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Selection of Sludge Treatment and Disposal Processes in a Water Purification System

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Abstract

In many places of the world, disposal of untreated sludges from water treatment plants is prohibited by law. Investment of money for sludge treatment facilities is sometimes comparable with that of purification facilities where environmental restrictions are severe. Therefore, a rational design of sludge treatment facilities is strongly required. Treatment processes can be selected by taking both factors in the raw water and environmental conditions of the individual water works into account. With respect to purification processes, the least amount of coagulant dosage is essential so as to improve treatability and decrease the amount of sludge generation. For this reason, direct filtration of low-turbidity water is recommended because of its much lower alminium/turbidity ratio. Sludge treatment processes can be selected mainly by the nature of sludges and the conditions of disposal and reuse. The authors show the advantages and drawbacks of typical systems. Quantitative experimental and statistical data with respect to those processes and systems are presented with discussions of the mechanism and theories of new processes. Disposability of treated sludges, secondary environmental pollution problems, reuse data of recovered alum, production of ceramics from sludges, and evaluation of sludge natures for gardening or agricultural use are discussed by the numerous experiences in the authors' research activities.

1. Introduction

From a technical viewpoint, water and wastewater treatment can be defined as the operation to fill quality gaps existing between raw water and required water by combinations of several treatment processes. At the same time, from an environmental viewpoint, the treatment can be understood as such operations that redistribute impurities in water (liquid phase) to the soil (solid phase) or air (gas phase) to improve usefulness or to limit deterioration of environments and/or resources.

If there were ample space in the environment to accept the flow of solid waste from water treatment operations, engineers could design and operate water treatment facilities only from a viewpoint of water purification. Because of environmental restrictions, however, disposal of untreated sludges from water treatment plant are not allowed by law in many areas of the world. The purpose of sludge treatment is to facilitate the return of solid impurities to the land with the least energy consumption, land use and manpower.

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Investment of money in sludge treatment facilities is sometimes comparable with that of purification facilities where environmental restrictions are severe. Therefore, the rational design of sludge treatment facilities is strongly required. Frequently, revising of the main water purification system is required to obtain total effectiveness of a whole water and sludge treatment system under given environmental conditions.

The authors intend to present numerous Japanese experiences for a period of more than twenty years as well as other methods practiced in other countries on the basis of the authors' classification and evaluation of various systems. Sludge treatment and disposal processes are selected by taking both factors in the raw water, and natural and social environments of the individual water works into account. A general flow scheme of water purification, sludge treatment and disposal is illustrated in Fig. 1.[15]

The prime requirement for a water treatment plant is to obtain safe potable water. Therefore, if environmental restrictions are not stringent, engineers can design and operate water purification processes merely from a viewpoint of producing good quality water.

