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Treatment of the HRT Steam System Water

Summary

Recommendations are made for possible chemical treatment of the water in the HRT steam system. The effectiveness of various chemical additives is unknown because of the presence of radiation in the HRT fuel heat exchanger. Initially it is recommended that the water be treated with sodium phosphates and hydrazine. The sodium phosphates are used for pH control and the prevention of caustic cracking, and the hydrazine is used as an oxygen scavenger. If the hydrazine fails to be satisfactory for the HRT steam system, the use of sodium sulfite for an oxygen scavenger is recommended. The latter would tend to cause foaming in the boiler and would probably require a large amount of blowdown in order to keep the sulfate concentration to a reasonable level. In all cases, the chemicals to be added to this steam system must be free of chlorides.

Samples are to be taken from ten points of the HRT steam system in order to keep careful control of the chemical addition. This is particularly important during the initial use of a particular additive.

A development program is recommended for the treatment of the water in the homogeneous reactor steam systems because of the lack of knowledge in this area.

Introduction

Dissolved oxygen and acid conditions in conventional boiler systems contribute to the corrosion of the containing vessel. (1,5,8,15,24) This corrosion usually can be kept to a minimum if the amount of dissolved gases is kept low and the pH is kept between 9.0 and 11.0. (1,5,17,19,27) Mechanical deaerators and chemicals, such as hydrazine or sodium sulfite, are used to

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remove the dissolved gases, and chemicals, such as phosphates, caustic soda, or morpholine are used for pH control in ordinary boiler systems.

The corrosion problem in the HRT steam system is more serious than those in the conventional plants because of the oxygen generation and the presence of stainless steel in the HRT heat exchangers. Presence of chlorides or free caustic in the water can cause stress-corrosion cracking of stainless steels^(7,19). The presence of deposits on stainless steel surfaces also causes stress-corrosion cracking, and this is believed to be due to the accumulation of free caustic or chlorides underneath the deposits surface⁽¹⁹⁾. Oxygen is generated in the HRT heat exchanger at a rate of approximately 0.54 moles per hour at 5 Mw operation as shown in Appendix A. This is an equivalent to a concentration of about 2.3 ppm. The recombination reaction is high for pressurized non-boiling systems, but the oxygen may be swept out of the water by boiling before the recombination reaction can occur in this case.

Chemical Treatment

All chemicals to be used for treatment of the HRT steam system should be checked for chlorides⁽⁶⁾. If the chlorides are present in appreciable concentrations, stress-corrosion cracking of the stainless steel portions of the HRT steam system may occur.

A coordinated pH-phosphate control treatment^(5,27) is recommended for pH control, the prevention of caustic embrittlement of carbon steels, and the prevention of stress-corrosion cracking of stainless steels⁽¹⁹⁾. This treatment is used by General Electric for their reactor at West Milton, New York.⁽⁷⁾ Trisodium-, disodium-, or mono-sodium phosphate are used for this treatment.

It is recommended that the HRT steam system water have an initial phosphate

concentration of approximately 60 ppm $(\text{PO}_4)^{(5,19,27)}$, and it is recommended that the pH be about 10⁽¹⁹⁾. Trisodium phosphate in water by itself will neither cause or prevent embrittlement or cracking of steels⁽⁵⁾. A plot of the approximate pH values for various phosphate concentrations of trisodium phosphate is shown in Fig. 1. If the pH of the steam system water is kept below this curve, such as by the addition of disodium phosphate or monosodium phosphate, it is possible to keep this water from developing embrittling and cracking characteristics^(5,19,27). If the pH is allowed to rise above this curve for any given phosphate concentration, embrittlement and cracking may occur.

Care must be taken to keep the hardness out of the water in the HRT steam system, otherwise the sodium phosphates will form insoluble calcium phosphate deposits, particularly in the feedwater supply piping.⁽²⁷⁾

Since the makeup water is building steam condensate, hardness precipitation should not be a major problem.

Hydrazine is recommended to be tried first as an oxygen scavenger for the HRT steam system. The dissolved oxygen concentration should be kept below 0.050 ppm as it has been shown that failures have occurred in low pressure boilers (500-1000 psi) usually when it is above this value⁽⁸⁾. Besides the oxygen that is generated in the HRT heat exchangers, oxygen and carbon dioxide will be present in the makeup water⁽²⁰⁾. The mechanical deaerator will remove most of this oxygen and carbon dioxide, but the remaining amounts of these gases will react or be bound by the hydrazine^(2,4,9,14).

The reaction products of hydrazine are gases, which eliminates the need of large amounts of boiler blowdown to remove the decomposition products.

