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In-Tank Evaporator Demonstrations During 1990/1991 at the ORNL Melton Valley Storage Tanks

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IN-TANK EVAPORATOR DEMONSTRATIONS DURING 1990/1991 AT THE ORNL MELTON VALLEY STORAGE TANKS

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IN-TANK EVAPORATION AT THE ORNL MELTON VALLEY STORAGE TANKS

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ABSTRACT

The results of this report indicate that in-tank evaporation (ITE) should be continued to reduce the inventory of supernate in the Melton Valley Storage Tanks (MVST) until additional storage tanks and/or treatment facilities can be installed. Several equipment problems were encountered during the initial operation of the ITE. All of these have been addressed with the exception of the replacement of the air compressor that was originally used in the hydrofracture process and the intermittent wetting of the high efficiency particulate air (HEPA) filters. The compressor is being replaced with a unit that is designed for continuous operation. Filter wetting needs further investigation. ITE will help reduce the supernate inventory in the MVST using the existing equipment but will not eliminate the need for solidification campaigns. Several options are available to increase the evaporation rate above that achieved in this study to minimize dependence on solidification campaigns until new tanks and/or treatment systems become available. These include increasing the air sparge flow rate through the MVST, adding heat to the MVST, and pumping the supernate to an evaporator located near the MVST. Evaluations of the feasibility and cost effectiveness for the more promising options began in FY 1991 and will continue in FY 1992.

1. INTRODUCTION

The MVST are an important part of the storage system for liquid low-level waste (LLLW) at Oak Ridge National Laboratory (ORNL). These tanks are used to collect LLLW that is currently concentrated by the LLLW evaporator and to store the waste until additional tanks and/or treatment facilities can be constructed. The Waste Handling and Packaging Plant (WHPP) that will process the stored waste in the MVST for final disposal will not come on-line before 2000. Funding delays could postpone startup an additional 5 years. Additional storage tanks are being planned to accommodate the delays in the treatment facilities, but these tanks will not be operational before 1997.

Historical data from 1986-1988 shows that an average of ~26,000 gal/year of liquid low-level waste concentrate (LLLWC) was transferred to the MVST during this time period.[1]

Volume reduction activities have reduced LLLWC generation rates to ~13,000 gal/year the last 2 years, but new programs and Isotopes Facilities Shutdown are likely to increase this rate to 18,000 gal/year for the next 5-10 years. Waste transfer from the remedial action programs will also increase the MVST inventory over the next 5-10 years.[2] At the present LLLWC generation rate, the MVST are expected to reach their maximum capacity during 1993 if no action is taken to reduce the volume of waste in the tanks. Bench-scale tests at ORNL have shown that 50-70% of the liquid in the MVST could be evaporated prior to solids precipitation.[3] Therefore, the near-term strategy for management of the LLLWC stored in the MVST is to sparge the tanks with air to evaporate the excess water from the tanks and to concentrate the stored LLLWC to the point of near saturation.[4,5] ITE at ambient temperatures is not expected to be sufficient to keep the LLLWC inventory below the maximum capacity of the MVST until 1997. Therefore, up to four campaigns (including one in 1989) are being planned to solidify 50,000 gal of supernate per campaign in concrete. Methods to enhance the supernate evaporation rate are also being considered to minimize the number of solidification campaigns.

A mathematical model was developed to predict ITE evaporation rates as well as to determine the power requirements necessary to heat the MVST LLLWC to obtain the enhanced evaporation rates. The modeling efforts were performed by Florida International University and Martin Marietta Energy Systems, Inc., Engineering on the ITE process.[6,7,8] Preliminary evaluations indicated that the evaporation rate from the MVST could help reduce the inventory of supernate. Adding heat to achieve faster evaporation rates would needed to be considered to avoid solidification campaigns and/or overfilling the MVST. The results from the modeling need to be verified with actual operating data.

Implementation of ITE at the MVST began in 1990 using 10-year old equipment installed for use in the hydrofracture process with the intent of sparging of the MVST over a 6-month period to verify the effectiveness of ITE.[9] Recommendations for future evaporation operations were to be made based on the evaluation of this data. ITE took place over 3 months in 1991 and was shut down because of breakdown of the air sparge compressor. This report summarizes ITE operations to date, evaluates the performance, compares actual data with the mathematical modeling, and makes recommendations for improving the evaporation process.