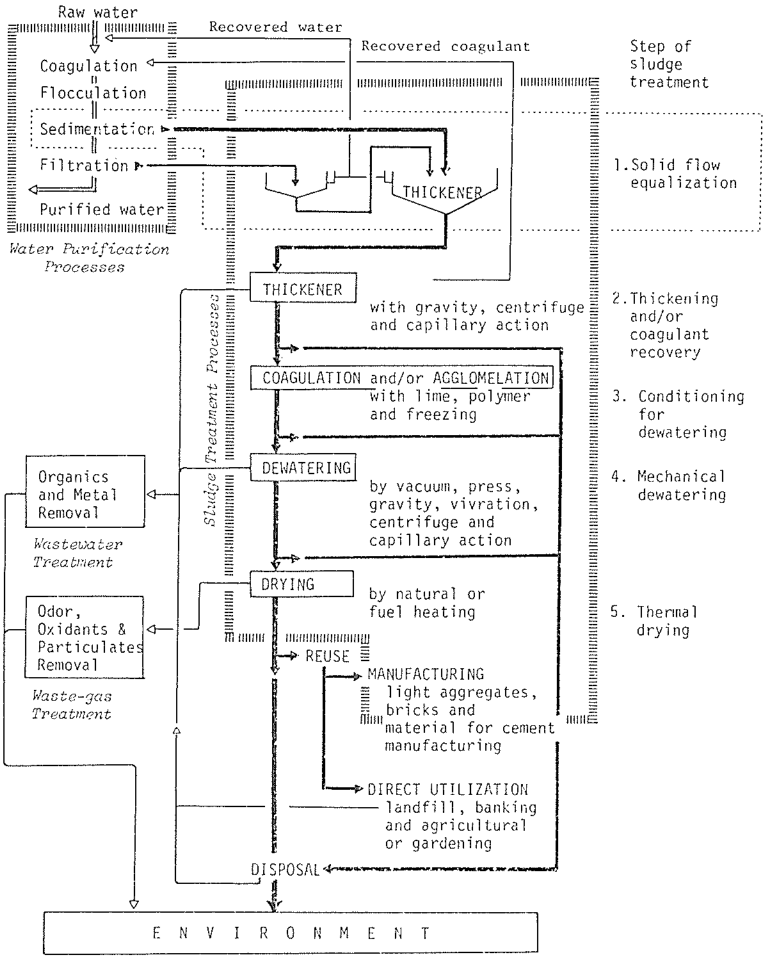

Fig. 1 Water and sludge treatment processes

However, when restrictions with respect to sludge disposal in the environment are imposed on engineers, it is necessary to devise a means of improvement of water purification processes so as to decrease sludge production as well as to add necessary sludge treatment processes to the purification processes. Therefore, discussion of the control of the impact of sludge discharge into the environment can be related to two categories of treatment processes. One is water purification and another is sludge treatment.

2. Sludge control in purification processes

In the purification processes, reduction of sludge production, and improvement of sludge characteristics at the production step with respect to thickening and dewatering are two major aims for the control.

a) Selection of raw water

The amount and properties of sludges vary considerably depending upon the characteristics of raw water and the types of treatment selected with respect to the raw water. Thus, the selection of raw water has a prime importance in the sludge treatment system design as well as in the purification process selection. Properties of suspended matters including coagulable colloids are important. Size distribution, ignition-loss and total concentration of the suspended and colloidal substances should be known for a whole year or at least with typical samples of the four seasons.

To estimate the amounts of an annual sludge production and chemical consumption, probability data of the turbidity occurrence are necessary. In addition to this long term data of the turbidity occurrence, the duration and frequency of high turbidity occurrence in a short time are also necessary to know how to design the necessary capacities of sludge flow regulation and treatment facilities. In water treatment plant design, steady state design for water purification processes and unsteady state handling for sludge treatment system are important basic characteristics to be marked.

b) Selection of operations

The least amount of coagulant dosage is recommended for the reason that it not only decreases the amount of sludge production but also improves treatability of the generated sludges throughout the following sludge treatment processes. Fig. 2 shows the case of clay turbidity removal by alum coagulation.[12] These figures show that at lower specific aluminium dosage with turbidity, i. e. Aluminium/Turbidity, or Al/T ratio, both thickening and dewatering properties are improved greatly. For the reasons of both decreasing sludge production and also improving treatability, for low turbidity conditions, use of direct filtration is recommended.[12]

For the coagulation of organic colloids such as colored waters, weak acidic pH range should be selected so as to attain the lowest aluminium or iron coagulant dosage.[12]

To decrease the amount of dosage, the use of cationic polymers has been proposed. To attempt effective coagulant recovery, the use of magnesium compounds was proposed.[7] However, the polymer is only effective for high turbidity conditions of coarse suspended matters and the use of magnesium is not popular.