The distribution coefficient of hydrazine between the vapor and liquid phases of the boiler water is high at the higher temperatures. Representatives from Babcock and Wilcox⁽¹⁹⁾ indicated that it may be difficult to keep the hydrazine in the water under the temperature and pressure conditions existing in the HRT heat exchanger⁽¹⁹⁾. (Hydrazine solutions, however, can be stored for long periods of time at room temperature.)

The hydrazine-oxygen reaction is a relatively slow reaction, particularly in a clean system^(14,19). It appears to be a surface reaction, and the presence of iron oxides, such as those in old boilers, increase the reaction rate. Leicester⁽¹⁴⁾ reports that the rate of reaction between hydrazine and oxygen in cold distilled water in glass containers is practically negligible, but it increases greatly with an increase in the alkalinity, temperature, and the presence of metal catalysts. Representatives from Babcock and Wilcox⁽¹⁹⁾ have found 5 to 10 minutes are required to remove oxygen from feedwater containing up to 0.050 ppm oxygen.

Hydrazine will decompose at higher temperatures^(1,9,14), in the range of 350-500 °F, forming ammonia and nitrogen.

It can thus be seen that hydrazine in water tends to be basic in nature which is an advantage in maintaining high pH's in the boiler water, but excessive decomposition is undesirable. TVA has been able to maintain a residual hydrazine concentration of 0.010 ppm in its 2000 psi steam units at Kingston, Tenn.^(17,18) Also, representatives from Babcock and Wilcox indicated from their experimental work that the thermal decomposition of hydrazine in the HRT steam system will

be small⁽¹⁹⁾. Leicester⁽¹⁴⁾ ran some tests on hydrazine in a pilot plant boiler at a pressure of 550 psig (approximately the same pressure as that in the HRT heat exchangers). The pH of the boiler water in these tests was 9.5 and the dissolved oxygen concentration was 0.2 ppm. For a hydrazine concentration of 4.5 ppm in the feedwater, he found a residual hydrazine concentration in the boiler water of 0.49 ppm; with 3 ppm of hydrazine in the feedwater, the residual hydrazine concentration in the boiler water was 0.44 ppm. Above this value, the curve of the hydrazine in the feedwater versus the residual hydrazine concentration increased rapidly.

Hydrazine also will decompose under radiation to form hydrogen and ammonia^(10,28). Studies were made of the gamma irradiation (7500 roentgens per minute) of feedwater solution containing 200 ppm phosphate (Na_3PO_4) and about 8 ppm hydrazine in Pyrex glass vials⁽¹⁰⁾. Under these conditions, 1.7 hydrazine molecules decomposes per 100 electron volts absorbed. Higher hydrazine concentrations show an increased rate of hydrazine decomposition under radiation, 3.1 molecules decomposing per 100 electron volts absorbed at a hydrazine concentration of 160 ppm, and 5.0 molecules decomposing per 100 electron volts absorbed at hydrazine concentrations of 320 ppm to 3200 ppm. Similarly, the hydrazine decomposition becomes less for lower concentrations, and it may even become zero for hydrazine concentrations of 1 ppm and less.

As shown in Appendix B, hydrazine would be consumed by radiation in the HRT fuel heat exchanger at a rate of approximately 3.7 moles per hour at 5 Mw operation if the decomposition rate is 1.7 molecules per 100 electron volts absorbed. This is equivalent to a concentration of 15.5 ppm. The effectiveness of hydrazine for removing oxygen under the conditions in the HRT steam system is unknown. It is recommended that hydrazine be tried as an oxygen scavenger, but no definite concentration can be specified. During the initial operation and

after any change of the operating conditions of the HRT, the situation existing in the steam system should be watched very carefully.

Ammonia formed by the decomposition of hydrazine by heat or radiation possibly may cause corrosion of the non-ferrous metals of the steam system Ulmer and Wood⁽²⁴⁾ report if the oxygen content is low, less than 0.10 ppm, and the pH is between 8.0 and 10.0, there is no noticeable attack of the copper and brass. TVA has had as high as 0.3 to 0.4 ppm ammonia in its steam units with no evidence of non-ferrous corrosion when the oxygen and carbon dioxide concentrations are low⁽¹⁷⁾ (less than 0.005 ppm). Representatives from Babcock and Wilcox have found the ammonia corrosion of brass and copper to be negligible for ammonia concentrations up to 5 ppm with oxygen and carbon dioxide present and a pH of about 10⁽¹⁹⁾. However, if the pH drops to 5 or 6, there is appreciable corrosion of the non-ferrous materials. It appears that the use of hydrazine will not affect the non-ferrous materials of the HRT steam system, but the samples collected from the system should be watched carefully for any dissolved copper.

