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SLUDGE FREEZING SEPARATION SYSTEM

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I. INTRODUCTION

In order to cope with the rapidly increasing amount of waste material, the laws concerning pollution control are gradually becoming more severe and public demands for effective waste treatment equipment are greater than ever before. Among such treatments, sludge treatment has always presented a problem because of the difficulty in filtration. The sludge treatment is carried out always at final stage in waste water treatment which can never be considered as complete if this treatment is overlooked.

Fuji Electric was commissioned to take part in the manufacture of some of the equipment based on the principle of the sludge freezing separation method developed by the Machinery and Metallurgy Research Institute of Chiba Prefecture. This equipment has been on sale since June, 1972, and it has met the imminent social demand.

II. SLUDGE DEWATERING

1. Outline of Dewatering Equipment

Generally the waste materials called "sludge" have a water content over 90%, but there are many cases in water content when dewatering is difficult. Therefore, techniques of sludge dewatering are most important, and it must not produce any secondary pollution and must also be economically feasible. *Table 1* shows the sequent stages of the sludge dewatering equipment described here.

Except for the drying and burning steps which require heat, the water content is generally reduced to min. 60～70% in the dewatering steps. In press-filters, the water content is reduced to 50～60% but maintenance is troublesome because of clogging and wear of the filter cloth.

In comparing these methods, the freezing separation method has been derived from a somewhat different idea and its main point is the pre-treatment.

Table 1 **Sequent stages of sludge dewatering**

Stages	Water content	Device
Thickening	ca. 90%	Gravity precipitation thickener (thickener clarifier, etc.)
Dewatering	ca. 80%	Centrifuge (centrifuging filter, decanter)
	ca. 70%	Vacuum filter (Oliver filter, belt filter, etc.)
	ca. 60%	Press filter (filter press, roll filter, etc.)
Drying	50～40%	Sunlight, air dryer, drying oven
Burning	0%	Incinerator

Table 1 describing the sequent stages of sludge dewatering is rewritten into *Table 2* showing the process sequence.

In former dewatering processes, the dewatering was the most important step and the only pretreatment considered was thickening. However, it is much better to perform a suitable pretreatment than to expend all efforts on mechanical dewatering. An example of such pretreatment is quality change of activated sludge by heating. After such pretreatment, dewatering is very easy. In the freezing separation method which utilizes quality change by freezing, the colloidal state of the sludge is eliminated and the settling and filtering rates are increased to values several ten times those before the freeze treatment. Therefore, mechnical dewatering equip-

Table 2 **Process of sludge treatment**

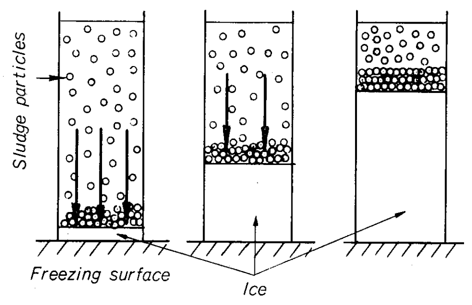
Pre-treatment → Dewatering → After-treatment

- Pre-treatment
  - Sedimentation
  - Thickening
    - —Quality change by heating
    - —Quality change by freezing
- Dewatering
  - —Vacuum filtration
  - —Filter pressing
  - —Centrifuging
  - —Gravity filtration
- After-treatment
  - —Filtered water treatment
  - —Solid treatment
    - —Transport
    - —Drying—Burning
    - —Re-use

ment is useful only as an aid. Depending on the case, gravity filtration is sometimes sufficient, and mechanical filtration equipment can be completely eliminated using this revolutionary method.

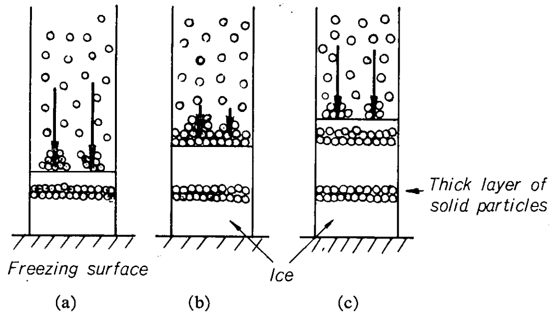
2. Principle of the Freezing Separation System

As can be seen in *Fig. 1* (*a*), when raw liquid sludge in the colloidal state is frozen, the water is first frozen on the freezing surface and as the ice grows as shown in *Fig. 1* (*b*) and (*c*), the boundry layer of the freezing is moved and the water in the sludge flows toward the freezing surface. However, the solid particles suspended in the sludge are pushed away and collect on the freezing boundary. This is known as a macromoving system. However, a micromoving system occurs simultaneously in accordance with the movement of the freezing surface as shown in *Fig. 2* (*a*). The flow of the water through the layer of concentrated solid particles to the freezing boundary is obstructed and a new freezing boundary is formed in a location where smooth flow is possible as shown in *Fig. 2* (*b*) and (*c*). The solid portion of thickened sludge is surrounded by ice and freezing continues. The water particles in the solid layers of thickened sludge are removed by capillary force so that dewatering is performed. When sludge is throughly frozen, the sludge particles are formed correspondingly into coarse particles.