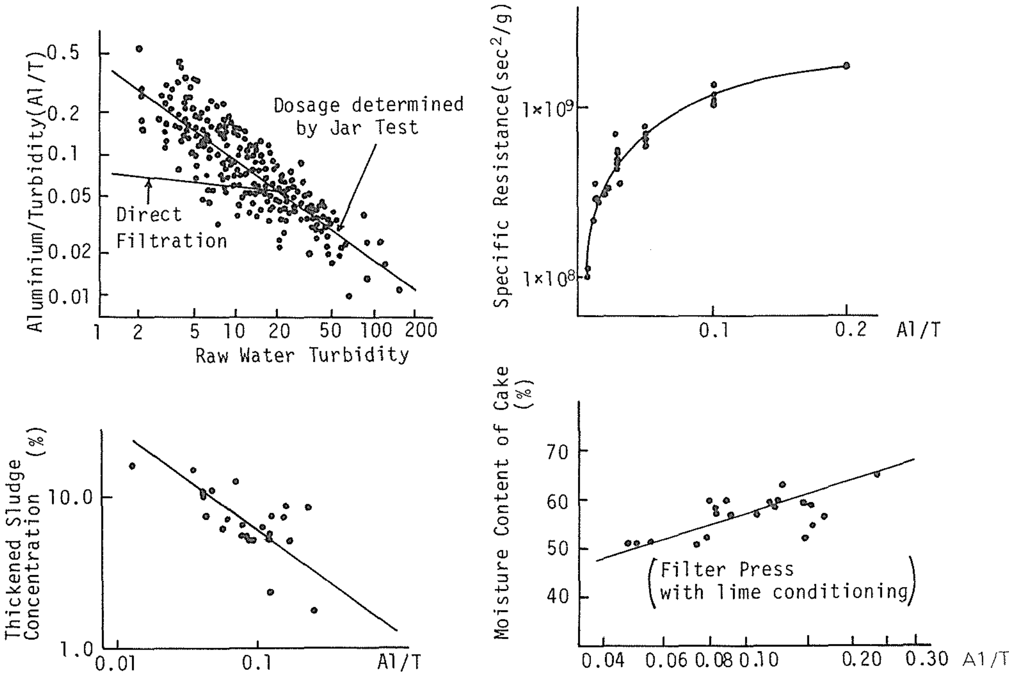

Fig. 2 Effects of specific alum dosage

3. Sludge treatment processes

a) Flow equalization

Wastewaters and sludges from backwashing of filters and sludge-blow operation of sedimentation basins are usually withdrawn intermittently. Therefore, a certain amount of storage capacity is required to flatten the intermittent flow of water and solid in connecting with the following thickening and dewatering processes, which are usually operated with a constant rate of flow for a certain period. Usually, these equalization basins are used as a primary or preparatory thickener.

Seasonal variations of sludge production should be averaged out by giving a large amount of storage capacity in the sludge treatment system. Usually, the sludge zone of the horizontal sedimentation tank functions adequately for the purpose.

b) Thickening

Thickening can be defined as the process of concentrating solids under the condition in which water is the basic continuum. Therefore, progress of the operation is evaluated by the increase of the solid concentration in water (g/l). Sludges withdrawn from sedimentation basins have usually 0.5-2% solid content depending upon the types of raw waters and sedimentation tanks, and methods of sludge withdrawal.[12] The upflow clarifier is apt to generate dilute sludge and needs a large thickener. For the driving force of the thickening, gravity is the most common. Centrifugal force or capillary action is used when very high concentrations are required from the following processes, such as sludge conditioning by freezing and thawing.

To improve the rate and extent of thickening of the bulky flocs, chemical conditioning is often used. One of the most popular methods is the addition of a certain amount of weak anionic or nonionic polymer to the sludges. Usually, one to several milligrams of polymer are applied to one gram of solid.[12] Polymer conditioning can be used for both clay and organic flocs coagulated by metal coagulants. Toxicity of polymer should be checked, especially when the supernatant liquid is to be returned to the raw water.

