparent when alkalinity is at least 40,000 mgm/l and the iron is being stressed to near its elastic limit. It may be thought, therefore, that at the present standard of 250 mgm/l or less there need be no concern. There is, of course, the chance that alkali will concentrate at seams and the like and cause weakening. Therefore, such places should be carefully checked during overhaul.

b. Mechanics of weakening. When the sodium hydroxide concentration exceeds any given value, then

$$NaOH \rightleftharpoons Na^+ + OH^-$$

ENCLOSURE (B), continued

The (OH^-) concentration increases and reacts with iron to liberate hydrogen:

$$3Fe + 4OH = Fe_3O_4 + 4H$$

This hydrogen immediately permeates the crystal structure of the iron resulting in an eventual weakening of the iron. In general, the impurities within the iron accumulate at the surfaces of the crystal. The permeated hydrogen reduces any oxides present at these surfaces and produces water vapor which has a tremendous volume. As a consequence, the crystalline structure is greatly weakened and splits open, causing a visible fracture. Now, if there is a stress on the plate, then a break in the boiler may result. Therefore, fissures or breaks resulting from alkali differ from mechanical breaks in that they occur at the borders of the crystals themselves.

c. Weakening by alkali versus hydrogen. A study of the literature shows one school which considers both to be of the same final result, while another school maintains they are distinct processes. The basis for thinking that both are distinct lies in the fact that examinations of test pieces show that a piece weakened by hydrogen retains most of its original elastic modulus while a piece weakened by alkali has its modulus reduced. Furthermore, hydrogen weakening can be prevented by heat treatment while alkali weakening cannot thus be prevented. Thus, hydrogen and alkali weakenings are considered distinct, separate processes.

d. Other items. The following are some items found:

(1) Straub claims, on the basis of his experiments, that alkali in the form of Na_2CO_3 has a destructive effect on iron at a concentration of about 6,000 gr/gal which is equivalent to 8.2% NaOH (82,000 mgm/l).

(2) He further claims that this effect can be avoided by a suitable amount of sodium sulphate. This is about three parts of Na_2SO_4 to each part of Na_2CO_3 for a tank operating at 20 kg/cm^2 pressure.

(3) It is also claimed that phosphates and nitrates possess this neutralizing effect.

(4) Some writers claim pure sodium hydroxide has no weakening effect, but that it is the occluded impurities such as silicates which are responsible.

(5) There are some who even claim there is no such thing as alkali weakening. In brief this so-called phenomenon is the subject of various explanations and there is still no plausible theory to which most people will subscribe.

POSTWORD

There are many more things that could be said here. We have not mentioned the over-all precautions to bear in mind in handling boiler water. We have not really delved into the chemistry and physics of the subject since it is felt that this is beyond the scope for which this publication is intended. If the contents of this text can be followed for the treatment of boiler water in some suitable manner and can serve as an aid to efficient boiler operation, then this writer will feel that his work has been amply rewarded.

ENCLOSURE (C)

LIST OF DOCUMENTS FORWARDED TO THE BUREAU OF SHIPS

Boiler Design Drawings

NavTechJap No.		
ND50-1950.1	BB YAMATO	Boiler assembly
.2		Details of steam and water drums
.3		Steam drum attachments
.4		Boiler tubes
.5		Downcomers
.6		Superheater drum
.7		Piping attached to superheater drum
.8		Front casing
.9		Firebrick arrangements
.10		Internal feed pipe
.11		Bottom blow valve
.12		Main and aux. feed water valve
.13		Main steam stop valve
.14		Safety valve
.15		Pilot valve for safety valve
.16		Internal superheater steam pipe in steam drum
.17		Float box for feed water regulator
.18		Steam baffle
.19		Dry pipe
.20		Combustion chamber baffle plates
ND50-1951.1	DD AKITSUKI	Steam drum details
		Tubes
.2		Tube layout
.3		Downcomer tube layout
.4		Alt. tubes of boiler tube plugs
		Superheater
.5		Tube layout
.6		Drum details
.7		Manhole
.8		Drum baffle
.9		Drum baffle
		Fittings, Gas side
.10		Furnace access door
.11		SH tube support plate
		Casing
.12		Front details
.13		Front details
.14		Furnace front
.15		Furnace rear
.16		Rear details
.17		Side details
.18		Furnace bottom
.19		Gas baffle plates
.20		Burner front support
		Brickwork
.21		Furnace front wall
.22		Furnace rear wall
.23		Furnace bottom

ENCLOSURE (C), continued

Boiler Design Drawings (cont.)

