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Report on
**SCALE DEPOSITION IN
WATER DISTRIBUTION SYSTEMS**
for
**STATE ELECTRICITY BOARD
ICELAND**

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**Sheppard T. Powell
Consulting Chemical Engineer
Baltimore, Md.**

October, 1946

Sheppard T. Powell
CHEMICAL ENGINEER

PROFESSIONAL BUILDING
330 N. CHARLES STREET
Baltimore, Md. 1

October 17, 1946

E. G. Eggertson, Inc.,
27 William Street,
New York 5, N. Y.

Dear Sirs:

We are transmitting herewith an original and two copies of our report covering our findings regarding the problem of scale deposition in the hot water pipe line distribution system at Reykjavik, Iceland. The data upon which we have had to base our conclusions were too meager to make firm recommendations regarding the manner in which the existing scaling condition can be corrected. However, there was sufficient information to permit us to draw certain general conclusions and we are recommending that a program of investigation be initiated to determine if these conclusions can be confirmed by more complete data.

You asked us to estimate the cost of our services for carrying out such a program. We believe approximately \$2500.00 would be sufficient to cover the services from our office, to which would have to be added all out-of-pocket expenses incurred in carrying out the work. This would include guidance in carrying out the program, analyses of the results and suggestions and recommendations regarding the most suitable method of overcoming present difficulties. It would not include any time in the field, if it were necessary to visit Iceland. If it were found that the data collected showed that the problem was different than now indicated, additional engineering services might be required.

If we can be of further assistance to you please feel free to call on us.

Very truly yours,


Sheppard T. Powell

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REPORT ON
SCALE DEPOSITION IN WATER DISTRIBUTION SYSTEMS
FOR
STATE ELECTRICITY BOARD
ICELAND

We have given appreciable thought to the problems discussed in my office on August 29th and are submitting herewith our opinions regarding the cause of the deposits in the piping system at Reykjavik and a suggested program for further evaluating and correcting this condition.

As you requested, we have had the scale deposit in the 1/2-inch diameter pipe analyzed gravimetrically and by the X-ray diffraction method. During our conference on August 29th, you informed us this was typical of the type of deposit occurring in the distribution system at Reykjavik. It was expected that the scale would prove to contain excessive silica but the analyses show that the predominant constituent is iron oxide 72.5 percent and 14.20 percent of silica which it is believed may have been occluded and precipitated by the oxide. These analyses and that of the water causing the scale are shown on Table I.

The corrosion which has occurred is demonstrated in the accompanying photograph (Exhibit A) in which two views of the half-inch tube are shown after being split in two lengthwise. One view shows the condition of the tube surface after partially removing the deposit but without cleaning the surface either mechanically

or with acid. The second view shows the surface after cleaning with inhibited acid. It is evident from this view that corrosion and pitting had been severe.

Using the analysis of the water that you informed us was representative of the supply which caused the deposit, we have calculated the Langelier Index for control of calcium carbonate scale. We understand that the latter water is quite comparable to the water delivered to Reykjavik. When corrected for temperature effects it is found that the index is positive and would be expected to deposit scale. The index, when calculated for various temperatures, suggests that the balance of the various ions is such that deposition would be somewhat heavier as the temperatures decreased due to cooling. However, only a trace of calcium was found to be present indicating that corrosion was the main cause of the accumulated solids.

The information and data now available are meager, but we are able to draw certain conclusions which are subject to confirmation or modification, depending on additional data which may be assembled by pilot plant studies.

Conclusions

- (1) The scale removed from the 1/2-inch diameter pipe was found to be essentially iron oxide and indicates that oxygen is finding its way into the distribution system.
- (2) Cleaning of the inside pipe surface with inhibited acid revealed that severe corrosion and pitting was occurring.
- (3) The silica found in the scale deposit probably was caused by the action of iron oxide which aids in its precipitation.

(4) The presence of oxygen may be due to the use of air lift pumps, storage in open reservoirs or direct air leakage.

(5) Air infiltration from any source must be prevented and if due to air lift pumps their use should be discontinued.

(6) Elimination of the oxygen that can not be prevented from being absorbed in the system can be accomplished by means of deaerating devices. The type used will depend upon the conditions existing at the location where deaeration is to be carried out.

(7) A deaerator could be installed at the wells to assure adequate protection of the 10 mile long pipe line which delivers the supply to Reykjavik. We do not know the manner in which the various open storage tanks are arranged nor their size, however, it will be necessary to protect the supply stored in these tanks from reaeration. If the tanks are not too large it would be possible to install floating covers to prevent reaeration. If they are extremely large units it would be necessary to provide for deaeration following the storage tanks (Fig. 1).

(8) The ideal plan for protection of the city system involves the use of an entirely closed system. New collection and return lines would have to be installed and the effluent from the houses pumped back to a common point. It would then be reheated in heat exchangers using raw water from the existing well supply as the heat source. This water would then be wasted without treatment. Additional heat could be supplied from the power plant services if required. The water supply recirculated throughout the distribution system could be a water from any desirable source

Sheppard T. Powell

because the make-up could be low in amount. This supply could be treated and deaerated so no corrosion would occur and no scale deposits would result (Figure 2).

(9) In order to determine the most suitable type of system to install it will be necessary to install certain equipment for carrying out pilot plant studies. A program should be initiated which will provide the necessary information to confirm the preliminary data made available to us. Attached hereto is a tentative outline of the type of program necessary to obtain the necessary information.

