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# Liquid Waste Evaporator Operating Experience

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## ABSTRACT

Atomic Energy of Canada Limited (AECL) operates the Waste Treatment Centre (WTC) to treat and immobilize some of the low-level radioactive waste (LLRW) streams at the Chalk River Laboratories (CRL). The WTC at treats low-level radioactive liquid waste by removing the contaminants from the wastewater, concentrating them, and immobilizing them.

The fundamental design concept for the WTC is to process the waste streams using forced circulation type liquid waste evaporation (LWE), to solidify the concentrates using thin film evaporator and to discharge the purified effluent into the Ottawa River following verification monitoring. The solidified product drums are stored in existing storage facilities in the CRL.

The LWE was installed in the WTC to treat the LLRW. After about four (4) years of design, construction and cold commissioning, the active commissioning of the evaporator process using radioactive waste streams commenced in February 2000. The LWE has overcome problems encountered with previous processing system such as fouling and enabled treatment of historical liquid wastes, which are currently stored in tanks at CRL, and waste from future CRL projects.

This paper summarizes some of the operating experience obtained during the last four years of operation.

## 1. BACKGROUND

AECL currently operates the WTC to treat and immobilize the low-level radioactive waste (LLRW) streams at the Chalk River Laboratories (CRL). Design and construction for a new LWE were carried out as part of a design/build contract with Adtechs Corporation Ltd. in July 1997. The LWE process commissioning, using clean water, was started in November 1999. Active commissioning, using radioactive waste streams, commenced in February 2000.

The LWE was installed to replace the aging microfiltration and reverse osmosis (MF/RO) system that was previously used to separate dissolved and suspended solids from the liquid waste streams, and with which many processing problems were experienced.

Figure 1 shows the WTC Liquid Waste Evaporator Process Flow Diagram.