If hydrazine does not prove satisfactory as an oxygen scavenger for the HRT steam system, sodium sulfite should be tried for this purpose. This compound reacts faster with oxygen than does hydrazine⁽⁴⁾. Its reducing property is illustrated by the following reaction^(5,27):

This type of treatment tends to lower the pH of the boiler water and add solids to the boiler water⁽³⁰⁾. The sodium sulfate also encourages foaming and priming in the heat exchangers. The American Boiler Manufacturer's Association specify the upper limit of solids in boiler water of 2500 ppm at the pressure existing in the HRT heat exchanger⁽⁵⁾. In order to keep the foaming and solids content to a reasonable level, considerable amounts of

blowdown from the HRT heat exchangers probably would be required^(5,27).

The equivalent weight of sodium sulfite to 1 ppm of oxygen is 7.875 ppm and a recommended dosage value is 11.67 ppm⁽²⁷⁾. This latter quantity assumes that the sodium sulfite is 90 percent pure and 75 percent effective. Therefore, 30 to 40 ppm sodium sulfite should be able to remove the oxygen providing that it is not affected by the radiation.

Jones⁽¹⁰⁾ reports a radiation oxidation value of sodium sulfite of 0.9 sulfite ions per 100 electron volts absorbed under gamma irradiation. This value is based on experiments conducted in Pyrex vials using distilled water, 200 ppm Na_3PO_4 , and sodium sulfite. These solutions were exposed to Co^{60} rays at a dose rate of 7300 roentgens per minute.

It is estimated that the sodium sulfite consumed by radiation in the HRT fuel heat exchanger would be about 1.9 moles per hour at 5 Mw operation as shown in the calculations of Appendix C. This is equivalent to a concentration of 26.3 ppm. It appears that the sodium sulfite concentration can be made high enough, possibly 50 to 60 ppm, to remove the oxygen from the liquid phase of the HRT heat exchanger. But this amount of sulfite would contribute to the acidity of the water and would increase the solid content of the water⁽³⁰⁾. As mentioned previously, a large blowdown requirement would be required for the HRT heat exchangers if this treatment is used.

Morpholine is often used for controlling the pH of boiler water^(17,18,30), and use of it has been suggested for the HRT steam system⁽¹³⁾. Under radiation, however, it polymerizes to form a tar-like material⁽²²⁾ and it is believed that such accumulations could decrease the efficiency of this steam system and possibly disrupt its operation. It is recommended that morpholine not be used in the HRT steam system.

Little is known about water treatment for homogeneous reactor steam systems, particularly concerning the radiation behavior of the water with various materials. A development program is strongly recommended to determine suitable materials of construction and water treatment for homogeneous reactor steam systems. (Reactors with closed pressurized water systems use very pure water with a few parts per million hydrogen to keep the amount of dissolved oxygen to a minimum^(25,29). At higher temperatures such as those existing in the HRT heat exchangers, the recombination rate of hydrogen and oxygen is greater than the decomposition rate of pure water⁽²⁶⁾ but the hydrogen and oxygen tend to sweep out with boiling before the recombination reaction takes place⁽¹⁰⁾. Hydrogen addition might be attempted with a homogeneous reactor steam system although it is doubtful if it could be effectively kept in solution. Other additives may be possible, but a development program would be required.

Method of Adding Chemicals

The phosphate solution and the oxygen scavenger solution (hydrazine or sodium sulfite) may be added to the boiler feed line (Line 354) at a point upstream of the junction of Line 370 with Line 354. In this manner, the HRT heat exchangers and the package boilers will be protected by chemical treatment.

A rough indication of the amount of chemical solutions required is shown in Appendix D. It can be seen that a proportioning pump delivering from 0 to 5 gallons of each solution per hour should be sufficient for use for the HRT steam system. The exact rates that the various solutions would be added depend on the analyses of the various water samples taken from the HRT steam system.