TABLE I

ICELAND - STATE ELECTRICITY BOARD

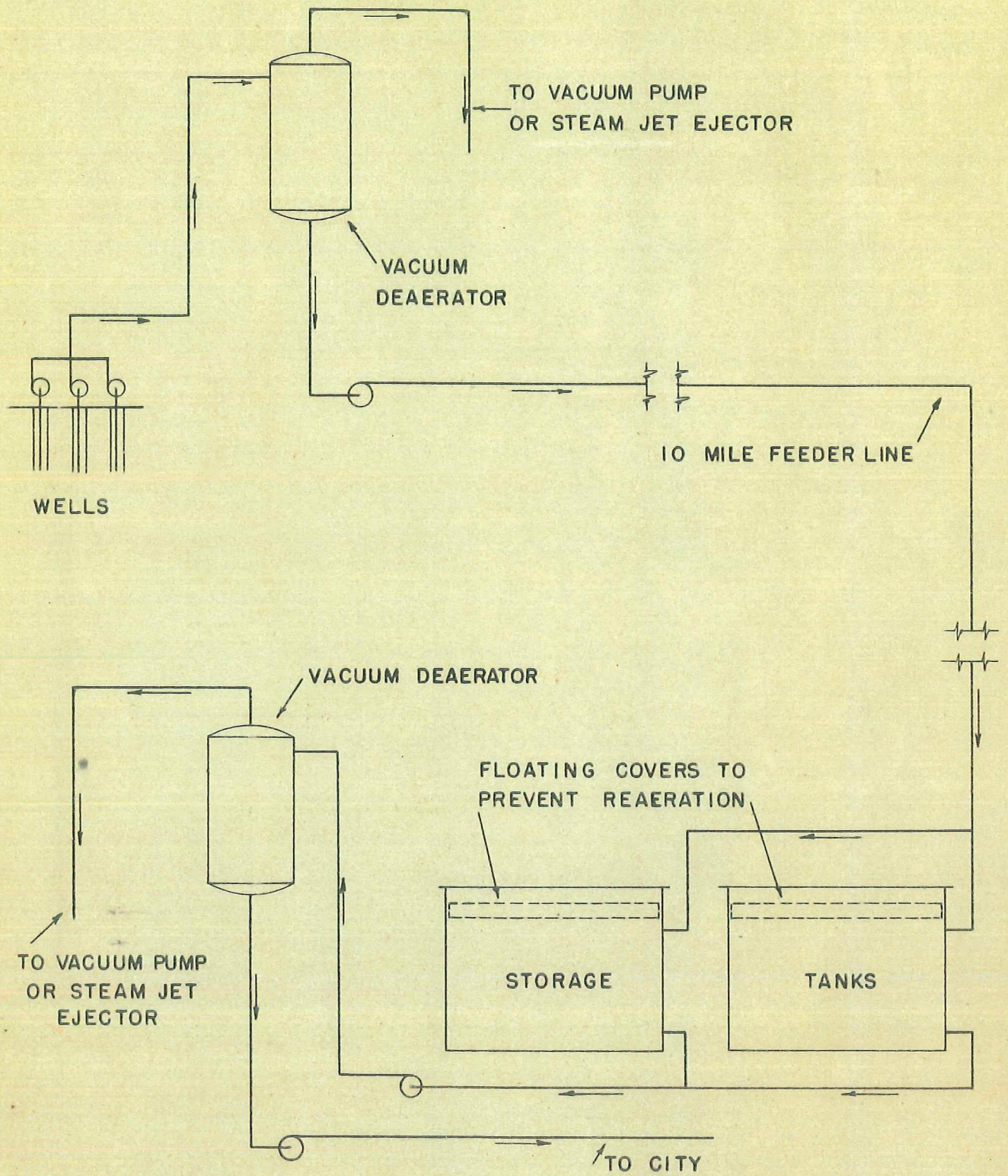
ANALYSES OF SCALE SAMPLE REMOVED FROM 1/2" DIAMETER PIPE AND THE
WATER WHICH CAUSED THIS DEPOSIT

Constituents	As	Water Sample No. 8	Constituents	As	Scale Sample No. 9
Calcium	Ca	98.00	Silica	SiO ₂	14.20
Magnesium	Mg	-	Iron Oxide	Fe ₂ O ₃	72.54
Sodium & Potassium	Na	217.00	Aluminum oxide	Al ₂ O ₃	0.20
Chloride	Cl	400.00	Calcium oxide	CaO	tr.
Sulphate	SO ₄	45.00	Magnesium oxide	MgO	0.16
Nitrate	NO ₃	+	Copper	Cu	0.00
Sulfide	S	-	Chloride	Cl	tr.
Bicarbonate	HCO ₃	8.30	Sulfur tri-oxide	SO ₃	tr.
Carbonate	CO ₃	60.30	Carbonate	CO ₃	tr.
Hydroxide	OH		Loss on ignition		8.68
Silica	SiO ₂	73.00	Manganese	Mn	0.08
Aluminum	Al	+	Loss at 100°C		5.80
Iron	Fe	3.00			
Ammonia	NH ₃	tr.	Spectroscopic Analysis:		
Sum		<u>904.60</u>		Fe	high
As Calcium Carbonate				Si	.5-5.0
Calcium Hardness		245.00		Mn	.1-1.0
Magnesium Hardness		-	X-ray Analysis:	Cu, Ca	.01-.1
Total Hardness		245.00	Iron Oxide	Mg	.001-.01
Sodium & Potassium		<u>471.50</u>	Cronstedtite		
Total Cations		<u>716.50</u>		Fe ₃ O ₄	80%
Total Residue		840.00		2 FeO.Fe ₂ O ₃ .	
pH		9.2		SiO ₂ .2H ₂ O.	20%
Corrected Saturation Index					
190°F		1.82			
167°F		2.05			
104°F		2.83			
207°F		1.80			

(8) Vatn frá Reykjanesi (Harkv 13.50°)

Note: Similar to City water - actual water that deposited scale.

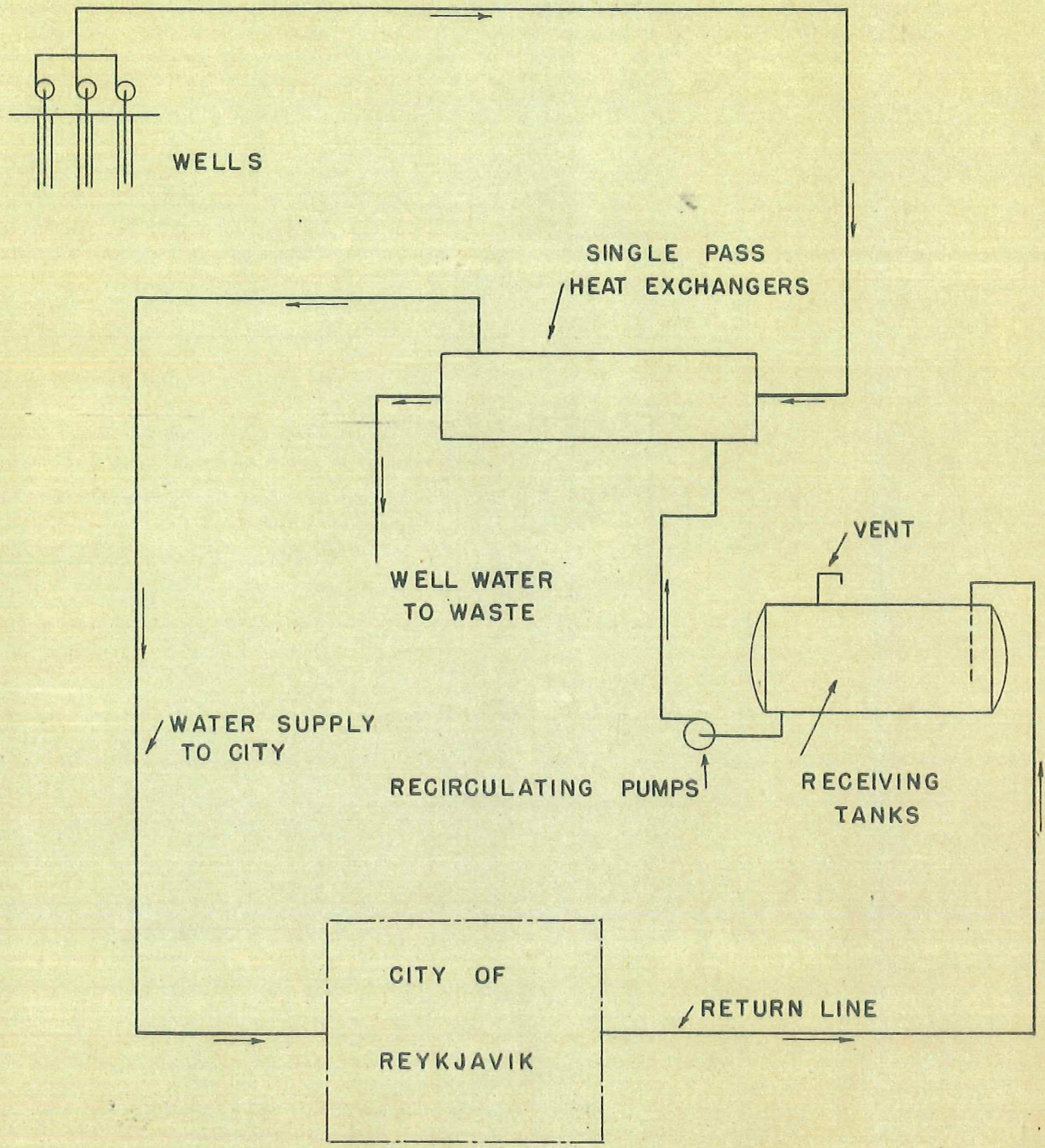
SCHEMATIC ARRANGEMENT OF EQUIPMENT FOR DEAERATING THE WATER SUPPLY TO CITY OF REYKJAVIK



