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SUBJECT: PRFR Pilot Leaching Plant - Preliminary Process Design

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SUMMARY

The preliminary process design of a PRFR pilot leaching plant, which is proposed to be located in Cell B of Building 3026 at ORNL, is considered. Chemical, physical, and nuclear parameters are investigated in order that the leaching operations may be carried out without any chemical or nuclear hazards.

Nitric acid solvents are used for leaching the uranium and/or thorium from the sheared spent fuel elements, and the dissolved fuel is sent through a shielded pipeline to the extraction plant in Building 3019 at ORNL for further processing. Recommended materials of construction are 304L stainless steel and 309SCb stainless steel, and maintenance is by direct procedures.

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Introduction

Mechanical processing of spent fuel elements from various power reactors consists of shearing these elements into short lengths which exposes the fuel, and subsequently leaching the fuel from these sheared lengths. This report considers the preliminary process design and the flowsheet of a pilot leaching plant for use in tests to prove the feasibility of mechanical processing.

This unit is to be located in Cell B of Building 3026 at ORNL, and it is designed such that it does not present a chemical or a nuclear hazard. The physical size of the leacher itself arbitrarily is limited to about 100 gal. No feed adjustment is made at this location but the dissolved fuel is sent to the chemical extraction plant in Building 3019 at ORNL through a suitable pipeline. The pressure inside the leaching plant equipment is to be maintained at a slight vacuum to insure air inleakage if a failure occurred in the walls of the equipment.

Shears for segmenting the spent fuel elements are to be located in Cell A of Bldg. 3026. Design of these shears and methods of transporting the segmented material from the shears to the leacher are not considered in this report.

Basic Chemistry

Nitric acid is used for leaching the UO_2 from the sheared fuel elements. The basic chemical reaction for this process is⁽¹⁾

For the leaching of the ThO_2 - UO_2 from the sheared fuel elements such as those from the Consolidated Edison reactor, nitric acid containing a small amount fluoride ion is recommended. The basic chemical reaction for this process is⁽¹⁾

Both of these chemical reactions are exothermic and provision must be made for the removal of this heat during the leaching process. A reflux condenser is chosen since the leacher is usually operated at boiling temperatures. Nitric oxide (NO) and nitrogen dioxide (NO_2) are produced during the dissolution of UO_2 . These oxides are gaseous, and they are absorbed at a relatively slow rate by water to form nitric acid. Since the rate of absorption is proportional to the vapor liquid interfacial area, a downdraft condenser is selected to maintain a greater nitric acid economy at the leacher.

Leaching times of UO_2 from sheared prototype PWR blanket elements in nitric acid have been determined by G. A. West.^(2,3) These times were obtained for elements sheared into various lengths, and the experimental results are shown in Figs. 1 and 2. Leaching times shown in Fig. 1 are for cases where the sheared pellets are placed with the nitric acid in a vessel at room temperature and subsequently brought up to boiling temperatures. Those shown in Fig. 2 are for the sheared pellets dropped into boiling nitric acid. For both sets of data, 10 molar nitric acid was used at a volume to mass ratio of about 3 ml of acid per g of

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CONDITIONS

VOLUME TO MASS RATIO: 2.5 ml/g UO_2

CLAD: 304-L SS, 0.40-in. O.D. WITH 0.010-in. WALL

PELLETS: ~ 0.370 -in. O.D., SINTERED, UNIRRADIATED

Figure 1. HNO_3 Leaching of Sheared SS Clad UO_2 vs Time. (2)

Figure 2. Boiling HNO₃ Leaching of Sheared SS Clad UO₂ vs Time. (3)

UO₂. These data indicate that the dissolution of the UO₂ in nitric acid is essentially complete in about 2 hours.

Foaming accompanied the dissolution process for both situations, but it was substantially less for cases where the pellets and acid were placed in a vessel at room temperatures and subsequently brought up to boiling temperatures. No residual UO₂ was found in the leached material.

On the basis of these experiments, 10 molar nitric acid is suggested for the leaching of the UO₂ from the sheared spent fuel elements. Further operating experience is required to determine whether the acid should be initially at room temperature or at the boiling temperature. The leacher should be filled only to half of its capacity (50 gal) in order to allow about 100% freeboard volume for the foam. The volume of acid suggested should be such that the final uranium concentration in the acid is 2 molar.

Leaching data for the dissolution of ThO₂-UO₂ fuel from the sheared elements are not as extensive as those for the sheared UO₂ material. Preliminary data obtained by L. M. Ferris⁽⁴⁾ show that about 90 to 95% of the fuel can be dissolved from the sheared elements in about 5 to 6 hours at boiling temperatures. The solvent used in these experiments was 13 molar nitric acid containing 0.04 molar sodium fluoride and 0.04 molar aluminum nitrate, which was used at a volume to mass ratio of 3.5 ml acid per g of oxide. Dissolution data of ThO₂-UO₂ pellets in this acid mixture have been obtained by W. D. Bond⁽⁵⁾. These data indicate that the 13 molar acid concentration is desired and that the dissolved thorium acts as an inhibitor to the dissolution process. When the dissolved thorium concentration is above 1 molar, the dissolution rate becomes negligible. Very little or no foaming accompanies this dissolution process.

On the basis of these experiments, 13 molar nitric acid containing 0.04 molar sodium fluoride and 0.04 molar aluminum nitrate at boiling temperatures is suggested for the dissolution of the ThO₂-UO₂ fuel. The initial acid charge suggested is that such as the final dissolved thorium concentration in the acid solution is 1 molar.

One proposed method of transporting the sheared fuel elements from the shears to the leacher is to can them in containers made from aluminum or carbon steel.⁽⁶⁾ These cans of the segmented material would be moved from the shears to the leacher by suitable methods, and the cans subsequently would be dissolved with the fuel in the leacher. The aluminum or the iron added to the solution would not affect the solvent extraction process which follows later.⁽⁷⁾ Aluminum will dissolve readily along with the uranium and/or thorium in nitric acid if a small amount of mercuric nitrate is added to the solvent. Since iron may cause an instability in the dissolved fuel solution, more experimental work is required before it is known whether this material is satisfactory for the transport containers.⁽⁸⁾

Materials of Construction

The use of nitric acid chemistry will permit the use of 304L stainless steel and 309SCb stainless steel as the materials of construction for the PRFR pilot leaching plant. Corrosion rates for these two metals in the Thorex pilot

plant have been determined by English. (9,10) Some of the results from samples placed in the Thorex dissolver and feed adjustment tanks are shown in Table 1. As can be seen from this table, the metal exposed to the vapor phase experienced more severe damage than that exposed to the solution phase. The corrosion was generally uniform except at the welds where some intergranular and knife-line corrosion took place.

Some specimens of 347 stainless steel were exposed in the Thorex plant also. The corrosion rates of this alloy were considerably higher than those for 304L and 309SCb stainless steel and therefore it is not recommended for use in the PRFR leaching plant.

Flowsheet

A flowsheet of the PRFR pilot leaching plant is shown in Fig. 3. The necessary equipment and facilities to make the operation of this pilot plant feasible and practical are summarized as follows:

- L - 1 Leacher
- L - 2 Condenser and Entrainment Separator
- L - 3 Recycle Acid Tank
- L - 4 Feed Acid Heater
- L - 5 Surge Tank
- L - 6 Solution Pipeline Pump
- L - 7 Solution Pipeline Pump
- L - 8 Turco 4501 Solution Storage Tank
- L - 9 Turco 4502 Solution Storage Tank
- L - 10 Caustic Scrubber (Optional)
- M - 1 Acid Feed Tank
- M - 2 Rinse Solution Tank
- M - 3 Makeup Acid Pump
- M - 4 Caustic Solution Tank (Optional)
- M - 5 Makeup Caustic Pump (Optional)

Items containing radioactive materials are located within shielded areas, and items containing nonradioactive materials are located outside of the shielding. Off gas produced during the leaching operations passes directly from the entrainment separator to the stack through the present off gas line discharging from Cell A of Building 3026. (11) Caustic scrubbing equipment, which would be required if the radiation level or the nitrogen oxides contents of the off gas are beyond the capacity of the off gas treating equipment at the stack, is shown as optional equipment on the flowsheet. Solutions containing the dissolved uranium and/or thorium are pumped from Building 3026 to Building 3019 for further chemical processing through a shielded 1/2 in. Sch. 40S pipeline.

To make the operation of this plant more convenient, additional vessels are added to those absolutely required and these include the recycle acid tank, the surge tank, the Turco solution tanks, and the rinse solution tank. The recycle acid tank permits a storage volume for the acid solvent used for the washing operations of the leached cladding. This acid may be then used in a subsequent leaching cycle, which greatly reduces the amount of evaporation required at the feed adjustment tank at the extraction plant. A surge

Figure 3. Pilot Leaching Plant - Flowsheet.

