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TITLE

Treatment and disposal of low-level sludges by solar evaporation

FINAL REPORT FOR THE PERIOD

1 June 1970 - 30 June 1972

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(3)

CERTIFIED BY: Howard R. [signature]

FINAL REPORT

(1) Contract number; 923/RB, 923/RI/RB

(2) Title of project:

Treatment and disposal of low-level sludges by solar evaporation

(3) Institute where this research was carried out:

Reactor Engineering Division
Atomic Energy Research Institute
Seoul, KOREA

(4) Principle scientific investigator:

Sang Hoon Lee

(5) Time period covered:

From 1 June 1970 to 30 June 1972

Contents

1. Introduction

In the previous studies of low-level radioactive liquid waste treatment by using domestic clay which were sponsored by I.A.E.A. (Contract No. 566/RB), it has been reached optimum operation conditions of three stage liquid waste treatment plant as following [1].

In the disposal problems of the active sludge and the practical liquid waste treatment, the optimum operating conditions of this plant were fixed up the flow rate as 2 liters per minute for feed solution containing 2% dosage of clay. The calculation of decontamination factors by the plant operation was satisfied with the theoretical one.

The plant has the treatment capacity of 1440 liters per month when running operation is allowed in the 6 hours a day. When 2% (by wt) clay minerals are used by this flow rate (2 liters per minute), approximately sludge is produced 0.3 ton per month. This sludge is generally bulky and required volume reduction before final disposal.

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

This final report is covered with the problems of the investigation 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 studies are based on Measurement and Estimation of Evaporation and evapotrans piration [2], and installed as following:

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

Two small experimental units of sludge evaporation pan are constructed (Fig. 1) and installed in front of waste disposal building. One is slightly large capacity of 300x1000x1000mm (B-pan) and the other 200x1000x1000mm (A-pan). These have transparent vinyl cover to prevent the spread of contamination and are expected to increase the dewatering rate of sludge by utilizing the "glasshouse" heating effect.

And one of them is reconstructed as shown in Fig. 2 and installed at the same place. This has the capacity of 300x1000x1000mm and consists of filtering media (glass wool, sand, gravel and iron-ware) and a 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 pan area of the container.

(b) Floating lysimeter

To investigate evaporation rate in the clay water system, lysimeter (Fig. 3), defined as a special type of evaportranspirometer designed to permit the measurement of water draining through the clay, is applied in this experiment. Lysimeter consists of major three parts and is not only relatively inexpensive but also reliable. A loss or gain of weight in the floating tank results in the change of liquid-level.

The method is besed on Archimedes' principle and can be used continuous reading by using stilling wells connected to the lysimeter pits located at underground level pipes. And evaporation can be calculated as following equation [2]:

$$h = \frac{d}{s} \frac{As}{(As+A)}$$

Where

h: equivalent depth of water lose in A tank.

d: equivalent depth of water loss in C tank.

A: sum of the annular liquid surface and the stilling well.

As: cross sectional area of the liquid waste tank.

S: specific gravity of luquid.

(c) 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 (Fig. 4) is small scale (200mm in diameter, 100mm in depth), and the other (Fig. 5) a cylindrical tank (1000mm in diameter, 600mm in depth) with a flat base. This is made of galvanized sheet iron 9mm 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 principle 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-budget method for measuring evaporation is 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):

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

Where

I_0 : initial volume of the pan or the tank,

O : volume of outlow from the pan or the tank,

P : amount of precipitation falling on the surface of the pan or the tank,

E : volume of evaporation from the pan or the tank, and

I : change in the volume of water contained in the pan or the tank.

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 advanced 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 following (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 during definit period (at 10:00 everyday) and computed the water loss on the basis of water-budget method.

In order to obtain it, a 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 freezed, but this work was continuously carried out. In measuring evaporation, a small commercial balance was used instead of level guage, i.e. measuring device of the large scale evaporimeter.

iii) Sludge evaporation pan, Floating lysimeter, and Sludge evaporation pan with filtering bed.

The main object of these devices is to determine the evaportion 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

(a) Evaporation rate from free water surface

Evaporation rate from free water surface was measured at this Institute from 1 September 1970 to 30 June 1972 by means of the small and the large scale evaporimeter, and it is shown in Table 1 and 2, and Table 3 presents results obtained by the small scale evaporimeter in which black-dye was placed to promote increasing of solar energy absorption.

In order to compare the evaporation rate of this Institute area with the data measured by the Central Meteorologicla Office (C.M.O.), the latter was quoted in this report (Fig. 6).