S. T. POWELL

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SCHEMATIC ARRANGEMENT OF EQUIPMENT FOR RECIRCULATION
OF WATER SUPPLY TO CITY OF REYKJAVIK, USING RAW WELL
WATER TO HEAT THE SUPPLY



I - PIPE SECTION CUT LENGTHWISE TO SHOW
ACCUMULATION OF SCALE DEPOSIT PARTLY
REMOVED.

II - PIPE SECTION CUT LENGTHWISE TO SHOW
PITTING FROM CORROSION AFTER REMOVING
SCALE WITH INHIBITED ACID.

SCALE DEPOSIT



CORROSION PITS



PROGRAM FOR INVESTIGATION OF WATER CONDITIONS
AT CITY OF REYKJAVIK

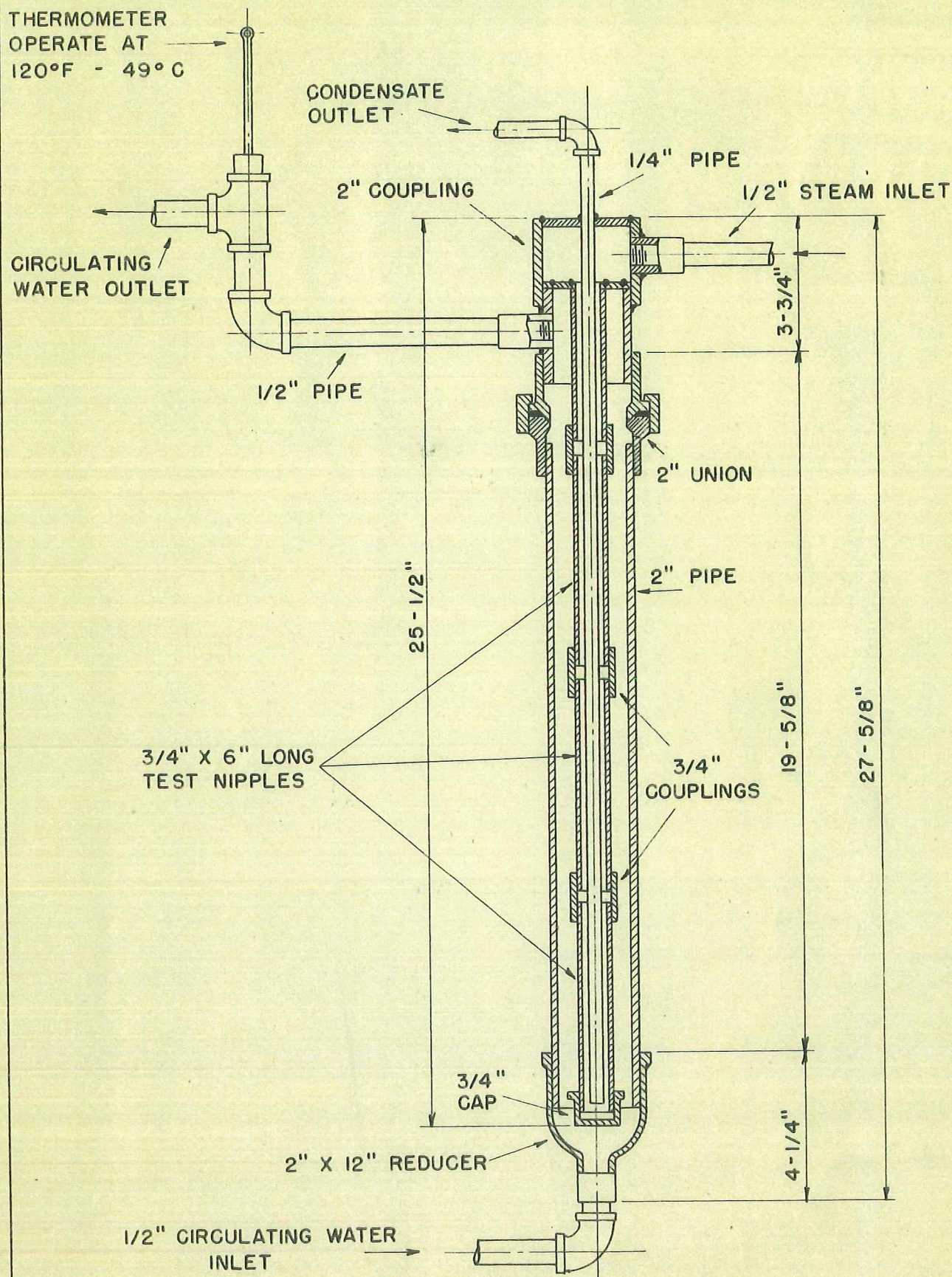
(1) Analytical data should be obtained to show the dissolved constituents contained in this water. Sufficient samples should be collected so any variations in quality can be evaluated.

(2) Dissolved oxygen should be determined at frequent intervals. It is desirable to determine if oxygen is present in the existing system and, if so, in what quantities, it also is important to find if it is present in larger quantities at one time than at another and whether it fluctuates in different sections of the City. Attached herewith is a procedure for making oxygen determinations. This may have to be modified if it is found that sulfides, iron or other interfering substances are present in appreciable quantities in the water. It is suggested that reference be made to the American Public Health Association standard methods of water analysis and that the analyst be guided by the information contained herein.