Table 1

Corrosion Rates for 304L and 309 SCb Stainless Steels Exposed in
the Batch Dissolver and Feed Adjustment Tanks of the Thorex Pilot Plant (9,10)

Period of Operation	Process Vessel	Specimen Location	Exposure* (hr)	Corrosion Rate (mpy)	
				304L	309SCb
Production	Batch dissolver tank	Solution	634	8.0 ± 0.4	3.1 ± 0.5
		Vapor	634	3.6 ± 1.7	2.0 ± 0.3
Development	Batch dissolver tank	Solution	2706	31.8 ± 0.9	15.0 ± 1.6
		Vapor	2706	40.3 ± 1.5	34.9 ± 1.9
Production	Feed adjustment tank	Solution	555	4.2 ± 0.4	6.1 ± 2.5
		Vapor	555	21.1 ± 2.0	35.0 ± 8.5
Development	Feed adjustment tank	Solution	2609	-----	41.4 ± 4.8
		Vapor	2609	94.8 ± 3.0	84.9
Development	Feed adjustment tank	Solution	2142	19.6 ± 2.8	24.9 ± 3.0
		Vapor	2142	29.7 ± 6.1	39.9 ± 4.0

* Holding time of solution at room temperature is not considered as a part of the exposure period.

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tank is included to store the solution containing the dissolved fuel prior to pumping it through the pipe line to the extraction plant and provide a drain volume for the pipe line. Tanks are provided for storing the Turco decontamination solutions since this material is relatively expensive and it can be used repeatedly. (19) The rinse solution tank is for storing the rinse solutions which may be used in some of the washing operations of the clad material.

Solutions from the acid feed tank and the rinse solution tank can be added to the leacher either directly, through the recycle tank and the acid heater, or through the surge tank. These liquids flow to these various vessels through U-bends, which provide a seal between the cell equipment which operates at a small vacuum (about 40 in. of water) and the makeup equipment which operate at a smaller vacuum (about 4-5 in. of water). Check valves are included in these lines to prevent the backflow of radioactive materials, and the makeup tanks serve as air breaks between the plant equipment and process water lines.

All radioactive liquid waste from inside the leaching plant equipment is jetted to the hot cell waste tank from only the surge tank in order that this liquid can be sampled and analyzed before it is discarded. (An exception is the optional caustic scrubber). This helps to insure that uranium and/or thorium will not be accidentally discharged to the waste area.

The flowsheet as shown in Fig. 3 permits the operation of this plant essentially in the following manner:

1. The sheared fuel elements are transported from the shears and placed in the leacher by suitable methods.
2. The openings in the leacher are closed.
3. Acid solvent is added to the recycle acid tank from the acid feed tank, or it has been added to the recycle acid tank from the leacher during the previous dissolution cycle.
4. The acid is jetted from the recycle acid tank through the acid heater to the leacher.
5. Uranium and/or thorium is leached from the sheared material by the hot acid. A downdraft condenser is used for removing the heat of reaction.
6. The solution containing the leached material is jetted into a surge tank and it is pumped through a shielded pipeline to the chemical extraction plant.
7. Fresh acid solvent is added to the leacher through the acid feed tank, the recycle acid tank, and the feed acid heater.
8. This acid is allowed to react with any fuel that possibly remains with the cladding in the leacher.
9. This second charge of acid is jetted back to the recycle acid tank.

10. Additional rinsings of the cladding are made with dilute nitric acid or water from the rinse solution tank if found necessary by analysis of the liquid samples taken from the leacher.

11. The cladding material remaining in the leacher is removed for disposal.

Although the above scheme is anticipated to be the usual method of operation for the PRFR pilot leaching plant, there is enough flexibility designed into the plant to permit alternate methods of operation. For example, if the solution in the leacher became unsuitable for transport to the chemical extraction plant, part or all of this solution could be jetted into and stored in the recycle acid tank. Materials for subsequent operations in the leacher could be added through the acid rinse tank. The stored solution could be then jetted back into the leacher at a desired rate.

Leacher

The design of the batch leacher selected at the time of this report (July, 1959) is rather unorthodox as shown in Figs. 4 and 5. Modified or new designs may be selected in the future as new methods of material transfer are developed. The unorthodox design selected here is based on consideration of criticality, the necessary volume to contain fuel and solvent, the loading and unloading of fuel segments and cladding, the offgas and instrument connections, and the possibility of scaleup.

As can be seen in Figs. 4 and 5, the leacher selected consists of a central tank containing the solvent acid and the dissolved fuel and two outboard pipes containing the chopped fuel elements. The nominal size of this leacher is arbitrarily limited to about 100 gal,⁽¹²⁾ and it contains 121 gal when it is completely flooded.

Approximately 50 gal of acid per charge is used for dissolving UO_2 to 2 molar uranium concentration and 100 gal of acid per charge is used for dissolving $\text{ThO}_2\text{-UO}_2$ to a 1 molar thorium concentration as summarized in Table 2. (A 100% freeboard volume is allowed for the foam which is produced during the dissolution of UO_2 with nitric acid.) The leacher is thus capable of handling approximately 100 kg of UO_2 or $\text{ThO}_2\text{-UO}_2$ for each charge.

The greatest concentration of U-235 contained in any of the fuel to be processed (See Table 2) is that in the Consolidated Edison outer region elements. (8.62 weight % of 93% enriched UO_2 .⁽¹³⁾) A cylindrical container containing this fuel must be 10 in. or less in diameter in order to be critically safe.⁽¹⁴⁾ Also, this cylinder must be kept at least 2 ft from a similar container filled with the same material and at least 1 ft from the acid solution tank.

The limiting condition for sizing the acid tank of the leacher is taken as a solution with a 4 molar concentration of uranium from the N.S. Savannah fuel. This is a double batch situation, and the solution contains 39.6 g U-235/liter. Although the Consolidated Edison outer region fuel contains a greater weight percent of U-235 than that for the N.S. Savannah, the dissolution rate of $\text{ThO}_2\text{-UO}_2$ in nitric acid containing 250 g/liter or more thorium is negligible.^(5,15) The U-235 concentration for the Consolidated Edison case is less than that above, and therefore is not the limiting condition.

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Figure 4. PRFR Batch Leacher for Mechanical Reprocessing of Spent Reactor Fuels.

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Figure 5. PRFR Batch Leacher.

Table 2

Acid Requirements and U-235 Concentrations for Leacher

- Bases: 1. U-235 concentrations are based on those in the fresh fuel elements.
 2. Each charge contains 100 kg UO_2 or $\text{ThO}_2\text{-UO}_2$.
 3. Final $\text{UO}_2(\text{NO}_3)_2$ concentration for UO_2 fuel is 2 molar.
 4. Final $\text{Th}(\text{NO}_3)_4$ concentration for $\text{ThO}_2\text{-UO}_2$ fuel is 1 molar.

Element	UO_2 %	ThO_2 %	U-235 % of Th,U,O	Pellet Density g/cc	Dissolved UO_2 & ThO_2 g/liter	Dissolved U-235 g/liter	Acid Volume liters	Acid Volume gal.	Acid Volume per charge ml/g
Consolidated Edison									
Inner Region	5.45	94.55	4.46	9.14	279	12.5	358	94.6	3.58
Middle Region	7.22	92.78	6.36	9.14	285	18.1	351	92.8	3.51
Outer Region	8.62	91.38	7.59	9.14	289	21.9	346	91.4	3.46
Rural Coopera- tive	4.47	95.53	3.65	8.97	276	10.1	362	95.6	3.62
Commonwealth Edison	100	-	1.32	9.64	540	7.13	185	48.9	1.85
Yankee Atomic	100	-	2.29	10.2	540	12.4	185	48.9	1.85
N. S. Savannah	100	-	3.67	10.1	540	19.8	185	48.9	1.85

A slab 6 in. thick is considered safe for a solution containing 39.6 g/liter of U-235.⁽¹⁴⁾ The actual liquid thickness in the acid tank of the leacher is only 5 in. in order to prevent a nuclear incident due to the possible bowing of the tank sides.

The top of the cylindrical outboard fuel tanks of the leacher are free of all connections in order that they may be opened for the charging of the sheared fuel elements and to permit the removal of the cladding material. Although Fig. 4 shows ordinary flanges for this purpose, other types of closures are being considered.

Several process lines are connected to the leacher to aid in its operation. These connections include:

1. Offgas line.
2. Condensate return line.
3. Acid feed line.
4. Rinse solution feed line
5. Outlet lines to the surge tank.
6. Outlet lines to the recycle acid tank.
7. Air sparging lines.
8. Sampling lines.
9. Temperature probes.
10. Liquid level probes.
11. Density probes.
12. Steam lines for the decontamination jets.
13. Steam lines for the heating and cooling jackets.
14. Condensate lines for the heating and cooling jackets.
15. Cooling water lines.

With the exception of the lines connecting the heating and cooling jackets, all process lines should enter through the top of the vessel whenever possible. This is done to minimize the effect of a failure which may occur at a welded joint. Should a weld failure occur, the dissolved uranium would not be lost out into the cell and the air leakage would be into the leacher. Thus the uranium solution could be contained and the cell contamination is held down to a minimum.

The heating and cooling of the liquid in the leacher is accomplished by heating and cooling jackets attached to the outboard pipes of the leacher. Two jackets are attached to each outboard pipe; the lower one being 2 ft long and the upper one being 1-1/2 ft long. Connections are made to these jackets to permit the use of 100 psig steam for heating or water for cooling. A jacket is not placed on the flat acid tank of the leacher because stress considerations would result in a very thick vessel wall.⁽¹⁶⁾ As shown in Appendix A, these jackets are capable of heating the acid solution in the leacher from room temperature to boiling temperature in about 1/2 hr, and they are capable of cooling this solution from boiling temperature to about 100°F in about 1 hr. Also, water can be evaporated from the solution in the leacher at a rate of about 0.4 gpm.