An air sparge system, previously used to mix the tanks for disposal of LLLWC by hydrofracture, is piped into each tank (Fig. 1). The sparge system consists of five 6-in.-diam draft tubes, each with a 1-in. internal air supply line. Compressed air is metered into the tanks by individual rotameters on each of these five lines. The design rate is 20 scfm at 30 psig per rotameter, which translates into 100 scfm per tank. Each tank is also equipped with an air line providing sweep air that operates when the tanks are not being sparged. If the tanks are being sparged, the flow of sweep air may be reduced or eliminated at the operators discretion. The air from both the spargers and the sweep exhausts through a flowmeter prior to entering a collection header serving all four tanks in a vault. The collection header discharges into a demister that removes entrained and condensed liquid and returns this liquid to one of two tanks. The air from the demister is heated to prevent condensation in subsequent filtration steps. The heated air is passed

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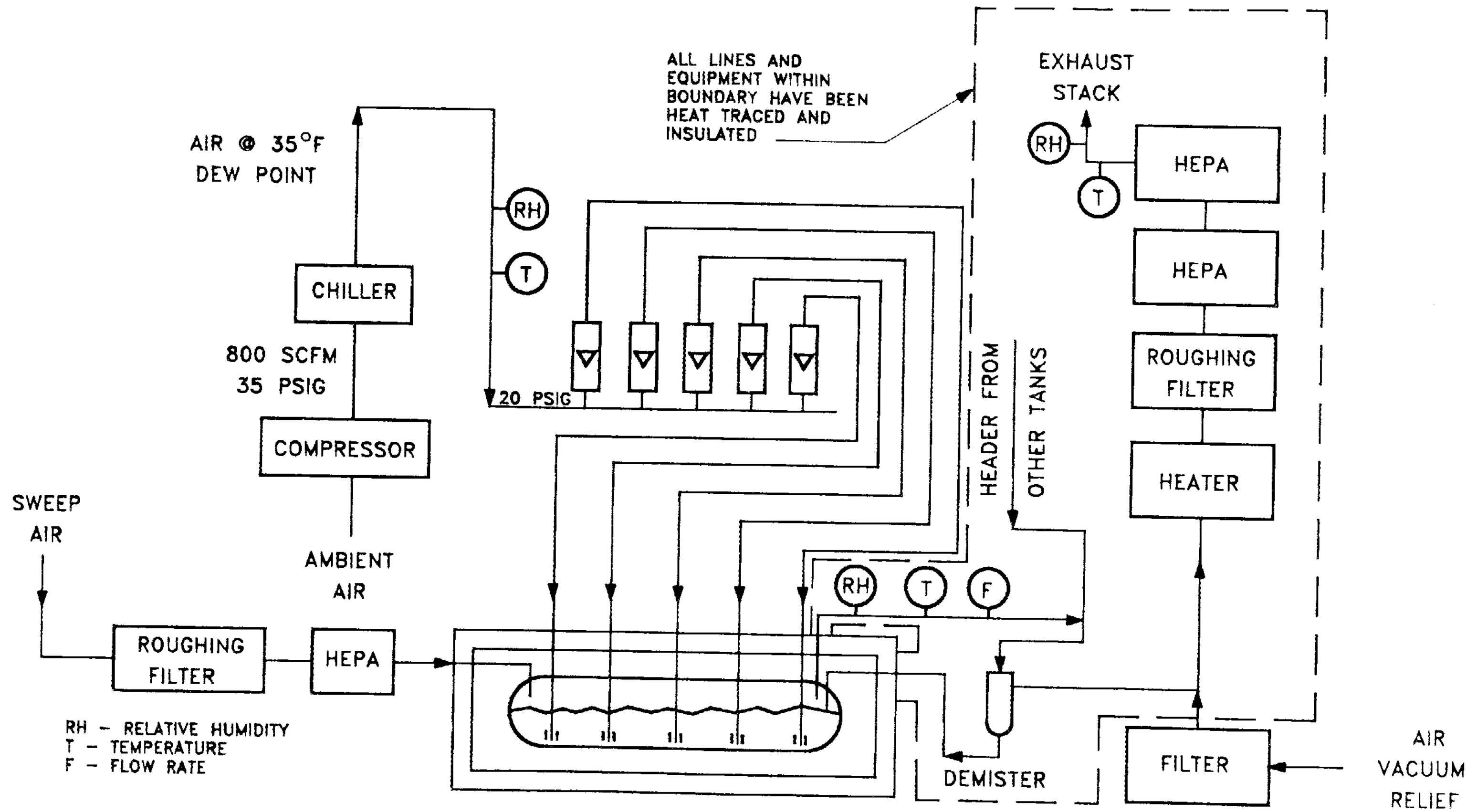

Schematic Diagram of the MVST Tank Ventilation System After Modifications.

through HEPA filters prior to exiting through a blower and a local 10-in.-diam, 12-ft-high stack. The exit filters are rated for 1,000 scfm. The compressor and chiller, which are located in Building 7860, supply 800 scfm of air at a 35°F dew point and 30 psig. All tank off-gas piping, filters, and stacks have been heat traced and insulated to prevent condensation in the off-gas lines.