(3) It is suggested that a scale testing apparatus similar to that shown on the attached prints, A-261, A-266 or AA-171, should be constructed. It would be desirable to construct these units of steel in order that corrosion and scaling rates can be observed simultaneously.

If it is found that oxygen is contained in the water supply steps should be taken to effect its removal prior to discharging the water through the scale testing apparatus. In this way the corrosive action of the water may be studied both before and after deaeration. Thus it can be determined if oxygen is the main factor responsible for the incrustation in the lines at the present time or if silica will continue to deposit regardless of the other conditions existing. The scale testing apparatus should be installed in a closed system and the conditions adjusted to approximate those that would exist in the town system if the water were recirculated. If calcium carbonate scale or silica were deposited it then could be determined if the condition could persist or reach an equilibrium in which no further scale would be formed. If desirable the pit could be controlled to eliminate the possibility of calcium carbonate precipitating. Removal of oxygen would eliminate corrosion in the system. This could be accomplished in the case of the pilot plant by chemical addition or making the system entirely closed. Such data would show if elimination of oxygen would correct the existing situation or whether it would be necessary to construct a closed system. It would also show whether it would be possible to use well water in such a plan or whether it would be essential to employ a high quality make-up water to the distribution system.

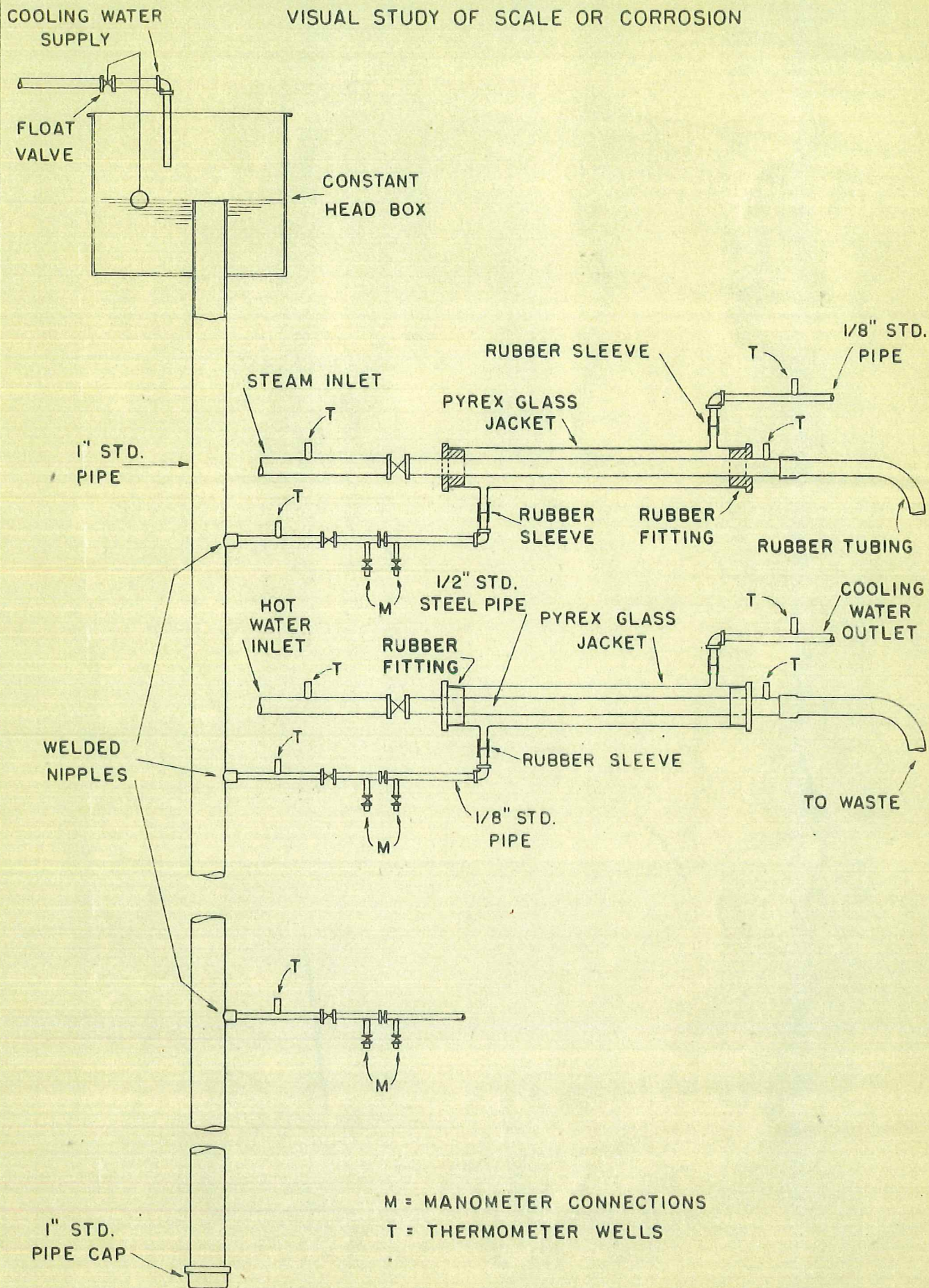
CORROSION TESTING UNIT



ORIGINAL DESIGN BY DOW CHEMICAL CO. FREEPORT, TEX.