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 (762mm). 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 in Seoul capital area 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 Seoul capital area, the amount of evaporation in this Institute area is less than that of Seoul capital area relatively and will be shown in Fig. 6. Depending on the data measured

Table 1. Evaporation rate by a small scale evaporimeter

Month	Average air temp (C)	Evaporation Total (mm)	Evaporation Average value (mm/day)	Evaporation Daily greatest (mm/day)
Dec. 70	-1.3	32.2	1.04	2.3
Jan. 71	-2.9	29.6	0.95	1.6
Feb. 71	-1.0	38.6	1.38	2.3
Mar. 71	1.8	70.5	2.27	5.1
Apr. 71	11.3	112.9	3.76	5.7
May. 71	16.2	144.9	4.67	8.8
Jun. 71	21.0	106.3	3.54	6.8
Jul. 71	23.6	85.7	2.76	7.6
Aug. 71	24.3	101.2	3.26	6.5
Sep. 71	20.3	102.1	3.40	5.2
Oct. 71	12.9	105.3	3.40	5.4
Nov. 71	8.3	77.2	2.57	4.2
Dec. 71	-1.3	48.0	1.55	3.0
Jan. 72	0.6	32.9	1.06	2.3
Feb. 72	-0.9	40.7	1.40	2.6
Mar. 72	4.5	77.6	2.50	4.5
Apr. 72	11.4	105.3	3.51	7.8
May. 72	16.3	134.4	4.34	7.3
Jun. 72	19.0	154.5	5.15	8.7

Table 2. Evaporation rate by a large scale evaporimeter

Month	Average air temp (C)	Average water surface temp (C)	Evaporation Total (mm)	Evaporation Average value (mm/day)	Evaporation Daily greatest (mm/day)
Sep. 70	20.2	21.9	78.3	2.94	4.8
Oct. 70	15.0	15.3	68.1	2.20	3.6
Nov. 70	5.7	5.6	41.8	1.39	3.4
Mar. 71	1.8	1.9	61.7	1.99	5.0
Apr. 71	11.3	11.2	93.5	3.12	5.4
May. 71	16.2	16.5	122.9	3.96	8.3
Jun. 71	21.0	20.7	84.8	2.83	6.5
Jul. 71	23.6	23.1	67.5	2.18	7.1
Aug. 71	24.3	24.0	83.6	2.70	5.7
Sep. 71	20.3	20.1	87.8	2.93	4.9
Oct. 71	12.9	13.0	90.4	2.92	4.7
Nov. 71	8.3	8.5	70.3	2.34	3.9
Mar. 72	4.5	4.5	66.7	2.15	4.4
Apr. 72	11.4	11.2	88.5	2.95	6.8
May 72	16.3	16.0	109.6	3.54	6.4
Jun 72	19.0	18.9	124.5	4.15	7.7

Table 3. Evaporation rate by a small scale evaporimeter(used blackdye)

Month	Evaporation Total (mm)	Average value (mm/day)	Daily greatest (mm/day)
Sep. 71	112.5	3.75	5.7
Oct. 71	113.8	3.67	5.9
Nov. 71	85.1	2.84	4.6
Dec. 71	52.9	1.71	3.3
Jan. 72	36.3	1.17	2.5
Feb. 72	44.9	1.55	2.9
Mar. 72	85.5	2.76	5.0
Apr. 72	116.0	3.87	6.6
May. 72	143.7	4.64	8.0
Jun. 72	168.4	5.61	9.3

by the small scale evaporimeter in 1971, the amount of evaporation in this Institute area recorded 1022.3mm (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.

(b) Evaporation rate from sludge surface

Lysimeter

In Table 2 and 4, the total amounts of evaporation by the large scale evaporimeter and the lysimeter are 700.8mm and 767.4mm from

Table 4. Evaporation data by lysimeter

Month	Evaporation		
	Total (mm)	Average value (mm/day)	Daily greatest (mm/day)
Apr. 71	108.4	3.61	5.2
May. 71	137.3	4.43	8.4
Jun. 71	92.1	3.07	7.0
Jul. 71	73.8	2.38	6.8
Aug. 71	90.9	2.93	5.7
Sep. 71	96.9	3.23	5.0
Oct. 71	95.7	3.09	5.2
Nov. 71	72.3	2.41	3.9
Total	767.4	2.79	8.4
Mar. 72	75.8	2.12	4.4
Apr. 72	102.3	3.41	7.5
May. 72	121.4	3.91	6.9
Jun. 72	136.6	4.55	8.4

April to November in 1971, respectively, and the ratio of the lysimeter to the large scale evaporimeter is about 1.1 Generally, it is shown that the evaporation from sludge surface is a little higher then that from free water surface.

Sludge evaporation pan

There are two types in sludge cakes; one is 5cm (A-pan) and the other 10cm (B-pan) thick. From Table 5, in the case of A-pan it takes average 15 days to be reached from initial sludge of 60% moisture content to the sludge cake containing in the range of 25-30%, and in the case of B-pan average 30.3 days.

In practical experience at Lucas Heights (5), the settled sludge is charged to the solar evaporation pond to the depth of about 10cm 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.

Table 5. Evaporation data by S.E.P. and small scale evaporimeter.

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

Sludge evaporation pan with filtering bed

Data measured from the ordinary sludge and the black sludge, in which black dye was placed, will be shown in Table 6 and 7, respectively. The moisture content of the ordinary sludge is reduced to the range of 53% after the sludge is filtered through the filtering bed. And then it takes 10-11 days 1 the sludge cake to be reached to the range of 25-30% of the moisture content.

