BENEFICIAL USE OF SLUDGE BY MELTING CRYSTALLIZATION FURNACE IN KYOTO CITY

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ABSTRACT

The construction of the sewerage system in Kyoto city started in 1930 and now it has almost been completed in urbanized areas. Approximately 860 thousand m3/day of the wastewater is treated everyday, and around 120 thousand ton/year of the dewatered sludge is generated. Two thirds of the sludge generated is incinerated and the other is melted. The majority of the incinerated ash is landfilled.

As Kyoto city is an inland city, it has faced difficulty in securing landfill sites. In the early stage of the sewerage works, the sludge drying bed had been used for dewatering. But in proportion to the progress of the sewerage service, the generated sludge volume had increased and the reduction of the disposed sludge volume had been pursued by the mechanical dewatering and the incineration. Furthermore, in order to cope with future difficulties for securing the landfill sites and for promoting the beneficial use of the sludge, the melting crystallization facility was constructed.

Through melting crystallization techniques, the melted glass quality slag is converted into crystallized quality which is equal to that of natural stones. In the case of the incinerated sludge, the crystallization by itself is hard due to a shortage of basicity, and hydrated lime is added to the ash. The crystallized slag excels in strength, in heat resistance and in chemical resistance. The masking effect of heavy metals in the slag also is excellent. In the first stage of the facility, the sludge is melted at 1,200 to 1,400℃. The melted slag is cooled spontaneously and after that it is introduced into the crystallization furnace and is crystallized at 1,100℃. The first furnace started operation in 1996, and the second one launched its operation in 2001.

The crystallized slag has a similar quality to that of natural stone and it can be used in various ways such as construction materials. It was named "MIYAKO ISHI", i.e. "the stone of the capital city", in order to encourage people to use it. The Home Page is also used effectively to promote the utilization of the MIYAKO ISHI. The bid for the MIYAKO ISHI commenced in 1999 and around 2,000 tons were sold in 2002. Many products made of MIYAKO ISHI have been manufactured and marketed by tile companies. The main products are outer wall tiles and permeable ceramic blocks. Those products are qualified as Eco-Mark Goods, and are used mainly for the public works. In addition to those usages, it is used for backfilling and mulching material in wastewater treatment plants and the total amount of the crystallized slag is utilized.

KEYWORDS

Beneficial use of sludge, Melting furnace, Crystallized slag

1. INTRODUCTION

Kyoto city is an international cultural and historical city that had been the capital of Japan for more than 1,000 years. It is located in the midway of the Yodo River basin, and has a population of 1.46 million. The water of the Yodo River which receives all of the urban drainage from Kyoto city is used as drinking water by about 11million people who live downstream. The sewerage works of Kyoto city has the duty not only to improve the living environment of the residents in the city, but also to conserve the water quality of the Yodo River.

The sewerage works of Kyoto city launched in 1930. In the mid 1960s, the construction of the sewerage system was defined to be an essential policy of the city. In 1994, the 1200th celebration of the capital city relocation to Kyoto city, the construction of the sewerage system in the urbanized area was almost completed. As of March 2003, the sewered population ratio has come to be over 99%. From now on, efforts will make to improve the quality of the sewerage systems by promoting the advanced treatments and improving the combined sewer systems.

In 2001, the Master Plan of sewerage works for 2025 was published and the basic idea of the sewage works of the city was presented. The main policy of the sludge treatment is fixed on adopting more effective treatment processes and promoting utilization of resources.