S.T. POWELL
A - 261

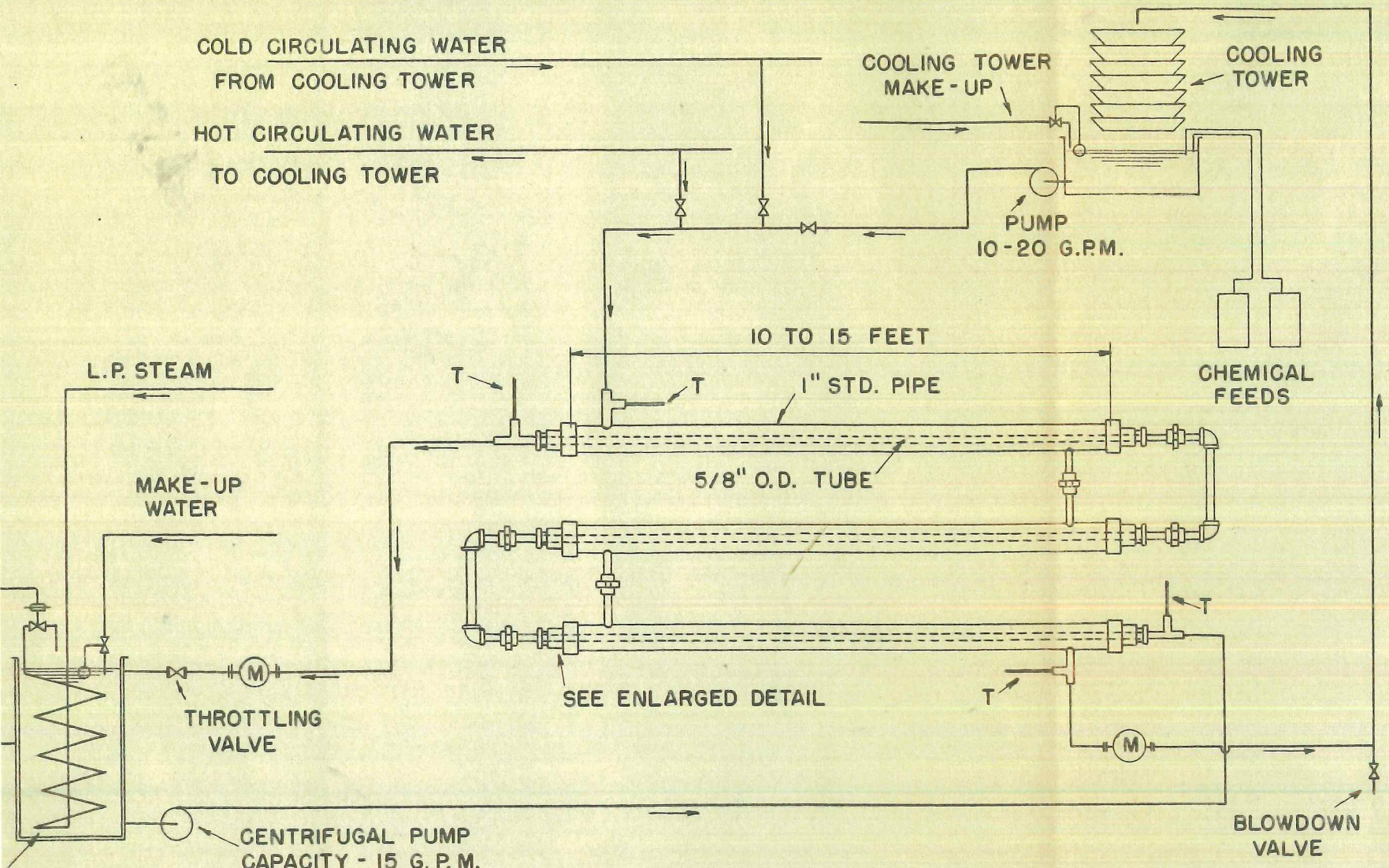
SCHMATIC FLOW DIAGRAM OF TEST ASSEMBLY FOR VISUAL STUDY OF SCALE OR CORROSION



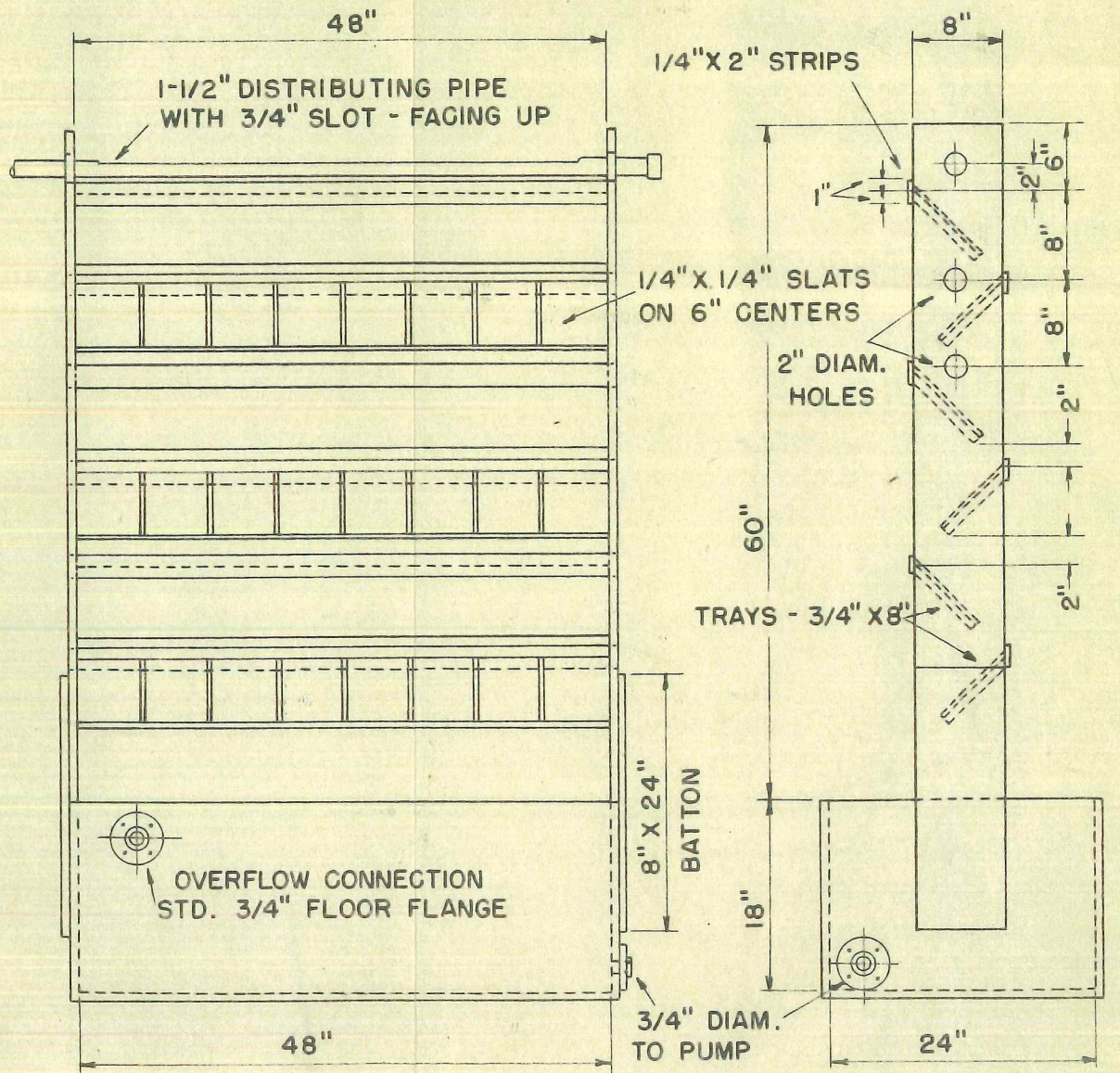
S.T. POWELL

SCHEMATIC ARRANGEMENT OF PILOT PLANT FOR SCALE & CORROSION STUDIES

FIGURE

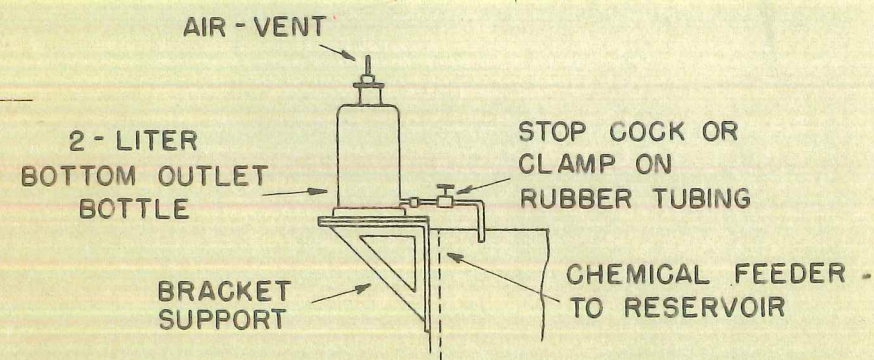
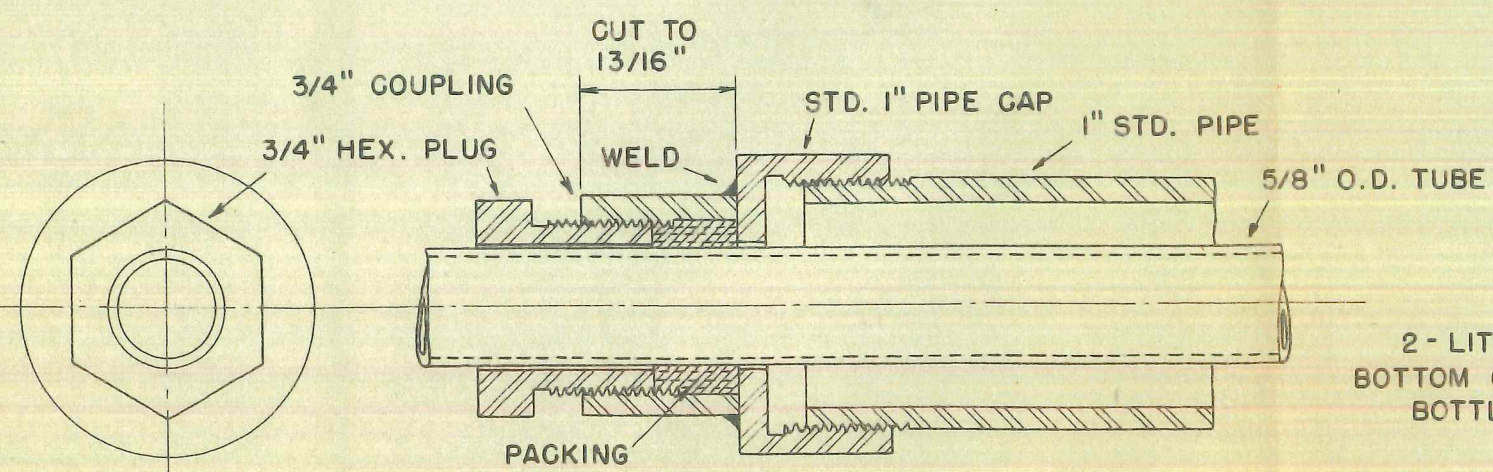


NOTE: 1-1/2" DISTRIBUTION PIPE MAY BE LOCATED AT VARIOUS ELEVATIONS IN ACCORDANCE WITH AMOUNT OF COOLING REQUIRED



NOTE: LENGTH & NUMBER OF TUBES DEPENDENT ON RANGE OF HEAT TRANSFER USED. DUPLICATE INSTALLATIONS SHOULD BE PROVIDED TO COMPARE TREATMENTS. M = VOLUMETRIC METER T = THERMOMETER

CONTACT HEATER MAY BE USED IN PLACE HEATING COIL



DETAIL OF COOLING TOWER TO BE CONSTRUCTED OF 7/8" DRESSED LUMBER - REDWOOD, GYPRESS, OR CEDAR

INSTRUCTIONS FOR MAKING THE TEST FOR OXYGEN IN FEEDWATER

The Winkler test, described below, is the recognized standard procedure for determining dissolved oxygen in water. Boiler feedwater should be so treated that the dissolved oxygen is completely removed, and when this test is made no more than a trace of oxygen should ever be found in the water. The accurate determination of dissolved oxygen in amounts between 0 and 0.1 cc. per liter is a delicate procedure which requires extreme care.

COLLECTION OF SAMPLE

The feedwater should be passed through a cooling coil such as is shown in Figure 0-1, which will cool it to 70°F., if possible. If it cannot be cooled down to this temperature because the cooling water is at a high temperature, it will be necessary, at a later step in the analysis, to immerse the sampling flask in ice water. All valves in the sampling line and coil ahead of the outlet valve on the coil should be wide open and the flow should be throttled by the outlet valve so that a minimum time of thirty seconds is required for filling the sample flask (Figure 0-2).

Attach the rubber inlet tube (No. 3) of the sampling flask to the outlet nipple in the bottom of the cooling coil, using an extra length of rubber tubing and a glass connector. Remove the pinch clamps from all three tubes of the sampling flask and, with the stopper removed, flood the flask in order to remove bubbles of air. Insert the stopper in such a manner that no bubbles are trapped on its lower side. Even minute visible air bubbles will influence the results and the sampling must be begun over if they