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

Table 6. Evaporation data by S.E.P.F.B. and S.E.P. (A-pan)

Sludge evaporation pan with filtering bed				A-pan	
Period	Amount of outflow (Kg)	Amount of evaporation(Kg)	Total	Amount of evaporation(Kg)	Period
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	38.0	8/17 - 9/1 (16)
9/2 - 9/11 (10)	12.2	25.8	38.0	38.4	9/2 - 9/17 (16)

Table 7. Evaporation data on the surface of the black sludge

Period	S.S.E. * Evaporation (mm)	S.E.P.F.B. Evaporation (Kg)	S.E.P.F.B. Outflow (Kg)	S.E.P.F.B. Total (Kg)	S.E.P. Evaporation (Kg)	S.S.E. Evaporation (mm)	Period
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 (45)
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.

ii) Application of mass-transfer equation

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 bee the same, the empirical formular is derived from the data of G.M.O by least square method as following.

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

where

E : evaporation rate in mm per day.

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

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

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

In Fig. 7, 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 amount of radioactive sludge treated by activated clay technique will be increased 4 times than that which is presently produced by operating the TRIGA MARK-III reactor reached to criticality recently.

The capital cost and the current operating cost [7] would be calculated as follow:

Volume of untreated sludge = $12m^3$

Volume of treated sludge = $5.4m^3$

i) Capital cost $484

Concrete pond for evaporation with a movable steel roof.

Surface area = $12m^2$

Depth = 0.3m

Thickness of concrete = 0.2m

ii) Current operating cost $142.0

Labour cost	$28.0
Maintenance	$20.6
Overheads	$28.0
Depreciation (10yr)	$48.4
Utilities	$17.0
Total	$142.0

The unit cost of the package for see-disposal with the sludge treatment by solar evaporation is estimated at $23 and that without the sludge treatment by solar evaporation is $25 per m^3 of untreated sludge. And then the former may be 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 following.

i) The volume reduction ratio of sludge cake (moisture content 25-30%) to slurry state sludge (moisture content 60%) is approached to 21. - 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 raidoactive sludge handling it is estimated to be 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 in order to caloulate a evaporation rate.

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

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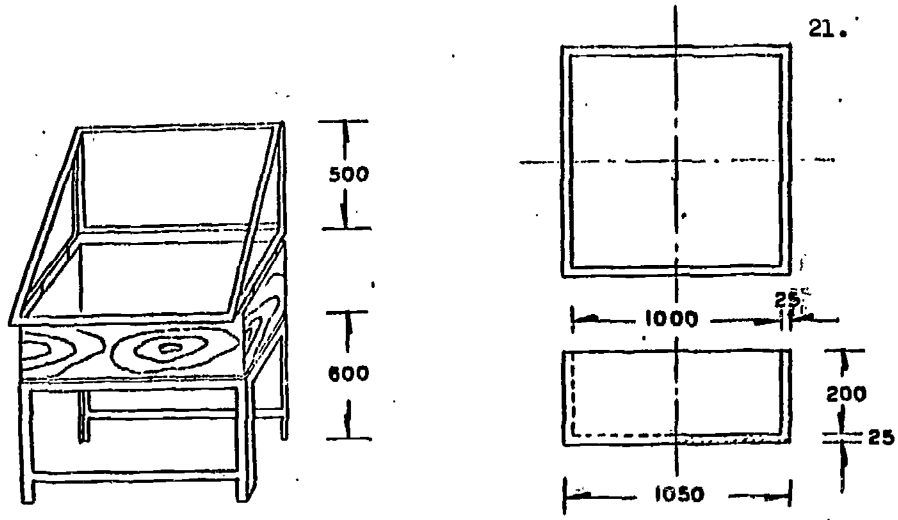


Fig (1) Sludge evaporation pan.