The size of the top connection between the flat acid tank and the outboard fuel pipes of the leacher is important in order that the entire leacher may be maintained below atmospheric pressure during its operation. As shown in Appendix B, the design offgas rate is set at 400 cfm. Assuming the pressure drop through this connecting pipe is essentially due to the pipe's inlet and outlet, the head loss of the gas

flowing through this pipe is estimated by

$$\Delta H = 1.5 \frac{V^2}{2g_c} \quad (1)$$

where ΔH = head loss

V = velocity through the pipe

g_c = conversion factor in Newton's law of motion

If this connection is a 4 in. Sch. 40 pipe, the head loss for 400 cfm of offgas

$$\Delta H = \frac{(1.5)(12)(0.000862) \left[\frac{(400)(144)}{(60)(12.73)} \right]^2}{(1)(2)(32.17)} = 1.4 \text{ in. water}$$

Although a 4 in. Sch. 40 pipe is satisfactory for this connection, a 6 in. Sch. 40 pipe is actually used to be conservative.

For the offgas pipe from the leacher to the reflux condenser, the pressure drop is assumed to be that due to pipe's inlet, outlet, and bend. Therefore, the head loss of the gas flowing through this pipe is estimated by

$$\Delta H = 1.4 \frac{V^2}{2g_c} \quad (2)$$

Using a 4 in. Sch. 40 pipe,

$$\Delta H = \frac{1.4}{1.5} (1.4) = 1.3 \text{ in. water}$$

A 4 in. pipe is satisfactory for this application also, but a 6 in. pipe is used again to stay conservative.

Scaling up of this particular leacher could be accomplished by adding more outboard fuel pipes and enlarging the central acid tank. As stated above, the outboard fuel pipes must be kept at least 1 ft from the acid tank and 2 ft apart from each other in order to be critically safe.⁽¹⁴⁾ The enlarged acid tank could be a large cylindrical tank containing poison rods to prevent any nuclear incident. Such a design has been shown possible by the calculations of B. E. Prince.⁽¹⁷⁾ This scheme was not adopted in this pilot plant leacher design because of the lack of experimental criticality data⁽¹⁴⁾.

Reflux Condenser

The reflux condenser for the PRFR pilot leaching plant is a shell and tube heat exchanger with the downflow of vapor through the tubes. As shown in Appendix C and Fig. 6, this heat exchanger contains ninety-six 5/8 in. 14 BWG tubes which are 45 in. long. These tubes are contained in a 12 in. pipe shell which has 1-1/2 in. connections to carry about 45 fpm of cooling water. The baffle spacing is 9 in.

This unit is designed to remove about 450,000 Btu/hr of heat from about 350 cfm of vapor. The inlet and outlet temperatures of the vapor are assumed to be 220 and 130°F, and those of the cooling water about 70 and 90°F. A vapor flow rate of

350 cfm is used for the condenser calculations since the 400 cfm design value shown in Appendix B is highly conservative and would result in an unreasonably large size heat exchanger. The head loss of the vapor flowing through this condenser is less than 1 in. of water.

Entrainment Separator and Offgas Pipe

The entrainment separator for the vapor leaving the reflux condenser is a 1 ft extension of the shell of the reflux condenser as shown in Fig. 6. The bottom drain consists of a 3/4 in. Sch. 40 pipe with about a 1 ft condensate trap in it. The head loss through this drain pipe is less than 1 in. of water and therefore there should be no flooding of the entrainment separator with the condensate. The offgas pipe leaving from the side of the separator is a 3 in. Sch. 10S pipe. Assuming two 90° bends in this offgas pipe, the head loss is (including the inlet and outlet losses)

$$\Delta H = 3.0 \frac{v^2}{2g_c} \quad (3)$$

From Appendix B, the maximum flow of the vapor leaving the condenser is about 200 cfm. The head loss through the offgas pipe for these conditions is then

$$\Delta H = \frac{(3.0)(12)(0.000862)}{(1)(2)(32.17)} \frac{(200)(144)^2}{(60)(8.35)} = 2.0 \text{ in. water}$$

Acid Feed and Rinse Solution Tanks and Pump

The acid feed tanks and the rinse solution tanks are each a 150 gal. tank located exterior to the shielding. These tanks are used for the dual purpose of making up solutions for the dissolution of the fuel from the sheared elements and for making up solutions for decontamination purposes. Drawings of these tanks are shown in Fig. 7.

Services for these tanks include as shown in Figs. 3 and 7

1. Water inlet lines.
2. Concentrated solution lines.
3. Vent lines.
4. Soluble powder addition point.
5. Overflow lines.
6. Drain lines.
7. Temperature probe.
8. Liquid level probes.
9. Density probes.
10. Steam lines for the heating coils.
11. Condensate lines for the heating coils.

As shown on the flowsheet of Fig. 3, acid is pumped from the receiving container into these tanks. This acid is diluted with process water which is satisfactory since this pilot plant is limited to dissolution operations. Mixing of the acid or the decontamination agents with the water is accomplished by recirculating the

Figure 7. Acid Caustic and Rinse Solution Tanks.

material in and out of the tanks with the acid makeup pump. Samples for analysis are taken from the acid addition line during this mixing operation. If for some reason the mixing by this method is unsatisfactory, mountings are provided (as shown in Fig. 7) for angular, off-center propeller mixers.

The vent lines from these solution tanks are connected to the main offgas line of the pilot leaching plant. Some suitable arrangement (an orifice) must be provided to limit the vacuum in these tanks to a much lower value than that in the rest of the leaching plant (approximately 3-4 in. of water). Drain and overflow lines are provided to permit the draining and preventing overflow of these vessels.

Solutions from the acid feed tank are fed into the leacher by first draining it from the acid feed tank into the recycle acid tank and subsequently steam jetting it into the leacher, or directly by gravity. Rinse solutions are added to the leacher from the rinse solution tank directly by gravity flow.

Solutions to be used for the decontamination of the pilot plant are made up in the same vessels, and steam coils are provided for heating these solutions prior to their addition to the leaching plant. As shown in Appendix D, coils consisting of 10 turns of 3/4 in. 16 BWG tubing on a 30 in. diameter will heat these liquids to the desired temperatures in less than 3/4 hr. The heating medium is 100 psig steam. The decontamination solutions can be added to the leaching plant either through the usual acid addition lines or through a quick disconnect panel similar to that used in the present Thorex pilot plant. (18) This quick disconnect panel channels the flow of the decontamination solution to various parts of the PRFR pilot leaching plant. (19)

A Series S Chem pump (40) is recommended for the acid feed pump. No packing is required for these pumps and the solutions are clean and nonradioactive. This pump serves several purposes.

1. Add concentrated acid to the feed tanks.
2. Recirculate the solutions for mixing purposes.
3. Pump decontamination solutions to various parts of the cell through a quick-disconnect panel and suitable spray nozzles.

The exact size pump is not selected here since layout and other considerations are necessary.

Recycle Acid Tank

The recycle acid tank as shown in Figs. 3 and 8 permits the recycling of the acid to and from the leacher without removing any material from the cell. This allows the acid used for rinsing the leached cladding to be used as the initial solvent during the next charge of material to be leached. The acid is moved between the leacher and the recycle acid tank by the means of steam jet syphons. Also, the recycle tank provides storage area for a solution that does not behave normally in the leacher and making an alternate treatment necessary for the fuel segments.

AIR SEPARATOR - 2 REQD.
SCALE 1" = 1"

RECYCLE TANK - 2 REQD.
SCALE - 1/4" = 1"

PARTS LIST

PART NO.	DWG. NO.	NO. REQD.	DESCRIPTION (NAME, SIZE, ETC.)	MATERIAL
1	This Dwg.	5	Pipe 1" Sch. 40S 0.133 wall 6" long	ASTM A182-80T F304L
2	"	2	Cap 3" Sch. 40S 0.216 wall	ASTM A182-80T F304L
3	"	1	Pipe 3" " " 0.216 wall 24" long	ASTM A182-80T F304L
4	"	2	Cap 12" Sch. 40S 0.375 wall	ASTM A182-80T F304L
5	"	2	Plate 16" Dia. x 1/4"	ASTM A182-80T F304L
6	"	1	Pipe 12" Sch. 40S 0.375 wall 10'-0" long	ASTM A182-80T F304L
7	"	1	" 1/2" Sch. 40S 0.109 " 6" "	"
8	"	1	" 1/2" Sch. 40S 0.109 " 8'-11 1/2" "	"
9	"	1	" 3/4" " " 0.113 " 6" long	"
10	D-33763	1	Level Probe 1/2" Sch. 40S Pipe 10'-11 1/2" Lg.	"
11	"	1	Sampler " 1/2" " " " 10'-11 1/2" Lg.	"
12	"	1	" " 1/2" " " " 10'-0" Lg.	"
13	"	1	" " 1/2" " " " 10'-10 1/2" Lg.	"
14	"	1	Temp. " 1/2" " " " 10'-8" Lg.	"
15	"	1	Density " 1/2" " " " 10'-11 1/2" Lg.	"
16	"	1	Level " " " " " 0'-16 1/2" Lg.	"
17	"	1	Density " " " " " 9'-11 1/2" Lg.	"
18	"	1	Cap 1/2" Sch. 40S	ASTM A182-80T F304L

GENERAL NOTES:

1. Material listed is for one assembly (2 each Req'd.)
2. Probes to be installed in only one Recycle tank.
3. Welding to be performed according to Welding Specification RD-1.2-2 and inspected to RD-1.4-1 Schedule C.

