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Selection of an Agitated Thin-film Evaporator for Processing a Radioactive Waste at ORNL

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OPERATED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/CF-89/289

Chemical Technology Division

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Date of Issue: October 1989

Prepared by the
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MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

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ABSTRACT

The agitated thin-film evaporator, which is a type of evaporator that uses mechanical agitation to spread a layer of solution over the heated surface, was evaluated for potential use in processing a radioactive waste at ORNL. The current processing scheme calls for the waste, which consists mainly of a basic sodium nitrate solution above a sludge of precipitated hydroxides and clay, to be either evaporated to dryness or melted. A review of the literature determined that at least 65 agitated-film evaporators have been used in radioactive waste processing, including a few in applications quite similar to that proposed for ORNL. Operating data specific for the ORNL waste was obtained by performing tests at the pilot facilities of two vendors. Critical characteristics of the machine were thus identified and a specially designed evaporator was procured for testing at ORNL.

1. INTRODUCTION

The agitated thin-film evaporator is being evaluated for potential use in processing several thousand gallons (~10 m^3) of radioactive waste currently stored at ORNL. This type of evaporator uses mechanical agitation to spread a turbulent thin layer of solution over the heated surface and is thus capable of handling feeds that contain suspended solids or have foaming characteristics. These capabilities are important because the waste to be processed consists of a basic sodium nitrate supernatant and a settled sludge. The agitated-film evaporator is also capable of obtaining high concentration factors in a single pass. A review of the literature determined that at least 65 of the evaporators have been used in radioactive waste processing, including a few in applications quite similar to that proposed for ORNL. Operating data specific for the ORNL waste was obtained by performing tests at the pilot facilities of two vendors. Critical characteristics of the machine were thus identified and a specially designed evaporator was procured for use in future testing at ORNL.

2. CHARACTERISTICS OF THE WASTE TO BE PROCESSED

The agitated-film evaporator is being examined to process the ~370,000 gal (~1400 m^3) of radioactive waste stored in the eight 50,000-gal (190-m^3) Melton Valley Storage Tanks (MVSTs) at ORNL. A study of processing alternatives concluded that solidification of the waste to a salt cake, without additives, and transport of the resulting waste packages to the Waste Isolation Pilot Plant (WIPP) was the most preferred method of disposition.[1] The processing facility is concepted to be completely remotely operated and maintained with manipulators.[2]

Most of the chemical and radionuclide data on the material stored in the MVSTs is given in the report by Peretz et al.[3] and will be briefly summarized here. The waste consists of two phases: supernatant and sludge. Although each tank is unique, in general the supernatant is a basic, concentrated sodium nitrate solution which also contains significant concentrations of calcium and magnesium cations, and hydroxide, carbonate, chloride, and sulfate anions. The sludge consists of carbonate and hydroxide precipitates of species present in the supernatant, and a large quantity of bentonite clay and some sand.

Radiological analyses of samples from the tanks show the presence of significant quantities of alpha-, beta-, and gamma-emitting radioisotopes. The alpha emitters, which include the transuranic (TRU) isotopes, are concentrated mainly in the sludge. Sr-90 is the predominant beta emitter and is also present mainly in the sludge. Cs-137 is the predominant gamma emitter and is present primarily in the supernatant.

3. DESCRIPTION OF COMMERCIALLY AVAILABLE AGITATED THIN-FILM EVAPORATORS

The agitated thin-film evaporator employs a rotor moving at a high speed [~40 ft/s(~12 m/s) at the tip] to mechanically agitate and spread a turbulent thin layer of solution over the entire heated surface.[4,5,6] The evaporator is commonly used to concentrate materials that are heat sensitive, viscous, have a high suspended solids content, or have scaling or foaming characteristics. It is also used to obtain high concentration factors in a single pass and can actually dry a solution to a powder.

The evaporators are usually heated with steam up to a maximum pressure of 200 psig (1.4 MPa). Higher temperatures can be reached in units that are heated with oil or with heat transfer fluids such as molten salts.

The evaporators can be divided into two general types: (1) vertical and (2) horizontal. Fig. 1 shows a typical vertical evaporator. In the vertical unit, feed is transported through the heated zone by gravity and falls in a helical pattern, due to the action of the rotor. In the horizontal unit, solution is pushed through the evaporator by incoming feed.

The deentrainment equipment in a vertical evaporator is quite elaborate. It typically consists of a cage of vertical stationary baffles, which are above the rotor in the expanded deentrainment section, and horizontal baffles, which are attached to the rotor. The baffles combine to force the exiting vapor along a tortuous path that contains multiple impingement surfaces, thus giving excellent separation of vapors from particulates and liquid. The horizontal evaporator has no special deentrainment equipment.

The residence time of a vertical agitated-film evaporator is short, on the order of a few seconds; and this is usually considered a desireable feature. However, it is possible to increase the residence time by installing a device, such as Luwa's patented RTC-Ring, on the bottom of the unit.[7] The ring is basically a weir that ensures that solution completely fills the cavity that exists between the tip of the rotor and the heated wall. Solution must overflow the ring in order to exit the evaporator. In contrast, controlling residence time in a horizontal unit discharging a liquid is much simpler — it is varied by adjusting the feed rate.