(a) Before freezing (b) Water flow during freezing (c) Freezing completed

Fig. 1 Macromoving mechanism



(a) Rapid water flow
(b) Formation of particle layer with high resistant
(c) Jamping of freezing layer

Fig. 2 Micromoving mechanism

When the frozen sludge is thawed, the coarse particles in the ice which are dewatered quickly settle and pure supernatant liquid is left above. In this state, the original colloidal state will not be restored even by mechanical agitation. As will be described later the settling and filtration rates are increased to values up to several ten times those before treatment so that dewatering can be performed by gravity filtration. Because the dewatering time is shortened, the purpose can be attained by using simple mechanical dewatering equipment such as a simple form of the vacuum filter.

3. Power Economy of the Freezing Separation Method

Table 3 shows a comparison using simple equipment between freezing and evaporation of one gram of water at room temperature.

The heat pump used has the following advantages:

1) Heat absorption Q_2 on the low temperature side is less than heat dissipation Q_1 on the high temperature side (refer to *Fig. 3*). In mechanical pumps, the water intake is normally equal to the water exhaust.

2) In accordance with the first law of thermodynamics, external work AL is needed to pump up the heat. However, $AL < Q_2$, namely an amount of heat greater than the amount of external work can be pumped up. This can be shown by the following equation:

$$Q_1 = Q_2 + AL$$

$$\varepsilon = \frac{Q_2}{AL} = \frac{Q_2}{Q_1 - Q_2}$$

$$\therefore \quad Q_1 = \left(1 + \frac{1}{\varepsilon}\right) Q_2$$

where $A = 860$ kcal/kWh
L: external work (kWh)
ε: coefficient of performance

Since ε is usually 2 in this type of equipment, the following can be obtained by substituting 2 for ε in the above equation:

$$AL = \frac{Q_2}{2}$$

$$Q_1 = 1.5 Q_2$$

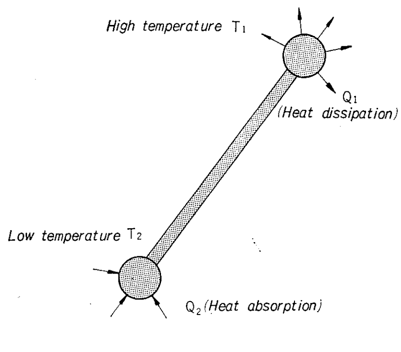


Fig. 3 Heat pump

Table 3 **Energy comparison between evaporation and freeze**

Evaporation ⟵ Boilng point ⟵ Room temp. ⟶ Freezing point ⟶ Cooling

Evaporation	Boilng point	Room temp.	Freezing point	Cooling
	100°C	20°C	−2°C*	−10°C

540 cal (Latent heat) + 80 cal (Sensible heat) = 620 cal (Evaporation)

22 cal (S.H.) + 80 cal (L.H.) + 4 cal** (S.H.) = 106 cal (Freezing)

Note: * Depression of freezing point by salt
** Specific heat of ice: 0.5

Summarizing the above, the ratio of the total energy requirements of evaporation of contained water to those of freezing is a large number as shown below. It is evident that use of the freezing method in dewatering is more advantageous.

evaporation energy / freezing energy

$$=620/(106/2)=11.7$$

III. CHARACTERISTICS OF FREEZING SEPARATION

The freezing separation method described above is unique in that it is not always necessary to use a coagulator for filtration, dewatering can be performed by simple equipment and the cake obtained is physically stable.

In order to determine whether the freezing separation method is suitable for various types of sludge, an experimental test of the freezing treatment was performed by means of plastics sample bottles and metal cans. Since good results were obtained in these tests, an experimental freeze / thaw treatment test was perfomed using 1 t/d prototype test equipment (tank capacity: 100 *l*).

1. Sample Bottle Test

1) Freezing method

Method A: The sludge was placed in 100 m*l* plastics containers and the parts of the containers containing sludge were completely immersed in a refrigerant (methanol cooled by dry ice) maintained at −25°C. Freezing occurred after about 90 minutes. After freezing, the containers were thawed naturally or in hot water and dewatering was then performed.

Method B: The sludge was placed in 1∼2 *l* polyethlene containers which were placed for a specified period of time in an air-circulation type low temperature tank maintained at −15°C to −25°C.

After freezing, the samples were thawed by heating or naturally.