Figure 2 is a sketch of the chemical feed facilities for the HRT steam

system. The pH control and the oxygen scavenger solutions are mixed and stored in covered 25-gallon tanks fitted with level gages. The solutions would be fed from these tanks into the steam system by a duplex proportioning pump, or two single proportioning pumps. In order that these chemicals can mix with the feedwater before it enters the feed line to the packaged boiler, the inlet to the feed stream should be a nozzle similar to an ASME sampling nozzle, with the holes in the nozzle facing downstream. Care must be taken to completely dissolve the chemicals in the storage tanks, and condensate must be used at all times for the dissolution of these chemicals. Since the solid chemicals dissolve somewhat slowly, it is recommended that they be placed in a wire mesh basket during the dissolution process or the chemical solution be drawn off from the side instead of the bottom of the tanks so that the solid particles of the undissolved chemicals would not tend to enter the strainers or the pumps. Face masks and other protection should be provided for the workman during the handling of the chemicals, particularly hydrazine. (Hydrazine occasionally causes a skin rash in some men.)

Samples

Facilities are recommended for the taking of the samples at the following ten points of the HRT steam system:

1. Blowdown from the HRT heat exchangers
 - a) Line 376
 - b) Line 379
2. Feed lines
 - a) From Line 358
 - b) From Line 368
3. Deaerator outlet line

From Line 354 at a point upstream where the chemicals are added

4. Makeup feed line
From Line 350
5. Condenser hotwell
From Line 348 at the chemical addition point
6. Steam killer outlet
From Line 345 at the chemical addition point
7. Steam lines
 - a) Line 301
 - b) Line 303

All these samples, except the sample from the makeup feed line, require sample station coolers, which are described in Appendix E. Calculations also shown in Appendix E, show that the same design and effective heat transfer area may be used for sample coolers for both water and steam samples.

The sample lines and the inside tube of the sample coolers are to be made of stainless steel. The valves are also to be constructed of stainless or some other high alloy steel so that contamination of the water samples will be kept to a minimum. Liquid samples are to be taken from ordinary taps in the water lines, but the steam samples are to be taken through standard ASME sampling nozzles^(17,24) in order to obtain representative samples.

Continuous flow of the sample streams is desirable^(17,18), but because of the limited size of the HRT steam system, samplers will be allowed to run only one or two hours previous to the actual collection of a sample. The flow rate of the condensed sample should be from 0.75 to 1 liter per minute^(17,18).

It is recommended that all samples except the oxygen samples be taken in polyethylene bottles^(17,18). The method of taking the oxygen samples is described in Appendix F, which requires the use of glass bottles.

A few ml. hydrochloric acid should be added to the bottles used for collecting

samples to be analyzed for iron to prevent the iron from precipitating out of solution⁽¹⁷⁾.

Required Analyses

Table I gives a summary of analyses recommended for the samples taken from the HRT steam system. The actual analyses to be performed will depend on the method and the success of the various water treatments.

The samples are to be analyzed for the following:

Iron	Chloride	
Nickel	pH	
Copper	Ammonia	} (Hydrazine Treatment)
Chromium		
Oxygen	Hydrazine	
Phosphate	Sulfates	} (Sulfite Treatment)
	Sulfite	

Conclusion

Coordinated phosphate and hydrazine are recommended as the first treatment to be tried in the HRT steam system. If the hydrazine treatment does not work, sodium sulfite treatment is recommended as a substitute. The recommended treatment procedures have not been proven under radiation and they must be observed very carefully, particularly during the initial operation. It is further recommended that a development program be initiated for the study of water treatment for homogeneous reactor systems.

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Table I

Routine Analysis to be Made on Samples from the HRT Steam System

Sample	Oxygen	Chlorides	Iron	Copper	Chromium	Nickel	Phosphates	pH	Ammonia (Hydra- zine treat- ment)	Hydrazine (Hydra- zine treat- ment)	Sulfite (Sulfite treat- ment)	Sulfate (Sulfite treat- ment)
1. Blowdown from Fuel Ht. Ex.	x	x	x	x	x	x	x	x	x	x	x	x
2. Blowdown from Blkt. Ht. Ex.	x	x	x	x	x	x	x	x	x	x	x	x
3. Feed Line to Fuel Ht. Ex.	x		x	x	x	x		x	x	x	x	x
4. Feed Line to Blkt. Ht. Ex.	x		x	x	x	x		x	x	x	x	x
5. Deaerator Outlet Line	x	x						x				
6. Makeup Feed Line		x	x	x	x	x						
7. Condenser Hotwell	x		x	x	x	x		x	x			x
8. Steam Killer Outlet	x		x	x	x	x		x	x			x
9. Steam from Fuel Ht. Ex.	x							x	x			x
10. Steam from blkt. Ht. Ex.	x							x	x			x

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Appendix A

Estimate of Oxygen Generated in the HRT Fuel Heat Exchanger

Segaser⁽²¹⁾ estimated that the radiation energy in the HRT fuel heat exchanger at 5 Mw operation is 8×10^{16} Mev/sec. He assumed 75 percent of this energy is absorbed in the HRT heat exchanger and 60 percent of this energy is absorbed in the steam system water.