For the clay-aluminium flocs, the addition of strong acid or alkaline solution to dissolve aluminium in the flocs can improve the rate and extent of thickening, and makes it possible to recover the aluminium as the coagulant.[2,6] Usually sulphuric acid is used to bring the pH down to about 2.0.[12] This acid process, however, can only be used for clay or coarse suspentions. Minute organic colloids or metal precipitates are resolved by the process and drawn out into the supernatant liquid. One hundred per cent recovery is possible in practice.[12] Resolved manganese in the reclaimed coagulants is completely removed in the filters by way of chlorination with autocatalytic reaction of precipitated manganese on the sand grains.[12]

Biodegradable organics in flocs consume oxygen in a thickener when too long a detention time is given in low turbidity drought seasons. Oxygen deficiency in the thickened sludges tends to resolve reduced metal ions and biodegradable matters as organic acid. The deterioration requires wastewater treatment facilities in the sludge treatment system.

c) Preparatory conditioning for dewatering

Dewatering can be defined as an operation that removes water from the thickened sludges by physical or mechanical means under the condition in which the solid is the basic continuum. Therefore, the progress of operation can be evaluated by the moisture content in a unit weight of sludge (weight per cent).

For mechanical dewatering such as cake filtration, the following three properties of sludge are necessary (refer Fig. 3) : (1) Original microflocs should be aggregated to keep the least size of secondary pore channels which enable water to pass with a reasonable rate of flow under a reasonable head, (2) Aggregation of the microflocs should not be so large as to allow unremovable water to remain in the primary pores, (3) Thin coagulant coverage on the original suspended particles is required so as to avoid an increase of

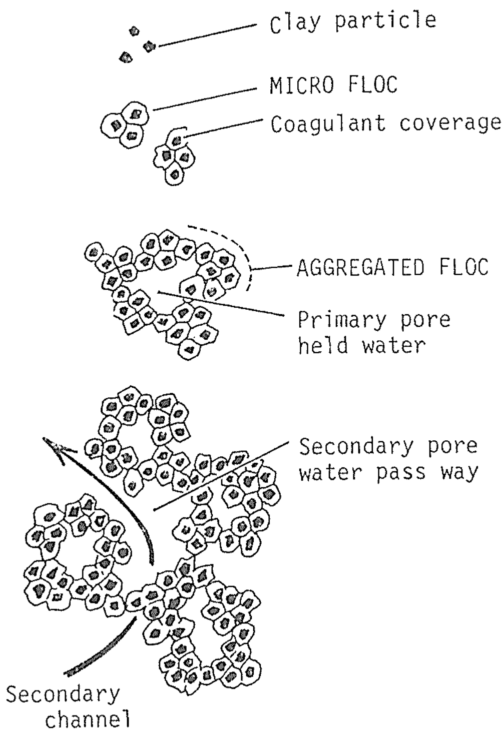

Fig. 3 Structure of floc and sludge

primary pore volume. The above mentioned characteristics are reflected in such indices in the following dewatering processes as the specific resistance and the coefficient of compressibility in the cake filtration, and the moisture content of the dewatered sludge.

Major processes being used are lime or polymer addition, and freeze-thawing.

Lime conditioning : By the addition of 10-50% of slaked lime to the thickened sludge, the specific resistance of the conditioned sludge cake is about one order or a little lower than that of the original sludges.[12] The pH of the sludges is about 12. Aluminium resolution and recoagulation with lime proceed at the same time. In this conditioning process, the insoluble part of lime may play an important role.[12]

Aluminium stripping in the thickening process is followed by recoagulation by lime in about 20% of solid at pH 12 or more.[12] This process has been used very widely since the 1960s in Japan.[6] However, the use is restricted to the sludges which do not include much organic content. This mechanism may be explained as follows : 1) By the addition of sulphuric acid, the bulky aluminium hydroxide is resolved, 2) The stripped clay is recoagulated by the lime. These lime coagulated flocs are much smaller aggregates than alum flocs and contain less interpore (primary pore) water with the least necessary intrapore (secondary pore or channel) required to pass water ; 3) As a result, cake filtration proceeds at a reasonable rate and the resultant cake has an acceptable moisture content.

The defects of lime conditioning are : 20% or more increase in the solid by the addition of a large amount of slaked lime, and the high pH of the generated cake which restricts freedom of final disposal.