2) Measurement of water content

In order to investigate the effects of the freezing treatment, raw sludge and freeze treated sludge were both filtered in vacuum with the suction funnel method and their water contents were compared. About 100 m*l* of sludge was used. The surface filter area of was about 30 cm^2 and the filtering was performed at 30 mmHg of vacuum for 10 minutes. The filtering was performed for 10 minutes because this equipment generally attains filtration equilibrium in 10 minutes and on this basis, dewatering of the freeze treated sludge was actually completed in 2∼3 minutes or less. Therefore, the water content values were often slightly lower than those obtained in actual filtering equipment because of these favorable conditions.

The water content was calculated by placing samples of 10∼15 g on 60 mmϕ dishes and measuring the weight reduction after drying for 16 hours in thermostatic oven at 105°C.

3) Composition analysis of dewatered cake

The chemical composition of the dewatered cake dried for 16 hours in thermostatic oven at 105°C was determined by the usual chemical analysis. Components in very small amounts were determined by the atomic absorption method.

4) Water quality analysis of filtrate

The filtrate obtained in separation of solid particles was subjected to a simple water quality analysis for total evaporated residue, soluble residue, oil content, etc. according to JIS K 0101. The dissolved elements were determined by the atomic absorption method but the favorable analytical methods were not constant because the contents were different in each lot of sample sludge and many samples are still continued to being analyze.

5) Test results

For the more than two hundred samples which have been freeze treated so far, the test results have been compiled and are shown is *Table 4*.

The water contents after freeze treatment were lowered to 50∼60% and depending on the type of sludge, some were as low as 40%.

In the case of plating sludge, the final water content differed from the case when lime was added as a neutralizer and flocculation agent, but in the case of water purification plant sludge, the water content of sludge precipitated by aluminium sulfate treatment was easily lowered to 50% without the addition of lime as flocculating agent. Therefore, the conventional neutralizing process using calcium hydroxide after the acid treatment is not necessary and the amount of cake is increased vainly by calcium salts precipitate. In the former method, since calcium hydroxide was present in the cake, the cake showed a high alkalinity and the cake containing lime did not have a good soil quality.

Table 4 **Some results of freeze dewatering**

Description of sludge	Water content (%)			Composition of sludge particles (%)						pH	Composition of filtrate (ppm)			
	Raw sludge	Vacuum filtration only	Vacuum filtration after freezing	Ignition loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	Others		Oil	Total evaporation residue	Soluble residue	Suspended solids
Plating sludge	97.7	87.4	69.3	24.2	10.6	7.9	4.4	tr	CuO 29.7, NiO 12.3	8.4	3.2	1,202	1,189	
Plating sludge	98.0	85.5	68.2	36.6	1.4	14.3	tr	1.7	CuO 13.2, Cr_2O_3 27.8	6.5	4.0	2,438	2,392	
Plating sludge	92.3	78.7	62.5	25.1	8.4	tr	23.9	15.7	CuO 5.0, Cr_2O_3 3.4, ZnO 2.2	7.2	2.2	1,233	1,204	
Plating sludge	94.5	80.9	54.6	30.8	2.3	6.7	3.6	27.3	CuO 0.6, Cr_2O_3 13.5	7,5				
Acid washing sludge	97.5	78.3	47.0	14.3	0.2	15.2	48.6	9.9	Cr_2O_3 1.9	7.2	—	3,624	3,490	4.8
Iron works sludge	97.2	85.1	55.2	15.6	3.3	11.4	36.7	21.5	ZnO 8.1	11.6	2.8	1,086	1,048	
Aluminum surface processing sludge	90.7	85.4	68.7	37.5	10.1	47.6	4.0	tr	MgO tr	7.6	2.6	1,275	1,270	5
Water purification plant drain sludge	95.1	72.1	56.2	28.1	34.4	29.7	6.4	tr	MgO 1.5	6.5	0.8	495	436	3.4
Water purification plant drain sludge	94.3	74.1	54.3	22.1	38.3	32.5	5.1	tr	MgO 0.7, MnO 0.03	7.0		179	152	
Water purification plant drain sludge	89.8	75.0	50.9	16.7	45.2	29.3	5.0	tr	MgO 0.99, MnO 0.04	6.5		196	171	
Water purification plant drain sludge	92.9	88.5	47.7							6.7				
Industrial drainage sludge	94.1	91.1	61.4							7.1				
Pulp sludge	96.2	79.4	65.4							7.2	0.4	1,439	1,395	
Pulp sludge	95.1	73.8	52.9							12.5	1.2	2,915	2,903	
Wool sludge	95.0	71.2	52.7							10.7				
Titanium sludge	91.8	82.0	34.0							6.2				

However, all these disadvantages have been eliminated with the freezing method.

The filtrate has a large total evaporation residue due to various dissolved salts except in the case of the water purification plant sludge, but there will be few problems caused by heavy metal ions if the neutralizing conditions are controlled sufficiently.

In the table there are cases when the pH of the filtrate is rather high but this is not the final filtrate to be discharged and it will either be returned to the neutralization tank or be reneutralized in some way.