The rate of O_2 formation is estimated to 1/2 molecule of O_2 per 200 electron volts of energy absorbed⁽²⁶⁾, and the rate of steam formation is 16,700 pounds per hour according to drawing D-18267-d. The rate of oxygen formation at 5 Mw operation is

$$\frac{(0.75)(0.60)(8 \times 10^{22})(1/2)(3600)}{(6.02 \times 10^{23})(200)} = 0.538 \text{ moles/hr}$$

and the equivalent concentration developed is

$$\frac{(0.538)(32)(10^6)}{(16,700)(454)} = 2.27 \text{ ppm}$$

Appendix B

Estimate of Hydrazine Consumed by Radiation in the HRT Fuel Heat Exchanger

At 8 ppm hydrazine concentration in water, hydrazine decomposes at the rate of 1.7 molecules per 100 electron volts absorbed^(10,28). Segaser⁽²¹⁾ estimated that the radiation energy is absorbed in the HRT heat exchanger's water at the rate of $(0.75)(0.60)(8 \times 10^{16})$ or 3.6×10^{16} Mev per second.

The rate of hydrazine decomposition is then

$$\frac{(3.6 \times 10^{22})(1.7)(3600)}{(100)(6.02 \times 10^{23})} = 3.66 \text{ moles/hr}$$

and the equivalent concentration developed is

$$\frac{(3.66)(32)(10^6)}{(16,700)(454)} = 15.5 \text{ ppm}$$

Appendix C

Estimate of Sodium Sulfite Consumed by Radiation in the HRT Fuel Heat Exchanger

The rate of sulfite consumption under gamma radiation is 0.9 molecules per 100 electron volts absorbed⁽¹⁰⁾. Segaser⁽²¹⁾ estimated that the radiation energy is absorbed in the HRT fuel heat exchanger's water at the rate of $(0.75)(0.60)(8 \times 10^{16})$ or 3.6×10^{16} Mev per second. The rate of sodium sulfite consumption is then

$$\frac{(3.6 \times 10^{22})(0.9)(3600)}{(100)(6.02 \times 10^{23})} = 1.94 \text{ moles/hr}$$

and the equivalent concentration is

$$\frac{(1.94)(142)(10^6)}{(16,700)(454)} = 26.3 \text{ ppm}$$

Appendix D

Estimate of the Rate of Consumption of Hydrazine and Sodium Sulfite Solutions

From Appendices A and B, it is assumed that the feedwater hydrazine concentration is about 20 ppm. If the rate of steam circulation is 16,700 pounds per hour at 5 Mw operation, the amount of hydrazine required each hour is then

$$\frac{(20)(16,700)}{(10^6)} = 0.374 \frac{\text{lbs } \text{N}_2\text{H}_4}{\text{hr}}$$

If the hydrazine is diluted to a 3 percent solution, the amount of solution required would be

$$\frac{(0.374)}{(0.03)(8.33)} = 1.5 \text{ gal/hr}$$

At 10 Mw operation, twice as much or 3.0 gallons per hour of hydrazine solution would be required.

The estimated concentration of sodium sulfite in the feedwater is about 45 ppm according to Appendices A and C. Therefore, the amount of this compound required for water treatment at 5 Mw operation is

$$\frac{(45)(16,700)}{10^6} = 0.800 \text{ lbs } \text{Na}_2\text{SO}_3/\text{hr}$$

If this is added to the feedwater in the form of a 5 percent solution, the amount of solution required at 5 Mw operation would be

$$\frac{(0.800)}{(0.05)(8.33)} = 1.9 \text{ gal/hr}$$

At 10 Mw operation, approximately 3.8 gallons per hour of sulfite solution would be required.

The above estimates are very approximate. Therefore, proportional pumps capable of delivering from 0 to 5 gallon per hour of solution to the HRT steam system should be satisfactory.

Appendix E

Sample Coolers

Coolers for the samples from the liquid lines and the steam lines are considered separately.

Liquid Sample Coolers

The highest-temperature liquid in the HRT steam system (as shown on Drawing D-18267-d) is 479°F in the blanket heat exchanger. Designing for this worst case, it is arbitrarily assumed that these samples are to be cooled from 479°F to 100°F. Although sample temperatures of less than 100°F are desirable, and probably will be obtained in most instances, the design temperature of 100°F results in practical amounts of 80°F cooling water consumption when the sample flow rate is about 1 liter per minute⁽¹⁷⁾.

