Treatment of Radioactive Liquid Waste by the Forced-Air Exhaust System - 15190

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ABSTRACT

A Natural Evaporation Facility (NEF) was constructed to treat low level (LL) radioactive liquid waste arising from a Radioactive Waste Treatment Facility (RWTF) at the Korea Atomic Energy Research Institute (KAERI). In order to process LL radioactive liquid waste, we investigated the influence of climate condition, mainly atmospheric humidity and temperature, on the amount of evaporation in a forced-air exhaust system in KAERI.

Evaporation media were made of cotton and polyester. Air exhaust in the facility was forced by exhaust fans. The evaporation rate and the decontamination factor were calculated and reported as shown in the results section. The evaporation and air supply flow increased at the same rate. In addition, the liquid waste feed rate and temperature of supplied air increased. Regarding the relative humidity of supplied air, the evaporation rate increased as the relative humidity decreased.

As the result of this study, the operating conditions for the NEF were optimized in the following areas: The air temperature above 8℃, the air relative humidity below 70%, the air flow rate 1.14-1.47 m/sec, and the liquid waste feed rate 4.6 ℓ/hr.m^2. The decontamination factor was 1.1×10^3.

INTRODUCTION

With the growth of the nuclear energy industry, there is a great quantity of low level radioactive liquid waste generated, not only in the nuclear power plant but also in the nuclear fuel cycle, hospitals, research institutes, etc. Therefore, its impact on the environment grows and interest in this phenomenon is also growing.

The original characteristics of radioactive liquid waste must be treated to be safe so as not to affect environmental pollution. Until now low level radioactive liquid waste has primarily been treated to reduce the volume using the ion exchange and the evaporation method. However, the ion exchange method has some problems with producing a lot of resin and having a short life time. The evaporation method has proven superior in controlling decontamination. However, its energy consumption is great and the volume reduction is limited. To present an efficient evaporation method in this study we constructed a Natural Evaporation Facility (NEF). Synthetic textile was used as an evaporation medium with a forced air circulation system that brought air from the outside.

Research on the natural evaporation has been conducted domestically and abroad.
Porous material in the ceramic system was used to facilitate the evaporation of radioactive liquid waste in India[1]. Non-conventional energy sources was used in New Deli, especially to increase the production of dry corn[2].

Aluminum hydro oxide in a solar pond was used in Austria to treat radiation liquid waste[3]. In El-Minia, Egypt, solar heat was used to increase the temperature of liquid to facilitate evaporation[4]. Domestic research into the nature of evaporation at the Resource Research Institute developed a drying system which utilizes solar heat more effectively[5]. A thermal coefficient interpretation of the solar pond was applied, producing a material that enhanced the performance of solar heat used in households.

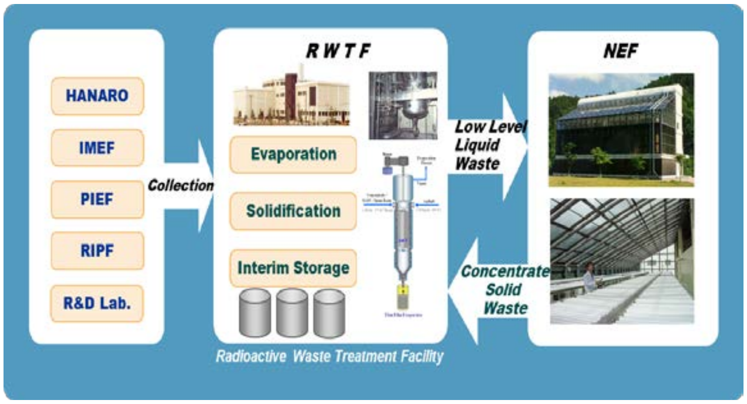


Fig. 1. No discharge of radioactive liquid waste in KAERI

As KAERI has a principle of ‘zero release,’ which does not allow any discharge of radioactive liquid waste into environment. Liquid waste was collected from the HANARO Research Reactor, Radioisotope Product Facility (RIPF), Irradiated Material Examination Facility (IMEF) and Post Irradiation Examination Facility (PIEF) through underground pipe lines and from the R&D laboratories by directly carrying to the RWTF (Figure.1).

