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<Orginal> Treatment and Disposal of Low-level Radioactive Sludges by Solar Evaporation

Sang Hoon Lee

Reactor Engineering Division, Atomic Energy Research Institute, Seoul, Korea

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Abstract

In this investigation, a solar evaporation method was studied to reduce the water content of the radioactive sludge produced from the clay adsorption liquid waste treatment.

The solar method to form sludge cake from sludge slurry could economically reduce the sludge volume and the operation cost of minimum 8% could be curtailed.

요 약

放射性 廢液處理에서 나오는 放射性 Sludge의 Solar energy에 依한 固化 處理方法은 가장 效果的이고 經濟的인 處理方法의 하나이다. 本硏究를 通해서 Sludge의 固化處理는 3月부터 8月사이가 가장 適正期이고, 또 Mass-transfer 方法에 依해 蒸發量 推定에 對한 實驗式을 誘導하였다.

1. Introduction

For the purpose of the treatment of its low-level radioactive effluent (gross β-activity; $10^{-4}-10^{-6}$ μCi/ml), Atomic Energy Research Institute has the three stage radioactive liquid waste treatment plant reached to the optimum conditions of operation as follows[1].

In the disposal problems of the radioactive sludge and the practical liquid waste treatment, the optimum operation of this plant was fixed up the flow rate as 2 liters per minute for feed solution containing 2% dosage of clay.

The plant has the treatment capacity of 14,400 liters per month when operation is allowed in the 6 hours a day. Radioactive sludge which is generally bulky and required volume reduction before final disposal produced 0.3 ton per month.

There are many techniques to pretreatment of radioactive sludge produced by low-level radioactive liqud waste treatment, not only freezing and thawing method but also solar evaporation method which is the safe and economical method of radioactive sludge concentration.