Design of these sample coolers are similar to those in use by TVA at the Kingston Steam Plant⁽¹⁸⁾. The inside tube through which the water sample flows is stainless steel in order to keep the contamination of the sample to a minimum. A 3/8 inch O.D. tube is selected since smaller diameter tubes increase the chance of accumulating foreign particles in the sample cooler. The wall thickness is selected to be 18 gauge (0.049 inches), and the water jacket is arbitrarily selected to be 3/4 inch, 18 gauge, brass or copper tubing.

The heat to be removed from the water sample is⁽¹¹⁾

$$463.0 - 68.0 = 395 \text{ Btu/lb}$$

Assuming that the flow is 1 liter per minute at 100°F, the weight of water flowing through the sample cooler is

$$\frac{(1)(60)}{(28.32)(0.01613)} = 131.4 \text{ lb/hr}$$

Therefore the heat load on this cooler is

$$395 \times 131.4 = 51,900 \text{ Btu/hr}$$

If a 120°F temperature rise is allowed for the cooling water, the amount of it required is

$$\frac{51,900}{(1)(120)} = 432.5 \text{ lb/hr}$$

or

$$\frac{(432.5)}{60} (0.01608)(7.48) = 0.868 \text{ gpm at } 80^\circ\text{F}$$

To obtain the average velocity of the liquid sample inside the cooler, the specific volume of 0.01735 cu ft/lb at the arithmetic average temperature of 290°F is used

$$\frac{(131.4)(0.01735)}{(3600)(0.000418)} = 1.515 \text{ ft/sec}$$

For the average velocity of the coolant, the specific volume of 0.01629 cu ft/lb at the arithmetic average temperature 140°F is used

$$\frac{(432.5)(0.01629)}{3600 \left[0.00232 - \frac{\pi(0.375)^2}{4 \times 144} \right]} = 1.262 \text{ ft/sec}$$

The inside heat transfer coefficient h_i under these conditions is 854 Btu/(hr)(sq ft)(°F) and the outside heat transfer coefficient h_o is 578 Btu/(hr)(sq ft)(°F)⁽²³⁾. The thermal conductivity of the stainless steel is 9.4 Btu/(hr)(ft)(°F)⁽³⁾, and therefore the wall heat transfer coefficient is $(9.4 \times 12)/(0.049)$ or 2300 Btu/(hr)(sq ft)(°F). The fouling coefficient is estimated to be 250 Btu/(hr)(sq ft)(°F)⁽¹²⁾. The overall coefficient based on the outside area is then

$$\frac{1}{U_o} = \frac{D_o}{D_i h_i} + \frac{D_o}{D_m h_w} + \frac{1}{h_o} + \frac{1}{h_s}$$

$$= \frac{(0.375)}{(0.277)(854)} + \frac{(0.375)}{(0.326)(2300)} + \frac{1}{578} + \frac{1}{250} = 0.00782$$

or

$$U_o = 128 \text{ Btu/(hr)(sq ft)(}^{\circ}\text{F)}$$

The logarithmic mean temperature difference in this cooler is

$$(\Delta T)_m = \frac{(479-200)-(100-80)}{\ln \frac{(479-200)}{(100-80)}} = 98.3^{\circ}\text{F}$$

Therefore the required cooling area is

$$A_o = \frac{q}{U_o(\Delta T)_m} = \frac{51,900}{(128)(98.3)} = 4.13 \text{ sq ft}$$

and the required length of tubing is

$$L = \frac{4.13}{0.0981} = 42.0 \text{ ft}$$

It is arbitrarily decided to make the sample coolers in the form of 8 inch diameter coils. The number of turns required would be

$$N = \frac{(42.01)(12)}{(\pi)(8)} \sim 20 \text{ turns}$$

Steam Sample Cooler

The assumptions used in calculating the heat transfer area for the liquid sample coolers may be used for the steam sample coolers except that a condensing steam coefficient must be substituted for the liquid film coefficient and the heat removal load is greater.