The KAERI facility has a forced air exhaust system, evaporation type, which has a vertical array of cloth for an evaporation bank. In this system, Low level radioactive liquid waste flows down the vertical array for a total area of 11,250 m^2. The intake of outdoor air through the air filter rises causing air to flow into the bottom of the vertical array via exhaust fans at and top of the facility contacting with a liquid stream counter currently and discharged to the outdoor.

In this experiment, we investigated the influence of climate condition (mainly atmospheric humidity and temperature) on the amount of evaporation in NEF. We attempted to determine the range of atmospheric condition through the regional atmospheric data for optimum operation of the facility. In addition, we compared an experimental equation applied in the facility design with our experimental equation obtained through the actual operation. The consistency between the designed capacity and the actual possible capacity of the facility has been examined.

The Empirical Formula of Mass Transfer

The factors which influenced the evaporation rate were intact air temperature, relative humidity, air flow rate, liquid flow rate and liquid temperature, and so on. To investigate the influence of each factor on evaporation rate, we operated NEF, changing one factor while the other factors were fixed. The same procedure was done for other factors. An investigation of the significance of these factors would real the most important factors and help in determining the operating range of conditions and the factors responsible for the most effective evaporation.

Intake air humidity and temperature depend on the weather condition. However, intact air flow and liquid flow rates are controllable. Therefore, under the various weather conditions during a long period of time, i.e. one year, we varied the air flow and liquid flow rates, and collected these experimental data. Air flow rate can be controlled by the limitation of a number of factors operating the fan, which is located on the exit trough.

Dalton’s equation applied to the calculation of annual treatment capacity is as following :

Eh = f(v) (Hw-Ha), where Hw was the saturation vapor pressure temperature on the evaporation surface; Ha was the actual vapor pressure; Eh was the actual amount of evaporation; and f(v) was the function of air velocity, generally expressed as f(v) = a +bv (a,b : constant).

We determined the following equation, based on several factors to apply Dalton's equation to the calculation of the actual amount of evaporation. Eh = (0.0178 + 0.0152v) x (Hw-Ha)

We obtained Hw, Ha from the air temperature and relative humidity, and calculated a,b from Hw, Ha and the amount of evaporation. We then compared Dalton's equation with our experimental equation, and estimated the possible annual treatment needed using our experimental equation.

Material and Methods

NEF constructed with concrete had four floors above ground and one underground. The total area was 1,100 m^2.[6] The wall of the second and third floors and the roof were made of glass so as to effectively receive the solar energy. There was a Low level radioactive liquid waste storage pool in the basement having a capacity of 860 m^3. The first floor consisted of a drying room to dry sludge and operated as a pump room. The evaporation zone was located between the second floor and third floors, in the evaporation zone, having 1032 cloth sheets 1 m × 5.4 m. These were vertically arrayed.

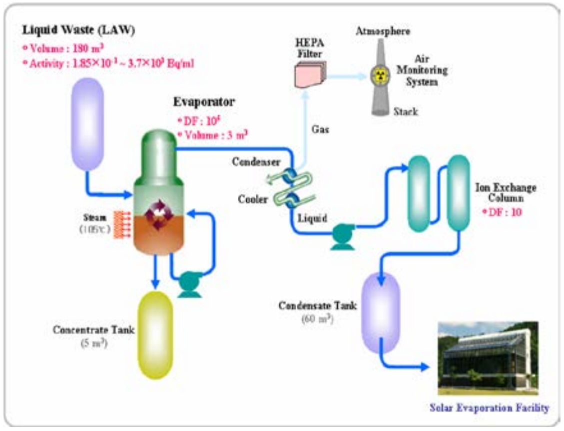
Ten exhaust fans (20 HP each) was equipped on the fourth floor. Low level radioactive liquid waste was pumped up from the underground storage pool to the buffer tank on the first floor by a make-up pump (3HP, 15m^3/hr). The circulation pump (15HP, 120m^3/hr) supplied the low level radioactive liquid waste arising from the Radioactive Waste Treatment Facility (RWTF), which was mainly condensate water from the evaporation process. To remove the impurities in the circulation liquid a 50 μm filtration cartridge type was used.