2. SYSTEM DESCRIPTION

The MVST system consists of eight 50,000-gal storage tanks located in two vaults. The tanks and the vaults have separate ventilation systems. Schematic diagrams of the vault and tank ventilation systems are presented in Figs. 1 and 2, respectively.

Filtered air is introduced into each vault near the ceiling through five 6-in.-diam pipe nipples (Fig. 1). The vault ventilation air exhausts through five 6-in.-diam pipe nipples located on the opposite wall. The vault ventilation system operates at flow rates up to 1,400 scfm and can be increased to 1,700 scfm if a vault plug needs to be removed. The exhaust air is passed through HEPA filters prior to exiting through the vault ventilation blower and the 8-in.-diam x 12-ft-high stack.

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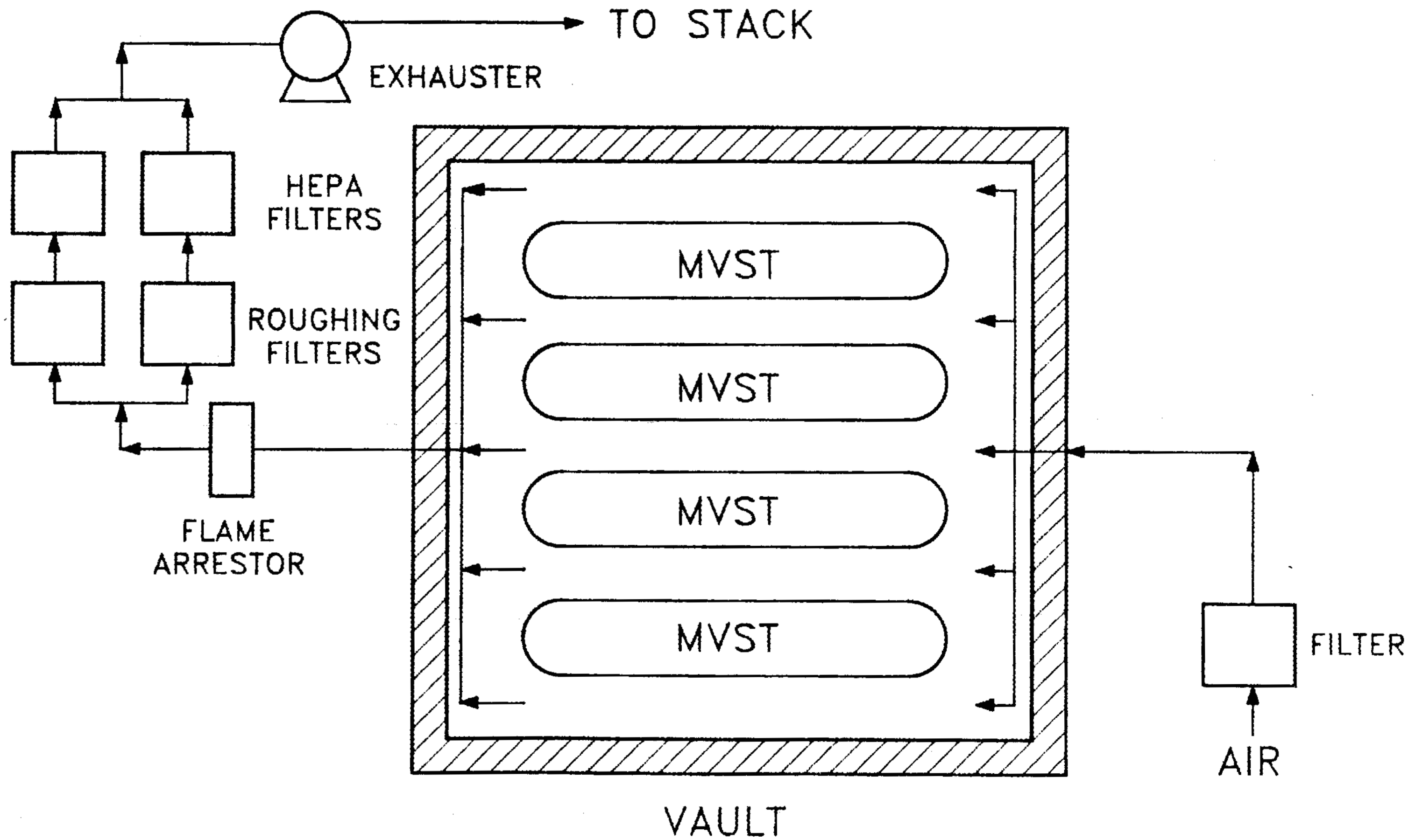