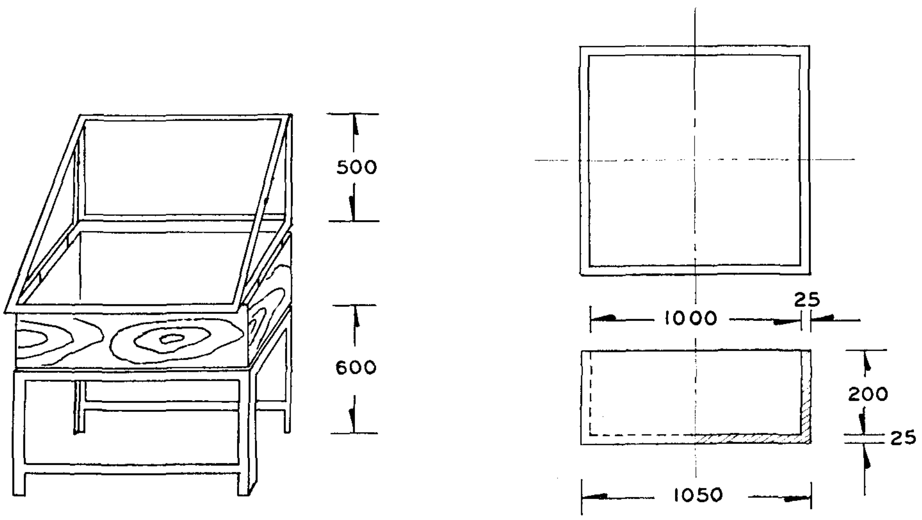

Fig. 1. Sludge evaporation pan

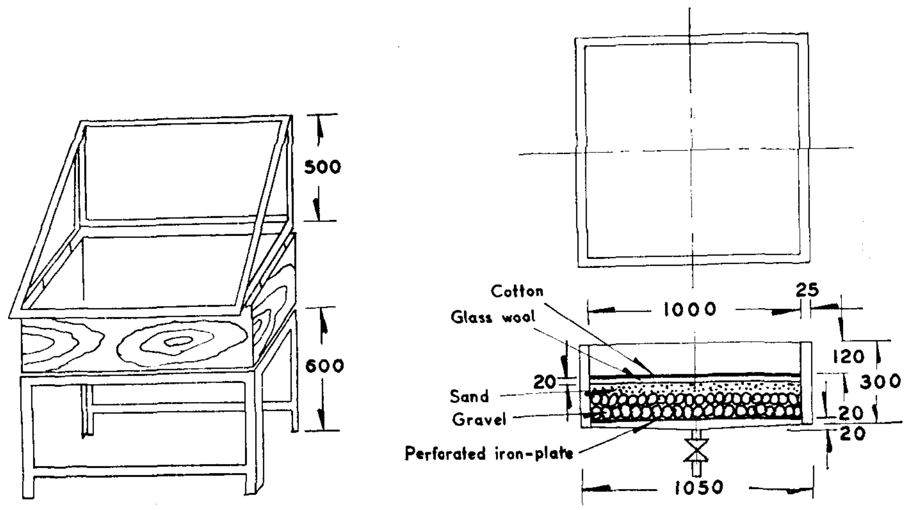

Fig. 2. Sludge evaporation pan with filtering bed

This investigation is covered with the problems of measuring evaporation rate and determining the optimum condition of sludge evaporation rate through the year, and also briefly evaluated economical problems for solar evaporation treatment techniques from the point of view of radioactive waste management.

2. Design and Installation

In order to determine a evaporation rate in the vicinity of the radioactive liquid waste treatment plant, the design of the devices for this study is based on Measurement and Estimation of Evaporation and Evapotrans piration[2], and installed as the following:

(a) Sludge evaporation pan, (S. E. P.) and sludge evaporation pan with filtering bed (S. E. P. F. B.).

Two small experimental units are constructed and installed in front of the waste disposal building. These have the capacity of $300\times1000\times1000^{mm}$ and the transparent vinyl cover to prevent the spread of contamination

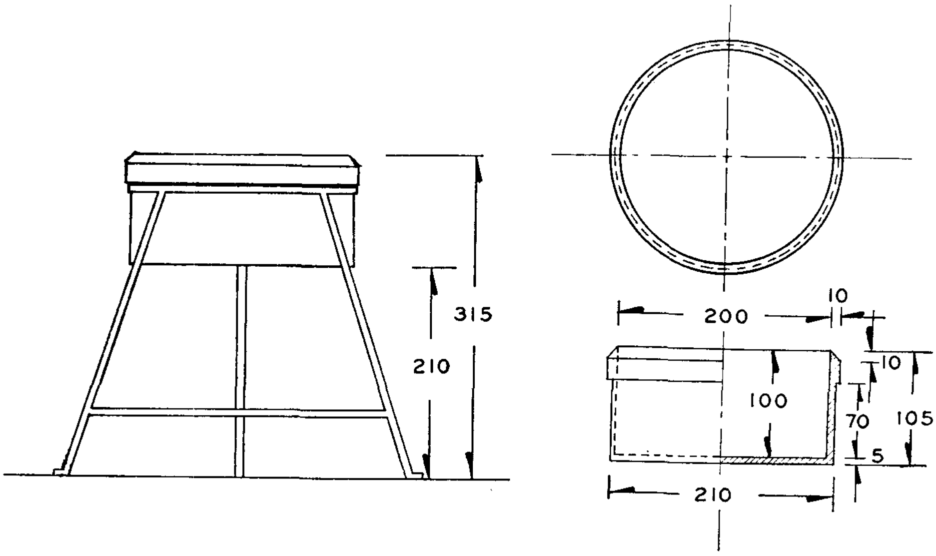

Fig. 3. Small scale evaporimeter

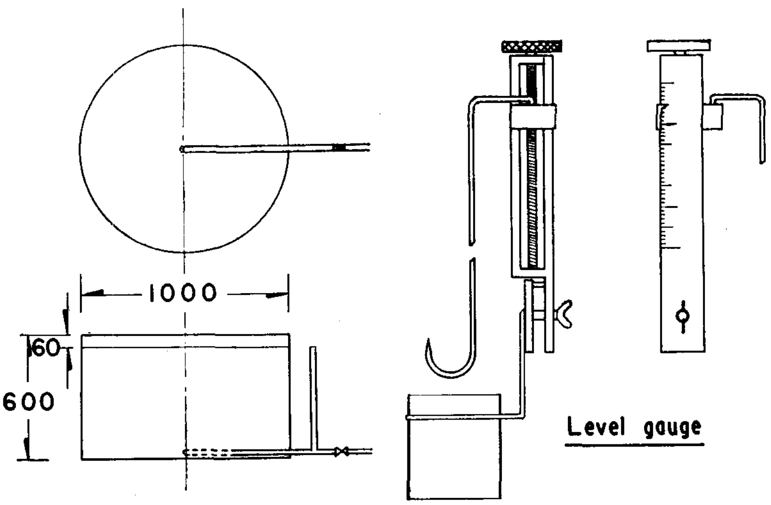

Fig. 4. Large scale evaporimeter

and are expected to increase the dewatering rate of sludge.