The evaporator of KAERI was a semi-batched forced circulation type and had a capacity of 1.0 m^3/hr and a decontamination factor of 100,000. The heating source for the evaporator was steam. The vapor generated from the evaporator became water through the condenser and cooler. This water was stored in a condensate tank, and finally, transported to the natural evaporation facility by tank truck (Figure.2).

Low level radioactive liquid waste, if it is judged to be suitable for the natural evaporation process through the chemical analysis and radiation measurement etc. was transferred to an underground storage pool of NEF by the transport truck with the 7m^3 liquid container. Low level radioactive liquid waste in the underground storage pool was pumped to the buffer tank and the circulation pump supplied the liquid waste to the trough. The liquid waste in the trough gravitationally flowed down to the evaporation zone. The cartridge filter on the line of circulation was used to remove the impurities.

The outdoor air introduced to the bottom of the evaporation zone through the air filter flowed up to the top contacted a liquid stream counter by suction fan at the top of NEF (Fig. 3).

The experiment applied the aforementioned theory to the vertical evaporation surface. A forced-air exhaust system produced a mass transfer of liquid at the Natural Evaporation Facility. The experiment used a direct, low level radioactive liquid waste. Experimental devices were installed for the rectangular evaporation media cloth, 1m wide × 5.4m long. A circulation pump and liquid cartridge filter were also installed.



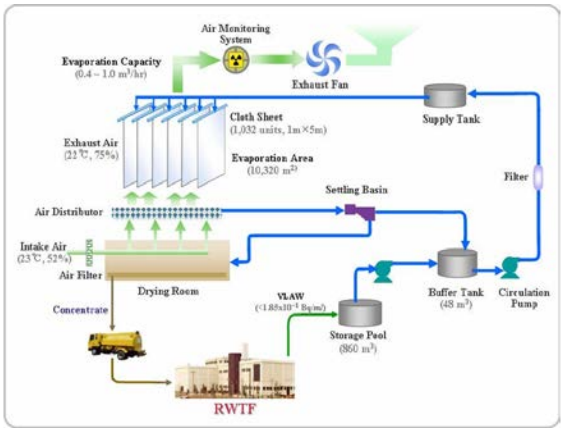


Fig. 2. Diagram of Evaporator Process

Fig. 3. Evaporation Flow Diagram of NEF

Cs-137 and Co-60 radioactivity of air flow were measured from an external cooling device. In addition, an air filter was installed to monitor the filtration intake air.
The following variables were examined: Air humidity from inflow, evaporation area, humidity, evaporation cloth using the interval of cloth distance, and current air speed. An attempt was made to deduce the optimal evaporation rate and manipulate the decontamination growth factor. Radioactive storage was collected from the radioactive liquid waste, with a radioactivity of Cs-137, 4×10^6 Bq/m^3 after being completely absorb by the cloth in the evaporation media. This process was operated by the pump and air blower fan.

Evaporation occurred on the surface of the evaporation zone was due to the difference between saturation vapor pressure of the liquid and vapor pressure of the air.

Liquid waste flowing down from the evaporation zone was recycled into the buffer tank continuously. When the system reached a steady state in the store tank water level, inflow temperature-humidity discharge was measured at a scheduled time interval using the air velocity cloth module.

A circulation pump fed the liquid waste to the nozzle which sprayed the waste onto the upper portion of an evaporation media cloth (rectangular form, width 1m a length 5.4m) by distributing the nozzle, which was located in the upper part of the evaporation device. The liquid waste formed a thin film on the cloth surface and flowed down from top to bottom. At this time evaporation happened in the exhaust fan due to the current air flow.

The water level recorder in the storage tank measured the evaporation rate for the experiment. This assessment examined the humidity change of air inflow, according to the flux change cloth interval of the liquid feed rate and air feed of current change which was supplied to the cloth. To find the evaporation rate per hour the temperature and humidity of the discharge was examined for 24 hours using natural evaporation equipment.