Polymer conditioning : The addition of nonionic or weakly anionic polymers improves the rate of dewatering remarkably. Polymer added at the stage of thickening is useful with a small amount of additional dosage for the dewatering. Increase of the aggregated floc size makes large interpore (secondary) channels making the draining of intrapore water very easy. Frequently by only the slow mixing of polymer with sludge for an extended duration pelleting will occur. In Japan, polymer coagulation in a rotating horizontal drum is widely used to carry out the pelleting and squeezing out of intrapore water by cyclic shearing forces, induced by the drum rotation (refer Fig. 4).[10] Squeezed water from the pellets during the drum rotation is discharged by gravity. Due to the large pellet size (1 mm-1 cm), the moisture content of the intrapores is still relatively high.[12] The pelleting treatment is effectively used for coarse suspensions. For organic colloid flocs, pelleting does not proceed effectively, but an improvement of dewatering is still possible. By a small amount of polymer addition, improvement in the rate of cake filtration proceeds, but increase of agglomerated floc size is apt to increase the moisture content of the squeezed cake. Toxicity of the polymers should be noted.

As it has been described above, polymers can be used with a wide range of dosage from a small amount for the filtrability improvement to a high-dosage for the pelleting. Toxicity of the polymers usually is caused by inevitably included monomeric compounds arising from incomplete polymerization. Therefore, the use of a high grade polymers with a lesser amount of remaining monomer is required. Polymers in the disposed cake decompose with

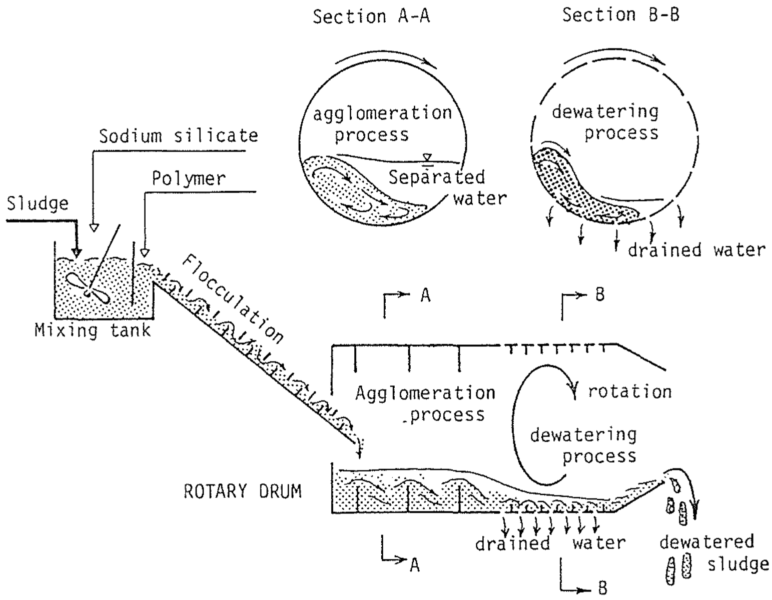

Fig. 4 Pelleting Process

time. However, it is reported that the rate of the decomposition of the polymer into monomer is much slower than the rate of monomer decompositon into inorganic non-toxic compounds with respect to weakly anionic polyacrylicamide which is the most commonly used polymer for the pelleting in Japan.

Freezing and thawing : A slow freezing of the thickened sludge causes the exclusion of solid particles from the ice crystals.[1,4] By increasing the ice pressure being exerted under confined conditions in a freezer, excluded flocs are agglomerated, compressed, and turned into high density aggregates. This process can be used for all kinds of usual sludges without adding chemicals if high energy consumption is acceptable. For saving of energy the freezing and thawing operations proceed at the same time in a twin container acting as a heat exchanger. For greater saving of energy, thickened sludge concentrations as high as 10% or more are required. For this purpose centrifugal thickeners are frequently used. The energy consumption for the centrifugal process is comparable to that of the freezing process itself. To overcome the deficit, other less energy-consuming thickening processes, such as capillary thickening etc. are being developed.

d) Dewatering

Dewatering of sludges can be done by various processes, from simple gravity drainage to sophisticated automatic pressure filtration with the choice depending upon the raw or conditioned sludge characteristics and the final sludge quality required for the disposal. Fig. 5 illustrates the combined performance of the dewatering and pretreatment processes in connection with the raw and attainable sludge concentration of the combination.