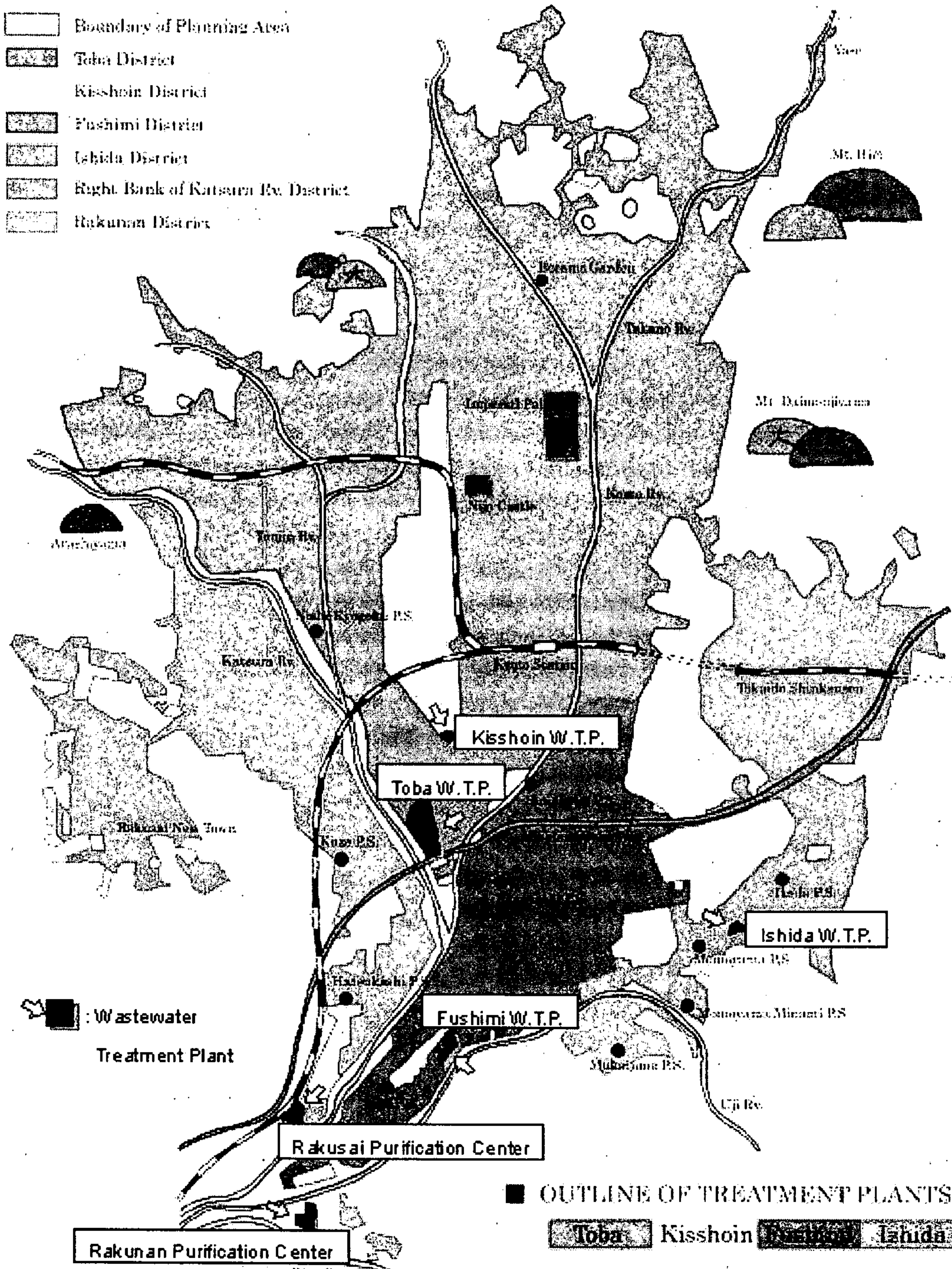
As Kyoto city is an inland city and has many important cultural inheritances and sites, the city has faced difficulties in securing sludge landfill sites. Ahead of the other cities, Kyoto city has been dealing with the problem by introducing sludge incineration and proceeding effective use of sludge and incinerated ash. The amount of sludge cake and ash which can be applied to effective uses is limited and a majority of it has to be transported to distant landfill sites. Effective beneficial use of sludge had to be established in order to cope with the future shortage of the disposal sites.

Under those conditions, a melting and crystallization plant was constructed. Sludge is first melted into slag and is crystallized by adjusting the components so as to obtain physical and chemical properties equal to natural stones, for proceeding sludge recycling.

2. OUTLINE OF SEWERAGE WORKS OF KYOTO CITY

2.1 Present state of sludge treatment and disposal

As shown in Figure 1, Kyoto city has six treatment districts, out of which four districts have their own treatment plants as the independent public sewerage systems. Table 1 shows the present condition of sewerage works of Kyoto city. Approximately 860 thousands m^3/day of wastewater is treated in those treatment plants. Around 120 thousands tons/year of dewatered sludge generated is incinerated and converted into around 7,000 tons of ash. And a major part of the ash is landfilled.



■ OUTLINE OF TREATMENT PLANTS

	Toba	Kisshoin	Fushimi	Ishida
Capacity (m3/D)	1,047,000	114,000	155,000	140,000
District Area (ha)	8,146	587	1,896	2,014
Site Area (m²)	496,100	28,999	134,230	87,593

(as of Apr. 2002)

Figure 1 Present condition of sewerage system in Kyoto city

Table 1 Up-to-Date Situation of the Sewerage System in Kyoto City (as of March 31, 2003)