Schematic Diagram of the MVST Vault Ventilation System

3. EVALUATION OF ITE PERFORMANCE

The ITE equipment was installed at the MVST in 1990. Existing equipment was used when possible to minimize costs. Most of the existing equipment had been installed for use in the hydrofracture process approximately 10 years ago and had not been operated for over 5 years. New instrumentation for determining the relative humidity and the temperature entering and exiting each tank was installed in order to follow the ITE process. Safety shutdown instrumentation was installed to eliminate the risk of tank overpressurization during sparging activities.

As would be expected with old equipment that had been shut down for years, several operational problems were encountered during the 1990 preoperational test period. The chiller/dryer that dehumidifies the sparge air entering the MVST did not operate properly and was replaced. The relative humidity/temperature probes did not function properly and were replaced with probes of a different design. The in-line heaters, which were designed to heat the off-gas from the MVST to prevent the HEPA filters from becoming wet, required maintenance before they operated properly. Operational pretesting was completed in 1990 and the ITE test was begun in early 1991 to demonstrate the effectiveness of the ITE process.

Two incidents of HEPA filter wetting occurred — one on April 2, 1990, 5 d after the total flow had been brought up to 600 ft^3/min, and then on April 23, 1991, after the system had been operating at about 400 ft^3/min for around 2 months. The currently installed demisters are ACS Industries mesh style 4BA, according to the drawings. The demister for each vault contains a pad 4-in. thick and 16-in. in dia. This style is recommended for clean liquids and should provide greater than 99% removal of drops 10 μm and larger. The design velocity through the pad is 10 ft/s for gases at the atmospheric density of air and higher (K=0.35). At a flow rate of 400 ft^3/min per vault, the velocity is 5 ft/s, somewhat lower than the design value. However, the efficiency does not drop off significantly for 10 micron drops until the velocity is below 2 to 3 ft/sec. Re-entrainment becomes a problem at 20 to 30 ft/sec, or a flow rate above 1600 ft^3/min per vault. It does not seem likely that the wetting was caused by excessive velocities through the demisters. A possible cause was malfunction of the heaters between the demisters and the filters.

3.1 In-Tank Evaporation Performance Data

The ITE equipment was operated almost continually on four of the MVST (W-24, W-25, W-26 and W-27) from February 4, through April 22, 1991. The air sparge rate was slowly ramped up to the maximum tested sparge rate of approximately 120 scfm per tank (468 scfm for 4 tanks) during the first half of the test period. The sparge air enters the MVST sparge tubes at about 12 psig and exits the tanks at atmospheric pressure. The sparge rate was not increased above 468 scfm because of concerns that higher flow rates might cause wetting of the HEPA filters. The system was shut down on April 22 because the air compressor began leaking unacceptable quantities of oil into the cooling water and sparge air.

During the 3-month operational period, about 900 gal of water were evaporated from the MVST as shown in Table 1. This figure was calculated from relative humidity, temperature and flow rate readings. Partial pressures of water in the exit air were calculated as shown in the Appendix.

3.2 Calculation of Approach to Saturation of Exit Air

The primary information required from the ITE experiments for design projections is the extent of approach to saturation of the sparge air as it leaves the tank. Data used to determine the degree of saturation of the exit air were taken between March 23 and April 5 when the compressor, chiller, and humidity probes were all working properly. The calculations (see appendix) indicate that the air was at 86% of saturation for an air flow rate of 274 ft^3/min, dropping to 73% of saturation at 430 ft^3/min. These are total flow rates for the four tanks at about 1 atm pressure. Equal flow rates among the four tanks were never used, so the correlation of approach to saturation with flow rate is somewhat imprecise.

3.3 Equipment Operation

Four kinds of equipment problems were encountered during the 1991 test period:

1. The compressor leaked oil into the compressed air. This coated temperature and humidity probes and caused erroneous readings. Some undesirable organic matter was added to the tanks.
2. The water drain line from the chiller plugged, and dehumidification of the inlet air stopped for about a 1-month period. The problem was corrected and additional humidity and temperature probes were installed to monitor the chiller performance more closely.
3. The compressor failed, terminating the experiment/demonstration.
4. The HEPA filter was found to be wet at the end of the demonstration.