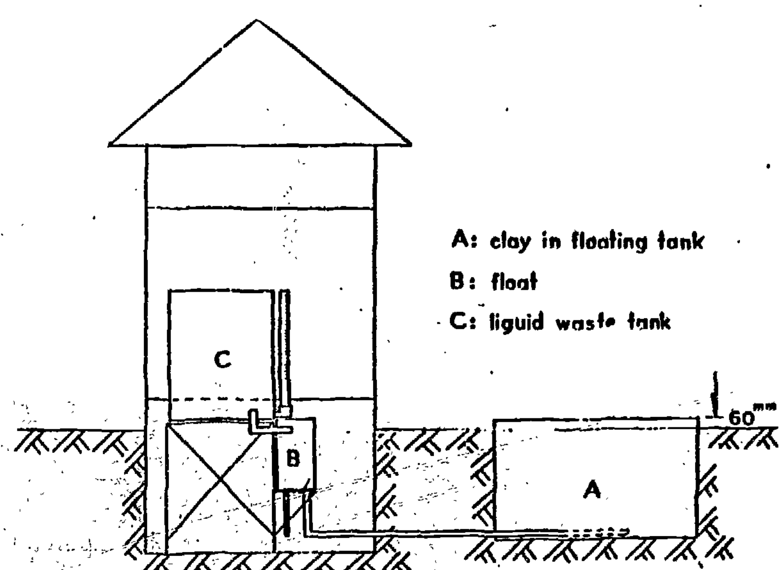


Fig.(3) Diagram of a floating lysimeter installation

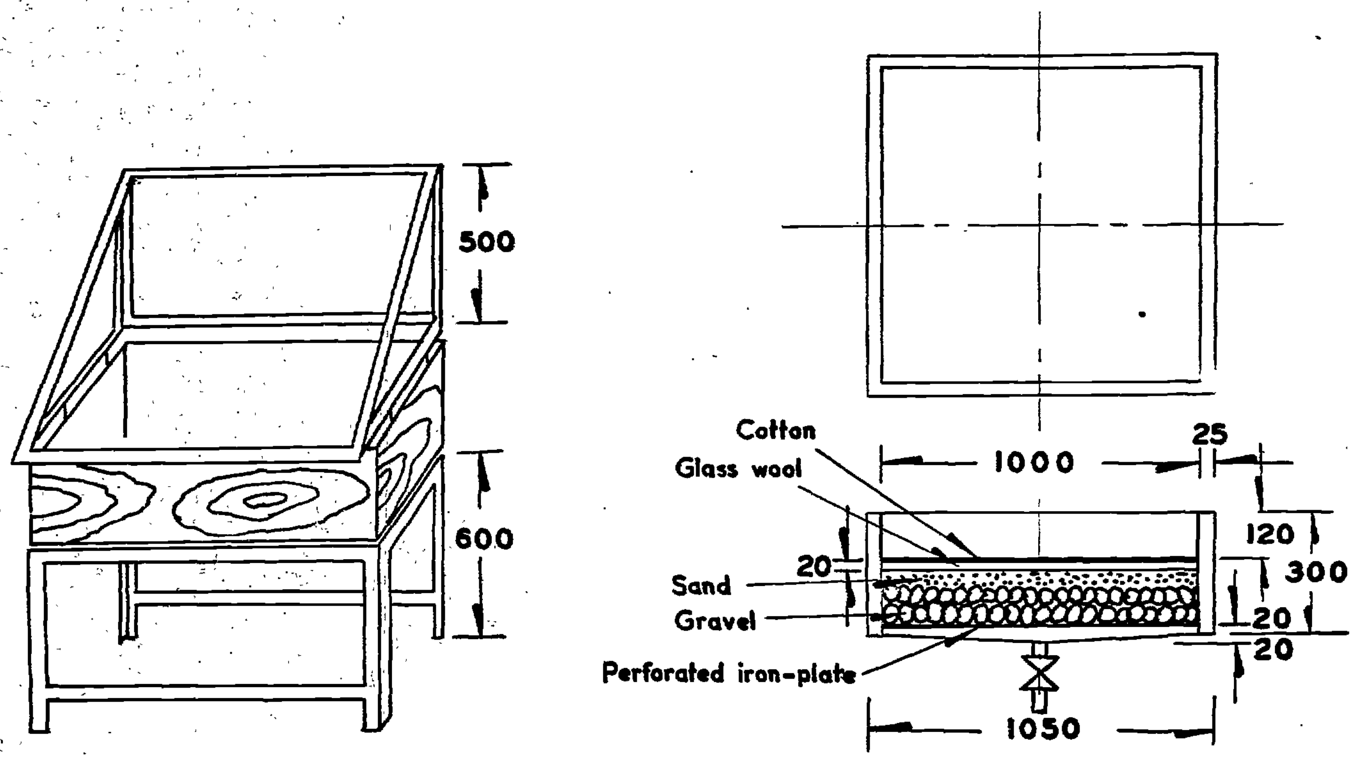


Fig.(2) Sludge evaporation pan with filtering bed