2. Experimental Freeze Treatment Test Using Metal Cans

In order to know more accurate conditions required for the freeze treatment, metal cans with various widths as shown in *Fig. 4* were prepared. The cans were filled with test sludge and subjected to freeze treatment by immersion in a cold brine tank with a given circulation rate. After freezing, the cold brine was replaced with tap water and the cans were thawed. A thermocouple was placed in the center part of the sludge and the freezing and thawing times were recorded. A typical example is shown in *Fig. 5*.

1) Influence of sludge thickness and can material on freezing time

Fig. 6 shows a few examples of the freezing curves when the thickness of the plating sludge used is changed. These are the results when the refrigerant at a temperature of $-25°C$ was circulating at a rate of 0.45 l/min. It is evident that freezing rate is lower in a stainless steel can than in a copper can because of the difference in thermal conductivity.

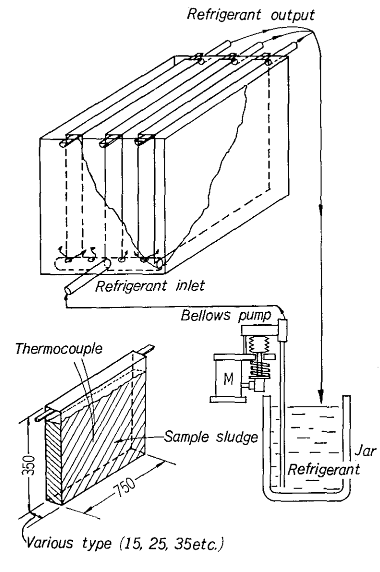


Fig. 4 **Freeze dewatering test device using ice can**

2) Influence of sludge concentration and freezing temperature on freezing time

Fig. 7 shows typical freezing curves when the concentration of the water purification plant sludge and the freezing temperature were changed. In this case,

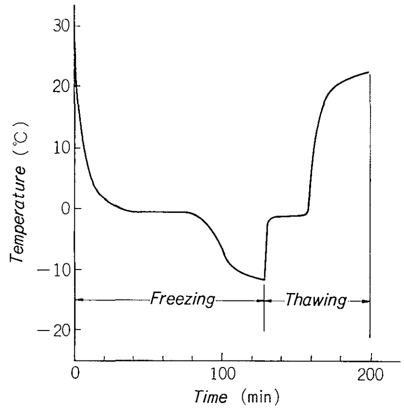


Fig. 5 **Freezing and thawing time**

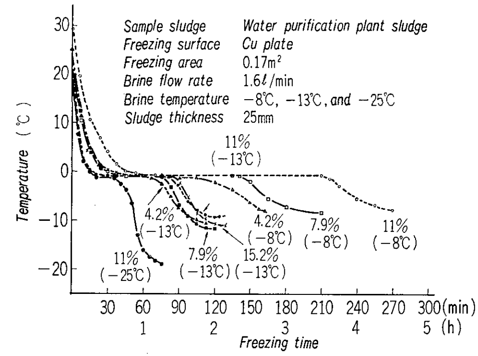


Fig. 7 **Relationship between sludge concentration and freezing time**

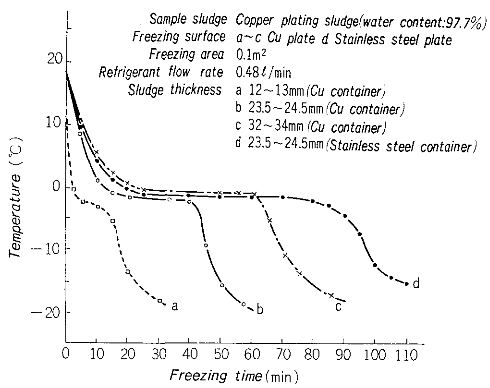


Fig. 6 **Relationship between sludge thickness and freezing time**

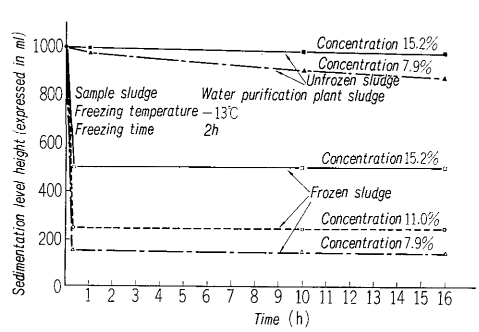


Fig. 8 **Settling rate**

the can was made of copper, the sludge was 25 mm thick and the cold brine was circulated at 1.6 l/min. in all cases. When the sludge concentration was high, the time required for freezing was extended and if the brine temperature was low, the time required for freezing was naturally shortened. The water content after vacuum filtration in this experiment is shown in *Table 5*. There was no important differences and the content was independent of the concentration of raw sludge.