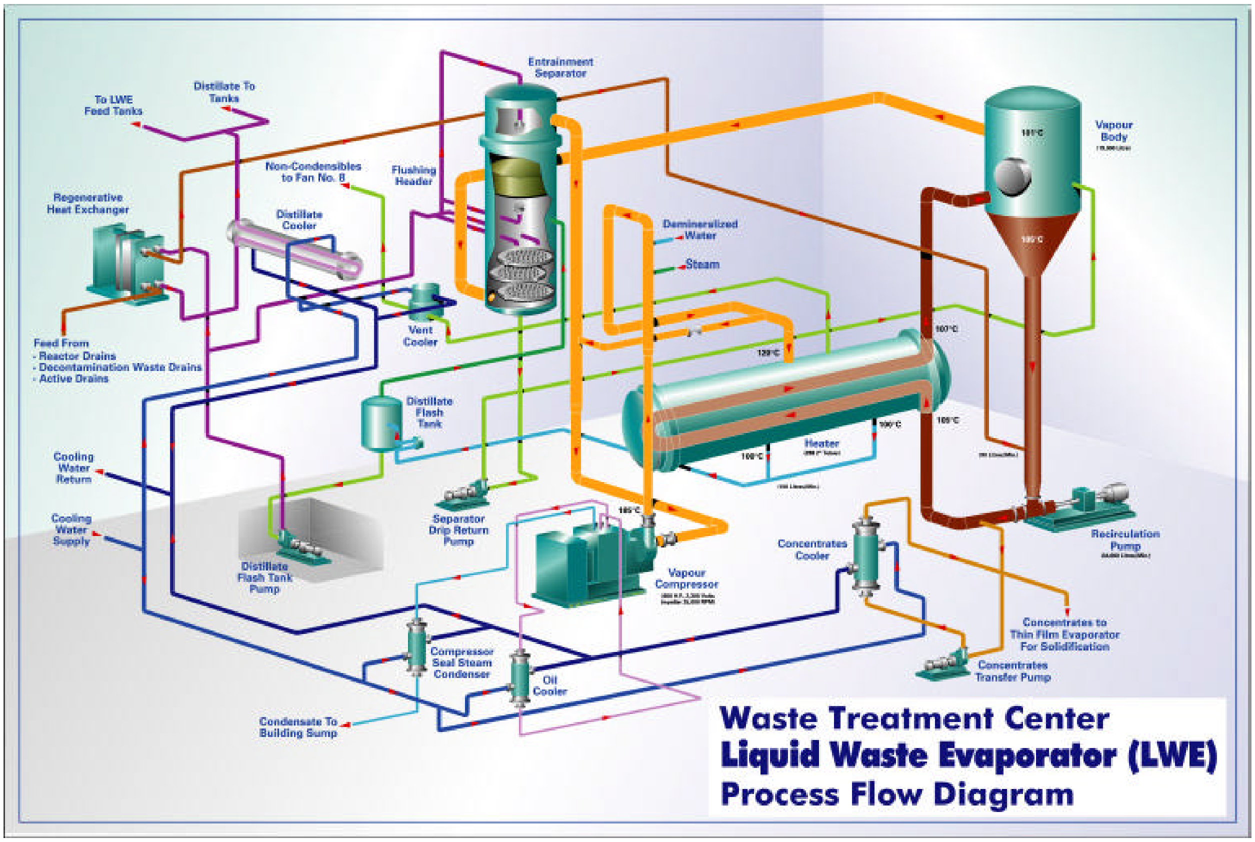

**Figure 1. WTC Liquid Waste Evaporator Process Flow Diagram**

The fundamental design concept for the upgraded WTC is to process the waste streams using evaporation, to solidify the concentrates, and to discharge the purified effluent into the Ottawa River following verification monitoring. The upgraded Facility includes modifications to improve the processing technology and increase the throughput capacity sufficiently that the low-level active liquid wastes at CRL can be treated reliably.

Operation of the upgraded Facility also enables treatment of liquid wastes currently stored in tanks at CRL and the treatment of waste from future projects such as decommissioning projects.

The forced circulation type LWE installed was developed to treat such waste streams, and specifically, to overcome problems such as fouling and corrosion encountered in earlier evaporator designs. With LWE in operation, the old MF/RO system is used as a backup to further increase the overall processing reliability. The MF/RO technology is proven technology that is widely used in industry and has been used in the WTC for many years.

Contaminants removed from the wastewater are solidified using a binding material, placed in drums, and stored in the Waste Management Areas (WMA) at CRL.

## 2. LWE SYSTEM OVERVIEW

The process equipment within the LWE can be roughly grouped into the following systems based on their functions:

- Liquid Waste Storage and Transfer System,
- Receiving, Preconditioning and Feeding System,
- Liquid Waste Evaporation System,
- Discharge and Monitoring System, and
- Solidification Feed System.

The Liquid Waste Storage and Transfer System stores waste streams. The liquid waste is transferred from the storage buildings to the WTC Evaporator Feed Tanks through a filtration system and coaxial underground lines.

The operation of this system involves operations of waste storage and transfer loops and two receiving tanks. The control philosophy for this system is to transfer the waste streams in the required ratio to optimize the batch processing capabilities.

The receiving tanks receive the liquid wastes to be processed in the LWE system. The feed flow into the tanks is monitored and totalized. Either tank can be selected via the operator console for receiving (filling), sampling, and pH adjusting, or for feeding to the LWE.

The feed line to the LWE system is connected to the LWE feed flow control valve. The feed rate to LWE is normally around 90 L/min.

The LWE system is a forced-circulation evaporator with the mechanical vapour compressor (Compressor) and was designed to concentrate liquid wastes up to 20%wt salts concentration. The LWE System (Figure 1) consists of the following main components:

1. vapour body,
2. main heater (Figure 2),
3. recirculation pump,
4. Entrainment separator (Figure 3) and the drip return pump,
5. mechanical vapour compressor,
6. distillate flash tank and pump,
7. regenerative heat exchanger,
8. distillate cooler,
9. concentrate cooler and the Batchout Pump, and
10. associated instrumentation, piping, and valves.