The heat to be removed from the steam sample is

$$1203.8 - 68.0 = 1136 \text{ Btu/lb}$$

Assuming that the sample flow is 1 liter per minute at 100°F, the weight of sample flowing through the cooler again is 131.4 lbs/hr. Therefore, the heat load on the steam sample cooler is

$$1136 \times 131.4 = 149,400 \text{ Btu/hr}$$

If a 120°F temperature rise is allowed for the cooling water, the amount required is

$$\frac{149,400}{(120)(1.0)} = 1245 \text{ lb/hr}$$

or

$$\frac{(1245)}{60} (0.01608)(7.48) = 2.50 \text{ gpm at } 80^\circ\text{F}$$

Since the steam is condensed and cooled, the heat transfer may be considered in two parts:

Part 1: The condensing section

Part 2: The subcooling section

Part 1

The latent heat removed by condensing the steam at 560 psia is 740.8 Btu per pound⁽¹¹⁾, or a total of

$$740.8 \times 131.4 = 97,300 \text{ Btu/hr}$$

The temperature in the cooling water at the point where the condensation is complete is

$$200 - \frac{97,300}{(1245)(1)} = 121.8^\circ\text{F}$$

Kern⁽¹²⁾ gives a method for calculating the inside condensing coefficient h_i in horizontal tubes

$$h_i \left(\frac{\mu_f^2}{k_f^3 r^2 g} \right)^{1/3} = 1.51 \left(\frac{h_{G''}}{\mu_f} \right)^{1/3}$$

where

$$G'' = \frac{w}{0.5 L_1 N_t} = \frac{\text{lb}}{(\text{hr})(\text{lin ft})}$$

L_1 is the linear length, ft, and N_t is the number of tubes.

The steam side film temperature is assumed to be

$$t_f = \frac{479 + \frac{200 + 122}{2}}{2} = 320^\circ\text{F}$$

Therefore for the steam sample cooler⁽¹⁶⁾

$$G'' = \frac{131.4}{(0.5)(L_1)(1)} = \frac{262.8}{L_1} \frac{\text{lb}}{(\text{hr})(\text{lin})(\text{ft})}$$

and

$$h_1 = 1.51 \left(\frac{4 \times \frac{262.8}{L_1}}{0.421} \right)^{-1/3} \quad (7730)$$

$$= 858 L_1^{1/3} \text{ Btu}/(\text{hr})(\text{sq ft})(^\circ\text{F}); \text{ where } L_1 = \text{ft}$$

As before, the wall coefficient h_w is assumed to be $2300 \text{ Btu}/(\text{hr})(\text{sq ft})(^\circ\text{F})$.

In estimating the outside coefficient, the velocity of the coolant is determined at the arithmetic average coolant temperature of 161°F .

$$\frac{(1245)(0.01640)}{(3600) \left[0.00232 - \frac{\pi(0.375)^2}{4 \times 144} \right]} = 3.66 \text{ ft/sec}$$

From Stoever⁽²³⁾, the outside coefficient is then $1470 \text{ Btu}/(\text{hr})(\text{sq ft})(^\circ\text{F})$.

The total fouling coefficient is assumed to be $333 \text{ Btu}/(\text{hr})(\text{sq ft})(^\circ\text{F})$.

Therefore, the overall heat transfer coefficient based on the outside area is then

$$\begin{aligned} \frac{1}{U_{o1}} &= \frac{D_o}{D_i h_i} + \frac{D_o}{D_m h_w} + \frac{1}{h_o} + \frac{1}{h_s} \\ &= \frac{(0.375)}{(0.277)(858 L_1^{1/3})} + \frac{(0.375)}{(0.326)(2300)} + \frac{1}{1470} + \frac{1}{333} \\ &= 0.00418 + \frac{0.00158}{L_1^{1/3}} \end{aligned}$$

The log mean temperature difference in this portion of the steam sample cooler is

$$(\Delta T)_m = \frac{(479-122) - (479-200)}{\ln \frac{(479-122)}{(479-200)}} = 316^\circ\text{F}$$

The length is related to area by

$$A_{o1} = 0.0981 L_1$$

therefore

$$A_o = \frac{q}{U_o(\Delta T)_m}$$

or

$$0.0981 L_1 = \frac{97,300}{316} \left(0.00418 + \frac{0.00158}{L_1^{1/3}} \right)$$

By trial and error

$$L_1 = 15.1 \text{ ft}$$

Part 2

The heat removed in cooling the condensate from 479°F to 100°F is 51,900 Btu/hr, as for the liquid sample cooler.

The inside heat transfer coefficient h_i is the same as that for the liquid sample cooler, 854 Btu/(hr)(sq ft)($^\circ\text{F}$), and the wall coefficient h_w is also the same, about 2300 Btu/(hr)(sq ft)($^\circ\text{F}$).

$$\frac{(1245)(0.01614)}{(3600) \left[0.00232 - \frac{\pi(0.375)^2}{4 \times 144} \right]} = 3.58 \text{ ft/sec}$$

From Stoever⁽²³⁾, the outside heat transfer coefficient is then 1170 Btu/(hr)(sq ft)($^\circ\text{F}$).