3) Freezing treatment and settling rate

Fig. 8 shows the settling rate curves of the above-mentioned water purification plant sludge before and after freezing treatment. The settling rate of the frozen sludge was much greater than that of the unfrozen sludge. No matter what the sludge concentration, settling was almost complete within 10 min. and a rate of over 500 mm/min. was achieved. The concentration of the settled sludge was also 2~6 times that of the non-frozen sludge.

Table 5 **Sludge concentration effect to freezing time and dewatering**

Raw sludge concentration (%)	Refrigerant temp. −8°C		Same as left −13°C		Same as left −25°C	
	Freezing time[1] (min)	Water content after vacuum filtration (%)	Freezing time[2] (min)	Water content after vacuum filtration (%)	Freezing time[3] (min)	Water content after vacuum filtration (%)
4.2	157	56.3	105	51.7	—	—
7.9	180	51.9	102	48.7	—	—
11.0	260	55.2	125	54.2	57	63.5
15.2	—	—	114	53.6	—	—

* 1) time until −7.5°C is reached
2) time until −10°C is reached
3) time until −15°C is reached

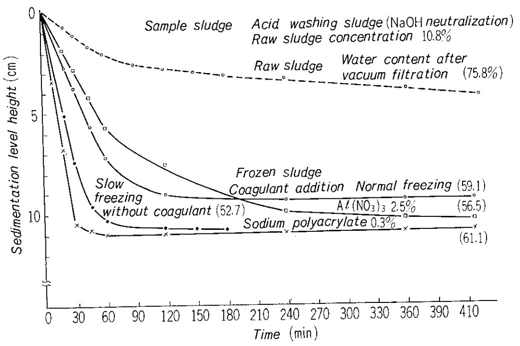


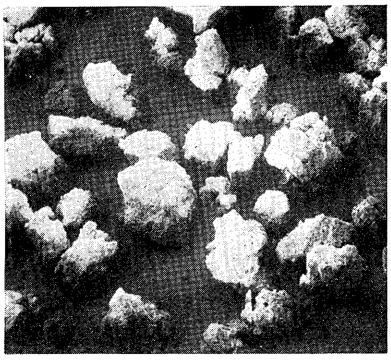
Fig. 9 Settling rate

Fig. 9 shows typical curves of the settling rate for pickling sludge of steel which was neutralized with NaOH. The settling rate of the frozen sludge was rather fast and the results were especially great when polymeric flocculants were added. Sludges which were frozen at lower rates (frozen for 5~6 hours in polyethlene containers holding 1 *l*) had a settling rate two times greater than the usual one. The figures in parenthese on the figure indicate the water contents of the final cake after vacuum filtration dewatering. However, it can not always be said that the addition of polymeric flocculant is favorable.

4) Changes in particle diameter and shape due to freezing

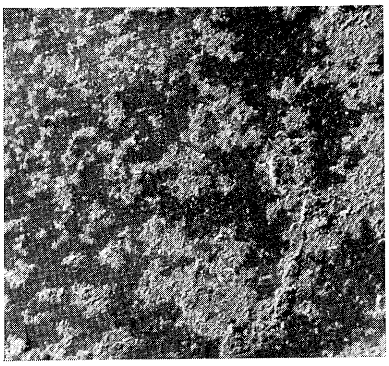
The sludge particles were examined by a scanning electron microscope before and after freezing. The results showed that the particle diameter increased greatly and the form was not uniform. *Figs. 10* and *11* show typical particles of sludge before and after freezing.

(a) Raw suldge ×150

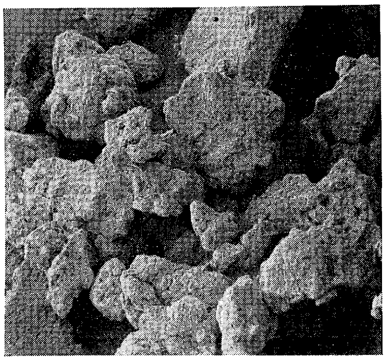


(b) After treatment ×50

Fig 10 Microphotograph of plating sludge



(a) Raw sludge ×150



(b) After treatment ×50

Fig. 11 Microphotograph of filtration plant sludge

The above-mentioned settling rate obeyed Stoke's formula. The rate was greatly improved after freezing because of the much larger particle size as shown in *Fig. 10* and *11*.

3. Freeze/thaw Experiment Using a Prototype Testing Device

The prototype testing device was produced with two opposing tanks (freeze and thaw tanks) in order to increase the scale of the formerly mentioned can system and also aid in the development of the 1 t/d packge type equipment to be mentioned later.

This prototype of equipment was provided with iron cooling plates to which were fixed on both ends horizontal tubes made of copper for circulation of the refrigerant. Freezing of the sludge was performed in the freeze tank (100 *l*) with cold gas expanded directly in tubes of the tank by the 3.7 kW refrigerator. In the thaw thank, the frozen sludge was thawed by the heat of hot gas from a refrigerator.