Figure 2.  Main Heat Exchanger

Figure 3.  LWE Entrainment Separator

The Discharge and Monitoring System consists of the following:

1. two existing Discharge Monitoring Tanks (DMT), and
2. associated pumps, instrumentation, piping, and valves.

The cooled distillate from the LWE system is transferred to the DMTs at the rate of 7.4 $m^3$/hr (33 USGPM). The DMTs are made of FRP, and therefore, it is essential to cool down the distillate below 65°C (150°F).

Grab samples are taken manually from the DMT recirculation loops. These samples are analyzed to confirm compliance to discharge limits. If the limits are not exceeded, the distillate is discharge to the Ottawa River via the CRL process sewer.

The heat source in the LWE is produced by a mechanical vapour recompressor (Figure 4). The compressor adds energy to the vapour by increasing its pressure before it is discharged to the main heater shell. This energy increase is used as a heat source to drive the evaporation process. All compressors have a tendency to raise the vapour temperature above the saturation temperature. This is due to the mechanical inefficiencies inherent in the compression process. This temperature increase is unwanted. It is the increase in pressure that is used to drive the evaporation process. As superheated steam can lead to localized boiling in the heater leading to physical erosion to the heat transfer surfaces, a desuperheater was added.

**Figure 4. LWE Vapour Compressor**

Since the act of boiling is generally violent at the surface, some liquid solution may be carried over with the water vapour. This unevaporated solution is called entrained solution or entrainment, and is considered a physical entrainment process. The entrained contaminants are further polished using an entrainment separator.

The LWE also includes a regenerative heat exchanger to preheat the feed to the vapour body and to subcool the evaporator distillate. The LWE uses a concentrate cooler to cool the concentrated waste during the batchout mode to prevent stress corrosion cracking in the stainless steel concentrated waste components.

Three Batch Storage Tanks (BST), as well as the two Concentrate Batch Tanks (CBT), serve as storage for the concentrate received from the LWE. The contents of the two CBTs can be fed to the solidification system. The batchout can be gravity fed or provided by pumping.

A Distillate Subcooler receives distillate from the LWE and cools this stream during normal operation using chilled water.

The source of water for the Distillate Subcooler is chilled water from a WTC Chilled Water System. The chiller package supplies the cooling needs for the Distillate Subcooler, as well as all the LWE cooling water.

## 3. MAJOR COMPONENT SUMMARY

### 3.1 LWE Vapour Body

Diameter - 8 feet
Straight Side - 8 feet
Materials of Construction - SB-443 Inconel 625
ASME Section VIII Code Stamped

### 3.2 Main Heater Exchanger

Overall length - 19 ft 10 inches
Diameter - 4 feet 5 ¼ inches
Tubesheet Face to Face Distance - 14 feet
Tubes - 298 x 2 inch x 16 BWG
Tube Surface Area - 2040 square feet in 2 passes
Shell Material - SA-240 Tp 316L
Tubes - ASTM SB-516 Inconel
Tubesheet - SB-443 Inconel
ASME Section VIII Code Stamped

### 3.3 Recirculation Pump

Type - 20-inch horizontal axial flow on spring-mounted base
Flow - 11000 USgpm at 14 feet TDH
Material - Alloy 20
split seal

### 3.4 Entrainment Separator

Diameter - 4 feet Internal
Overall Height - 14 feet 4 ½ inches
Material - SA 240 316L
Number of Entrainment Trays - 3

### 3.5 Mechanical Vapour Compressor

Single Stage Centrifugal
Lube Oil System - Self-contained shaft driven main pump, and electric auxiliary pump
Inlet Pressure - 0 psig
Outlet Pressure - up to 14.3 psig
Flow - up to 8000 standard cubic feet per minute
Speed - 21000 rpm
Adjustability - Inlet guide vanes

## 4. OPERATING EXPERIENCE

### 4.1 Feed Streams

Before the evaporator can process the liquid waste streams, the following restrictions must be imposed on the feed streams:

1. The feed cannot contain ion exchange resin beads or fines. At the evaporator operating temperature (100°C), the resin will decompose releasing organics, amines and other volatile and non-volatile materials. The organics will foul the heat exchanger tubes, can cause excessive foaming in the vapour body and are usually volatile resulting in poor quality distillate. Amines are also volatile and will lead to poor quality distillate.