There are five vendors of agitated film evaporators in the United States. Important characteristics[8-12] of each particular machine are given in Table 1. There is also a manufacturer of small units: Pope Scientific. Their evaporators are in the 2 to 6-in. (5 to 15-cm) diameter range, are made of glass or stainless steel, and are heated electrically or with steam or hot oil.

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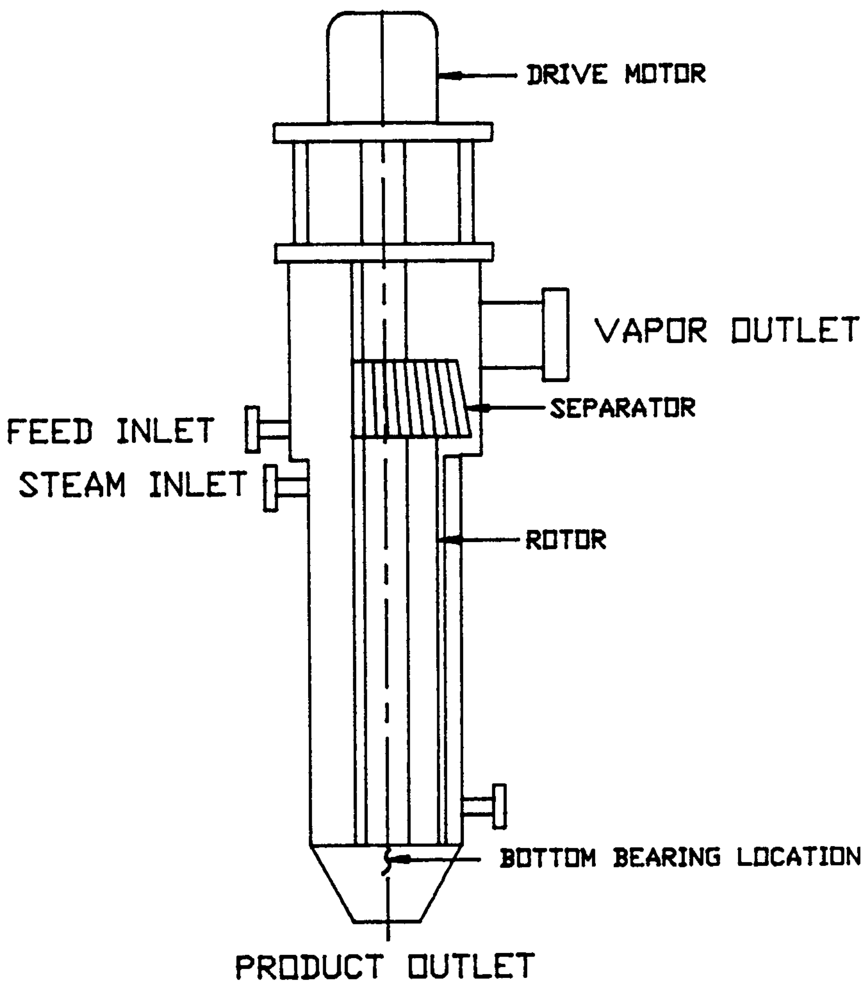

Fig. 1. Typical vertical agitated film evaporator.
Source: "Luwa Thin-film Evaporation Technology," Bulletin EV-24(1982).

Table 1. Characteristics of standard commercially available agitated film evaporators

Manufacturer				
Luwa	Votator[a]	Pfaudler	Artisan Ind.	Kontro
Evaporator orientation:				
Vertical, cylindrical wall (also horizontal cylindrical dryers)	Vertical, cylindrical wall	Vertical, cylindrical wall	Horizontal, cylindrical wall	Horizontal, tapered wall
Entrainment Separator Description:				
Internal, with horizontal and vertical impingement surfaces	Internal, with horizontal and vertical impingement surfaces	None	None	None
Driven end seal type:				
None required	Mechanical with external bearing, none required with internal bushing	Mechanical	Mechanical	Mechanical
Driven end bearing type:				
Internal pin and bushing	External roller or internal pin and bushing	None	Unknown	Radial/thrust
Feed distributor?:				
Yes	No	Yes	No	No
Liquid-vapor flow direction:				
Countercurrent	Countercurrent	Condensed and separated	Cocurrent or countercurrent	Cocurrent
Testing services available?				
Yes	Yes	Yes	Yes	No

[a]Anco/Votator, a division of Cherry Burrell

Votator and Luwa manufacture primarily vertical, agitated-film evaporators; and they are similar in design. (Luwa also manufactures horizontal evaporators which they call dryers). Votator's name for their evaporator is the Turba-film Processor. Both manufacturers provide two basic types of rotors. The standard is the fixed-clearance rotor with four blades, and Luwa's version of this is shown in Fig. 2. The typical clearance between the blades and the heated wall is 0.02 to 0.06 in (0.5 to 1.5 mm). Rotors with hinged blades, which swing open due to centrifugal force, are also made; and they are usually used when the product is a powder or in situations when a fixed clearance rotor could be damaged by material accumulating on the heated wall. When producing a powder, hinged blades that actually contact the wall, termed zero clearance, are recommended by Luwa. (Ideally, the blades do not actually touch the wall, but instead, contact the powder on the wall. Under this condition, wearing of the rotor blades and the evaporator body should not be significantly greater than if a fixed clearance rotor were used.)