Table 6 shows typical results of freeze treatment performed by this testing device. For comparison, the results before and after laboratory treatment of the some sludge with the can system are included, but they are almost the same as those obtained with the prototype testing device. The water content was somewhat lower when centrifuge dewaterizer was used but this problem of dewatering method should be decided in accordance with the workability, price, maintenance, control, etc. of the equipment.

***Table 6* Some results by prototype testing device**

Treatment	Dewatering	Water content of dewatering cake (%)		
		Water purification plant sludge	Plating sludge	Al surface processing sludge
Raw sludge	—	94.3	94.5	90.1
Frozen sludge by experimental container freezing method	Vacuum filtration	54.3	56.2	68.9
Sludge frozen by prototype device	Vecuum filtration	55.5	57.0	69.3
Sludge frozen by prototype device	Centrifugal filtration	52.4	55.6	68.5

Freezing/thawing conditions of prototype device
Refrigerant evaporation temp.: −25°C
Time required for freezing: 2 hrs
Time required for thawing: 1.75 hrs

4. Test Results

The main points from the above test results are as follows:

1) This method is effective in the dewatering of sludges in colloidal state which are difficult to filter and dewater. It is very effective with metal hydroxide sludges as well as with viscous clay-like sludges such as those from water purification plants.

2) The freezing rate is the main factor in freezing condition and the sludge concentration and freezing temperature have rather no effect. There is no factor related to the thawing conditions.

3) It is not always necessary to add coagulants, but the effect is generally greater if they are added. Coagulants are especially effective in the case of organic sludges. However, they do not seem to have any major effect on the dewateribility or final water content.

IV. ECONOMY OF FREEZE DEWATERING

It is difficult to consider the cost of freeze dewatering in general terms but it is clear as was described above that the power required for evaporation of the water is 11 times that required for freezing.

When comparing the costs of sludge treatment equipments, the main difference in economical comparison between other plants and sludge equipments is that the sludge treatment costs differ greatly in accordance with the disposal method. Therefore in comparing the economy of sludge equipments, it is necessary to add the equipment costs, chemical costs, fuel costs, maintenance costs and repair costs to the disposal costs. The principle in the treatment of all waste materials, not only sludge, is to dispose of as reduced mass as possible. For example, the complete costs for the treatment of one ton of plating sludge with a water content of 95% will be compared for the following cases:

1) Disposal untreated
2) Weight reduction by vacuum filter
3) Incineration
4) Freezing separation

1) Disposal untreated

The cost for disposal in concrete containers in the sea is 26,000 yen per ton.

2) Weight reduction by vacuum filter

When the water content is reduced to 75% by a vacuum filter and then the sludge is disposed of in the sea in concrete containers, the depreciation and operation costs of the vacuum filter are 1,500 yen per ton and the disposal are reduced to 1/5 due to the decrease in the water content from 95% to 75%. Therefore the total cost per ton is 1,500 yen + 5,200 yen = 6,700 yen.

3) Incineration followed by disposal in concrete containers

The depreciation, operation and fuel costs for incineration are 5,400 yen per ton. The incineration reduces the disposal costs in the sea to 1/20 or 1,300 yen. Therefore the total cost per ton is 6,700 yen.

4) Weight reduction by freezing separation

The depreciation and operation costs for the freezing separation method are 1,900 yen per ton. The freeze dewatering reduces the water content from 95% to about 50% so that the amount to be disposed of is reduced to 1/10 and the cost will be 2,600 yen, for at total of 4,500 yen.

From the above, it is evident that the weight reduction has considerable influence on the cost. If the plating sludge is simple sludge such as hydroxide nickel, of chromium, or copper with little impurity, it is possible to sell the sludge which has been dewatered by the freezing method. For example, if the sludge in the above mentioned case with a water content of 50% can be sold for 1,000 yen, per ton then the disposal cost by the freezing method is reduced to 900 yen.

In the case of the equipment for water purification plant sludge, the disposal method is also a very important point. The quality of the sludge after dewatering varies depending on the location and the season and it is difficult to determine disposal costs. Generally the sludge after freezing treatment changes to excellent properties in respect to soil mechanics so that the disposal costs decrease.

The fact that the freeze-dewateing method causes no secondary pollution means that additional equipment costs required when pollution control become more severe in the future will not be needed. This is an advantage which is difficult to incorporate in the present economical comparison figures, but it is very important since the legal responsibility for pollution will be applied retrospectively.

V. OUTLINE OF SMALL CAPACITY EQUIPMENT

An outline is given below of one of the standard models of small capacity equipment, the package type FSS-1 which is capable of treating 1,000 *l* of raw sludge in 24 hours.