One is sludge evaporation pan and the other sludge evaporation pan with filtering bed. The latter cosists of filtering media (glass wool, sand, gravel and iron-ware) and drain-pipe at the bottom[3,4].

It is known that the minimum area of an opening required around the base of the cover for the maximum removal of water vapor is 10% of the plan area of the container[5].

(b) Evaporimeter

In order to obtain the information concerning evaporation practices in the vicinity of the waste disposal plant, a small and a large scale evaporimeter were installed.

Generally, the estimation of evaporation by using tanks is introduced in this experiment as a direct method. The tanks are circular; one is small scale (200 mm in diameter, 100 mm in depth), and the other a cylindrical tank (1000 mm in diameter, 600 mm in depth) with a flat base. This is made of galvanized sheet iron 9 mm in thickness, and set it on a wooden floor of the ground.

3. Experiments

(a) Selection of the methods for measuring evaporation rate.

Water vapour brought by evaporation is the principal factor in the many energy exchange taking place in the atmosphere. Measurement of evaporation from the free liquid water surface is of importance in many scientific fields. Determination of sludge dewatering rate by reliable evaporation data is required for the design of the radioactive sludge treatment.

The estimation of evaporation by means of pans or tanks, computational method and water-budget method are considered. In order to obtain information concerning evaporation practices in these experiments, these are applied in this research.

i) Water-budge method

The water-budge method for measuring evaporation is relatively simple in principle. After allowing for any change in the volume of water in the pans or the tanks amount of evaporation is computed as the difference between outflow and inflow.

The water-budget method may be expressed as follows[2]:

$$I_0-I-O+P=E$$

where

I_0: initial volume of the pan or the tank (cm^3),

O: volume of outlow from the pan or the tank (cm^3),

P: amount of precipitation falling on the surface of the pan or the tank (cm^3),

E: volume of evaporation from the pan or the tank (cm^3), and

I: change in the volume of water contained in the pan or the tank (cm^3),

This water-budget method is possible to determine evaporation from not only a free water surface but also a few lakes. Their efforts to study the problems measuring evaporation from a free water surface have been also demonstrated in many countries.

ii) Mass-transfer method

Mass-transfer equations have been proposed in order to estimate evaporation in meteorological and oceanographical field. Generally, the evaporation is proportional to the product of the wind speed and the humidity gradient. The formula can be expressed as follows[2]:

$$E=Nu(e_o-e_a)$$

where

E: evaporation

N: constant

u: wind speed

e_o: saturation vapor pressure corresponding to the water surface temperature

e_a: vapour pressure of the ambient air

(b) Procedures

i) Large scale evaporimeter

The volume change of water was measured by level gauge after a definite period of time (at 10:00 everyday) and computed the water loss on the basis of water-budget method.

In order to obtain it, an average temperature of water surface was checked 4 times(04:00, 10:00, 16:00 and 22:00) a day with the thermometer set up at the central part of water surface.

ii) Small scale evaporimeter

This small scale evaporimeter was installed as an auxiliary device of the large scale evaporimeter to measure the evaporation rate in such method as one mentioned above during winter when the water surface is frozen, but this work was continuously carried out. In measuring evaporation, a balance was used instead of level gauge, *i. e.* measuring device of the large scale evaporimeter.

iii) Sludge evaporation pan, and sludge evaporation pan with filtering bed.

The main object of these devices is to determine the evaporation rate from the radioactive bulky sludge produced by three stage liquid waste treatment using activated clay minerals. And in order to shorten the period required for the volume reduction of sludge before final disposal, dehydration of the sludge depending on the sludge evaporation pan with filtering bed is accepted in both filtering through the filtering bed and the evaporation of water from the sludge surface.

(c) Results and discussion

i) Experimental data

(i) Evaporation rate from free water surface.