AIR SEPARATOR & RECYCLE TANKS - DETAILS		D-33763
REFERENCE DRAWINGS		DWG. NO.
PREF. MECHANICAL REPROCESSING		W.D. NO. 4505
AIR SEPARATOR AND RECYCLE TANKS - ASSEMBLY		
OAK RIDGE NATIONAL LABORATORY OPERATED BY UNION CARBIDE NUCLEAR COMPANY DIVISION OF UNION CARBIDE CORPORATION OAK RIDGE, TENNESSEE		
SUBMITTED	ACCEPTED	APPROVED
		REV
D-33762		

GENERAL SPECIFICATIONS:
1. Break all sharp edges 1/64 max., unless otherwise specified.
2. The fabricator may choose the type, grade or finish of material unless otherwise specified.
MACHINE FINISH SPECIFICATIONS:
1. Finish symbols are in accordance with ASA Standard B46.1-1956.
2. Roughness height values are the maximum arithmetical average deviation from the mean surface, expressed in microinches.
3. For surfaces not otherwise indicated, roughness height shall not exceed 1/64.

CLASSIFICATION
Not Classified
C.V. Collins
LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED
FRACTIONS: ± 1/64
DECIMALS: ± .005
ANGLES: ± 2°
SCALE: Noted.

LTR	REVISIONS	DATE	APPD	APPD
DRAWN	DATE	CHECKED	DATE	APPROVED
R.D.S.	3-26-59	CNC	4-1-59	FCZ APP
DESIGNED	DATE	SUBMITTED	DATE	APPROVED

PRELIMINARY
NOT FOR CONSTRUCTION

Figure 8. Recycle Acid Tank.

This recycle acid tank is constructed of two 12 in. Sch. 40 pipes, each 11 ft long, which gives a capacity of 120 gal. Criticality considerations necessitated the 12 in. maximum diameter for each pipe, and an edge to edge distance of at least 2 ft. ⁽¹⁴⁾ The design basis for the maximum U-235 concentration in these recycle tanks is the possible double batching of the dissolved fuel from the N. S. Savannah fuel elements of 39.6 g U-235/liter.

The services to permit the effective operation of the recycle acid tank include as shown in Figs. 3 and 8.

1. Acid inlet line.
2. Solution inlet line.
3. Drain lines.
4. Vent lines.
5. Sampling lines.
6. Temperature probe.
7. Liquid level probes.
8. Density probes.
9. Steam lines for the decontamination jets.
10. Steam lines for the heating and cooling jackets.
11. Condensate lines for the heating and cooling jackets.
12. Cooling water lines.

As for the leacher, all process lines should enter through the top of the vessel whenever possible. The exceptions here are the drain lines and the lines connecting the heating and cooling jackets.

Heating and cooling jackets are necessary for cooling the solution prior to steam jetting it to the leacher and for decontamination purposes. As can be seen from Appendix E, two jackets each 3 ft long permit the heating of the solution in about 1/2 hr. The inlet steam lines are 3/4 in. Sch. 40 pipes and the condensate lines are 1/2 in. Sch. 40 pipes. The cooling water connections are 1 in. Sch. 40 pipes.

Feed Acid Heater

The feed acid heater shown in Figs. 3 and 9 is for heating the acid solution from 110°F to just below boiling temperatures when jetting the acid from the recycle acid tank to the leacher. The acid can be preheated to 110°F in the recycle acid tank prior to jetting it to the leacher. It is not heated to higher temperatures since the steam jet eductor does operate satisfactorily with liquids at higher temperatures.

This heater consists of a 7 in. coil with 19-1/2 turns of 5/8 in. 16 BWG tubing inside a 8 in. Sch. 10S pipe. The liquid flows inside the tubing and it is heated by 100 psig steam condensing on the outside surface. Calculations in Appendix F show that this arrangement will give satisfactory heating of the fluid. The inlet steam connection is a 3/4 in. Sch. 40 pipe and the condensate connection is a 1/2 in. Sch. 40 pipe.

PARTS LIST

PART NO.	DWG. NO.	NO. REQD	DESCRIPTION (NAME, SIZE, ETC.)	MATERIAL
1	THIS DWG.	1	NIPPLE $\frac{3}{4}$ " SCH. 40S PIPE x 5 $\frac{3}{8}$ " LG. SMLS.	304L SS
2	PURCHASE	2	CAP 8" x .148 WALL	
3	"	1	SHELL 8" SCH. 10S x 24 LG.	
4	"	1	TUBE $\frac{3}{8}$ " OD x 16 GA. (065) W. x 38" LG. SMLS.	
5	THIS DWG.	1	NIPPLE $\frac{1}{2}$ " SCH. 40S PIPE x 3 $\frac{3}{8}$ " LG. SMLS.	

NOTES:

1. TUBE BENDS TO HAVE $3\frac{1}{2}$ " RADIUS
2. WELDS TO COMPLY WITH SPECS RD-1.2-2 & RD-1.4-1, SCH. B

PRELIMINARY
NOT FOR CONSTRUCTION

REFERENCE DRAWINGS		DWG. NO.
PRFR - MECH.		SLIDE NO.
ACID HEATER		
OAK RIDGE NATIONAL LABORATORY OPERATED BY UNION CARBIDE NUCLEAR COMPANY DIVISION OF UNION CARBIDE CORPORATION OAK RIDGE, TENNESSEE		
SUBMITTED	ACCEPTED	APPROVED
SCALE: NTS.		D-33765

GENERAL SPECIFICATIONS:
1. Break all sharp edges $1/64$ max. unless otherwise specified.
2. The fabricator may choose the type, grade or finish of material unless otherwise specified.
MACHINE FINISH SPECIFICATIONS:
1. Finish symbols are in accordance with ASA Standard B46.1-1958.
2. Roughness height values are the maximum arithmetical average deviation from the mean surface, expressed in microinches.
3. For surfaces not otherwise indicated, roughness height shall not exceed $63\sqrt{}$.

CLASSIFICATION
UNCLASSIFIED
LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED
FRACTIONS: $\pm 1/16$
DECIMALS: $\pm$
ANGLES: $\pm 1/2^\circ$
SCALE: NTS.

LTR	DATE	REVISIONS	DATE	APPD	APPD
DRAWN	DATE	CHECKED	DATE	APPROVED	DATE
HAYNES	6-3-59	CAC	6-4-59		
DESIGNED	DATE	SUBMITTED	DATE	APPROVED	DATE

Figure 9. Feed Acid Heater.

Surge Tank

The surge tank shown in the flowsheet Fig. 3 is identical in construction to the recycle acid tank shown in Fig. 8. This tank provides a storage space for the dissolved fuel solution prior to pumping it through the pipeline to the extraction plant and a drain space for the solution pipeline. All solutions jetted to the hot cell waste tank pass through this vessel. (An exception is the waste from the caustic scrubber if it is included in the pilot plant.) By this method, all the solutions can be sampled and analyzed before they are drained to the waste area. All solutions can be transferred between the leacher and the surge tank by means of steam jet syphons. Steam jet syphons are chosen in preference to air lifts for these applications because of layout considerations. Connections are also made between these tanks and the tanks for storing the Turco solutions used for decontamination purposes. (19)

Criticality and heat transfer considerations used in the design of the recycle acid tank apply for the surge tank, and all the connections and instruments used for the recycle acid tanks are included here. In addition to the connections, the following are required for the surge tank:

1. Inlet from the Turco 4501 solution storage tanks.
2. Inlet from the Turco 4502 solution storage tanks.

Consideration was given to the use of the recycle acid tank as the surge tank also. This arrangement would require a smaller number of vessels to be placed within the cell. However, the flexibility of the PRFR leaching plant would be greatly reduced, particularly when some material would have to be stored within the cell outside of the leacher and some other solution was in the leacher and required transfer to the chemical extraction plant. Also, the leaching plant would have to be shut down if the pipeline required a drain space if it needed repair.

Turco Solutions Storage Tanks

Storage tanks are provided for each of the Turco 4501 and Turco 4502 solutions since these solutions are relatively costly and can be used repeatedly. These solutions are recommended for the decontamination of the PRFR pilot leaching plant. (19) The location of these tanks should be in some shielded area exterior to the main processing cell as shown schematically in the flowsheet, Fig. 3.

Because of criticality and volume requirements, these tanks are identical in size and construction to the recycle acid tank. The inlet and outlet lines of these tanks are connected to the surge tanks, and the vent lines from these tanks are connected to the surge tank vent line. No provisions are made for taking samples from these tanks since analysis of these materials are required only when they are in other process vessels. Heating and cooling jackets are provided for these tanks since the solutions require cooling before jetting them to the surge tanks and also may need heating if the storage tanks themselves require decontamination. Only level and temperature instruments are required for these units.

Solution Pipe Line and Pumps

The solutions containing the $\text{UO}_2(\text{NO}_3)_2$ and/or $\text{Th}(\text{NO}_3)_4$ are pumped from the PRFR pilot leaching plant in Building 3026 to the chemical extraction plant in Building 3019 through a shielded pipe line^(20,21) (1/2 in. Sch. 40 stainless steel) about 585 ft long.⁽²²⁾

This implies an inventory volume of 1.235 ft^3 which can be readily contained in the surge tank. The height from the floor of the cells in Building 3026 to the ceiling of the cells in Building 3019 is 49 ft.