The purchase and installation of a new centrifugal air compressor should eliminate oil leakage into the sparge air and provide reliable sparging for at least 5 years. Present estimates for the new compressor/air dryer system are about $140,000. This appears to be an attractive option for making new storage space available in the MVST.

3.4 Projected In-Tank Evaporation Effectiveness

The calculations in Table 1 taken for air sparge rates >400 ft^3/min (measured at the exit when all four tanks were sparged) indicate that 6.8 gal/d/tank were evaporated from the MVST during the test period. The inlet air during the test was dried to a 40°F dew point by the chiller. Assuming that ITE is on line 80% of the time, the inlet air is dried to a -40°F dew point by a desiccant dryer, and six tanks are sparged; 17,000 gal/year could be evaporated. If the air compressor is replaced in mid-1992, 76,000 gal of supernate could be evaporated before 1997 when additional LLLW storage tanks are scheduled to be operational. Under these conditions, ITE would be capable of evaporating the newly generated waste produced from normal operations during this time. However, it would not be capable of working off any of the existing inventory nor would it provide the capacity to handle emergencies or waste transferred from the inactive LLLW tanks. ITE would eliminate the need for a 50,000-gal solidification campaign before 1997.

Table 1. In-tank evaporation performance from February 4, to April 22, 1991

ID#	Air flow rate[a] (ft³/min)	Period (d)	Water out (gal/d)	Water in (gal/d)	Amount of water evaporated Net (gal/d)	Amount of water evaporated Total (gal)
1-54	180	6.83	12.9	3.32	9.58	65.4
55-98	163	10.0	10.9	3.68	7.22	72.2
99-107	134	1.0	9.48	5.66	3.81	3.8
108-194[b]						
195-199	296	1.83	26.4	7.10	19.3	35.3
200-225	439	8.20	34.3	10.6	23.7	194.7
226-233	328	1.83	24.0	7.95	16.0	29.4
234-236	363	1.0	27.6	8.81	18.8	18.8
237-238	274	1.33	23.6	6.61	17.0	22.6
239-252	362	5.5	34.7	8.69	26.0	143.0
253-266	468	8.33	43.3	13.2	30.1	250.4
267-269	420	2.5	40.0	11.8	28.2	70.6
TOTAL						906.2

[a]Measured at the MVST effluent.
[b]Chiller condensate drain plugged.

4. COMPARISON WITH IN-TANK EVAPORATION MODEL PREDICTIONS

Previous modeling work on the ITE system by Florida International University and Martin Marietta Energy Systems, Inc., Engineering predicted that the exit air from the MVST would be nearly saturated with moisture at the temperature of the liquid in the tanks (approximately 50°F).[6-8] Under these conditions (assuming an air sparge rate of 400 ft^3/min), the models predicted a total removal rate from four tanks of 36.6 gal/d. ITE operating data indicate that the air only reached 73 to 86% saturation, and an average of 27 gal/d of water was removed. The actual removal rate was approximately 75% of the rate predicted by the model. The modeling approach is very uncertain because sludge surrounds the draft tubes enclosing the spargers. The draft tubes probably contain some sludge, and the degree to which the tube vents are open is unknown. The models assume no sludge is present to affect air flow. The simplified assumptions for the model result in over prediction of the ITE effectiveness.

5. METHODS TO ENHANCE EVAPORATION RATES

Evaluation of the ITE performance data in Sect. 4 indicates that evaporation rates of 17,000 gal/year are achievable using the existing ITE system (after the leaking compressor is replaced). This is only sufficient to process the predicted waste generation rates in the near future. In order for ITE to process the expected future waste generation plus work off the present inventory in the MVST to avoid solidification campaigns before 1997 (when new tank capacity is expected to be available), measures will need to be implemented to enhance the evaporation rate. The following options are available: (1) increasing the air sparge flow rate through the MVST, (2) adding heat to the MVST, and (3) pumping the supernate to an evaporator located near the MVST, that is, out-of-tank evaporation (OTE). Each of these will be discussed below.

5.1 Increasing the Air Sparge Rate

Steady year-around sparging is assumed for tanks W-24, 25, 26, 27, 28, and 31. Tanks W-29 and 30 will not be sparged to permit the supernate to settle in preparation for a solidification campaign. It is also assumed that the compressor is operated at its full rated capacity and the flow is evenly distributed among the six tanks. This would result in flows of at least 150 ft^3/min per tank depending on ambient temperature.