NavTechJap No.			
	DD	AKITSUKI	Insulation
ND50-1951.24			Casing
.25			Casing
			Blower Fittings, Steam Side
.26			SH inlet valve
.27			Burner oil supply tubes
.28			Main and aux. stop valve fitting
.29			Water column shut-off valve
.30			Press. relieving valve
.31			SV pilot
.32			SV relieving assembly
.33			Saturated steam stop
.34			Main feed check
.35			Aux. feed check
.36			Main feed stop
.37			Special wrenches
.38			Water gauge glass (BB)
.39			Water gauge glass (Jorgensen)
.40			Main and aux. stop valve filling
.41			WC piping spools
.42			WC piping spools
.43			Smoke-maker nozzle
.44			Erection tools
.45			SH piping
.46			Erection trams
.47			Name plate
.48			Instruction plates
.49			Fittings--instruction burner sequence
.50			Drum intervals
.51			Internal feed pipe
.52			Bottom-blow strainer
.53			Screw fitting pipe
.54			Burner number plates
.55			SH inlet valve reach rod
.56			Main stop valve reach rod
.57			Aux. stop valve reach rod
.58			Bottom-blow valve reach rod
.59			Air vent valve reach rod
.60			Hand relieving gear
.61			Hand relieving gear
.62			Hand relieving gear
.63			Furnace peep-hole door open rig
.64			Main steam flange
.65			SV inlet valve reach rod
.66			Piping gaskets
.67			Valve name tags
.68			Phonograph finish met. gasket
.69			SH pipe supports
.70			Inner casing revisions
.71			SH drain reach rod
.72			Bottom-blow reach rod
.73			Gauge valve fitting
.74			Water sample fitting
.75			SV drain valves
.76			Air vent valve
.77			SH drum drain valve
.78			SH inlet drain valve
.79			Pressure gauge shut-off valve

ENCLOSURE (C), continued

Boiler Design Drawings (cont.)

NavTechJap No.			
	DD	AKITSUKI	Soot Blowers
ND50-1951.80			Soot blower head
.81			Soot blower arrgt. and elem. detail
.82			Soot blower elbow supports
			Casing Seats
.83			Pipe stuffing boxes, inner casing
.84			Pipe stuffing boxes, inner casing

Acceptance Run Records

ND50-1952.1	BB	YAMATO (1 of 2)
.2	BB	YAMATO (2 of 2)
.3	BB	MUSASHI
.4	CV	SHOKAKU (1 of 3)
.5	CV	SHOKAKU (2 of 3)
.6	CV	SHOKAKU (3 of 3)
.7	CV	SHOKAKU
.8	CV	TAIHO (outline)
.9	CV	TAIHO
.10	CVL	ZUIHO
.11	XCV	HIYO
.12	XCV	JUNYO
.13	CVL	CHIYODA (ex CVS - converted 43)
.14	CA	TONE
.15	CVE	KAIYO
.16	DD	AKITSUKI
.17	DD	HATSUZUKI
.18	DD	NOWAKI
.19	DD	YUKUMO
.20	SS	I-1
.21	SS	I-6 (outline)
.22	SS	I-6
.23	SS	I-7 (2 of 10 dated Nov. 36)
.24	SS	I-7 (dated Jan 37)
.25	SS	I-7 (dated 8 Mar. 37)
.26	SS	I-7 (17 Mar. 37)
.27	SS	I-7 (starboard engine)
.28	SS	I-7 (port engine)
.29	SS	I-7 (port engine)
.30	SS	I-9 (dated 26 Sept. 40)
.31	SS	I-9 (dated 1 Oct. 40)
.32	SS	I-12
.33	SS	I-15
.34	SS	I-16
.35	SS	I-54
.36	SS	I-61
.37	SS	I-62 (outline)
.38	SS	I-62
.39	SS	I-65
.40	SS	I-68
.41	SS	RO-33
.42	CVS	MIZUHO
.43	AV	AKITSUSHIMA
.44	AS	TAIGEI (converted to CVL RYUKO)
.45	CM	OTORI
.46	CM	WAKATAKA
.47	CM	YAEYAMA

ENCLOSURE (C), continued

Acceptance Run Records (cont.)

NavTechJap No.		
ND50-1952.48	PG	UJI
.49	AGS	TSUKUSHI
.50	AK-AO	SHIOYA
.51	AO	SUNOSAKI
.52	AG	HAKACHI
.53	AM	No. 12
.54	AM	No. 17
.55	LSM	No. 151
.56	CMc	No. 1
.57	CMc	NASAMI
.58	CMc	SAISHU
.59	CMc	SARUSHIMA
.60	ESCORT VESSEL	No. 1
.61	ESCORT VESSEL	No. 18
.62	ESCORT VESSEL	ETOROFU
.63	SC	No. 1
.64	SC	No. 53
.65	Stores Ship	KASHINO
.66	TB	CHIDORI
.67	AS	TAIGEI (outline)

Miscellaneous

ND50-1952.68	Mark 2, Model 10 Int. Comb. Engine #1392
.69	Mark 2, Model 10 Int. Comb. Engine #1492
.70	Mark 2, Model 10 Int. Comb. Engine #1502
.71	Mark 2, Model 10 Int. Comb. Engine, Ship #204