Evaporation rate from free water surface was measured at this institute from 1 January 1971 to 30 June 1972 by means of the small and the large scale evaporimeter, and the small scale evaporimeter in which black-dye was mixed to promote increasing of solar energy absorption are illustrated in Fig. 5.

According to the experiment at the Lucas Heights Atomic Energy Research Institute in Australia solar evaporation method[5] is obviously suitable for the areas having a mean annual evaporation of more than 30 inches (762 mm). By the data of C. M. O. the amount of a mean annual evaporation[6] indicated about 43 inches as a result of measurement by a small scale evaporimeter at the downtown area of Seoul during last 6 years. And in 1971, it was given in 44 inches (C. M. O.).

As the air temperature of the vicinity of this institute is usually lower than the downtown area, the amount of evaporation in

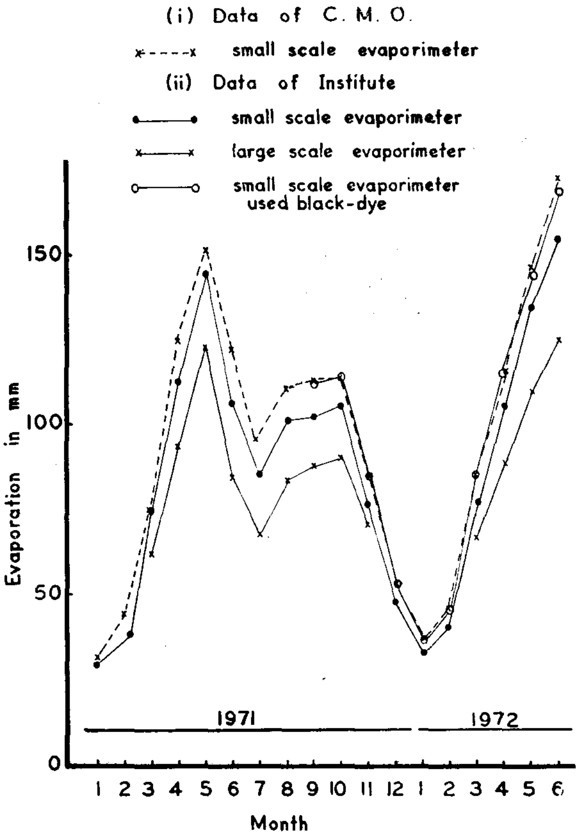

Fig. 5. Evaporation data

this institute area is less than that of the downtown area relatively and will be shown in Fig. 5. Depending on the data measured by the small scale evaporimeter in 1971, the amount of evaporation in this institute area recorded 1022.3 mm (about 40.2 inches).

Comparison of the data in Table 1 and 3 shows that the amount of evaporation from the surface of the water used black-dye is more than from the colourless water and the average ratio of them (black water to colourless water) is about 1.09.

(ii) Evaporation rate from sludge surface

Sludge evaporation pan

There are two types in sludge cakes; one is 5 cm(A-pan) and the other 10 cm (B-pan) thick. From Table 1, in the case of A-pan it takes average 15 days to be reached from initial sludge of 60% moisture content to the

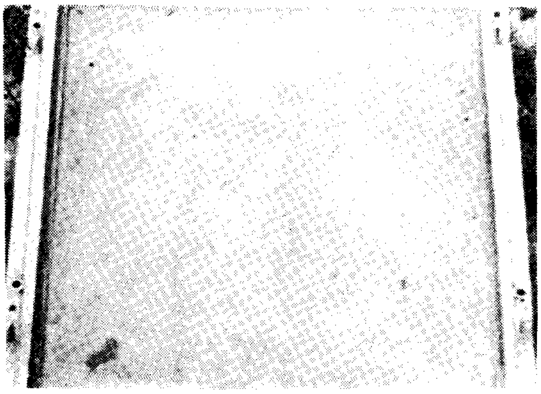

Fig. 6-1. A-pan (Moisture content 60%)

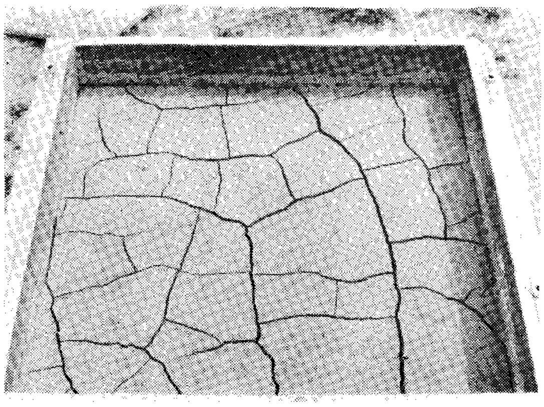

Fig. 6-2. A-pan (Moisture content 40.3%)

sludge cake (gross β-activity, $4.5\times10^{-3}\sim4.5\times10^{-5}$ μCi/gr) containing in the range of 25-30%, and in the case of B-pan average 30.3 days.