In the early 1960s when sludge treatment was gradually being introduced into water treatment plants, vacuum filtration with lime conditioning was the most common one for

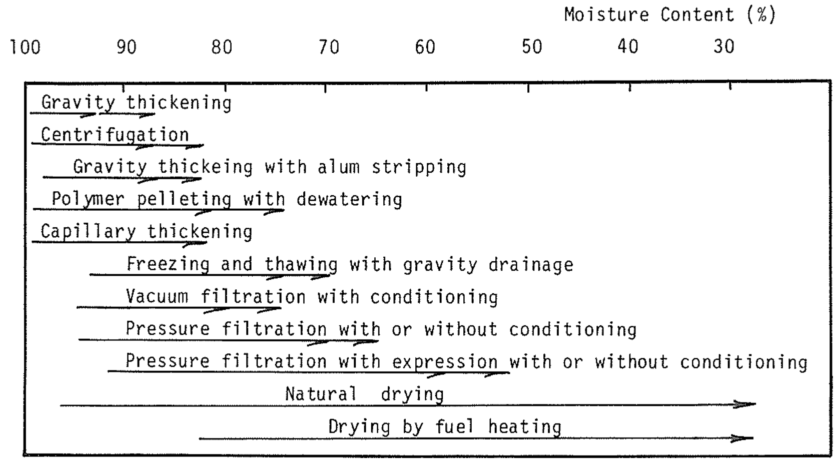

Fig. 5 Performance of thickening, dewatering and drying

handling large amounts of sludge where drying beds could not be used due to shortage of land area.[6]

The Development of automatic control techniques has made possible efficient automatic pressure filters. By automation, the use of large numbers of thin filter chambers with a short cyclic operation time which brings about a high rate of cake production with low final moisture content,[14] becomes possible. Sludge is pumped into the chambers with a pressure of 3-5 kg/cm^2 and pressed at 10-15 kg/cm^2. Nowadays, pressure filtration with or without conditioning is considered to be a more reliable and efficient dewatering process. The largest apparatus has fifty 2.5×2.5 m chambers.

e) Drying

Thermal drying is used for further decrease in moisture content of the dewatered sludge. Using fuels or electricity to improve poor performance of pretreatment or dewatering is the worst use of the method. Such processes should be limited to the preparation of reusable sludge.

The most common drying method is the natural drying bed. The batch drying bed usually behaves as a gravitational drainage bed in the first stage of the operation, either with or without suction head application to the drainage system. The bed is not only used for natural drying but is also used as a natural freezing bed in winter in cold areas.

It is recommended that a certain size of drying bed be added to all sludge treatment systems to increase storage capacity to level out sludge flow variation and to serve in case of an emergency.

4. Sludge treatment system

Fig. 6 shows typical sludge treatment systems being used in Japan. Specific characteristics of these systems can be understood from the characters of the component processes described in the preceding section and are summarized in Table 1. Fig. 7 is a schematic diagram for selecting an optimum sludge treatment system with respect to the raw water