Average supernate temperatures were assumed to track average air temperatures as follows:

Months Measured	Average air temperature (°F)	Assumed average supernate temperature (°F)
December - February	41	45
March - May	57	55
June - August	75	70
September - November	59	60

The composition of the exit air is then estimated:

Super temperature (°F)	Vapor pressure water (mm Hg)	Vapor pressure water x 0.92 (mm Hg)	Saturation effectiveness	Air Composition (mol %)
45	7.6	7.00	0.75	0.0070
55	11.1	10.2	0.75	0.0102
70	18.8	17.3	0.75	0.0173
60	13.2	12.1	0.75	0.0122

The total pressure was taken as 749 mm Hg in this calculation.

The design specifications of the new compressor are 1150 scfm at 30 psig referred to inlet conditions of 14.7 psig and 94°F; however, 207 ft^3/min will be used to regenerate the desiccant dryer. Thus, the compressor can provide 64.0 lb/min of sparge air at the reference conditions. The maximum mass flow rate for a centrifugal one-stage compressor would increase by 23% when the inlet temperature drops to 40°F. Average air mass flow rates for the four seasons are estimated as follows, assuming a linear relationship with absolute temperature: winter, 77.3; spring, 74.5; summer, 70.5; and fall, 73.2. The yearly average mass flow rate is 73.9 lb/min. The new desiccant air dryer has a dewpoint specification of -40°F, or a humidity ratio of 0.00008 lb water/lb air. The air entering the tanks would bring in about 1.0 gal/d of water. The water carried out with the exit air is obtained from the exit air compositions in the above table. The compositions are converted to humidity ratios by multiplying by the ratio of molecular weights (18/29).

	Humidity ratio of exit air ($lbH_2O/lbAIR$)	Water out (gal/d)	Water out minus in (gal/d)
Winter	0.0043	57.4	56.4
Spring	0.0063	81.0	80.0
Summer	0.0107	130	129
Fall	0.0076	96.0	95.0

Assuming that the air sparge is done 80% of the time during a year, the total amount of water evaporated is estimated to be 26,000 gal. This estimate assumes that a flow of about 150 ft^3/min of air could be sparged through each tank, compared with the 100 ft^3/min assumed in previous estimates. A review of the piping between the compressor and the tanks with Engineering Personnel indicates that it can accommodate the increased flow rate. If air flow is limited to 100 ft^3/min per tank for the six tanks, the amount of water evaporated would be reduced by one-third, or to about 17,000 gal/year.

5.2 Vault Heating

The temperature of the supernate strongly affects the rate of evaporation. Heating the sparge air is certainly the most effective way to enhance the rate, but experimentation is required to provide an estimate of the amount. The modeling approach is very uncertain because of the sludge that surrounds the draft tubes enclosing the spargers. The draft tubes probably contain some sludge, and the degree to which the tube vents are open is unknown. The evaporation data provide a basis for estimating the fraction of the heat that would be transferred from the air to the liquid, but the fraction transferred that actually vaporizes water cannot be reliably predicted.

The approach of heating the vault air was addressed in considerable detail by the Process Engineering Section of the Engineering Division.[7] Taking into account heat exchange through the vault walls to the ground and ambient air, their analysis showed that supplying 150°F air to the cells would raise the average waste temperature to 75°F in about 5 months. Temperatures would fluctuate seasonably during subsequent years, generally remaining in the 70 to 80°F range. This would require a power supply of about 80 kW and an annual power cost of about $30,000. Using an average supernate temperature of 75°F and a saturation efficiency of 75%, the evaporation rate would be increased to about 30,000 gal/year, sparging six tanks at a rate of 100 ft^3/min each.

Heating the sparge air, as opposed to the cell air, would put the heat at the air-supernate interface where evaporation takes place. In the cell air heating case above, a flow rate of 2800 scfm was used. The sparge air flow is only 600 ft^3/min by contrast. It is recommended that an experimental run be made with heated sparge air to measure the effectiveness of this option.

It is estimated that heating of the MVST could not be implemented before 1993. Since solidification campaigns are scheduled for FY 1991, 1992, and 1993, this process probably only has the capability to avoid one solidification campaign if waste generation rates remain at present levels and new storage tanks stay on schedule.

5.3 Out-of-Tank Evaporation

There are about 200,000 gal of supernate in the six MVST that have been analyzed.[10] The total in all eight tanks is estimated to be about 270,000 gal.[9] Walker reports volume reduction results for air-sparging experiments with maximum solids concentrations ranging from 640 g/L for W-31 to 823 g/L for W-28.[3] These air-sparging results were used to predict OTE volumes as shown in Table 2.