are discovered at any time. Permit the water to overflow through the rubber tubes Nos. 1 and 2 for not less than five minutes, then disconnect the flask from the sampling cock of the cooling coil and place one of the pinch clamps on tube No. 3.

ADDING THE REAGENTS

The flask should now be full of water, which should also extend up to the top of the three rubber tubes on the stopper. Fill a 2 ml. pipette with manganous chloride solution and insert the tip into rubber tube No. 1, making sure that there are no air bubbles in the top of the pipette or in the rubber tube. Allow 2 ml. of the solution to flow through the tube into the flask. When this is done it will displace water from the flask out through tube No. 2.

Disconnect the flask from the pipette and insert the tip of a second 2 ml. pipette containing sodium hydroxide-potassium iodide solution into tube No. 2. Never add Solution No. 1 and Solution No. 2 through the same tube, or with the same pipette. Add 2 ml. of the solution, which will displace water through tube No. 1.

Now place pinch clamps on all of the tubes below the water level, so that no air bubbles are caught below the clamps. Rinse off the tubes and the stopper and invert the flasks several times to mix thoroughly. Set the flask aside until the precipitate settles out, which will require 3 to 4 minutes.

Remove the clamps from tubes No. 2 and 3 and add 2 ml. of sulphuric acid solution through tube No. 3. Replace the clamps, being careful not to retain air bubbles, and invert to mix thoroughly. The precipitate will be dissolved by the acid. When the con-

tents of the flask are clear the sample is fixed and there is no further danger of contamination by exposure to air. However, the sample must be cooled to 70°F., or lower, before completing the test. Insert a thermometer in the flask and, if necessary, immerse it in ice water to cool it. This is important, since the test is not accurate at temperatures above 70°F.