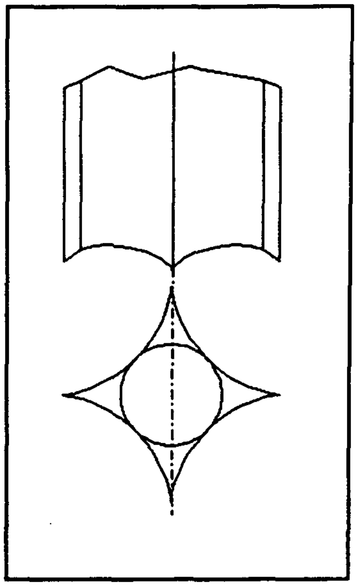

Fig. 2. Typical fixed clearance rotor (Luwa Type N)
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Pfaudler manufactures a vertical evaporator of a somewhat different design. Pfaudler uses exclusively a zero clearance rotor with replaceable blades which are made of graphite or Teflon. The blades can be either spring-loaded or free-floating, and are slotted, to produce a downward pumping action. Another unique feature is the absence of a bottom bearing. The blades then serve the additional purpose of helping keep the rotor aligned. The Pfaudler evaporator is squatter than other vertical units, which allows the rotor to run at a lower rotational speed and helps rotor stability.

Artisan Industries and Kontro are the major manufacturers of horizontal agitated-film evaporators. The unique features of the Kontro evaporator are its reverse-tapered shell (larger in diameter at the feed end than at the product end) and its adjustable clearance rotor. Tapering the shell is supposed to ensure that a thin film is maintained at all times along the heated wall, regardless of how much feed is evaporated off. The

Artisan evaporator has straight walls and can be operated with the off-gas and feed moving either co- or counter- currently. A ribbon-type blade is available for use with low viscosity materials.

4. APPLICATIONS OF AGITATED THIN-FILM EVAPORATORS IN RADIOACTIVE WASTE PROCESSING

Agitated thin-film evaporators have been used to concentrate radioactive wastes since the early 1950s. Purcell provides a compilation of operating experience, both in the pilot and the processing plant, with radioactive waste for each of the vendors' machines.[13] He also describes the characteristics of the machines available and compares their performance in concentrating radioactive solutions. Purcell's review determined that 85 agitated-film evaporators have been used to process radioactive waste. He concluded that the horizontal evaporator was preferable to the vertical one and that the Kontro evaporator was the most preferred.

One area in which the evaporators have been studied, or are currently used, is in waste fixation. A horizontal reverse-tapered machine was examined for concentrating a simulated Purex waste, with the ultimate goal of coupling the evaporator to a melting system and directly converting the liquid waste to a borosilicate glass.[14] A commercially available fixation process uses a Luwa vertical evaporator to solidify liquid waste in asphalt. The waste and asphalt are added as separate streams to the evaporator and mixing and evaporation of water occur inside the evaporator.[15] This process was actually tested with a surrogate of the MVST supernatant, but subsequent concern about the potential for an explosive reaction between the asphalt and the nitrate in the waste eliminated this option from consideration.

A vertical agitated film evaporator was used to concentrate and dry sodium sulfate solutions.[16] The rotor used was apparently a hinged-blade type with a clearance between the tip of the blade and the heated wall. The application was the drying of radioactive wastes generated by nuclear power plants. The major conclusion of that study was that the powdering capacity increased with the rotor rotational speed. The change was significant in the low rotational region, but not in the high rotational region.

Unfortunately, since the rotational speed was given as a percentage of the maximum speed and the maximum speed was not identified, the actual rotor velocity could not be determined. The paper also provides a model which describes the powdering process.

Savannah River Laboratory (SRL) studied using agitated-film evaporators to concentrate aqueous alkaline wastes from the Purex process.[17] As concepted, the evaporator would be mounted on top of an existing underground waste holding tank and the bottoms from the evaporator would drop directly into the tank.[18] The tank would contain cooling coils and as the waste cooled precipitated solids would fall out. Supernatant would be removed from the tank and returned to the evaporator.

The SRL Purex waste is chemically similar to the MVST supernatant. The reported composition is 3.4 M $NaNO_3$, 0.35 M Na_2CO_3, 0.08 M Na_2SO_4, 0.3 M NaOH, and 0.55 M $NaAlO_2$. (Actually, the feed to the SRL evaporator would have much higher concentrations of sodium nitrate and sodium hydroxide than given above. This is because in the SRL processing scheme supernatant is recycled and is, therefore, enriched in the more soluble species, which would not precipitate out in the storage tank.)