As shown schematically in Fig. 3, the solutions would flow from the surge tanks through valves located in a shielded valve pit, through the pumps located in a shielded area, and through the shielded pipe line up to the chemical extraction plant. Bellows sealed valves such as those are presently used in the chemical pilot plant are recommended.⁽²⁴⁾ Two centrifugal pumps are placed in parallel in two separate shielded areas which allow one pump to be repaired while the other one is in operation. Freeze jackets are placed on the lines to and from the pumps in the valve pit which can be used to form freeze plugs in order that the pumps may be serviced safely. These freeze plugs are similar to those presently being used on the homogeneous reactor test.⁽³⁹⁾

Two Chempumps purchased for use with the proposed PAR slurry loop for the Oak Ridge Research Reactor are presently available (July, 1959).⁽²⁰⁾ These pumps have high purity aluminum oxide bearings and are fitted with a tubular type of filter (Porolloy-3 micron porosity) in the discharge line so that the purge fluid for the pump must pass through this filter. The performance of these pumps are similar to those of the Series CFH-3 Chempump (about 180 ft at shutoff and about 160 ft at 30 gpm for water at 20°C). It is recommended, however, that the performance and the bearing thrust of these pumps be measured experimentally. If they are unsatisfactory or can not be modified for this particular service, new pumps are recommended. Also, the stability of the aluminum oxide used in the bearings of these pumps in the contacting solutions such as nitric acid and the Turco solutions should be investigated. If they are unsatisfactory other material of construction should be used for the bearings such as graphitar and stainless steel.

The solution should be pumped through this pipeline at a rate of at least 3 gpm in order to prevent the fines (particles of 1000 micron or less diameter) from settling out in the pipeline.

Samplers

The samplers are to take representative solution samples from the leacher, the recycle acid tank, the surge tank and the caustic scrubber (if installed). Because of the success of the sampling units in the Thorex plant^(23,24), units similar to these are recommended for the PRFR pilot leaching plant. Fig. 10 shows the principle of this type of sampler.⁽²⁵⁾ A liquid stream from the vessel to be sampled is circulated through a sample bottle by the means of an air lift.

Figure 10

Schematic Diagram of the Thorex Sampling Unit

After a satisfactory period of circulation, the sample bottle is removed from a shielded sampling blister with a representative sample of the solution in the vessel. The sampling bottle is kept 80 to 85% full during the sampling operation by the means of a floating pressure regulating valve. This floating type valve compensates for the various submergence levels of the sampler's air lift, thus insuring a constant flow rate to the sample bottle. The flow through the sampler is automatically interrupted if this bottle is removed from the sampler.

Hot Cell Waste

The hot waste from the cell passes to a holdup tank in the hot waste tank farm of the Laboratory, which is a cylinder 5 ft 6 in. in diameter and 7 ft 4 in. high. The capacity of this tank is rated at 1000 gal. and it ordinarily contains about 700 gal. of liquid.⁽²⁶⁾ Critical concentrations of dissolved uranium and/or thorium are shown in Fig. 11. These concentrations were determined by the modified one-group criticality formula and the information calculated by Prince.⁽¹⁷⁾ This formula is

$$\eta_{25}^{fp} = 1 + M^2 B^2 \quad (4)$$

The fp curves for the dissolved fuel from various reactor elements shown in Fig. 11 were calculated by Prince⁽¹⁷⁾, and the critical upper limits of fp are given by $(1 + M^2 B^2) / \eta_{25}$ shown as straight lines. For these calculations, the migration area M^2 is assumed to be 32 cm², η_{25} is 2.08, and the geometric buckling B^2 is that for a cylinder. To account for any water which might surround the waste tank and act as a reflector, 6 in. were added to the liquid height and the diameter in calculating the geometric buckling B^2 .

In case of an accidental discharge of 100 gal of dissolved Consolidated Edison fuel to the waste tank, a critical incident would not occur since the maximum concentration of thorium that can be obtained by dissolution is 250 g/liter.⁽¹⁵⁾ (The U-235 content in this solution is 22.0 g/liter.) A 100 gal quantity of double batch concentration (4 M) of dissolved fuel from the N.S. Savannah fuel elements (39.6 g U-235/liter) could cause a critical mass. This situation is very unlikely to occur because of the following reasons:

1. Only 50 gal. of acid are used for each batch of fuel in the leacher which yields a fuel concentration of 2 M.
2. A double charge of fuel yields only 50 gal. of 4 M solution.
3. 100 gal. of acid reduces the above concentrations by a factor of two. To get 100 gal. of 4 M $\text{UO}_2(\text{NO}_3)_2$, four charges of the segmented fuel to the leacher are required. This situation is extremely improbable.
4. The fuel for reprocessing ususally contains less than the initial amounts of U-235 due to burnup in the reactor.
5. Additional liquid usually is present in the waste tank which will dilute the fuel solution.

U Concentration of Dissolved UO_2 Fuel
or Th Concentration of Dissolved $\text{ThO}_2\text{-UO}_2$ Fuel g/liter

Figure 11-11

Critical Concentrations in Hot Cell Waste Tank

Off-Gas Removal

Off gas from the PRFR pilot leaching plant is presently planned (July, 1959) to pass directly from the entrainment separator to the stack.⁽¹¹⁾ A 3 in. pipeline carries the off gas from the entrainment separator in Cell B of Building 3026 to the stack connection at Cell A of Building 3026. This connection is a 4 in. pipeline which leads to a Cottrell precipitator and absolute filters at the base of the stack.

If the off gas facilities at the base of the stack are found unsatisfactory, piping changes will be made at the stack to pass the leaching plant off gas through a spray type caustic scrubber in addition to the Cottrell precipitator and the absolute filters.⁽¹¹⁾ If this arrangement is found unsatisfactory also, additional equipment such as caustic scrubber shown as optional equipment in the flowsheet, Fig. 3, will be included in the leaching plant.

Steam Jet Eductor

Steam jet eductors are used for moving the solutions between the recycle acid tank, the leacher, the surge tank, and the Turco solution storage tanks. All the steam jet eductors shown in the flowsheet, Fig. 3, are of the standard 1/2 in. size. The characteristics and steam consumption for this type of eductors are shown in Table 3, and the recommended steam supply for these eductors is 60 psig. These eductors are simple and are well suited for handling radioactive solutions. Also they are capable of moving any suspended fines since they have been shown to be capable of passing up to 30 to 40 mesh sand without any difficulty.⁽²⁸⁾

From Table 3, it can be seen that the lower the temperature of the liquid being transferred, the greater the quantity of liquid transferred for the same amount of steam. This implies a lower dilution for the solutions transferred at the lower temperatures. Also liquids moved at higher temperatures flash in the throat of the eductor which interferes with the transfer operation. It is recommended, therefore, that the solutions be cooled to 100°F or less before they are transferred by the eductors.

Air Lifts

Air lifts which are capable of handling radioactive solutions up to boiling temperatures are used for moving solutions to the samplers.

The submergence* of these lifts must be at least 35% for these to function properly, since lower submergence results in excessive slugging of the fluid and vibration of the pipe. Details of the design and characteristics of these devices are well summarized by Kearsley.⁽²⁹⁾

Building 3026 Services

As shown above, steam and air services are required to operate the PRFR pilot leaching plant. The following are available at Building 3026:⁽²⁶⁾

* Submergence is the ratio of the distance between the air inlet and the inlet liquid level to the overall length of the air lift column,

Table 3

Water Flow Through a 1/2-Inch Steam Jet Eductor (27)

Steam pressure: 60 psig

Steam consumption: 54 lbs/hr

Suction capacities in gpm of water:

<u>Suction Lift</u>	<u>Discharge Head</u>	<u>Suction Temperature</u>			
		<u>70°F</u>	<u>90°F</u>	<u>110°F</u>	<u>130°F</u>
1 ft	0 ft	6.33 gpm	5.33 gpm	4.54 gpm	3.78 gpm
1	20	6.00	5.40	4.67	3.90
10	0	4.58	4.15	3.30	2.60
10	20	4.63	4.01	3.39	2.72
15	0	3.69	3.26	2.76	2.10
15	20	3.94	3.35	2.72	2.08

1. 125 psig and 25 psig steam.
2. 80 psig and 15 psig air.
3. 40 in. water vacuum in the off gas line.

Conclusion

The preliminary process design for a leaching plant for leaching and recovering uranium and/or thorium from sheared spent fuel elements has been completed. Nitric acid chemistry can be used satisfactorily, and the materials of construction can be either 304L stainless steel or 309SCb stainless steel. With the exception of criticality and radioactivity considerations, no unusual process design features exist in this leaching plant.

Material handling and pilot plant studies may result in modifications in the detailed design of the leacher. Such modifications should not present any difficulties in the process design of this plant.