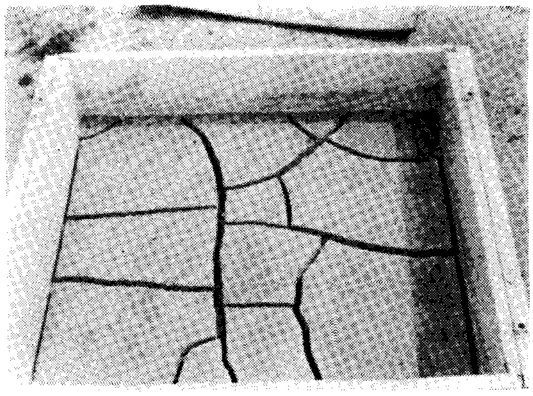

Fig. 7. B-pan (Moisture content 36.3%)

In practical experience at Lucas Heights[5)], the settled sludge is charged to the solar evaporation pond to the depth of about 10 cm and when in 30 to 40 days the sludge cake has reached the moisture content in the range 23-33%, that is shovelled into drum.

Sludge evaporation pan with filtering bed

Data measured from the ordinary sludge and the black sludge, in which black-dye was mixed, will be shown in Table 2 and 3, respectively. The moisture content of the ordinary sludge is reduced to the range of 5% after the sludge is filtered through the filtering bed. And then it takes 10-11 days for the sludge cake to be reached to the range of 25-30% of the moisture content.

Table 1. Evaporation data by S. E. P. and small scale evaporimeter

Period	Amount of evaporation				Period
	Small scale evaporimeter (mm)	A-pan	B-Pan	Small scale evaporimeter (mm)	
1971 3/17-4/5 (20) 4/6-4/19 (14)	51 52.9	37.9 38.4	76.5	108.2	3/17-4/20(35)
4/21-5/3 (13) 5/4-5/14 (11)	53.1 48.5	38.7 38.2	77.7	107.0	4/21-5/15(25)
5/17-5/25 (9) 5/26-6/11(17)	54.4 63.7	38.6 38.1	76.5	123.5	5/17-6/12(27)
6/15-6/28(14) 6/29-7/18(20)	52.5 57.7	37.6 37.8	75.4	115.5	6/15-7/20(36)

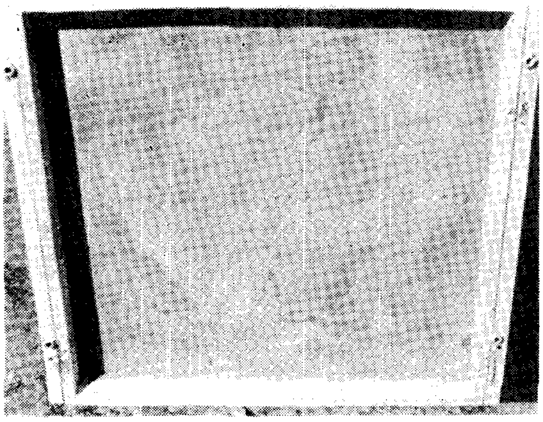

Fig. 8-1. S. E. P. F. B. (Moisture content 53.2%)

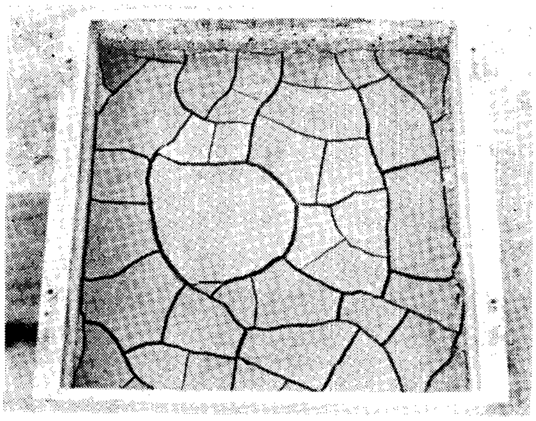

Fig. 9-1. A-pan (Blackdye, Moisture content 44.5%)