The SRL process starts with a concentrated sodium nitrate feed and employs an agitated film evaporator to produce a salt cake as the product, which is quite similar to the proposed disposition of the MVST waste. Most of the work on the evaporator at SRL was done by Claude Goodlett between the late 1960s and the early 1980s and he was contacted for additional information. Experience at SRL processing simulated Purex waste that is very relevant to selecting an evaporator for processing the MVST waste include:

1. The evaporators tested at SRL were fabricated of type 304L stainless steel, and caustic stress corrosion cracking (SCC) of the stainless steel was originally a concern. However, after 2,093 h operation, one of the evaporators was inspected and showed no evidence of excessive corrosion. It is probable that nitrate being present in such a high concentration inhibits caustic SCC.
2. There was a problem with plugging at the discharge end of the evaporator which was caused by the bottoms cooling, solidifying, and then accumulating. On several occasions, the accumulated solids bent the rotor.

3. A mechanical seal that used a carbon rotating ring and a 17-4 PH stainless steel stationary ring showed appreciable wear, while a seal that had both the rotating and stationary rings made of tungsten carbide showed no appreciable wear.
4. An average overall heat transfer coefficient of 236 Btu/(h · ft^2 · °F) [1340 watt/(m^2 · K)] was calculated when the synthetic Purex waste was concentrated to a slurry that solidified upon cooling to room temperature.
5. Large decontamination factors were obtained with both the horizontal and vertical evaporators. They ranged from 1 in 10,000 to 1 in 200,000 parts sodium in the condensate per part sodium in the product.

5. RESULTS OF VENDOR TESTS

The generally positive experiences reported in processing applications similar to that being considered at ORNL indicated that further evaluation of the evaporator was warranted. Tests were then arranged with equipment vendors on both a vertical and a horizontal evaporator. The Kontro evaporator could not be tested because they did not offer testing services. (They did, however, have a 1-ft^2 (0.09 m^2) rental evaporator which will probably be leased). The Pfaudler evaporator was totally eliminated from consideration because: (1) of concern about the freezing of the rotor blades at high concentration factors, as observed by Goodlett; and (2) periodic replacement of the rotor blades, which are standard wear components, would be unacceptable in the actual processing plant. Preliminary evaluation left Artisan, Luwa, and Votator as the remaining candidates. Because of difficulty in arranging a test with Artisan, the decision was made to only test a Votator vertical evaporator and a Luwa horizontal evaporator and, if necessary, test an Artisan horizontal evaporator at a later date. Due to limited time, the tests focused on the equipment rather than on processing parameters.

Each test used two, different, nonradioactive surrogates of the sludge and supernatant from the MVSTs. As shown in Table 2, the difference between the two solutions was the presence or absence of clay and sand.

Table 2. Composition of the MVST surrogates used in the vendor tests

Component	Concentration (g/L)	
	Surrogate 1	Surrogate 2
$NaNO_3$	300	300
$Ca(NO_3)_2$	60	60
Na_2CO_3	15	15
NaCl	5	5
$Al(NO_3)_3$	1	1
NaOH	0.3[a]	0.3[a]
Bentonite Clay	0	20 g/L
Sea Sand	0	9 g/L[b]

[a]M.
[b]Sand was not used in Votator tests because of pumping problems.

5.1 RESULTS OF TESTS PERFORMED AT THE VOTATOR FACILITY

The tests at the Votator Pilot Plant were conducted on a Model 04-020 Turba-film Processor. The evaporator is a vertical type with a 4-in. (10 cm) ID heat transfer pipe and 1.7 ft^2 (0.16 m^2) of heat transfer area. Operation of the unit with both a standard fixed-clearance rotor and a hinged rotor was examined. The unit was operated under a slight vacuum, pulled from the condenser condensate outlet, to keep water vapor from exiting with the bottoms.

The steam chest pressure was kept constant at 120 psig (0.83 MPa) [the maximum steam pressure available – the unit is rated for 150 psig (1.0 MPa) steam] and the feed rate was varied to produce as concentrated a product as possible. Samples of the bottoms were analyzed for moisture content. Samples of the condensate were brought back to ORNL for sodium analysis, to determine the degree of entrainment.

The test results, which consist of observations about the equipment and operation and some quantitative results, are presented below.

1. Plugging was a problem when the feed was concentrated to a high solids content slurry. The first evaporator configuration tested had a bottom center discharge and an internal bushing (for the rotor). A spider held the bushing in place. Concentrate draining from the bottom of the evaporator often bridged across the spokes of the spider and plugged the discharge. In an attempt to solve this problem, a unit with an external bushing was tested. Because the bushing is external, a bottom center product outlet cannot be used. Instead the discharge must come off the side. This arrangement was also found to be very susceptible to plugging, even though all of the piping was heated.
2. Bottoms as concentrated as 81 wt % total solids was produced before turning into a powder. The consistency at this concentration was that of a thick paste. Attempts to produce the powder continuously were unsuccessful – the bottoms cycled between a fine powder and a watery solution. The cycling was attributed to powder accumulating on the heated wall and decreasing the heat transfer coefficient.
3. An evaporative capacity of 5.3 gal/(h) $\cdot$ (ft^2) [215 L/(h $\cdot$ m^2)] was obtained when the bottoms was ~80 wt % total solids.
4. Ten condensate samples were analyzed for sodium to determine the extent of entrainment. An average decontamination factor of 3,500 was calculated.
5. Two types of rotors were tested – hinged blade with clearance and fixed clearance. No affect on the operation of the evaporator was observed that could be attributed to the type of rotor used.
6. Buildup of material inside the evaporator was accompanied by: (1) an increase in the operating noise, which was a combination of scraping and rotor vibration; and (2) an increase in the current drawn by the drive motor.
7. The presence of clay in the feed was found to have a noticeable effect upon the product. When the feed was concentrated all the way to a solid, a light powder

was produced when clay was present, while a chunky solid was produced from the same feed that did not contain clay. This behavior was attributed to the clay absorbing water and also inhibiting caking of the salt crystals.