The evaporation rate was assessed using the low level radioactive liquid waste evaporation volume from the level indicator in the store tank. The decontamination factor was also measured. The flux of the feed rate was controlled by the valve. The air inflow went through the evaporation device and monitored the temperature and humidity. The air current, which passed between the cloth, was controlled by the air blower. The air flow followed the cloth with the liquid waste producing an evaporation latent heat in the liquid. A cloth utility material with an evaporation surface was made of a synthetic textile made of cotton (35%) and polyester (65%) which is widely used. To induce solar energy more efficiently, the wall between the second and third was made of glass. A central control room was used to maximize control of the machinery and tools.

To examine the degree of exhausted air in the environment effected by the evaporation a radiation material from an evaporation surface was released into the air with the exhaust air.
A multi-channel analysis was applied to measure the radioactivity for estimation of the decontamination factor and to monitor the discharged air.

The treatment capacity of the facility was 1,200 m^3/yr, and the final concentrated liquid volume was 20m^3. This concentrated liquid was returned to RWTF for further treatment. After this long process, some solid particles could be found in the recycling liquid buffer tank. These particles may be dust normally found in the introduced air. The particles in the liquid could be settled in the precipitation area located on the first floor during the circulation of the liquid waste, dried in the drying room forming cake, collected as solid waste, and transported to the RWTF.

Results and Discussion

The evaporation rate of radioactive liquid waste by a forced-air exhaust system was primarily influenced by natural and engineering variables. The natural variables were the temperature of the air and air humidity. The engineering variables were the interval and length of the evaporation media and the liquid waste supply flux. These were located inside the system's air speed distribution and in the dead space.

One of the most important variables which had an influence on the evaporation rate on the dependent measures was relative humidity. Air speed and temperature of waste feed rate were fixed. As the relative humidity increased from 40% to 80%, the evaporation rate was rapidly reduced (Fig. 4). In addition, the evaporation did not occur in relative humidity in excess of 80%.

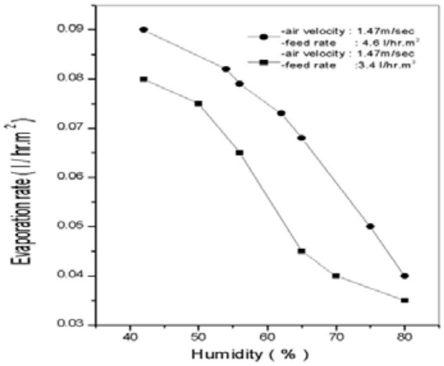


Fig. 4. Effect of Humidity on Evaporation Rate

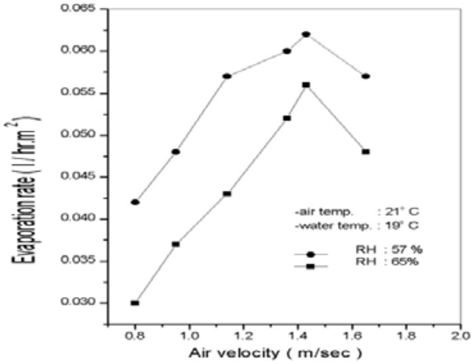


Fig. 5. Effect of Air Velocity on Evaporation Rate

When the air speed was 1.47 m/sec evaporation was maximized, however, the correlation of the evaporation rate and the air speed was not completely linear. As air speed increased, so did the evaporation rate. However, the evaporation rate was reduced when the air speed increased. The air speed increased the evaporation rate; however, it decreased when the air speed increased. The clothes attached to each other reduced the evaporation area and decreased the evaporation rate (Fig.5). Over a 24 hour operation period, the results showed an hourly evaporation rate change, as shown in Fig.6. Dae jeon province's (Korea) monthly mean evaporation rate changed according to the change in temperature and humidity at the natural evaporation facility in May. Liquid waste was examined. The evaporation rate changed as the humidity changed from air inflow. Evaporation did not occur at all after sunset.

Evaporation began at 10:00 a.m. Maximum evaporation occurred between 1:00 and 4:00 p.m.
The evaporation equation of Dalton's -type equation was as follows: Eh = (0.0178 + 0.0152V) x (Hw – Ha).

The comparison of Dalton's equation 'A' with our experimental equation 'B' is shown is Fig.7. Air flow rate was 0.8, 1.14, 1.82 m/sec. As a result of plotting the normalized evaporation rate (Eh / ΔH) versus Air velocity (V), Eh/ΔH showed up-and-down distribution at each air flow rate.
The difference caused by the amount of evaporation between A and B was the effect of solar heat, which was considered in the design of the facility was insignificant. Actual evaporation area was decreased due to channeling.