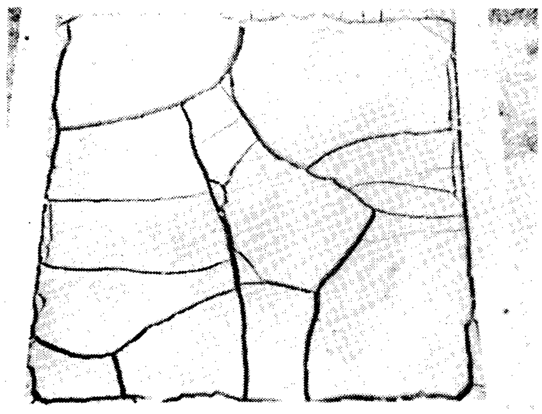

Fig. 8-2. S. E. P. F. B. (Moisture content 34.4%)

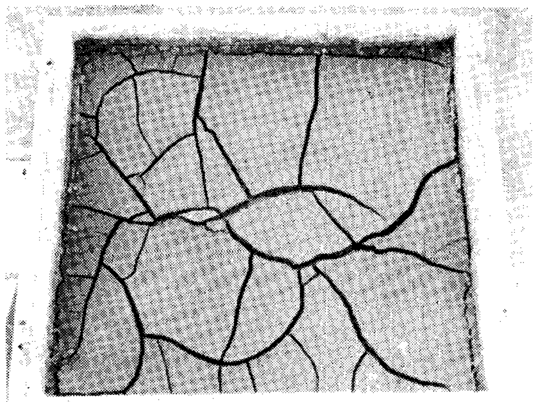

Fig. 9-2. S. E. P. F. B. (Blackdye, Moisture content 42.4%)

By these experiments, we obtained result that the period can be shortened 1-2 days in the case of the black sludge than the ordinary sludge by S. E. P..

ii) Application of mass-transfer epuation

Mass-transfer method to estimate the evaporation has been mentioned in the previous section. Based on the mass-transfer principle, empirical formulars are developed in several advanced countries.

Assuming that the temperature of ambient air and water surface be the same, the empirical formular is derived from the data of C. M. O. by least square method as the following.

$$E=0.07+0.32u_6\ (e_o-e_a)$$

Table 2. Evaporation data by S. E. P. F. B. and S. E. P. (A-pan)

Period	Sludge evaporation pan with filtering bed			A-pan	
	Amount of outflow (kg)	Amount of evaporation (kg)	Total	Amount of evaporation (kg)	Period
1971					
8/1-8/8 (8)	12.0	26.7	38.7	38.5	8/1-8/15(15)
8/17-8/29(13)	12.5	25.9	38.4	38.9	8/17-9/1(16)
9/2-9/11 (10)	12.2	25.8	38.0	38.4	9/2-9/17(16)

Table 3. Evaporation data on the surface of the black sludge

Period	S.S.E.* Evaporation (mm)	S.S.E.* Evaporation (Kg)	S.E.P.F.B. Out flow (Kg)	S.E.P.F.B. Total (Kg)	S.E.P. Evaporation (Kg)	S.S.E. Evaporation (mm)	Period
1971							1971
9/19—9/29(11)	34.1	25.6	11.7	37.3	37.2	52.7	9/19—10/4(16)
10/6—10/14(9)	35.8	26.5	12.1	38.6	37.9	53.8	10/6—10/19
10/24—11/3(11)	35.9	26.9	12.0	38.9	38.4	54.3	10/24—11/10(18)
11/12—11/24(13)	36.5	26.7	11.5	38.2	38.3	54.3	11/12—11/30(19)
					38.1	54.1	12/6—1/8(34)
					38.9	55.3	1/10—2/23(21)
1972							
3/8—3/21(14)	36.1	26.9	11.4	38.3	39.0	55.2	2/28—3/19(21)
3/25—4/4(12)	33.9	25.8	12.0	37.8	37.2	52.6	3/25—4/9(16)
4/13—4/22(10)	35.7	26.7	12.2	38.9	39.1	55.4	4/13—4/26(14)
4/28—5/5(8)	35.5	26.5	11.9	38.4	38.1	53.8	4/28—5/9(12)
5/11—5/17(7)	34.3	25.8	12.5	38.3	40.1	56.9	5/11—5/21(11)
5/23—5/31(9)	35.7	26.6	11.9	38.5	38.6	54.8	5/23—6/3(12)
6/5—6/10(6)	35.1	26.2	11.8	38.0	37.1	52.6	6/5—6/15(11)
6/17—6/22(6)	33.3	24.9	12.2	37.1	37.4	53.0	6/7—6/26(10)