5.2 RESULTS OF TESTS PERFORMED AT THE LUWA FACILITY

The tests at the Luwa Pilot Plant were conducted on a Model D-0100 horizontal, agitated-film evaporator. It is referred to as a dryer by Luwa, since drying is the typical application for their horizontal units. The evaporator has 10.8 ft^2 (1.0 m^2) of heat transfer area and was heated with steam of varying pressure. Production of both a concentrated slurry and a powder were examined.

The rotor for Luwa's horizontal evaporators is quite different than that used in their vertical evaporators. It is composed of many small blades which bolt to the rotor shaft, and each blade has a unique function. Some are used to transport the powder while others are used for such purposes as inducing back-mixing and spreading the thin film.

Powder was produced first. No moisture analysis was run on the powder, but it was somewhat sticky and came out of the evaporator as small granules. The evaporator reached steady state in <0.5 h and continuously produced powder without problems. The rotor was removed to examine the inside of the unit. No excessive accumulation of material on either the rotor or the heated surface was seen.

The next series of runs examined the production of a concentrated slurry. A different rotor configuration was used for this — all of the blades were the fixed-clearance type. The material, just before turning into a powder, had the consistency of a thick paste. (As also observed in the Votator tests, the transition from paste to powder is quite abrupt). Even though the bottoms discharge pipe was heated, it plugged. In the opinion of the Luwa test engineer, their horizontal evaporator could be used to produce the free-flowing powder product, but not the highly concentrated paste.

6. DESCRIPTION OF THE AGITATED THIN-FILM EVAPORATOR PROCURED FOR PILOT TESTING AT ORNL

The vendor tests uncovered no obviously insolvable problems with the agitated-film evaporator, so the decision was made to procure one for further testing at ORNL. The evaporator is to be a component of a cold pilot facility dedicated to examining the solidification of the material in the MVSTs.

6.1 REQUIREMENTS OF THE EVAPORATOR AND CONSIDERATIONS THAT WENT INTO SPECIFYING THE MACHINE

1. The current concept calls for the evaporator to be located in a facility that is totally remotely operated and maintained with manipulators.
2. The machine should drain by gravity, without obstruction in the discharge pipe.
3. There shall be sufficient heat transfer area to concentrate a 30 wt % solution to 60 wt % at a feed rate of 0.5 gpm (1.9 L/min). (This is somewhere between a half-size and full-size machine for the currently concepted processing schedule).
4. The evaporator shall have the capability to produce either a concentrated slurry or a powder.

6.2 SPECIFIC REQUIREMENTS WHICH WERE DELINEATED IN THE SPECIFICATIONS

1. The evaporator shall be a vertical type.

   The vertical evaporator was preferred to the horizontal because: (1) it drains by gravity, (2) the rotor is much easier to remove, (3) it is more versatile and can be used as either a concentrator or solidifier, and (4) a greater decontamination factor may be achievable because of the elaborate deentrainment equipment.
2. The heat transfer area, based upon the heated pipe ID, shall be 5.4 ft^2 (0.50 m^2).
3. The evaporator shall be designed so that it can be disassembled and reassembled without shimming or other special adjustment to obtain alignment.
4. The unit shall have no bottom bearing.

   This is referred to as a cantilevered, or overhung, rotor design and is beneficial in two respects: (1) it eliminates the restriction in the bottom of the evaporator, and (2) it leaves only a single normal maintenance item, the upper seal, in the hot cell. A drawback to this design is that it increases the overall height of the evaporator. This is because rotor stability is achieved by making the rotor longer and then running the extra length between two bearings.

5. The evaporator heated section shall be capable of withstanding at least full vacuum coincident with an external pressure of 150 psig (1.03 MPa) saturated steam.
6. All wetted parts shall be fabricated of Type 304L stainless steel. The heating jacket shall also be fabricated of Type 304L stainless steel.
7. A standard cone bottoms discharge port shall be provided. It shall bolt to the evaporator and be removable.

   This will facilitate equipment reconfiguration as the product is alternated between a slurry and a powder.
8. The interior of the evaporator body and the discharge cone shall have a No. 4 sanitary finish.

   This is a smoother finish than is usually provided and will help evaluate how easily the evaporator can be decontaminated.
9. Three thermowells shall be installed along the length of the heated body.
10. Seals shall be double-mechanical cartridge type with a tungsten carbide rotating ring and tungsten carbide stationary ring.
11. The bearings shall be lubricated with high temperature grease and be sealed.
12. The unit shall have an entrainment separator that has both horizontal and vertical baffles with one set of baffles being stationary and the others moving with the rotor.
13. Two rotors shall be supplied. Both shall extend completely to the bottom of the evaporator but not into the discharge cone. The rotors shall be dynamically tested at rotational speeds above and below typical operating speeds. One of the rotors shall be a standard fixed clearance type. (This rotor will be used to produce a concentrate). The other rotor shall be a hinged blade type with blades that contact the heated wall. (This rotor will be used to produce a powder). The blades shall not be spring loaded nor considered to be wearing parts.