Table 2. Predicted out-of-tank evaporation results

Tank	Supernate Volume (gal)	Solids concentration Presently (g/L)	Solids concentration After evaporation (g/L)	Water evaporated (gal)
W-24	34,200	377	698	15,700
W-25	24,000	348	679	11,700
W-26	30,100	369	671	13,500
W-27	29,200	358	725	14,800
W-28	43,600	485	823	17,900
W-29	unknown			
W-30	unknown			
W-31	39,600	351	640	17,900
TOTAL				91,500

The average amount that can be evaporated from each of the six tanks sampled is estimated to be 15,250 gal. If this amount could be evaporated from W-29 and W-30, the total water evaporated would be 122,000 gal. This estimate assumes that the OTE campaign is done in a short time span (a few months), so that the amount of fresh incoming waste slurry is not significant. If the evaporator were left in place and operated over a period of years, much more water could be evaporated. Since this process probably could not be implemented before 1993, it could only be used to avoid one of the presently planned solidification campaigns.

An evaporator that might be considered for this service is one of the Licon Aquavap VC series. A VC-300 (300 gal/h) is in use at Three Mile Island (TMI) Unit II processing radioactive water resulting from the 1979 accident. The major constituent of the water at TMI is boron, which enters the evaporator at a concentration of 3500 ppm. The overheads concentration averages 3.5 ppm, for a decontamination factor of 1000 based on the feed. The evaporator achieves a solids concentration of 10%, so that the decontamination factor between the liquid and vapor phases is about 28,000.

The radioactivity of the MVST supernates is dominated by ^{137}Cs, which ranges from 1.88×10^5 Bq/mL in W-30 to 2.21×10^6 in W-26. Assuming that the supernate of W-26 is concentrated by a factor of 1.8 (672/369) and a decontamination factor of 28,000 is applied, the overheads concentration of ^{137}Cs would be 140 Bq/mL. In comparison, the waste acceptance criteria for the Process Waste Treatment Plant (PWTP) is 400 Bq/L. A large dilution factor is required in order for the overheads to be sent to the PWTP.

Operational concerns include: (1) shielding requirements, (2) process flow arrangements, and (3) evaporator location. From the radionuclide inventories of the tank supernates, it is clear that ^{137}Cs dominates the shielding requirements. Using W-31 as an example, the products (curies x gamma million electron volts) are taken for each nuclide and ^{137}Cs accounts for 94% of the total, ^{134}Cs for about 5%, and the remainder of the nuclides for 1%. Therefore, the dose rate from ^{137}Cs can be used to a good approximation.

The supernate of W-26 is the hottest and gives an unshielded dose rate of 206 mrem/h/L as a point source. The concentrate tank of the VC-300 evaporator has a volume of 110 gal in a 2 x 3 x 3 ft shape. The relaxation length for ^{137}Cs in water is 11 cm, so, accounting for self-attenuation, the tank would effectively represent a volume of 11 cm x 3 ft x 3 ft, or about 20 gal. The unshielded dose at one foot distance from the concentrate tank is then estimated as 15 rem/h. Shield thicknesses to reduce the dose rate to 1.5 mrem/h (a factor of 10,000) are about 2 ft of ordinary concrete or 3 in. of lead. Remote operation and maintenance of the evaporator would be required.

The volume of supernate that would be held at the evaporator facility would be small compared to the 30,000 to 40,000 gal of supernate in a single tank. Clearly, it would be extremely undesirable to return the concentrate from the evaporator to the tank from which the evaporator is being fed. If this were done, the concentration of the feed stream from the tank would increase with time, the supernate would cycle through the evaporator many times as it was concentrated and rediluted, and the evaporator would be operating for much of the time on highly-concentrated feed. The system would work best if one tank could be emptied of supernate by some means (perhaps by a solidification campaign or ITE), so that it could receive evaporator concentrate. Thus, as the tanks were processed, one would always be available to receive concentrate. The question of whether the piping arrangements are in place to permit this scheme of operation must be answered if OTE is to be seriously considered.

6. SUMMARY AND RECOMMENDATIONS

The ITE equipment was installed at the MVST in 1990. Existing equipment was used as much as possible. Most of the existing equipment had been installed for use in the hydrofracture process approximately 10 years ago, was not designed for ITE service, and had not been operated for over 5 years. As would be expected, several operational problems were encountered. All of these have been addressed except the replacement of the air compressor and the wetting of the HEPA filters. The purchase and installation of a new centrifugal air compressor should eliminate oil leakage problems and provide reliable sparging for at least five years. The cause of the wetting of the filters must be investigated and corrected. Present estimates for the new compressor/air-dryer system are about $140,000. This appears to be an attractive option for making new storage space available in the MVST and the unit is being replaced.