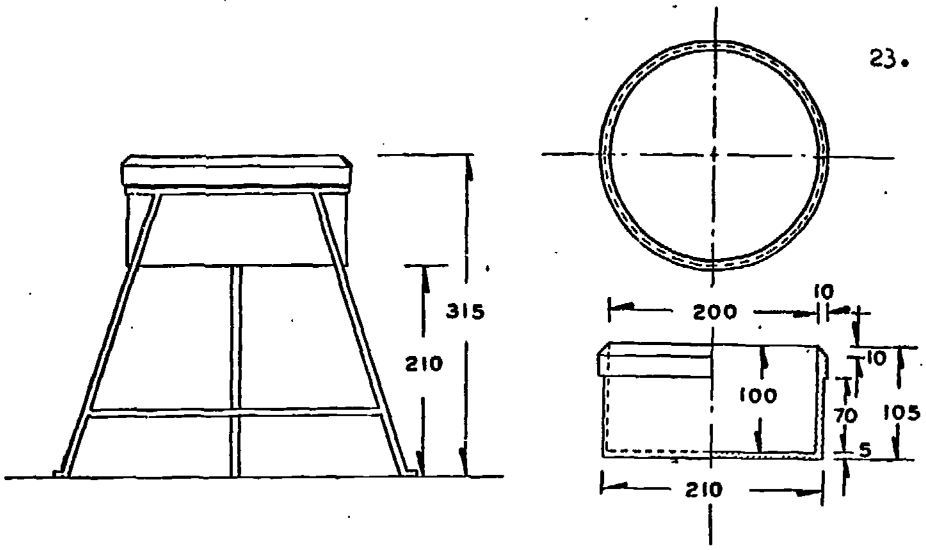


Fig (4) Small scale evaporimeter

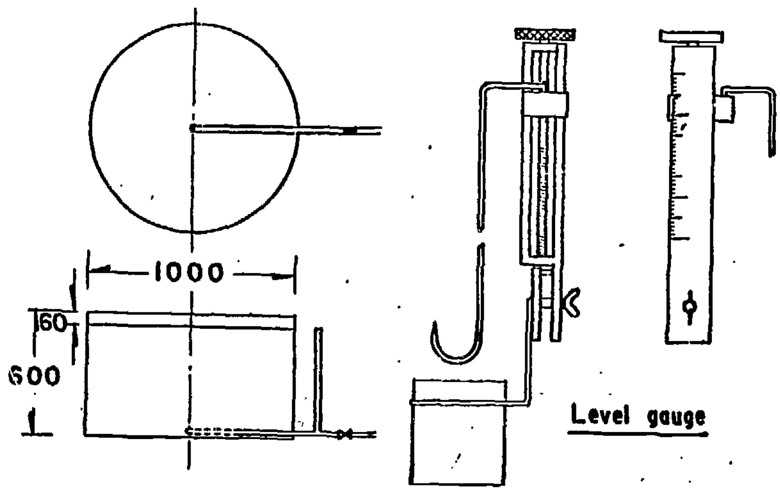


Fig (5) Lagrge scale evaporimeter