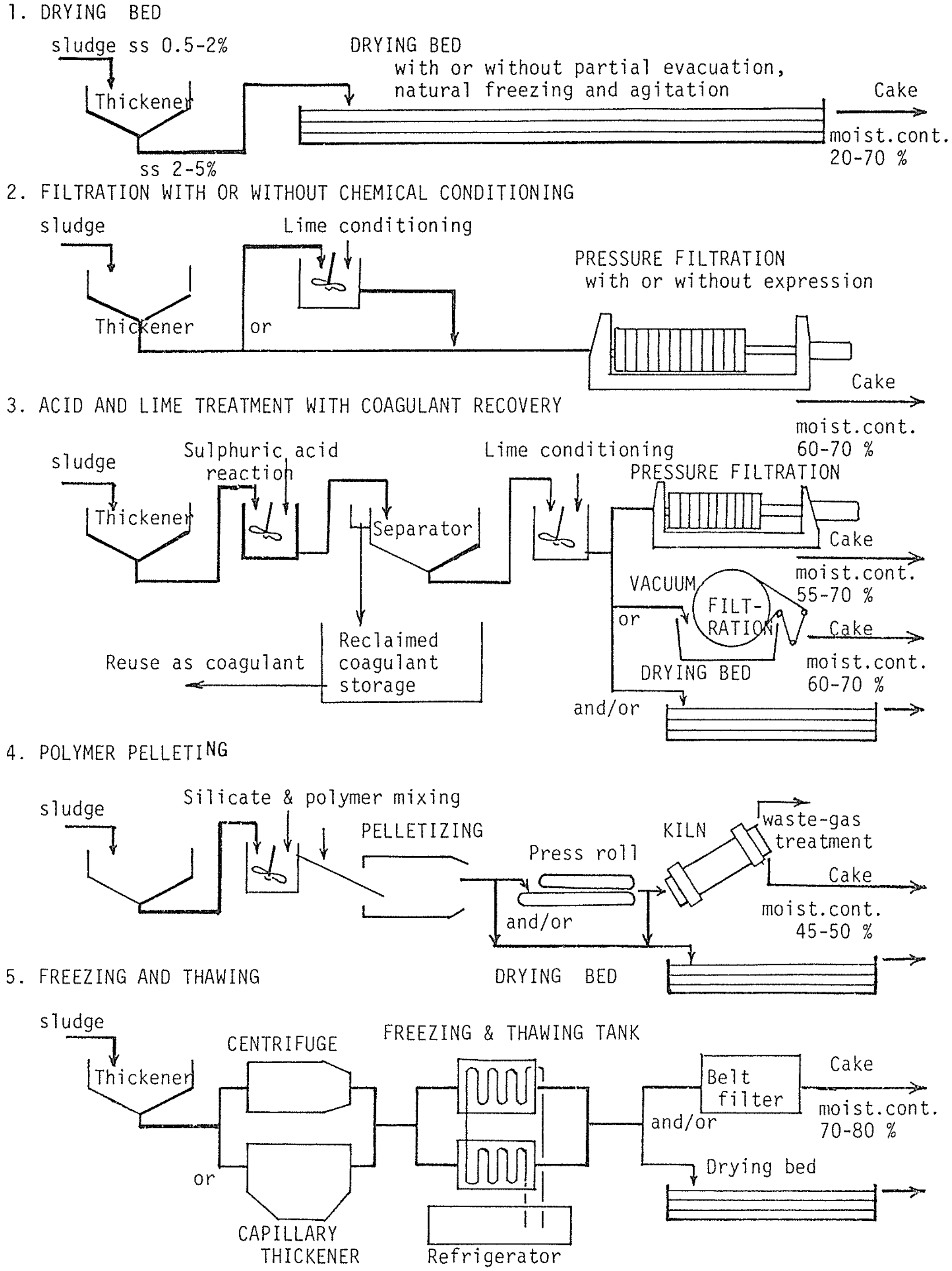

Fig. 6 Typical sludge treatment processes in Japan

Table 1. Dewatering process evaluation

	1	2		3	4		5
System / Item	Drying Bed	Direct Filtration	Filtration with Lime Conditioning	Filtration with Acid and Lime Treatment and Alum Recovery	Polymer Pelleting without Dryer	with Dryer	Filtration with Freezing
Mechanism & Driving Force	Sun dry, freezing sand percoration	Pressure	Re-coagulation, pressure	Aluminium stripping, re-coagulation, pressure	Polymer mollecular attraction ——	heat dry	Phase conversion
Plant Space	huge	medium	small	small	small		small
Energy Consumption	low	medium	medium	medium	low	very high	high
Instrumentation	none	light	light	medium	medium	heavy	heavy
Investment Cost	depend upon Land price	medium	medium	medium	medium	high	high
Operation Cost	low	medium	medium	medium	medium	very high	high
Secondary Environmental Impact	small	none	High pH of cake. Leach of pollutants from the cake	High pH of cake. Leach of heavy metals and organics in recovered alum	Polymer toxicity(?)	Air pollution	none
Disposability	excellent	excellent	caustic	caustic	good	excellent	excellent
Reuse	Landfill, gardening and agricultural use	Landfill, gardening and agricultural use	Isolate disposal	Alum recovery as coagulant	Landfill	Landfill, gardening & agricultural use	Landfill, gardening and agricultural use