2. The LWE System does not have an ammonia scrubber, therefore, the ammonium content in the feed cannot exceed 1000 ppm. During evaporation, ammonia could be released in the vapour causing the pH to drop in the liquid (ammonia could be suppressed if the evaporator liquid feed is slightly acidic). The low pH, combined with high chlorides and boiling temperatures, will cause pitting and corrosion of the evaporator equipment including equipment fabricated from Inconel.

## 4.2 Main Heat Exchanger

Vapour from the compressor discharge enters the heater and delivers the energy on the shell side. This steam passes over tubes that contain the liquid waste. The vapour condenses as it passes over the tubes. The amount of energy to condense the vapour in the heater to a liquid distillate is transferred as heat is added to the tubes. The tubes heat the liquid waste that passes through the tubes and this ultimately drives the evaporation process in the vapour body.

The rate at which the latent heat of vapourization is delivered though the tube wall is governed by the equation:

$$Q = U \times A \times \Delta T.$$

Where: Q = the BTU's per hour to cause evaporation from the compressor's vapour
A = the tube area
?T is the logarithmic mean temperature differential from the four temperature nodes into and out of the heater:

$$\Delta T = \frac{T_{liq\_out} - T_{liq\_in}}{Ln\left(\frac{T_{satd\_steam} - T_{liq\_in}}{T_{satd\_steam} - T_{liq\_out}}\right)}$$

If ? T continues to rise over time, this would indicate problems developing inside the heater.

Three factors can contribute to heater problems in transferring the heat required for evaporation.

1. A material buildup on the tubes, known as fouling, can diminish the heat transfer capability notably.
2. A buildup of non-condensable gas such as air in the heater will reduce heat transfer since any air does not condense on the tubes and transfer energy as is done with water vapour.
3. Condensate flooding in the heater can reduce the tube area available for heat transfer of the incoming vapour. This will cause the vapour compressor to pressurize to compensate for the lost area and ? T will subsequently rise.

Close monitoring of the heat coefficient has helped early detection of heat transfer degradation. So far, the WTC has only experienced material buildup on the tubes. On-line acid flush has been sufficient to return the coefficient to a normal value.

## 4.3 Heating

The maximum time required to restart the vapour compressor from a cold condition is 8 hours. During this time it is important to ensure that all the piping is heated properly. The piping on the concentrate loop heats up quite quickly and it is very important to make sure that all the piping on the vapour side is heated as well. If the piping on the vapour side is not heated sufficiently, the vapour could condense before reaching the suction of the Vapour Compressor. Water droplets hitting the blade can cause catastrophic damage to the Vapour Compressor.

When the vapour compressor is first started, the Vapour Compressor Surge Curve is closely monitored to prevent any surge.

### 4.4 Distillate Quality

During the transition phase, and until the reflux flow to the entrainment separator is set to the proper position, it is important to direct the distillate flow back to the feed tanks. Since the distillate produced during this period is not always of high quality, it could contaminate the distillate tanks. Full recirculation (distillate is sent back to the feed tanks) should continue for the first hour of Steady-State Operation to flush the distillate piping and allow the Distillate Flash Tank to completely pump out several times. This will assist in producing the highest quality distillate possible.