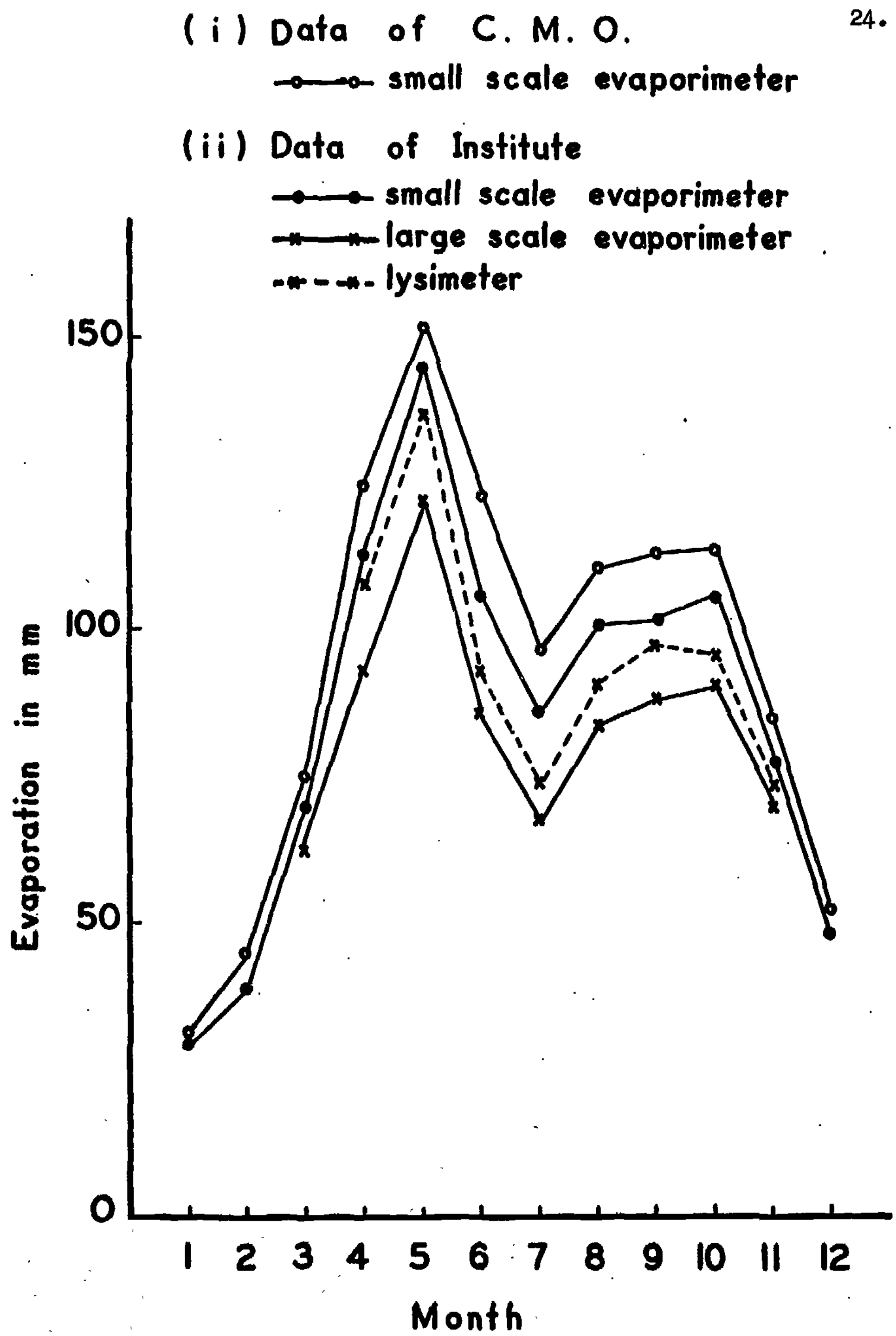


Fig. (6) Evaporation data in 1971

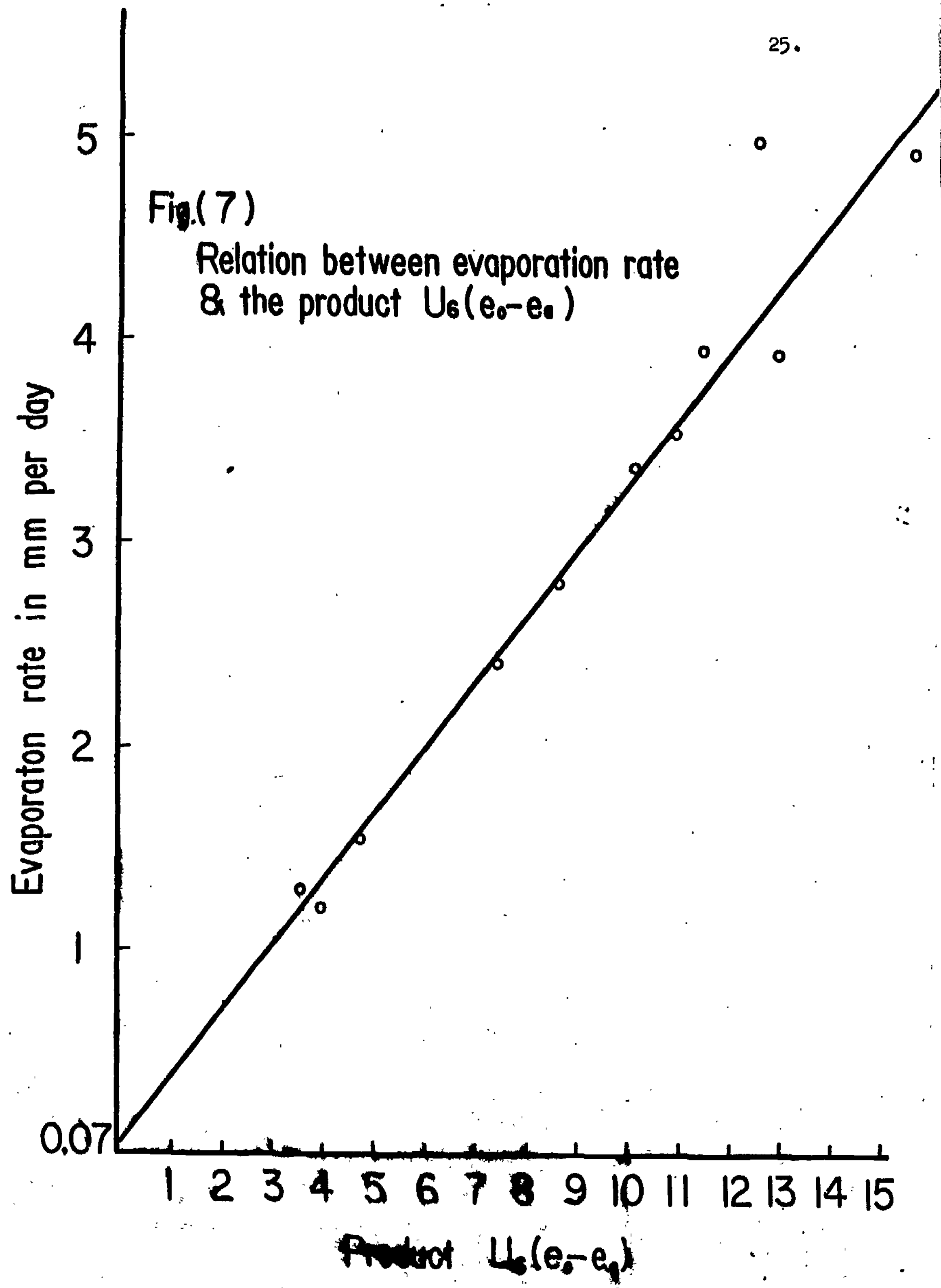
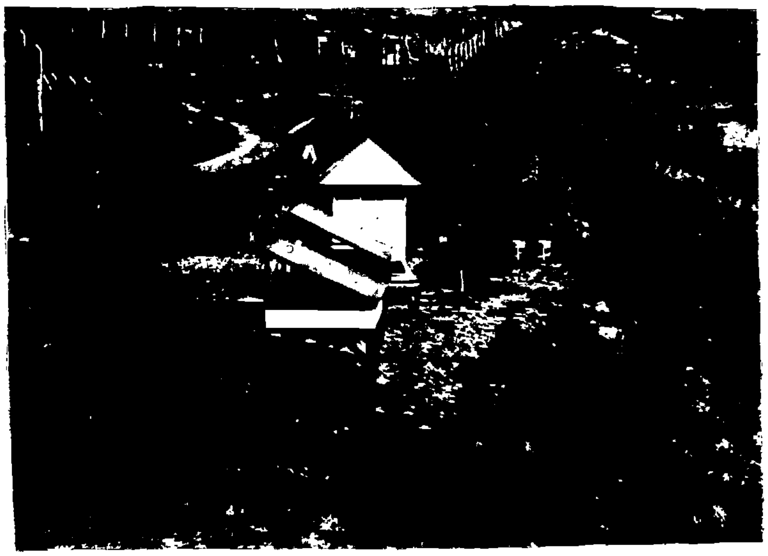
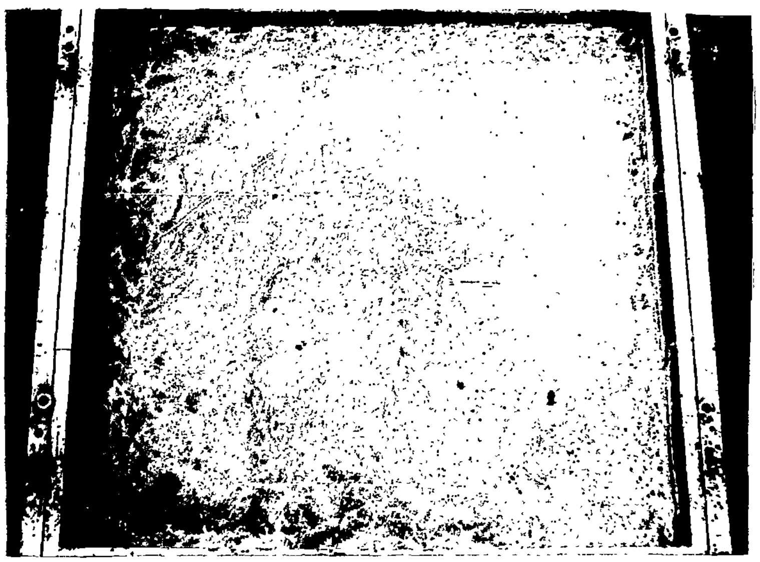