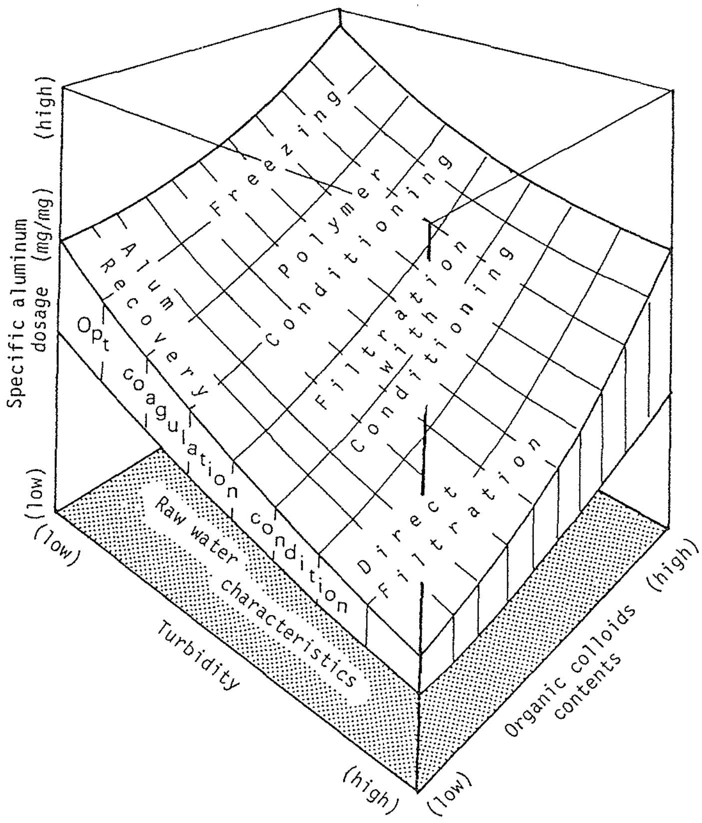

Fig. 7 Selection of Sludge treatment processes

conditions, i. e. turbidity and organic content, and the coagulation conditions which are selected from the raw water characteristics.

5. Disposal and reuse

Dewatered sludges are returned to the land with or without drying. Landfill is the most popular method of disposal. Frequently, such sites are reused for factories, houses and parks after a period of consolidation. Sludge cakes have a little interior strength and permeability compared with natural soils because the finer particle size distribution causes a higher moisture content.[12] Therefore, for the stabilization of a filled land, an under-drainage structure or a sand drain method is often used.

Polymer conditioning with thermal drying generates a micro-granular structure of high strength and permeability.[12] These particular sludges can be used for many purposes such as agriculture, gardening, landfill, embankments and other uses. Toxicity of the polymers is usually caused by the monomer which is inevitably present arising from incomplete polymerization. Therefore, the use of a high grade polymer with less monomer impurity is necessary. Polymers in the sludge cake decompose with time. However, it is reported that the rate of decomposition of the weakly anionic polyacrylicamide which is the most commonly used one for the pelleting in Japan, is much slower than the rate of decomposition of the monomer into inorganic nontoxic compounds.[15]

The lime cake landfill generates an alkaline leachate to the surrounding environments, and damages plants and other living creatures. Therefore, an interception wall surrounding the landfill area and a covering of natural top soil are necessary for the protection of the environment.[10]

By the decomposition of organics in the filled body, the oxygen in the filled cake is consumed and an anaerobic condition begins. The decomposition of the organic generates such hazardous gases as CH_4, H_2S and others. Under the condition, metal ions such as Fe^{2+}, Mn^{2+} and others are resolved out easily. At times, a wastewater treatment facility is required for the treatment of the leachate from the landfill.

The sludges are sometimes reused as raw materials for the production of light aggregates, bricks and cements.

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