14. The rotor drive system shall be a direct-drive type and shall include a variable frequency motor controller to adjust the rotational speed of the rotor.

Three vendors were selected as qualified to bid on fabricating the evaporator: Artisan Industries, Luwa, and Votator. Artisan chose not to bid. Of Luwa and Votator, Luwa was the preferred company because: (1) they have more evaporators being used in radioactive waste operations; (2) they have built more evaporators of the overhung rotor design (more than a dozen vs 1 for Votator, built in 1968); and (3) they have a patented residence time control device. The machine that Luwa offered is shown in Fig. 3. The Votator evaporator was similar, but had a 10 in. OD heated section, a 15-in. deentrainment section, and was 8 ft 10 in. in overall length.

Also, a lab-scale agitated-film evaporator made by Pope Scientific[19] was purchased. It uses a zero clearance rotor with Teflon or carbon blades. The body is made of 2-in. (5 cm) glass and it is electrically heated with metal band heaters. The rated evaporative capacity is 24 mL/min of water. Pope also manufactures an oil-heated unit which, when used with a glass evaporator, allows viewing of the interior of the evaporator during operation. It was not purchased, however, because of the high cost and assurances by the manufacturer that internal viewing is also possible with the metal band heated unit.

7. PROCESSING SCHEMES TO BE EXAMINED WITH THE AGITATED THIN-FILM EVAPORATOR

The agitated film evaporator will be examined in two general processing schemes. It will be evaluated to concentrate a slurry of sludge and supernatant from the MVSTs, with the concentrate then serving as the feed to a higher temperature process in which the sodium nitrate is melted. In addition, it will be examined to directly solidify the slurry and produce the final waste form in a single step.

7.1 WASTE FORM REQUIREMENTS

Since the current concept calls for the solidified waste to be transferred to WIPP, the waste form must meet the WIPP Waste Acceptance Criteria (WAC).[20] Specific applicable requirements are:

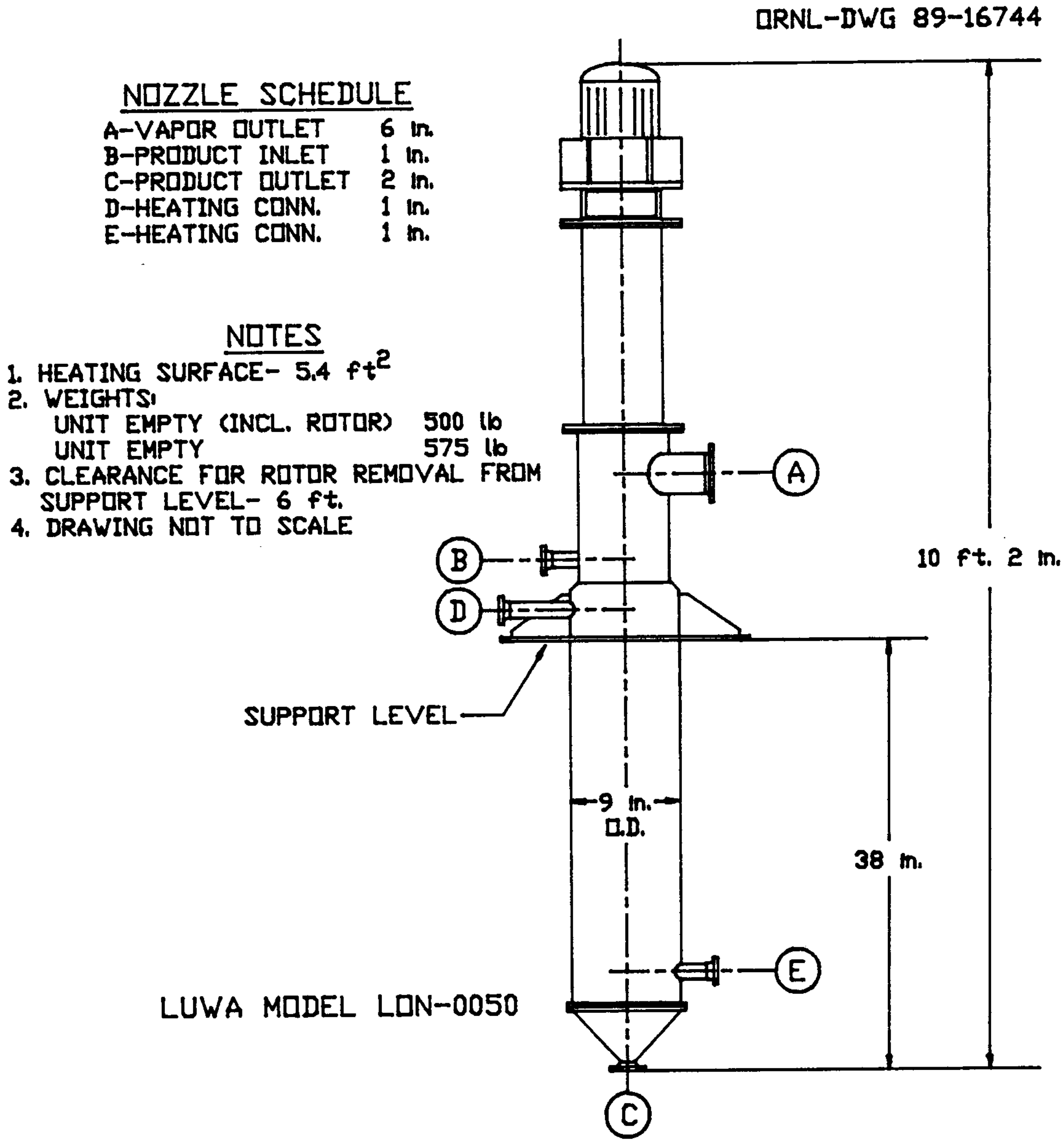

Fig. 3. The Luwa evaporator

1. Particulate waste materials must be immobilized if more than 1 wt % of the waste matrix is in the form of particles below 10 μm, or if more than 15 wt % is in the form of particles below 200 μm. Desiccants are not considered particulate waste material.
2. "TRU waste must not be in liquid form".

Regarding the criteria for fines, the powder that is produced from the evaporator is fairly large crystals. Powders produced from the Luwa evaporator from the two feeds described in Table 2 were sieved and found to easily meet the WIPP WAC fines limit. Additionally, since the powder is hygroscopic, it will absorb water with the result that the crystals will fuse (called caking) and thus increase the size of the particulates. Table 3 gives the critical humidities[21] and the stable phases[22] at 15°C for the major compounds found in the MVSTs. The compounds absorb water when the atmospheric humidity exceeds the critical humidity and since the waste packages must be vented, the solidified waste will likely be exposed to air of varying humidity. The clay, which is present in the waste may, however, hinder caking and chemical manufacturers often add it to salts to inhibit this phenomenon.

Regarding the free liquid criteria, since the salt cake is not stable, it is possible that as the temperature and humidity change, absorbed water will be released. This issue will be studied in the pilot tests by long term evaluation of the waste forms.

7.2 USE OF THE EVAPORATOR AS A CONCENTRATOR

The most basic requirement of the evaporator is that it be able to concentrate a slurry of sludge and supernatant from the MVSTs to the maximum extent possible, while the slurry still remains pumpable. Based upon laboratory tests with surrogates, the slurry would be ~60 wt % total solids. The product concentration would be controlled by adjusting the feed rate based upon the bottoms temperature. As concepted, the concentrate would fall by gravity into a holding tank, with the tank and all associated piping being heated. The concentrate would then be metered to a second piece of equipment in which the sodium nitrate is melted and the final waste form is made.

Table 3. Critical humidities for major constituents of the MVST waste

Substance	Stable phase at 15°C	Relative humidity (%)
Na_2CO_3	$\bullet 10H_2O$	90
NaCl	anhydrous	78
$NaNO_3$	anhydrous	77
$Ca(NO_3)_2$	$\cdot 6H_2O$	60
NaOH	$\bullet 4H_2O$	5[a]

[a]At 20°C.

7.3 USE OF THE EVAPORATOR AS A SOLIDIFIER

The more desireable situation is to produce the final waste directly with just the evaporator. The product in this case would probably be a powder. Vendor tests and published information indicate that this may be possible. Significantly, however, the bottoms from the evaporator does not have to be a solid in order for the collected product to set up with no free water (i.e., meet the WIPP WAC). This is because the salts and other compounds which make up the waste are dehydrated in the evaporator and will, as they cool in the product container, rehydrate. Thus, if there is not too much free water, they will absorb it completely and solidify.

As a simplified example of how this strategy would work, consider a solution of the composition given in Table 4. The compounds have no waters of hydration at 115°C, which is a reasonable operating temperature for the evaporator. If 1 L of the solution were evaporated, the compounds present, upon cooling, would be able to absorb ~72 mL (4.08 mol x 18 g/mol x 1 mL/g) of free water as waters of hydration.

As previously stated, the example simplified the real situation. Estimation of the actual quantity of free water that can be absorbed is difficult due to the formation of double salts, which typically have fewer waters of hydration than either of the pure salts. (In the system $NaCl/NaNO_3/Na_2SO_4/H_2O$, the double salt darapskite,

Table 4. Capacity of the MVST waste to absorb free water upon cooling

Compound	Concentration (M)	Number of waters of hydration at 15°C: Per mol compound	Per liter solution
$NaNO_3$	3.53	0	0
$Ca(NO_3)_2$	0.37	4	1.48
Na_2CO_3	0.14	10	1.40
NaCl	0.09	0	0
NaOH	0.30	4	1.20
		Total	4.08

$NaNO_3 \cdot Na_2SO_4 \cdot H_2O$, which has only a single water of hydration, is the precipitate at high $NaNO_3$ concentrations).[23] Nonetheless, the example does illustrate that complete removal of the water is not required to produce a waste form that has no free water.