1. Construction of Main Parts

1) Capacity of freezing equipment

In order to treat 12 batches of a total of 1,000 *l*, the amount of sludge treated per batch is to be 84 *l* and the freezing equipment load was decided as 5,340 kcal/h from the following equation.

$$\left\{M\cdot C_W(t_0-t_f)+S_f\cdot M+M\cdot C_S(t_f-t_e)\right\}\frac{60}{120-T}\quad\cdots(1)$$

where : M: sludge weight per batch in kg

C_W, C_S: specific heat of liquid and frozen sludge, kcal/kg°C

S_f: latent heat of freezing, kcal/kg

t_0, t_f, t_e: intitial sludge temprature, freezing temperature and temperature when freezing completed, °C

T: operation time for sludge insertion, min, etc.

Therefore, the refrigerator used was a semi-enclosed motor driven compressor of 3.7 kW with a capacity of 5,500 kcal/h at a condensation temperature of 38°C and an evaporation temperature of −15°C.

2) Sludge tank

When the water is frozen, the volume of the ice expands to 1.09 times the original volume of the water. Because of such expansion, pressure is applied to the inner walls of the tank and there is a danger of breakdown. In order to prevent this, the freezing tank in this equipment is of cylindrical form which is strong against internal pressure and it is provided with a cushion layer to absorb the expansion during freezing. The bottom of the tank is in the shape of a cone with angles which facilitate sliding of solids so that the solid part can be removed easily after freezing. The outlet is a gate operated by compressed air. The structure of tank is of the monocock type insulated thermally with flexible foam.

3) Freeze/thaw coil

The coils are in direct contact with the sludge and must have a high coefficient of overall heat transmission. Therefore, rust-proof metal tubes are used. Suitable corrosion resistant tubes are elected in accordance with the type of sludge to be treated.

The coils are arranged so as to freeze completely down to the conic bottom and to reduce the pressure applied to the inner walls. In order to avoid thermal stress during freezing and thawing, rigid attachment is avoided to the utmost.

4) Control system of refrigerant

At the beginning of first operation, the tank on the thawing side is empty and can not be used as a condenser. Therefore, a forced air cooled type condenser which can handle all heat given off is employed. *Fig. 12* is a flow sheet of the freeze separation system.

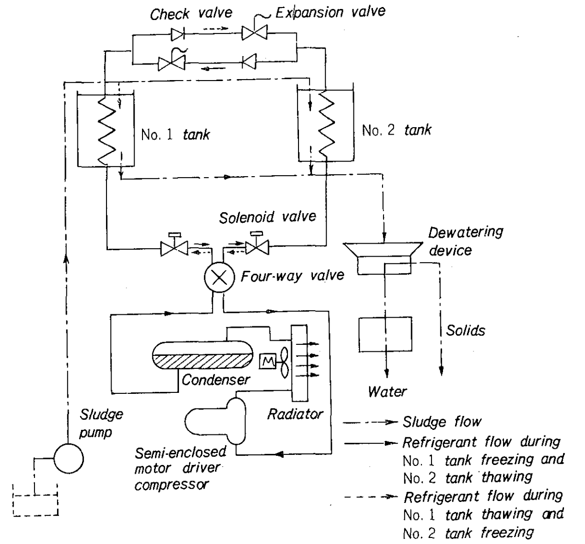


Fig. 12 **Flow sheet of freeze separation system**

According to calculations from this freezing circuit, the coefficient of overall heat transmission is decreased in accordance with the formation of the frozen layer on the coil surface during the process of the absorption of the latent heat of freezing. However, the freezing rate can be kept almost constant by increasing the surface area. When frozen sludge on the adjacent pipes mutually come into contact, the freezing rate decreases and the evaporation temperature of the refrigerant also falls from −11°C or −13°C to about −20°C.

5) Design of the dewatering device

The sludge treated by the FSS model has its particles bound together by freezing and separation of the hydrated layers on the surfaces of minute particles and coarse particles are formed, which are easy to dewater. The dewatering equipment should be designed so that these coarse particles are not destroyed and the shearing force does not effect the sludge or the cake. The FSS-1 model uses a vacuum filtration device with no mechanical agitation or impact action.

6) Control sequence

This equipment operates automatically from feed of the sludge until removal of the cake. The unit is divided into three parts : feed of sludge, freezing/thawing and dewatering. The amount of sludge fed is controlled by a level switch and a timer, and the cycle of freezing/thawing by a liquid-sealed temperature regulator and a timer. This is in the form of a sequence with a fail-safe mechanism by means of the timers. The necessary interlocks are provided to prevent sludge feeding when the freezer is not operating, on the other hand sludge feeding when gate is open.

2. Specification

The above section has discussed the design of each part in detail. The specifications of the FSS-1 model are given in *Table 7*. *Fig. 13* shows an outline drawing and *Fig. 14* an outer view of the model.