Foaming creates a situation where carry over of contaminants to the Entrainment Separator is possible causing poor distillate quality. Foaming can cause a problem with the operation of the Entrainment Separator as well. Foam comes down to the suction of the Separator Drip Return Pump. Since the suction pressure of the pump is lower from the foam in the line, the pump flow slows down and cannot keep up with the drips. This can cause flooding of the Entrainment Separator.

### 4.5 Batchout

Problems removing the total solids and suspended solids from the Vapour Body concentrate loop have been experienced. The solids have to remain entrained in solution and not allowed to settle out in order to remove the solids from the concentrate loop. The recirculation pump has to be used as long as possible to keep the solid entrained.

More frequent partial batchouts are now performed to improve solid removal and full batchouts are scheduled periodically.

### 4.6 Troubleshooting Tools

Historical data trends can be brought up on the Human Machine Interface (HMI). Data trending is a major asset when attempting to optimize the operation of the LWE, when troubleshooting to determine the cause of an unexpected shutdown, and during routine operation to more closely monitor the process.

Some standard trend forms were developed for various activities performed such as batchouts.

## 4.7 Instrumentation

The vapour body level is controlled by performing an over mass balance. A slight instrument drift can cause a malfunction of the overall balance. It is crucial to have reliable and repeatable instruments under a good preventive maintenance program.

Foaming causes inaccurate vapour body level readings. Foaming will give a false low-level reading, as the foam will decrease the specific gravity of the vapour body concentrate. The foam can easily cause an LWE automatic shutdown.

Since the liquid entering the Distillate Flash Tank flashes to release energy and cool the liquid further, the level in the tank leaps with the flashing. This causes peaks in the distillate flow rate that in turn causes peaks in the feed flow rate. A vent line leading back to the Entrainment Separator helps to reduce the magnitude of the pulses in the tanks level. This works as a dampening factor to smooth out the flow rates.

## 4.8 Chemistry Control

Chemistry control of the concentrates in the vapour body is of utmost importance. The pH and chloride concentrations can cause corrosion, stress corrosion cracking or pitting of the Inconel 625 in the LWE vessels and piping. The total solids and suspended solids concentrations can cause scaling and fouling of the components in the concentrate loop and increased radiation fields.

### 4.8.1 pH Adjustment

Adjustments to pH of the waste in the feed tanks are performed with nitric acid and/or sodium hydroxide using the chemical addition skid. Although the pH of the feed is recommended to be above 8.5 (when chlorides are present) to prevent stress corrosion cracking and pitting of the LWE vessels and piping, operating experience has shown that the pH in the LWE concentrate loop increases as it gets more concentrated. Also, higher pH values promote precipitation of solids. It is not recommended that the LWE concentrate be allowed to exceed a pH of 9. This helps prevent fouling and scaling of the components in the concentrate loop.

### 4.8.2 Chloride Concentration

The chloride concentration should not exceed 8000 mg/L. If chloride concentrations are kept low, the pH in the concentrate loop can go as low as 6 without fear of stress corrosion cracking. However, as the chloride concentration in the concentrate loop increases, stress corrosion cracking and pitting of the LWE vessels and piping becomes a valid concern.

Chloride concentration concerns are such an important matter that the chloride concentration on its own could be the cause of an early Vapour Body batchout. Concentrations are measured after each run.

### 4.8.3 Total Solids and Suspended Solids

The maximum total solids (TS) design limit in the LWE concentrate loop is 200 g/L or 20 wt%. The absolute maximum suspended solids (SS) limit is 17 g/L or 1.7 wt%. If either value is reached, it is recommended to batch the concentrate out of the Vapour Body. However, the TS concentration is never expected to exceed 80 g/L. During normal operation, once the concentrate reaches 30 to 40 g/L TS, a small volume Vapour Body batchout will most likely take place. This approach has been allowed to reduce the overall radiation field and improved equipment maintainability.

During batchout of the Vapour Body, the recirculation pump is run for as long as possible during the batchout. Operating experience during batchout has shown that the recirculation pump trips out on high vibration once the vapour body level reaches 26%. Once the pump is shutdown, the solids tend to settle quickly and a large portion of the solids is left in the concentrate loop after batchout.