The results of this report indicate that ITE should continue to reduce the inventory of supernate in the MVST until additional storage tanks and/or treatment facilities can be installed. The ITE data indicate that 17,000 gal/year could be evaporated under the demonstrated operating conditions. Assuming the air compressor is replaced in mid-1992, 76,000 gal of supernate could be evaporated before 1997 when additional LLLW storage tanks are scheduled to be operational. Under these conditions, ITE would be capable of evaporating 90% of the newly generated waste produced from normal operations during this time period, which would avoid one 50,000-gal solidification campaign before 1997.

In order for ITE to process the expected future waste generation in addition to working off the present inventory in the MVST in an attempt to avoid up to two solidification campaigns before 1997, measures will need to be implemented to enhance the evaporation rate. The options are available: (1) increasing the air sparge flow rate through the MVST, (2) adding heat to the MVST, and (3) pumping the supernate to an evaporator located near the MVST (i.e., OTE). Increasing the air sparge rate appears to be the most attractive option at the present time. The feasibility and implementation costs for these options have been evaluated in more detail during of FY 1992.

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Appendix. CALCULATION OF PERCENT SATURATION FOR SPARGE AIR

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The extent of approach to saturation of the air leaving the MVST was calculated as follows:

1. The partial pressure of water in the combined exit air from the tanks was obtained from humidity and temperature readings at W-stack (instruments 9 and 10) and W-stack 2 (instruments 3 and 4). The duplicate humidity readings agreed within 2 or 3% and the temperature readings within 1 or 2°C. The instruments are located after an air heater, which prevents condensation in the exit line.
2. The vapor pressure of the supernate is calculated from the average tank temperature and corrected for the effect of the salts by the method of Kusik and Meissner.[11] For the four tanks W-24 through W-27, sodium concentration varied from 2.9 to 4.3 ***M***, potassium from 0.2 to 1.3 ***M***, nitrate from 3.3 to 4.5 ***M***, and chloride from 0.07 to 0.1 ***M***. Many other constituents are present in trace amounts. Total cations averaged about 4.1 ***M***, and total anions about 4.1 ***M***. The vapor pressure correction factor for 4 ***M*** sodium nitrate is 0.91 at 77°F. Lowering the temperature to 45°F increases the factor to 0.93. Increasing the concentration to 5 ***M*** decreases the factor to 0.88. Thus, the factor is not very sensitive to the range of variables in this system.
3. The approach to saturation of the exit air is obtained from the ratio of the partial pressure of water in the exit air to the vapor pressure of the supernate. Liquid temperatures in the MVST increased by about 6°F between February 4 and April 22. This increase indicates that the tanks are fairly responsive to ambient air temperature. Temperatures among the four tanks varied by about 4°F. The temperature average of the tanks was used in looking up vapor pressures.

Calculations for the partial pressures follow:

Record	Exit H (%)	Exit T (°C)	Vapor Press (mm Hg)	Partial Pressure (mm Hg)	Air Flow rate (ft³/min)
197	43	23	21.1	9.1	296
198	27	27.5	27.5	7.4	296
199	35	23	21.1	7.4	296
				8.0 average	
200	27	25.5	24.5	6.6	430
201	27.5	26	25.2	6.9	430
202	34.5	22.5	20.4	7.0	430
				6.8 average	
229	42.5	19	16.5	7.0	328
230	30	24.5	23	6.9	328
231	25	28.5	29.2	7.3	328
232	28.5	26	25.2	7.2	328
				7.1 average	
234	29.5	25	23.8	7.0	363
235	30.5	26	25.2	7.7	363
236	41	20.5	18.1	7.4	363
				7.4 average	
237	31.5	25.5	24.5	7.7	274
238	41.5	23.5	21.7	9.0	274
				8.3 average	

Having obtained water partial pressures in the exit gas, we now proceed to find supernate vapor pressures:

Date	Records	Supernate temperature (°C)	Vapor pressure water (mm Hg)	Salt factor	Vapor pressure supernate (mm Hg)
3/23	197 to 199	11.4	10.1	0.92	9.3
3/24	200 to 202	11.4	10.1	0.92	9.3
4/2	229 to 232	11.6	10.2	0.92	9.4
4/3	234 to 236	11.6	10.2	0.92	9.4
4/4	237 to 239	11.9	10.5	0.92	9.7

Estimates for the degree of approach to saturation achieved in these experiments are:

Flow rate[a] (ft³/min)	Percent of Saturation (%)
274	86
296	86
328	76
363	79
430	73

[a]At MVST exit

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