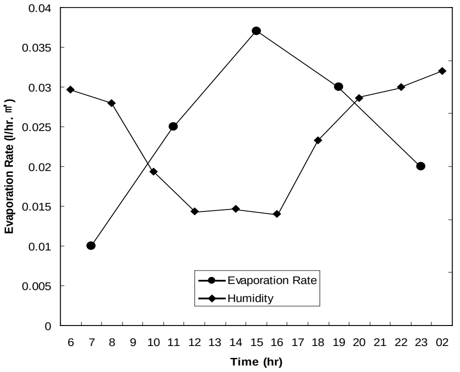


Fig. 6. Transition of Evaporation Rate for 24 Hours

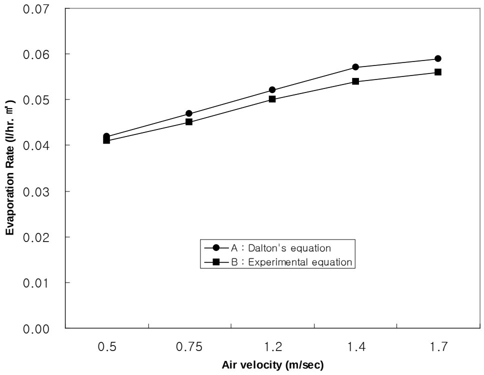


Fig. 7. Effect of Velocity on Normalized Evaporation Rate

The possible annual amount of treatment can be calculated with our experimental equation, substituting air velocity (V) for 1.82 m/sec in the maximum valve, on the assumption that this facility is operated from March to October. After inserting the average Hw and Ha for each month to equation the amount of evaporation per unit area and unit time can be calculated. Then multiplying this amount of evaporation by the total evaporation area, total evaporating time can be calculated.

A forced-air exhaust system which treats liquid waste was used so that the environment would not be polluted with radioactive material.

The decontamination factor and radioactive air discharged variables experienced a change in evaporation. In addition temperature and liquid waste flux were altered due to humidity and a change in air velocity. Throughout the experiment radioactivity was treated 4×10^6 Bq/m^3 and the decontamination factor was 1.1×10^3. The radioactivity of Cs-137 air out flow was 4.7×10^3 Bq/m^3.

DF = Ca / Cb

Ca : radioactivity of feed liquid, Cb : radioactivity of condensate

Optimized Evaporation Condition

The optimum evaporation work range on the humidity chart was determined by the condition of the air. The optimized evaporation of liquid waste was the flux and temperature 3.4 ℓ/hr.m^2, over 10°C and 1.14 ~ 1.47 m/sec. A maximum evaporation condition existed in the flux of liquid waste 4.6 ℓ/hr and air speed 1.47 m/sec.

CONCLUSIONS

The evaporation rate was the difference between air speed and vapor pressure. The difference in vapor pressure confirmed the relationship between air humidity with the liquid temperature. This study showed that the evaporation rate can be increased. When humidity of air inflow is low, the speed of the air, temperature, and flux of the liquid waste increased.

Optimal work conditions were determined while considering weather condition and evaporation processing capacity as 70% less than the humidity of air inflow. Optimized evaporation conditions for flux and temperature of a supply liquid waste were 3.4 ℓ/hr.m^2, over 10℃ and 1.14 ~ 1.47 m/sec. A maximum evaporation condition of the flux of a supply liquid waste was 4.6 ℓ/hr and air speed of 1.47 m/sec.
As a result of the radioactivity from the discharged air that went through the stack the decontamination factor became the standard at 1.1×10^3. The radioactivity of the air released was Cs-137, air out flow was 4.7×10^3 Bq/m^3.

As a result of experiments, effective operating condition was above 5℃ of relative humidity. In addition, we applied an experimental equation, applying the amount of evaporation, air flow rate, and vapor pressure to Dalton’s type equation. Bored are the calculated annual amount of treatment using the experimental equation which considered the atmospheric condition from March to October, it was deemed possible to treat only about 1,200 m^3/yr.

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