A drum heater could also be employed to remove a small amount of residual water from the evaporator product. The bottoms from the evaporator would drain directly into the heated product drum, as shown in Fig. 4. A level indicator in the drum would shut the pump off if the liquid or foam height became excessive. Two characteristics of the agitated-film evaporator — small holdup and short residence, are vital to this control scheme. The feed rate to the evaporator would be controlled by the bottoms temperature (the temperature being related to concentration).

A further use for the drum heater is for controlling the cooling rate of the solidified waste. In crystallization, a slow cooling rate produces large crystals and this is beneficial for meeting the WIPP WAC fines limit.

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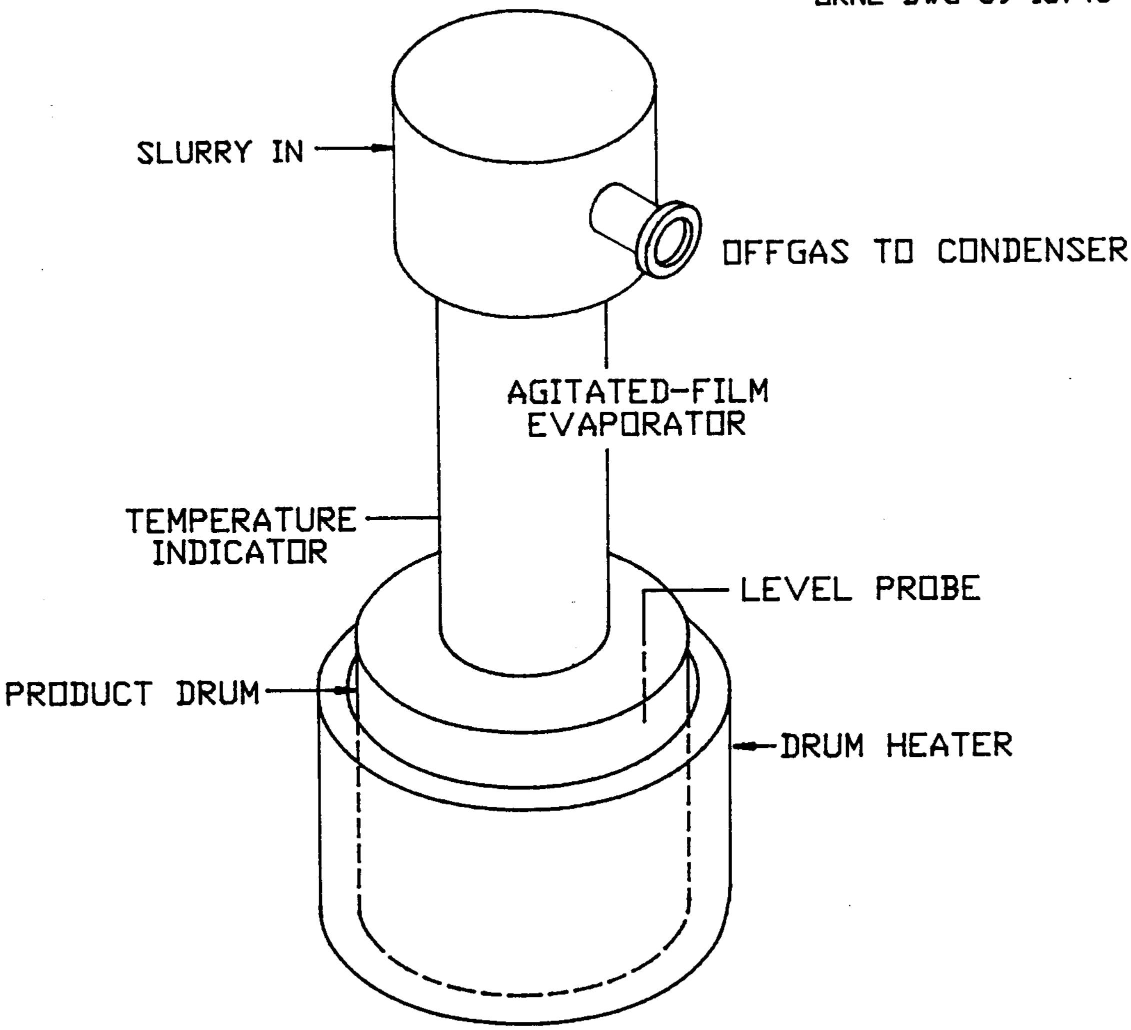

Fig. 4. Evaporator coupled to drum heater

8. CONCLUSION

A vertical agitated thin-film evaporator with an overhung rotor design was procured for testing in radioactive waste processing at ORNL. The unit was purchased after: (1) a review of the literature found that agitated-film evaporators had been used successfully in similar processing applications, and (2) vendor tests with nonradioactive surrogates uncovered no fatal flaws with the machine. The evaporator will be a component in a pilot plant dedicated to evaluating options for solidifying the ~370,000 gal (~1400 m^3) of TRU waste currently stored in the Melton Valley Storage Tanks at ORNL. The general processing schemes to be studied include the use of the evaporator as: (1) a concentrator, to evaporate a slurry before feeding to a higher temperature process; and (2) as a solidifier, to directly produce the final waste package. The current concept calls for the waste to be solidified without additives and the salt cake transferred to WIPP.

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