Bibliography

1. J. P. Nichols, Personal Communication, (Dec. 1958).
2. G. A. West, "Chemical Technology Division Unit Operations Section Monthly Progress Report, April 1959," ORNL CF 59-4-47. (July 21, 1959)
3. G. A. West, "Chemical Technology Division Unit Operations Section Monthly Progress Report May 1959," ORNL CF 59-5-47. (To be issued)
4. L. M. Ferris, Personal Communication, (Feb. 1959).
5. W. D. Bond, "Dissolution of Sintered Thorium-Uranium Oxide Fuel in Nitric Acid-Fluoride Solutions," ORNL-2519, (Oct. 28, 1958).
6. C. D. Watson, Personal Communication, (June 1959).
7. R. H. Rainey, Personal Communication, (June 1959).
8. L. M. Ferris, Personal Communication, (June 1959).
9. J. L. English, "Thorex Pilot Plant Corrosion Studies: 1. Corrosion of Types 304L and 309SCb Stainless Steel During Production and Development Periods," ORNL-2673, (Apr. 27, 1959)
10. J. L. English, Personal Communication, (May 1959)
11. H. A. McLain, Memo to E. J. Witkowski, "Off Gas Removal from Cell Boof Building 3048," (June 9, 1959)
12. H. A. McLain, Memo to C. D. Watson, "Pilot Leaching Plant for Mechanically Divided Fuel Elements," (Jan. 9, 1959)
13. J. W. Ullmann, Consolidated Edison Reactor Data Sheet, (Apr. 15, 1959)
14. J. T. Thomas, Personal Communication, (May 1959)
15. A. R. Irvine et al., "Request for Preliminary Criticality Review of Reactor Fuel Reprocessing Schemes," ORNL CF 58-9-77, (Sept. 24, 1958)
16. C. W. Collins, Personal Communication, (Feb. 1959).
17. B. E. Prince, "Poison Rod Requirements for a Solid-Fuel Leacher Tank," ORNL CF 59-3-7, (Mar. 2, 1959)
18. K. H. McCorkle and W. R. Winsbro, "Decontamination of the ORNL Thorex Pilot Plant," ORNL-2058, (July 12, 1956)
19. H. A. McLain, "Decontamination of the PRFR Pilot Leaching Plant," ORNL CF-59-7-75, (July 23, 1959).
20. W. F. Schaffer, Personal Communication, (May 1959)

21. C. D. Watson, Personal Communication, (May 1959)
22. J. H. Gibson, Personal Communication, (June, 1959)
23. F. R. Bruce, "The Thorex Process," Symposium on the Reprocessing of Irradiated Fuels Held at Brussels, Belgium, May 20-25, 1957, TID-7534, pp 180-222.
24. W. E. Unger, "Auxiliary Radiochemical Equipment," Loc. cit., pages 891-981.
25. J. W. Landry, Memo to E. M. Shank, "Thorex Sampler Evaluation and Adjustment," (Oct. 7, 1954)
26. O. H. Freeland, Personal Communication, (May 1959)
27. Schutte and Koerting Co., "Steam Jet Syphons," Bulletin 2A, (October, 1954)
28. W. R. Winsbro, Personal Communication, (Feb. 1959)
29. G. W. T. Kearsley, "Use of an Air Lift as a Metering Pump for Radioactive Solutions," ORNL-2175, (Oct. 9, 1956)
30. C. J. Claffey, Personal Communication, (March 1959)
31. W. H. McAdams, Heat Transmission, 3rd Ed., McGraw-Hill Book Co., New York, (1954).
32. G. A. West, "Chemical Technology Unit Operations Section Monthly Progress Report January 1959," ORNL CF 59-1-74, (April 30, 1959).
33. C. H. Gilmour, "Shortcut to Heat Exchanger Design - I," Chemical Engineering, 59, 144-148, (October 1952).
34. C. H. Gilmour, "Shortcut to Heat Exchanger Design VI," Chemical Engineering, 61, pp 209-213, (March 1954).
35. C. H. Gilmour, Letter to M. I. Lundin, (January 14, 1959)
36. J. H. Perry, Chemical Engineer's Handbook, 3rd Ed., McGraw-Hill Book Co., New York, (1950).
37. H. J. Stoever, Applied Heat Transmission, McGraw-Hill Book Co., New York (1941).
38. D. Q. Kern, Process Heat Transfer, McGraw-Hill Book Co., New York, (1950).
39. R. C. Robertson, "Permanent Freeze Jackets for HRT Process Lines 1/2 in. and Smaller," ORNL CF 56-2-127, (Feb. 23, 1956).
40. Chempump Corporation, "S Series Chempump," Bulletin 1030-1.

Nomenclature

A	Surface area
A_o	Outside surface area
B^2	Geometric buckling
c	Specific heat
D_i	Inside diameter
D_m	Mean diameter
D_o	Outside diameter
f	Thermal utilization factor
G	Mass flow rate per unit cross sectional area
g_c	Conversion factor for Newton's law of motion
Gr	Grashof number
h_i	Inside heat transfer coefficient
h_o	Outside heat transfer coefficient
h_s	Scale heat transfer coefficient
h_w	Wall heat transfer coefficient
ΔH	Heat loss
Δh	Enthalpy of vaporization
k	Thermal conductivity
L	Length
M^2	Migration area
m	Mass
Nu	Nusselt number
p	Resonance escape probability
Pr	Prandtl number
q	Heat transfer rate
Re	Reynolds number

T	Steam or coolant temperature
t	Liquid temperature
$(\Delta T)_M$	Log mean temperature difference
Δt	Temperature difference
U	Overall heat transfer coefficient
U_i	Overall heat transfer coefficient based on inside diameter
U_o	Overall heat transfer coefficient based on outside diameter
V	Velocity through pipe
W	Evaporation rate
w	Steam rate
β	Volumetric coefficient of expansion
η_{25}	Neutrons produced per neutron absorbed in U-235
θ	Time
θ_c	Cooling time
θ_h	Heating time
ρ_f	Fluid density

Appendix A

Heat Transfer Through Leacher Heating and Cooling Jackets

The heating and cooling jackets of the leacher surround the 10-in. Sch. 40 stainless steel outboard pipes; the lower jackets being 24 in. long and the upper jackets being 18 in. long. This arrangement allows 3.94 ft² of heat transfer area for each of the upper jackets and 5.25 ft² of heat transfer area for each of the lower jackets based on the inside diameter of the 10 in. pipe. The pressure of the available steam is 100 psig, and the inlet and outlet cooling water temperatures are assumed to be 70°F and 90°F.

Heating

There is about 50 gal of acid in the leacher for the dissolution of UO₂, and there is about 100 gal of acid in the leacher for the dissolution of ThO₂-UO₂. This acid can be either preheated and added to the leacher, or it can be added to the leacher at room temperature and brought up to the operating temperature. The latter situation is considered here.

A heat balance may be written for the rate of heat transfer from the steam to the liquid in the leacher. Assuming a uniform temperature for the liquid in the leacher,

$$mc \frac{dt}{d\theta} = UA (T - t) \quad (5)$$

where m = mass of liquid in the leacher
 c = specific heat of liquid in the leacher
 t = temperature of liquid in the leacher
 θ = time
 U = overall heat transfer coefficient
 A = heat transfer area
 T = steam temperature

Assuming a constant heat transfer coefficient and constant steam temperature, the time required to raise the liquid temperature from t_1 to t_2 may be found by integrating the above relation.

$$\theta_h = \frac{mc}{UA} \ln \frac{T - t_1}{T - t_2} \quad (6)$$

The temperature of the 100 psig steam is 338°F, and it is assumed that acid raised from room temperature which is 68°F (20°C) to 230°F (110°C). The density of the liquid solution is assumed to be 1.37 g/cc and the specific heat is assumed to be 0.63 Btu/lb solution °F. For the heating of 50 gal of acid, only the lower two jackets are used, and for heating 100 gal of solution all four jackets are used.

To estimate the overall coefficient U , the individual film coefficients must be first determined. The steam condensing coefficient h_o and scale coefficient h_s are each assumed to be 1000 Btu/hr-ft²·°F. The wall coefficient is

$$h_w = \frac{9.7}{\frac{0.365}{12}} = 319 \text{ Btu/hr-ft}^2\cdot\text{F}$$

For the estimation of the inside coefficient h_i , natural convection is assumed. McAdams⁽³¹⁾ gives the necessary relations for estimating natural convection coefficients in the form of

$$Nu = fn (Gr \cdot Pr) \quad (7)$$

where Nu = Nusselt number

Gr = Grashof number

Pr = Prandtl number

In addition to the physical properties mentioned above, the following properties are assumed for the nitric acid:

Viscosity, μ = 2.4 lb/ft hr

Thermal conductivity, k = 0.28 Btu/hr·ft·°F

Volumetric coefficient of expansion, β = 3.3×10^{-4} °F⁻¹

Assuming a film temperature drop, Δt , of 100°F, the Grashof number for the lower jackets is

$$\begin{aligned} Gr &= \frac{L^3 \rho_f^2 g_c \beta_f \Delta t}{\mu_f^2} \\ &= \frac{(2)^3 (65.5)^2 (4.17 \times 10^8) (3.3 \times 10^{-4}) (100)}{(2.4)^2} \\ &= 8.2 \times 10^{10} \end{aligned}$$

and the Prandtl number is

$$Pr = \frac{c_p \mu}{k} = \frac{0.63 \times 2.4}{0.28} = 5.4$$

Therefore for the lower jackets⁽³¹⁾

$$Nu = 0.13 [8.2 \times 10^{10} \times 5.4]^{1/3} = 990$$

$$h_1 = \frac{Nu \cdot k}{L} = \frac{(990)(0.28)}{2} = 140 \text{ Btu/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$$

Because the length term L cancels out of the relation used for estimating h_1 , the film coefficient for the upper jackets is the same.