TITRATING THE SAMPLE

Use the excess of treated sample above the 500 ml. calibration on the flask to rinse out at 750 ml. porcelain casserole. Then transfer the remaining 500 ml. sample to the casserole, and add 3 ml. of starch solution. Titrate with N/40 sodium thiosulphate solution until the disappearance of the blue color. Each ml. of N/40 thiosulphate required for this change is equivalent to 0.28 ml. per liter of dissolved oxygen in the sample.

EXAMPLE:

Suppose that a 500 ml. sample of feedwater required 0.4 ml. of N/40 thiosulphate to discharge the blue color. Then $0.4 \times 0.28 = 0.11$ ml. per liter of dissolved oxygen present in the sample.

NOTES CONCERNING THIS TEST

(1) When the manganous chloride and alkaline potassium iodide are added a white precipitate will be noticed, which is manganous hydroxide.

(2) If oxygen is present a brown-colored precipitate will appear in a quantity depending on the amount of oxygen present.

(3) The addition of sulphuric acid dissolves the brown precipitate and sets free an amount of iodine equivalent to the quantity of oxygen in the sample.

(4) The solution at this time will be yellow in color, the depth of the color depending upon the amount of oxygen present.

(5) If oxygen is present and starch is added to the solution at this stage, the color will change to blue, the intensity of which depends on the amount of oxygen present.

TOLERANCE

With care, this method will give reproducible results for quantities of oxygen as small as 0.01 ml. per liter.

PRECAUTIONS TO BE OBSERVED IN MAKING THIS TEST

The determination of dissolved oxygen in amounts less than 0.05 ml. per liter is an extremely delicate one and the accuracy of the results will depend largely on the accuracy of the technique of the analyst. The following precautions should be taken in order to assure accurate results:

- (1) The temperature of the sample as collected should be 70°F. or less.
- (2) Only chemicals which are free from oxidizing impurities should be used.
- (3) Water for making test solutions should be free from nitrites, sulphites, organic matter, and ferrous or ferric iron.
- (4) The sample should be drawn through copper tubing and all joints should be brazed wherever possible.
- (5) Sampling cocks and unions should be made tight by shellacking.
- (6) New lines should be flushed out for four hours before using.
- (7) Red lead used for making joints will introduce a large error. Lines containing such joints should be flushed out

one or more days before a sample is drawn for the test.

(8) New rubber tubing should not be used, since appreciable errors are introduced by dissolved sulphur.

TESTS FOR INTERFERENCE IN DISSOLVED OXYGEN DETERMINATION

Collect another 500 ml. sample of the water to be tested without observing the precautions described above. Add the oxygen reagents in following order: alkaline potassium iodide, sulphuric acid, manganous chloride. Mix after each addition, being careful that the alkaline solution is thoroughly neutralized with acid before adding the manganous solution. Transfer to a casserole, add starch and stir. If the sample turns blue, oxidizing substances are present, which will give high oxygen results. This may be nitrites, iron, lead oxide or other contaminants. Unless its source can be found and eliminated, titrate with thiosulphate to determine the exact amount required to destroy the blue color, and use this as a correction to be deducted when determining dissolved oxygen.

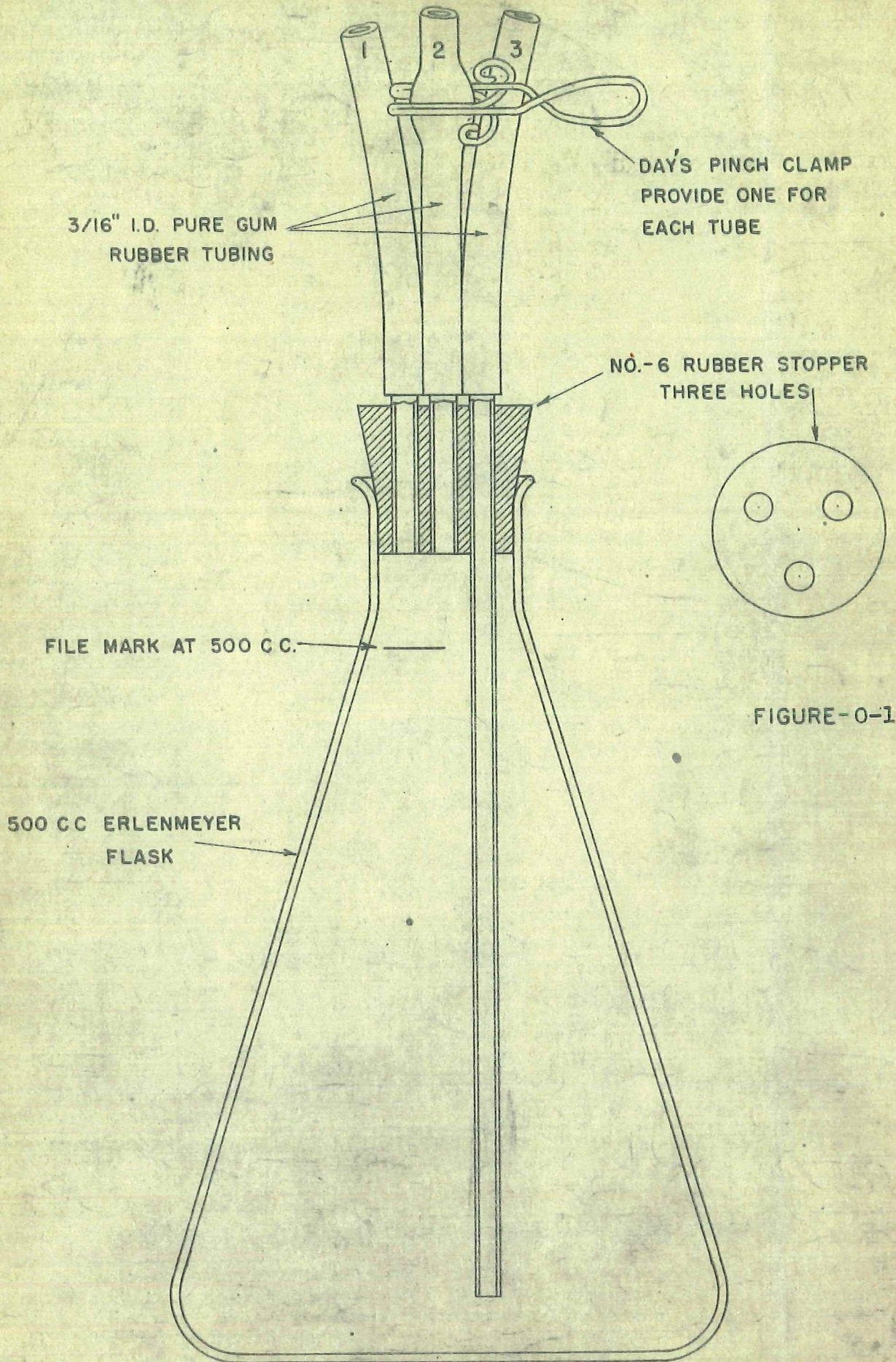
If no blue color develops, indicating the absence of positive interference, add one drop of iodine solution (approximately N/40). If a blue color does not develop, negative interference is present and the results for oxygen will be low. The necessary correction can be estimated by continuing to add iodine from a burette until a blue color develops and then titrating with thiosulphate an equal amount of iodine solution, added to distilled water.