Fig.(7)
Relation between evaporation rate & the product $U_s(e_o-e_a)$

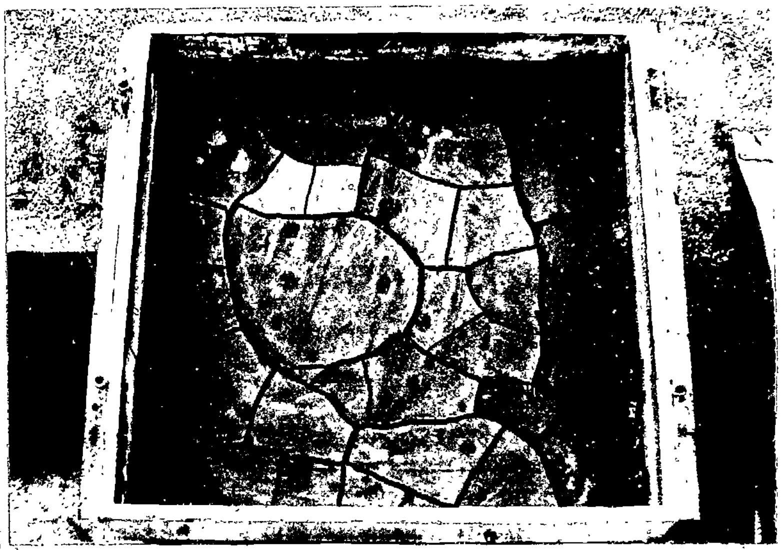


Experimental area

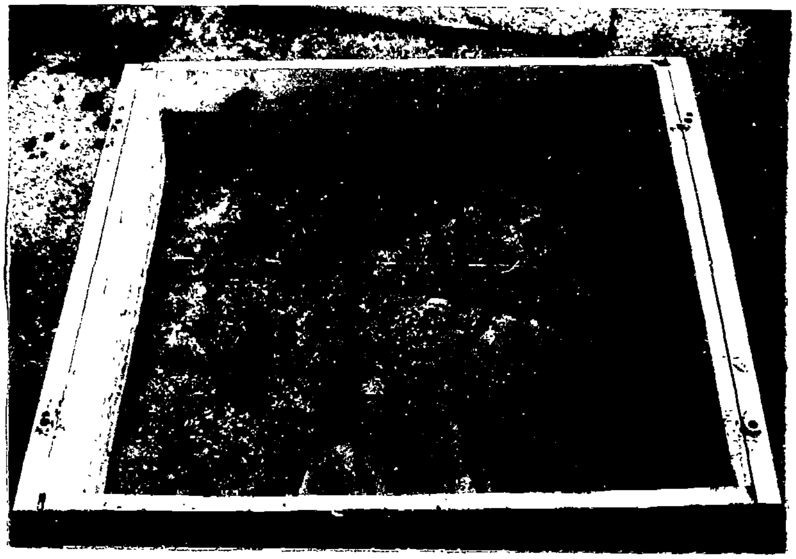


A-pan (Moisture content 60%)

A-pah (Moisture content 40.3%)

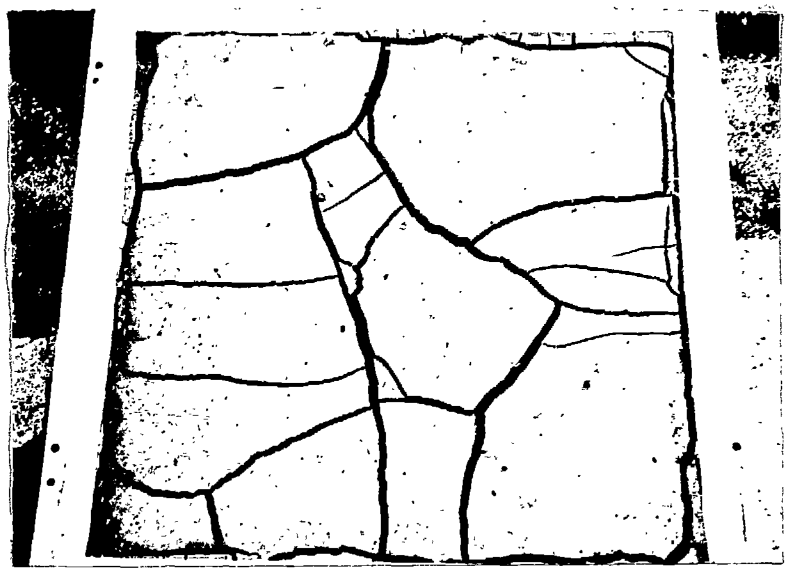


A-pan (Blackdye, Moisture content 44.5%)