Assuming the total fouling coefficient to be 333 Btu/(hr)(sq ft)($^\circ\text{F}$), the overall heat transfer coefficient based on the outside area is then

$$\frac{1}{U_{O_2}} = \frac{D_o}{D_i h_i} + \frac{D_o}{D_m h_w} + \frac{1}{h_o} + \frac{1}{h_s}$$

$$= \frac{(0.375)}{(0.277)(854)} + \frac{(0.375)}{(0.326)(2330)} + \frac{1}{1170} + \frac{1}{333} = 0.00594$$

or

$$U_{O_2} = 168 \text{ Btu/(hr)(sq ft)(}^{\circ}\text{F)}$$

The log mean temperature difference in this position of the steam sample cooler is

$$(\Delta T)_m = \frac{(479-122) - (100-80)}{\ln \frac{(479-122)}{(100-80)}} = 117^{\circ}\text{F}$$

Therefore, the area required for cooling is

$$A_{O_2} = \frac{q}{U_o(\Delta T)_m} = \frac{51,900}{(168)(117)} = 2.64 \text{ sq ft}$$

and the required length of tubing is

$$L_2 = \frac{2.64}{0.0981} = 26.9 \text{ ft}$$

The total length of 3/8 inch O.D. tubing required for the steam sample cooler is then

$$L = L_1 + L_2 = 16.1 + 26.9 = 42.0 \text{ ft}$$

As above, the sample coolers are to be made in form of an eight inch diameter coil, and the number of required turns would be

$$N = \frac{42.0 \times 12}{\pi \times 8} = 20$$

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It is observed that the same number of turns are required for both the liquid sample and the steam sample coolers. Therefore, all of the sample coolers can be of a standard design.

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Appendix F

Procedure for Collecting Samples to be Analyzed for Oxygen

Samples for oxygen analysis must be taken in such a manner that oxygen from the surrounding air is not absorbed by the sample. The procedure described here is the one that is in use by the TVA^(17,18).

Figure 3 shows the sampling apparatus required for these samples. Two 250 ml and one 500 ml glass stoppered bottles are placed in a special pail. The tops of the bottles are at the same level, and the volume of the bottles are accurately adjusted by the use of glass beads. All connections requiring rubber tubing are to be made with pure gum rubber tubing.

To start the collection of the sample, the water sample pipe outlet is connected to the inlet of the manifold with its outlet ends resting on the bottom of the pail. The water is allowed to flow into the pail and out through the overflow for about 15 minutes. This is to be done in such a way as to exclude as much air as possible from the pail.

The three bottles are immersed in the pail and the sample flow rate should be between 0.75 and 1 liter per minute. The temperature of this water should preferably be less than 70°F, and never above 90°F. After the water sample has passed through the sample bottle for at least 20 minutes with the sample water still flowing, the manifold is raised from the bottles and then lowered into the pail. The outlets of the manifold should not be raised above the water level during this procedure.

One of the 250 ml bottles is stoppered, and the fixing solutions are added to the other two bottles with the bottles under water. The fixing solutions are stored in 200 ml polyethylene bottles. These bottles are closed with rubber stoppers which have a 5 ml graduated pipette through them.

The pipettes mounted this way may be filled by simply squeezing the bottles.

Two ml of the above three solutions are added to each of the two bottles underwater. Glass stoppers are placed on the bottles between the addition of the various chemicals. The chemicals to be added are manganous sulfate, alkaline potassium iodide, and hydrochloric acid. Details on the nature of these solutions and the analytical procedure may be obtained from R. E. Corcoran of ORNL. The first two solutions are added to the glass bottles by filling the pipettes with solution placing the top of the pipette under water and allowing a little of the solution to flow into the pail in order to remove any contamination, and then placing the required amount of solution in each of the two bottles. These two bottles with the glass stoppers are removed from the pail, and the solution and the samples are mixed by inverting the bottles several times. The bottles are then returned to the pail and the third solution is added. All the samples are then removed from the pail, and the two bottles with the solutions are again mixed by inverting the bottle several times. The sample is then ready for titration in the laboratory.

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Fig. 1. APPROXIMATE pH VALUES OF Na_3PO_4 SOLUTIONS (5)

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FIG. 2 CHEMICAL FEED EQUIPMENT FOR THE HRT STEAM SYSTEM

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ORNL-LE-DWG -17443
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HRT STEAM SYSTEM
SAMPLING PAIR & TRIDENT FOR DISSOLVED
OXYGEN TEST

Figure 3

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