Therefore the overall heat transfer coefficient is

$$\begin{aligned} U_1 &= \frac{1}{\frac{1}{h_1} + \frac{D_1}{h_w D_m} + \frac{D_1}{h_o D_o} + \frac{D_1}{h_s D_o}} \\ &= \frac{1}{\frac{1}{140} + \frac{10.02}{319 \times 10.38} + \frac{10.02}{1000 \times 10.75} + \frac{10.02}{1000 \times 10.75}} \\ &= 81 \text{ Btu/hr}\cdot\text{ft}^2\cdot^\circ\text{F} \end{aligned}$$

The time to heat 50 gal of acid with the lower jackets is

$$\begin{aligned} \theta_h &= \frac{(572)(0.63)}{(81)(10.50)} \ln \frac{(338 - 68)}{(338 - 230)} \\ &= 0.4 \text{ hr} \end{aligned}$$

and that to heat 100 gal of acid with all four jackets is

$$\begin{aligned} \theta_h &= \frac{(1144)(0.63)}{(81)(18.38)} \ln \frac{(338 - 68)}{(338 - 230)} \\ &= 0.4 \text{ hr} \end{aligned}$$

Hence the acid could be heated in about 1/2 hr.

Evaporation

At times evaporation of part of the liquid in the leacher may be desired. Assuming that the liquid is at the boiling temperature and that only the lower jackets are used for heating, the rate of evaporation is calculated as follows:

The boiling film heat transfer coefficient h_1 is assumed to be 1000 Btu/hr·ft²·°F, and the overall heat transfer coefficient is

$$U_1 = \frac{1}{\frac{1}{1000} + \frac{10.02}{319 \times 10.38} + \frac{10.02}{1000 \times 10.75} + \frac{10.02}{1000 \times 10.75}} = 170 \text{ Btu/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$$

The rate of evaporation is then

$$W = \frac{(170)(10.50)(338 - 230)}{960} = 200 \text{ lbs/hr}$$

$$= 0.4 \text{ gpm of liquid}$$

From this, one can see that about 4 hrs are required to evaporate 100 gal of liquid. However, for most cases, the amount of liquid to be evaporated from the leacher will usually be much less.

Cooling

Before the solution is removed from the leacher by means of the steam eductor, it should be cooled to 100°F or less to prevent excessive dilution by the condensed steam. For design purposes the cooling water inlet temperature is 70°F and the outlet temperature is 90°F which gives an average temperature of 80°F. Writing a heat balance similar to that used for calculating the heating time, the cooling time is expressed as

$$\theta_c = \frac{mc}{UA} \ln \frac{t_1 - T}{t_2 - T} \quad (8)$$

where T = cooling water temperature.

(To estimate the outside film coefficient h_o , it is assumed that about 30 gpm of cooling water flows in the annular space between a 10 in. Sch. 40 pipe and a 14 in. Sch. 10 pipe. Assuming turbulent flow, McAdams⁽³¹⁾ recommends the following relation for predicting heat transfer coefficients for turbulent flow in concentric annuli.

$$Nu (Pr)_b^{2/3} \left(\frac{u_w}{u_b} \right)^{0.14} = \frac{0.023}{(Re)^{0.2}} \quad (9)$$

$$\text{where } Nu = \frac{h_o}{c_{pb}} G$$

G = mass flow rate per unit cross sectional area

Subscript b = bulk conditions

Subscript w = wall condition

Using this relation, the outside heat transfer coefficient h_o is about 600 Btu/hr ft² °F.

For estimating the inside heat transfer coefficient h_i , it is assumed that temperature drop across the inside film is about 50°F. The inside

coefficient is then about

$$h_1 = \left(\frac{50}{100}\right)^{1/3} (140) = 110 \text{ Btu/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$$

The overall coefficient is therefore

$$U_1 = \frac{1}{\frac{1}{110} + \frac{10.02}{319 \times 10.38} + \frac{10.02}{600 \times 10.75} + \frac{10.02}{1000 \times 10.75}}$$

$$= 67 \text{ Btu/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$$

The time to cool 50 gal of solution with the lower jackets is

$$\theta_c = \frac{(572)(0.63)}{(67)(10.50)} \ln \frac{(230) - 80}{(100 - 80)}$$

$$= 1.0 \text{ hr}$$

and that to cool 100 gal of solution with all four jackets is

$$\theta_c = \frac{(1144)(0.63)}{(67)(18.38)} \ln \frac{(230 - 80)}{(100 - 80)}$$

$$= 1.1 \text{ hr}$$

Hence, about 1 hr is required to cool the solution before it is removed from the leacher. Cooling water temperatures lower than those assumed above will shorten the cooling time.

Appendix B

Off Gas Rates from Leacher

Since the dissolution rates of UO_2 in nitric acid are greater than those of ThO_2-UO_2 , (5,32) the off gas rates are estimated here for UO_2 dissolution only. Figs. 1 and 2 show the leaching rates of sheared rods containing rejected PWR fuel. (2,3) From these graphs, it can be seen that the initial dissolution rates of the rods sheared into 1/2 in. lengths are 0.0812 g U/min·g total U and 0.1074 g U/min·g total U respectively in acid originally at boiling temperature and that originally at room temperature and subsequently brought up to boiling temperatures.

For these calculations, it is assumed that the basic equation for UO_2 dissolution in HNO_3 is valid. (1)

Also it is assumed that the heat of reaction is removed in the form of saturated steam at 1 atmosphere, and that about 10 cfm of air is introduced through the air spargers. Assuming a 100 kg UO_2 charge in the leacher, the theoretical off gas rates for these two initial dissolution rates are as follows:

Dissolution rate	0.0812 $\frac{\text{g U}}{\text{min} \cdot \text{g total U}}$	0.1074 $\frac{\text{g U}}{\text{min} \cdot \text{g total U}}$
NO and NO_2 formation	61.0 cfm	87.1 cfm
Steam formation	72.5 cfm	103.5 cfm
Sparging air	10 cfm	10 cfm
Total	144 cfm	200 cfm

The above data are for the dissolution of UO_2 in 10 M HNO_3 . G. A. West has found that the initial dissolution rates of UO_2 in 13 M HNO_3 is higher than that in 10 M HNO_3 by a factor of 127/89. (32) Using these data for 13 M HNO_3 and assuming again an air sparging rate of 10 cfm, the initial off gas rates are then:

Dissolution rate	0.116 $\frac{\text{g U}}{\text{min} \cdot \text{g total U}}$	0.153 $\frac{\text{g U}}{\text{min} \cdot \text{g total U}}$
NO and NO_2 formation	87 cfm	124 cfm
Steam formation	104 cfm	149 cfm
Sparging air	10 cfm	10 cfm
Total	201 cfm	283 cfm

Inspecting these off gas rates and assuming a safety factor, the off gas rate for design purposes is assumed to be

NO and NO ₂ formation	177 cfm
Steam formation	213 cfm
Sparging air	10 cfm
Total	400 cfm

Appendix C

Reflux Condenser Heat Transfer

Since the vapor entering the reflux condenser contains a large amount of noncondensibles and the heat load is not known accurately, the heat transfer calculations here are based on a simplified method developed by C. H. Gilmour. (33,34) This method has been found to be satisfactory for the design of heat exchangers used for similar service for the Union Carbide Chemicals Company, (35)

For the purposes of the calculations here, the heat transfer area is divided into two regions. The first region is that for cooling the vapor to the dew point, and the second region is that for the condensation. Although the nitrogen oxides in the vapor will be partially absorbed in the condensate, it is considered as an inert material here. This assumption is conservative.

Since the off gas flow rate used for design purposes of 400 cfm as shown in Appendix B is highly conservative, the following off gas rate is assumed in order to obtain a reasonable size heat exchanger.

NO and NO ₂	155 cfm
Steam	185 cfm
Sparging Air	10 cfm
Total	350 cfm

It is also arbitrarily assumed that the vapor is cooled from 220°F to 130°F in this heat exchanger. This latter temperature is selected in order that the water loss from the leacher during the leaching operations is reasonably small. The inlet and outlet temperatures of the cooling water in condensing portion of the condenser are 70 and 90°F. The heat required to be transferred under these conditions is about 450,000 Btu/hr. Fig. 12 shows the vapor and cooling water temperatures in the condenser which were obtained by heat balance calculations.

The dew point of the above mixture is about 189°F. The cooling of the vapor from 220°F to this temperature is considered as the first region of the heat exchanger, and the subsequent cooling and condensing from 189°F to 130°F is considered as the second region of the heat exchanger.

For the first region, the heat transfer rate is about 12,000 Btu/hr. The log mean temperature drop of 114°F is assumed to be the mean temperature difference. Using the method shown by Gilmour, (33) a heat exchanger containing ninety-six 5/8 in. 14 BWG tubes 9 in. long is sufficient to cool the vapor to its dew point. Details of the calculations by this method are not shown here since it is not warranted in this report.

The remaining heat is transferred in the second region of the heat exchanger. Since the specific heat of the vapor and condensate are varying in this region, the logarithmic mean temperature difference is not the average temperature difference between the vapor and the cooling water. Using

Figure 12-

Vapor and Cooling Water Temperatures
in the Reflux Condenser

the method described by Gilmour,⁽³⁴⁾ the average temperature difference between the condensing vapor and the cooling water is 87°F. Gilmour's method⁽³⁴⁾ for calculating the heat transfer in the region assumes the vapor cools to a fictitious temperature, the condensing takes place at this temperature, and the condensate and the remaining vapor then cools from this fictitious temperature to the temperature of the vapor at the heat exchanger's outlet. This fictitious temperature is assumed to be the mean vapor temperature in the condensing region of the condenser which is 168°F. Using this method, a heat exchanger containing ninety-six 5/8 in. 14 BWG tubes which are 36 in. long is sufficient to partially condense and cool the vapor from its dew point to 130°F. The baffle spacing on the shell side of this heat exchanger is assumed to be 9 in. Details of these calculations are omitted here also since they are not warranted in this report.