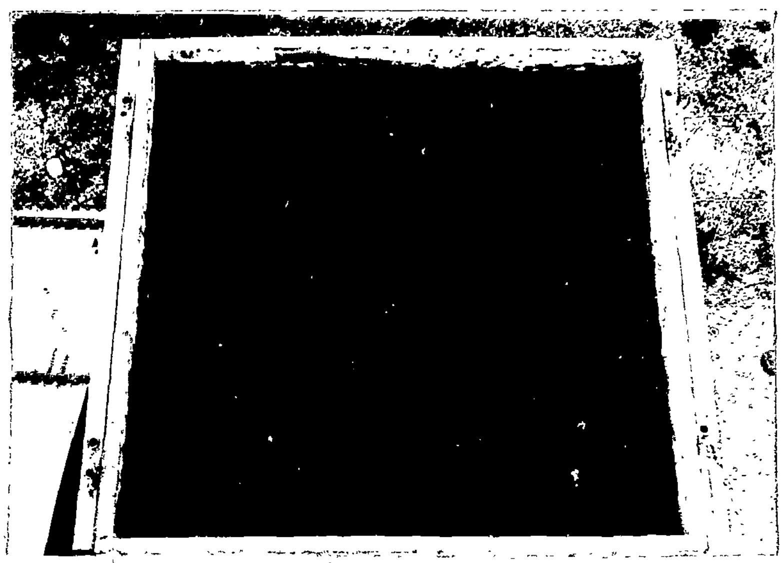


B-pan (Moisture content 36.3%)

S.E.P.F.B. (Moisture content 53.2%)



S.E.P.F.B. (Moisture content 34.4%)



S.E.P.F.B. (Blackdye, Moisture content 42.4%)

Summary of Final Report

Contract No. 923/RB and 923/RI/RB

Sang Hoon Lee

Atomic Energy Research Institute

Seoul, Korea

Title

Treatment and disposal of low-level sludges by solar evaporation

Research institute

Atomic Energy Research Institute, Seoul, Korea

Chief scientific investigator

Sang Hoon Lee

Period of contract

1 June 1970-30 June 1972

Scientific background and scope of project.

The optimum operational conditions of the three stage radioactive liquid waste treatment unit using domestic clay minerals for treatment of low level radioactive liquid wastes have been already decieded, but no sludge treatment or disposal facilities have been provided yet.

At the present, several gallons of slurry state sludge are produced from the plants. The most economical method for volume reduction of the low-level radioative sludge might be the sludge concentration by solar evaporation.

It is indicated that amount of a mean annual evaporation in the site of this institute is above 30 inch (76cm), and it seems to be likely that the method would be of use in the site of our Institute. Thus the work on sludge concentration by solar evaporation is to be investigated.

The problems of sludge treatment would be very significant when a large amount of sludges are produced from liquid wastes of our MW research reactor which are reached to criticality recently.

Experimental methods

Water vapour brought by evaporation is the principle factor in the many energy exchange taking place in the atmosphere. Measurement of evaporation from the free 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.

Water - budget method is possible to determine evaporation from not only a free water surface but also a few lakes. Mass-transfer equation also 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.

Results obtained.

As the air temperature of the vicinity of this Institute is unually lower than the Seoul capital area, the amount of evaporation in this Institute area is less than that of Seoul capital area relatively. Depending on the data measured by the small scale evaporimeter in 1971, the amount of evaporation in this Institute area recorded 1022.3mm (about 40.2 inches).

(a) Evaporation rate from free water surface.

Evaporation rate from free water surface was measured at this Institute from 1 September 1970 to 30 June 1972 by means of the small and the large evaporimeter. And comparison of the data 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.

(b) Sludge evaporation pan

There are two types in sludge cakes; one is 5cm (a-pan) and the other 10cm (B-pan) thick. In the case of A-pan it takes average 15 days to be reached from initial sludge of 60% moistute content to the sludge cake containing in the range of 25-30%, and in the case of B-pan average 30.3 days.

On the other hand, sludge evaporation pan with filtering bed modified sludge evaporation pan in order that sludge is immediately filtered through filtering bed. ~~and discharged into drain-pipe.~~ From this experiment, the moisture content of the ordinary sludge is reduced to the range of 53%. And then it takes 10-11 days for the sludge cake to be reached to 25-30% moisture content. By using black-dye into the sludge, 1-2 days can be shorten in the same moisture content.

(c) Application of mass-transfer equation

Assuming that the temperatute of ambient air and water surface are the same, the empirical formular of mass-transfer equation is derived from the data of Central Meteorological Office by least square method as following.

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

And then 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.

Conclusions

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

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

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

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

iv) The empirical formular obtained by the mass-transfer method can be applicable in order to calclulate a evaporation rate.

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