### 4.8.4 Phosphate

Unusual problems have been encountered during processing of the some of the waste. On two occasions, it caused severe fouling in the regenerative heat exchanger that an intervention was needed during the run to add acid to clean the process system on-line. Following batchout, the total solid in the LWE concentrate could be increased rapidly.

It appears that the phosphate in both the feed and the LWE concentrate caused fouling, poor heat transfer and high total solid.

### 4.8.5 Reliability

Analysis was performed to identify critical components of the LWE system, such as main heat exchanger tube plugging or change out, Entrainment Separator mesh pad and bubble tray assembly change out, etc. Spare parts were purchased as required and maintenance requirements reviewed.

Efficiency of the Entrainment Separator must be checked regularly by obtaining grab samples.

To discover any further problems with the mechanical seal, the Pump Seal Cooler is sampled for contamination periodically.

During routine sampling, if contamination is found in the chilled water system, all the heat exchangers should be tested individually to determine the source of the contamination.

The Chilled Water system could become contaminated with oil if a leak is present in the Chiller Compressor or the Oil Cooler on the Vapour Compressor. Tests are to be done to determine the source if water is found to be contaminated by oil from either of these sources.

## 4.9 Design Issues

The design of an instrument rack, with respect to the possible backflow of the Vapour Body concentrate to main heat exchanger, could lead to the waste in the Vapour Body to empty through the instrument rack if a valve or flowmeter has sprung a leak. The system is isolated when not in service to prevent backflow.

The installation and position of the pH probes were found inadequate. The probes were not kept wet at all time and were not all flushed adequately which results in a false reading.

The mechanical seal on the recirculation pump needs to be replaced regularly.

## 4.10 Maintenance Issues

The pH probes require frequent calibration and maintenance to maximize the accuracy and life of the probes.

A procedure for changing the mechanical seal is required and has been implemented successfully.

# 5. OVERALL PERFORMANCE

The liquid waste evaporator (LWE) is capable of processing 30 USGPM (6.8 m3/hr) when operating with the use of the mechanical vapour compressor.

LWE system operation continued to meet or exceed the design requirement for a system Decontamination Factor (feed-to-distillate ratio) of 125. The decline in the last three-year trend can be attributed to the more frequent sample results at the detection limit artificially causing a Decontamination Factor decrease.

**Table 1. LWE Decontamination Factors**

| | **Feed Activity** | | **Distillate Activity** | | **DF (feed/distillate)** | |
|---|---|---|---|---|---|---|
| | **Alpha (Bq)** | **Beta-Gamma (Bq)** | **Alpha (Bq)** | **Beta-Gamma (Bq)** | **Alpha** | **Beta-Gamma** |
| 2002 | 5.13 E09 | 3.52 E12 | 2.09 E07 | 3.36 E08 | 245 | 10 476 |
| 2003 | 3.25 E10 | 6.22 E12 | 5.18 E07 | 7.34 E08 | 627 | 8 474 |
| 2004 | 7.57 E08 | 5.02 E11 | 1.15 E07 | 1.20 E08 | 66 | 4 183 |

### Table 2. Liquid Waste Treatment Operations

| Liquid Waste Treatment Operation | Volume Of Waste | | |
|---|---|---|---|
| | 2002 | 2003 | 2004 |
| Total Liquid Waste Available to Process ($m^3$) | 3 059 | 4 179 | 3 827 |
| Number of Product Drums Produced | 35 | 38 | 40 |

A strong chemical analysis support and well implemented maintenance program has contributed to the reliability of the system.

## 6. REFERENCES

[1] L.W. Thomson, "LWE Commissioning Report", AECL WTC-01410-l-CMQA Rev 0, 2001 October.

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[3] F. Farinoso, "Liquid Waste Evaporator Design Manual", 2000 October.