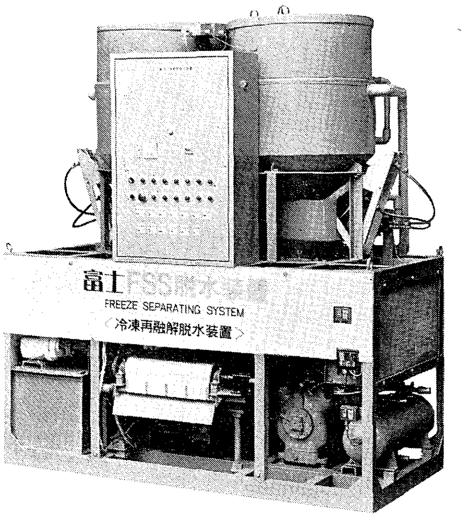


Fig. 13 Outline of type FSS-1

VI. CONCLUSION

The above article has given an outline of the principles and characteristics of the freezing serara-tion method, comparisons of economy and the small capacity model FSS-1 as an example of the practical application of the method.

However, the freezing separation method has shown that it has excellent dewatering capability for drain sludges from municipal water purification plants, iron and steel works, pulp and paper mills. Therefore, it is expected that the method will be utilized more and more in these fields where a large amount of sludge must be treated.

Table 7 **Specifications of type FSS-1**

			Type FSS-1 Sludge Freezing Separation System
Power source			3ϕ, 200/220 V, 50/60 Hz
Current			20 A
Dimensions		Height	2,300 mm
		Breadth	2,000 mm
		Depth	1,000 mm
Weight			ca. 1,700 kg
Capacity			1,000 *l*/day
Refrigerant system	Compressor		Semiclosed
	Compressor motor	Type	4 poles, 3ϕ induction motor ×1
		Rated output	3.75 kW
	Condenser	Type	Fin coil forced air cooled
		Blower motor	4 poles 3ϕ induction motor 100 W×2
	Refrigerant controller		Automatic thermal expansion valve
	Freeze coil		Corrosion resistant helical coil
	Refrigerant		R-22 17 kg
	Oil		SUNISO 3G 3.3 *l*
Operation	Operation switch		Push button and rotary switch
	Pilot lamp		3 colors (power supply, operation, abnormal)
	Freeze/thaw temp. control		With thermostat
Controller			Full automatic and manual
Protecting device			High and low pressure switch, crank case, heater overcurrent relay, fuse, overflow switch, internal thermostat
Vibration & noise counter measure			Resilient rubber for compressor
Remarks			Capacity at ambient temp. 32°C and sludge temp. 30°C

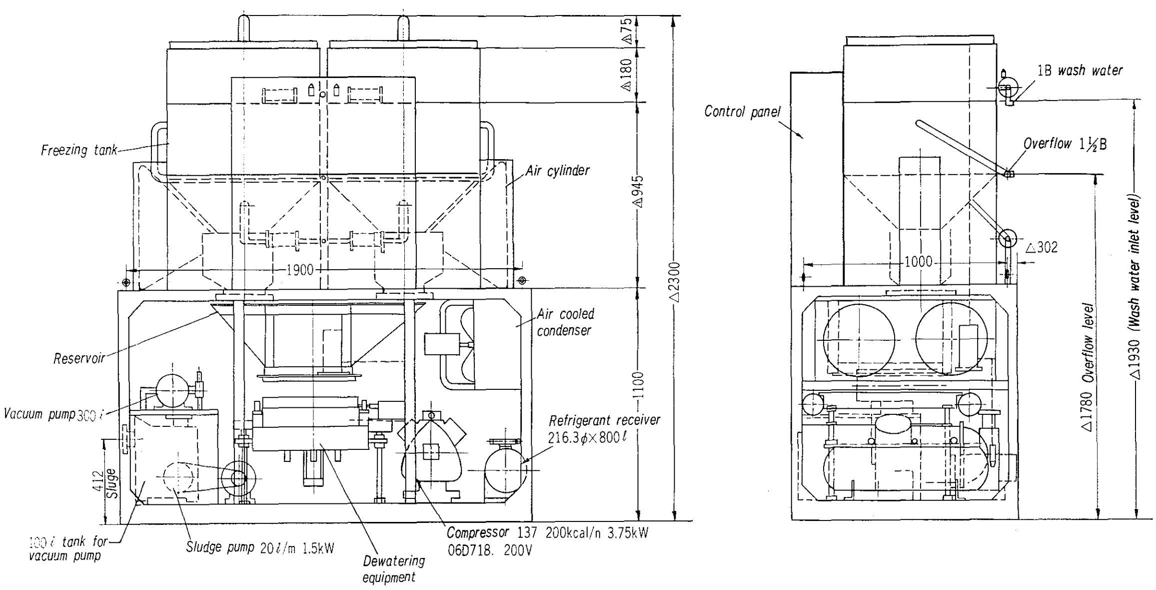


Fig. 14 Outline of type FSS-1