REAGENTS REQUIRED:

- (1) Manganous chloride solution. Dissolve 425.5 grams of crystalline manganous chloride, $MnCl_2 \cdot 4H_2O$, in one liter of distilled water.

- (2) Alkaline Potassium Iodide. Dissolve 700 grams of c.p. potassium hydroxide, and 150 grams of c.p. potassium iodide, in separate portions of distilled water.
- (3) Sulphuric Acid, 1:1. Mix c.p. concentrated sulphuric acid (sp. gr. 1.84) with an equal volume of distilled water, pouring the acid into the water in a small stream and stirring constantly.
- (4) Starch Indicator Solution. Dissolve 5 grams of arrowroot starch in 50 ml. of distilled water to make a thin paste and then pour into 200 ml. of boiling water and continue boiling for 4 or 5 minutes. When cold add a few drops of chloroform and transfer to a dark glass-stoppered bottle. Starch solution does not keep well and should be made fresh every week.
- (5) Standard N/40 Sodium Thiosulphate Solution. This solution is not permanent, and must be replaced every two weeks, or calibrated weekly by titrating an N/40 standard solution of potassium dichromate, potassium permanganate or standard iodide iodate solution used for the sulphite test. To prepare the thiosulphate solution, dissolve 6.205 grams of chemically pure recrystallized sodium thiosulphate in water and dilute to one liter. The water used must be distilled and freshly boiled and cooled.

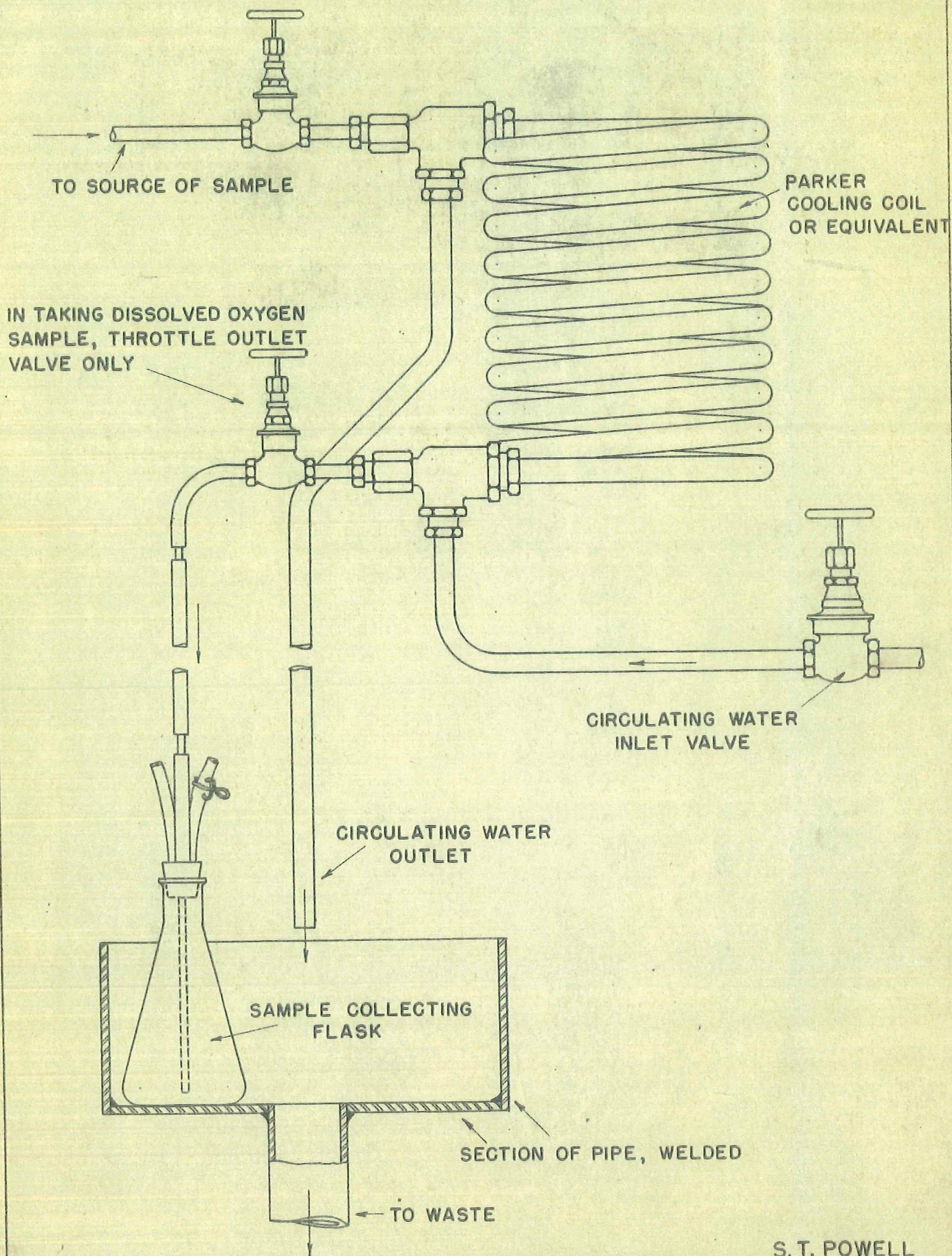
SAMPLING FLASK FOR DISSOLVED OXYGEN TEST



S.T. POWELL

A-194

ARRANGEMENT OF COOLING COIL AND SAMPLING FLASK FOR DISSOLVED OXYGEN TEST



S. T. POWELL
A - 220

MODIFIED MARBLE TEST FOR SATURATION INDEX DETERMINATION

When inhibitors are present in the water the Calculated Langelier Index indicates a higher scaling value than is actually the case. For cases such as this it is advisable to use the Marble test method to determine the Saturation Index. The following method can be used to determine the Saturation Index directly, with the only test required being pH.

The theory of the method is that if a water that is not in equilibrium is brought in contact with calcium carbonate the water will attain equilibrium. If it is under-saturated with respect to calcium carbonate, which is the same as having a negative saturation index, the water will dissolve sufficient calcium to saturate the solution, making the saturation index zero. If the water is super-saturated, which is the same as a positive saturation index, the excess calcium carbonate will precipitate, causing the saturation index to be zero.

The method is as follows:

1. Determine the pH of the same as collected at room temperature. This is the actual pH (pH_a).
2. Place 200 ml. of the sample in a 500 ml. Erlenmeyer flask and add sufficient powdered calcium carbonate to saturate the sample (about a teaspoonful). Shake the flask with a swirling motion to mix the calcium carbonate and water at frequent intervals for five minutes.

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