* S.S.E. is small scale evaporimeter.

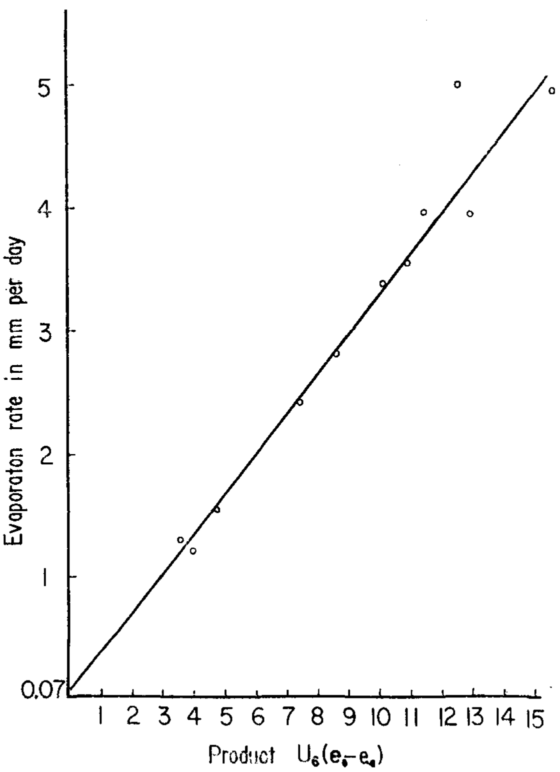

Fig. 10. Relation between evaporation rate and the product U_6 (e_o-e_a)

where

E: evaporation rate in mm per day.

u_6: wind speed in m per second. (at the hight of 6 m)

e_o: saturation vapor pressure correspond to the air temperature. (at 1.5 mm above the ground)

e_a: vapor pressure of the ambient air. (at 1.5 m above the ground)

In Fig. 10, this empirical formular can be applicable in the estimation of evaporation rate, when the value of product $u_6(e_o-e_a)$ is less than 11.

4. Cost Evaluation

The capital cost and the current operating cost[7] are calculated as follows;

Volume of untreated sludge = $12m^3$

Volume of treated sludge = $5.4m^3$

i) Capital cost..............₩193,600

Concrete pond for evaporation with a movable steel roof.

Surface area = $12m^2$

Depth=0.3 m

Thickness of concrete=0.2 m

ii) Current operating cost............₩56,800

Labour cost	₩ 11,200
Maintenance	₩ 8,240
Overheads	₩ 11,200
Depreciation(10yr)	₩ 19,360
Utilities	₩ 6,800
Total	₩ 56,800

The unit cost of the package for sea-disposal with the sludge treatment by solar evaporation is at 9,200 won and that without the sludge treatment by solar evaporation is 10,000 won per m^3 of untreated sludge. And then the former is 8% less than the latter.

5. Conclusions

From the data presented in the experiments for the treatment of radioactive sludge by solar evaporation final conclusion has been reached as the following.

i) The volume reduction ratio of sludge cake (moisture content 25-30%) to slurry state sludge (moisture content 60%) is approached to 2.1-2.4.

ii) Period required for making suitable sludge cake takes average 15 days from March to August. And also it can be shortened in 13-14 days when black-dye used to increase energy absorption.

iii) In the cost evaluation of radioactive sludge handing it is able to curtail about 8% of the present cost of operation for sea-disposal when slurry state sludge is transformed into the sludge cake form by means of solar energy.

iv) The empirical formular obtained by the mass-transfer method can be applicable for the calculation of a evaporation rate.

Therefore, the solar energy is successfully able to be utilized for the evaporation of radioactive sludge at this institute.

Acknowledgement

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