A heat exchanger containing ninety-six 5/8 in. 14 BWG tubes 45 in. long is capable of serving as a reflux condenser for the PRFR pilot leaching plant. These tubes are to be mounted in a 12 inch shell which contains baffles 9 in. apart. The cooling of water requirement is about 45 gpm which requires 1-1/2 in. connections to the shell of the heat exchanger.

Appendix D

Heat Transfer Through the Coils of the Acid Feed and Rinse Solution Tanks

Steam coils are used for the heating of the decontamination solutions in the acid feed and rinse solution tanks. For the purposes of these calculations, the following assumptions are made.

1. Each tank contains 150 gal of solution.
2. The solution is heated from 70°F to 220°F.
3. The solution density is 74.3 lb/ft³.
4. The solution specific heat is 0.825 Btu/lb °F.
5. 100 psig steam is available for heating.
 - a. Steam temperature is 338°F.
 - b. Steam heat of condensation is 881 Btu/hr.

The heating time is determined by the same relation as that for the leacher as shown in Appendix A, i.e.,

$$Q_h = \frac{mc}{UA} \ln \frac{T - t_1}{T - T_2}$$

From above, the total heat capacity of the material in each tank is

$$mc = \frac{150}{7.48} (74.3)(0.825) = 1230 \text{ Btu/°F}$$

The overall heat transfer coefficient U is estimated to be about 100 Btu/hr.ft²·°F from information available in Perry.⁽³⁶⁾ Assuming that it is desired to heat the solution in about 3/4 hr, the necessary heat transfer area is then

$$\begin{aligned} A &= \frac{mc}{UQ_h} \ln \frac{T - t_1}{T - t_2} \\ &= \frac{(1230)}{(100)(0.75)} \ln \frac{338 - 70}{338 - 220} \\ &= 13.5 \text{ ft}^2 \end{aligned}$$

Selecting 3/4 in. 16 BWG stainless steel tubing for the steam coils, the necessary length of this tubing to obtain the above heat transfer area is

$$\frac{13.5 \text{ ft}^2}{0.1963 \text{ ft}^2/\text{ft}} = 69 \text{ ft}$$

If the coils are assembled on a 30 in. diameter, $69/\pi (2.5) = 9$ turns are required. Therefore, coils with 10 turns of $3/4$ in. 16 BWG tubing on a 30 in. diameter should be satisfactory for this application.

Appendix E

Heat Transfer Through Recycle Acid Tank's Heating and Cooling Jackets

Steam jackets are used for heating the decontamination solution in the recycle acid tank. It is assumed for design purposes that this tank contains 120 gal of solution. This is conservative since by the use of decontamination jets, the actual volume of decontamination solution used ordinarily is much less. These jackets can be also used for partially heating or cooling the acid prior to jetting it to the leacher. Only the heating of the decontamination solution is considered here since the amount of required heat transfer is the greatest for this case. The assumptions here are the same as those in Appendix D with the exception that the vessel contains only 120 gal. of solution.

The total heat capacity of the solution is then

$$mc = \frac{120}{7.48} (74.3)(0.825) = 984 \text{ Btu/}^{\circ}\text{F}$$

The inside, wall, outside, and scaling heat transfer coefficients are respectively estimated to be (37)(38)

$$h_i = 150 \text{ Btu/hr.ft}^2.^{\circ}\text{F}$$

$$h_w = \frac{(9.4)(12)}{0.375} = 300 \text{ Btu/hr.ft}^2.^{\circ}\text{F}$$

$$h_o = 1500 \text{ Btu/hr.ft}^2.^{\circ}\text{F}$$

$$h_s = 1000 \text{ Btu/hr.ft}^2.^{\circ}\text{F}$$

The overall heat transfer coefficient is then

$$\begin{aligned} U_o &= \frac{1}{\frac{D_o}{h_i D_i} + \frac{D_o}{h_w D_m} + \frac{1}{h_o} + \frac{1}{h_s}} \\ &= \frac{1}{\frac{12.750}{(150)(12.000)} + \frac{12.750}{(300)(12.375)} + \frac{1}{1500} + \frac{1}{1000}} \\ &= 80 \text{ Btu/hr.ft}^2.^{\circ}\text{F} \end{aligned}$$

and the heat transfer area is

$$\begin{aligned} A_o &= 2 D_o L = (2) (\pi) \frac{12.750}{12} (30) \\ &= 20 \text{ ft}^2 \end{aligned}$$

Using the same relation as for the leacher as shown in Appendix A, the heating time is

$$\begin{aligned} \theta_h &= \frac{mc}{UA} \ln \frac{T - t_1}{T - t_2} \\ &= \frac{(984)}{(80)(20)} \ln \frac{338 - 70}{338 - 220} \\ &= 0.5 \text{ hr} \end{aligned}$$

This time is considered satisfactory and therefore two 3 ft long heating and cooling jackets on recycle acid tanks will be sufficient.

For sizing the inlet steam line, the initial steam rate for each jacket is

$$w = \frac{U_o A_o \Delta T}{\Delta h} = \frac{(80)(10)(268)}{(881)} = 244 \text{ lb/hr}$$

Assuming the design velocity of the steam flowing through the inlet pipe to be 5000 ft/min, the necessary pipe area required is then

$$\frac{(244)(3.882)(144)}{(60)(5000)} = 0.456 \text{ in}^2$$

A 3/4 in. Sch. 40 pipe will satisfy these conditions. A 1/2 in. Sch. 40 pipe will be satisfactory for the drain line.

Appendix F

Heat Transfer in the Feed Acid Heater

The heat transfer surface of the feed acid heater consists of 19-1/2 turns of 5/8 in. 16 BWG stainless steel tubing on a 7 in. circle. The length of this tubing is then about 36 ft and its surface area based on the outside diameter is 5.85 ft². It is assumed that the liquid solution is heated from 110 to 220°F inside the coiled tubing by condensing 100 psig steam. The log mean temperature difference for this condition is:

$$(\Delta T)_M = \frac{(338 - 110) - (338 - 220)}{\ln \frac{(338 - 110)}{(338 - 220)}} = 167^\circ\text{F}$$

Information shown in Table 3 for jet eductor capacities show that the flow rate of the liquid solution through this heater may vary from about 30 to about 50 lb/min. The maximum and minimum rates of heat transfer through these coils are (assuming a specific heat of 0.63 Btu/lb °F)

$$q_{\max} = (50)(60)(0.63)(110) = 208,000 \text{ Btu/hr}$$

$$q_{\min} = (30)(60)(0.63)(110) = 125,000 \text{ Btu/hr}$$

Therefore, the necessary overall heat transfer coefficients U_o based on the outside surface area are then

$$U_{o\max} = \frac{208,000}{(5.85)(167)} = 213 \text{ Btu/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$$

$$U_{o\min} = \frac{125,000}{(5.85)(167)} = 128 \text{ Btu/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$$

Using the Dittus-Boelter⁽³¹⁾ equation and assuming a solution thermal conductivity of 0.31 Btu/hr·ft·°F and a solution viscosity of 2.4 lb/hr·ft, the inside heat transfer coefficients h_i are

$$h_{i\max} = 1740 \text{ Btu/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$$

$$h_{i\min} = 1150 \text{ Btu/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$$

The wall heat transfer coefficient h_w is

$$h_w = \frac{(9.4)(12)}{0.065} = 1740 \text{ Btu/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$$

From the information in Stoever⁽³⁷⁾, the outside coefficient for the condensing steam h_o is assumed to be

$$h_o = 1000 \text{ Btu/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$$

and the scale coefficient h_s is assumed to be

$$h_s = 1000 \text{ Btu/hr.ft}^2.\text{°F}$$

Therefore, the maximum overall heat transfer coefficient U_{max} is estimated to be

$$\begin{aligned} U_{\text{max}} &= \frac{1}{\frac{D_o}{h_i D_i} + \frac{D_o}{h_w D_m} + \frac{1}{h_o} + \frac{1}{h_s}} \\ &= \frac{1}{\frac{(0.625)}{(1740)(0.495)} + \frac{(0.625)}{(1740)(0.560)} + \frac{1}{1000} + \frac{1}{1000}} \\ &= 296 \text{ Btu/hr.ft}^2.\text{°F} \end{aligned}$$

and the minimum overall heat transfer coefficient U_{min} is estimated to be

$$\begin{aligned} U_{\text{min}} &= \frac{1}{\frac{(0.625)}{(1150)(0.495)} + 0.00264} \\ &= 268 \text{ Btu/hr.ft}^2.\text{°F} \end{aligned}$$

Hence the heat exchanger as shown in Fig. 9 is conservatively designed.

The initial steam requirements are

$$\frac{(208,000)(3.882)}{(881)(60)} = 15.3 \text{ cfm}$$

A good design velocity for the inlet steam is 5000 fpm. The necessary pipe cross section to carry this amount of steam is

$$\frac{(15.3)(144)}{5000} = 0.44 \text{ in}^2$$

It is recommended, therefore, that the inlet steam line be a 3/4 in. Sch. 40 pipe and the condensate line be a 1/2 in. Sch. 40 pipe.

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