Total area of Kyoto City		61,022	ha
Urbanized area		15,000	ha
Total population of Kyoto City		1,462,083	
Sewered area		15,074	ha
Sewered population		1,451,000	
Ratio of sewered population		99.2	%
Capacity of treatment plant		1,420,000	m^3/day
Average daily influent wastewater		860,210	m^3/day
Dewatered sludge (total)		125,844	ton/yr
Toba W.T.P		117,560	ton/yr
Ishida W.T.P (Co-combustion with municipal waste)		8,284	ton/yr
Disposal vol. of incinerated ash(total)		10,232	ton/yr
Landfill disposal	:Suzaki	3,152	ton/yr
	:Mizuho	1,753	ton/yr
	:Osaka Bay	2,500	ton/yr
Utilization	:Soil amendments	23	ton/yr
	:Construction material	9	ton/yr
	:Slag use	2,795	ton/yr

Figure 2 shows the sludge treatment system in each plant. The sludge generated from Toba, Kisshoin and Fushimi plant is treated in the Toba plant. From the Kisshoin plant, raw and excess sludge is pumped 1.5km by a pipeline and from the Fushimi plant, dewatered sludge is transported around 4km by truck. In the Ishida treatment plant, dewatered sludge is co-combusted with municipal refuse at adjoining refuse incineration plant.

At the Toba plant, the gravity thickening tanks and the flotation thickening tanks are used. Except a part of the thickened sludge introduced into the digestion tanks, all of the sludge is dewatered by using polymer coagulants. The polymer coagulants are also used in the Fushimi and the Ishida plant. Since 1973, all of the dewatered sludge has been incinerated. Now, the stoker furnaces and the melting furnaces are used for incineration.

A major part of the incinerated ash is trucked to the Mizuho final disposition center, managed by Kyoto Environmental Preservation Public Corporation which is located in around 50km northwest of Kyoto city. It is also trucked to the Amagasaki waste disposal site of the Osaka Bay Phoenix Project, managed by Osaka bay regional offshore environmental improvement center, which is jointly used for waste collected from 195 municipalities along Osaka bay, approximately 45km southwest of Kyoto city.

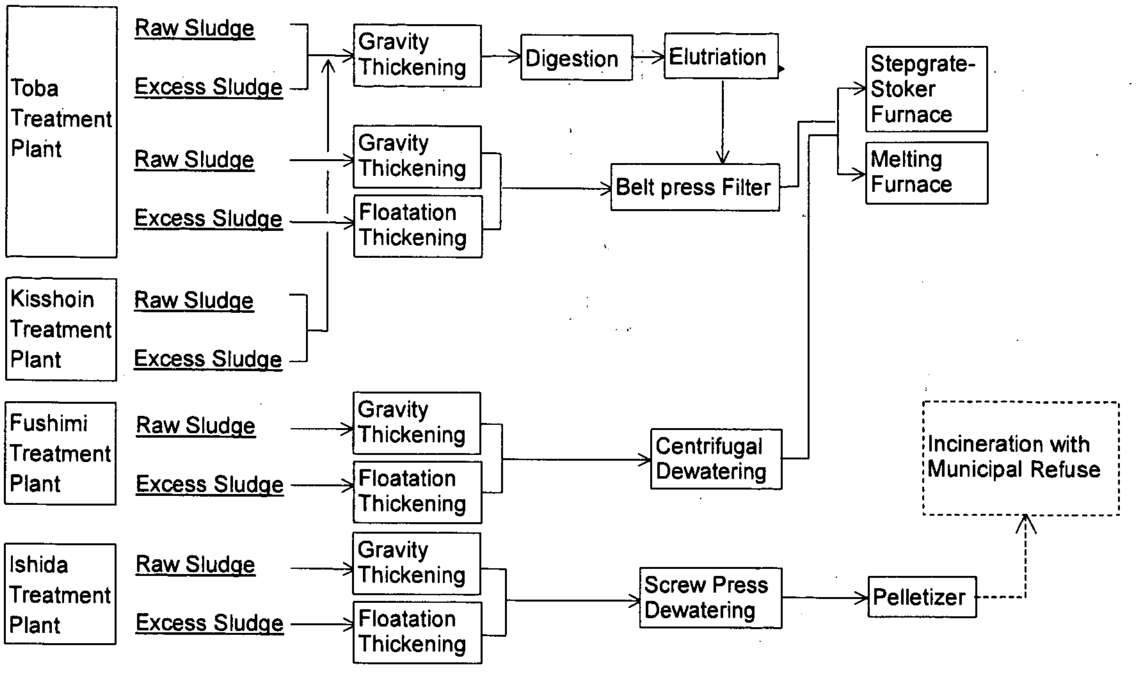


Figure 2 Sludge treatment system of each treatment plant

2.2 Progress of sludge treatment and disposal

Figure 3 shows the amount of wastewater and sludge treatment in Kyoto city. In the dawn of the sewerage works, the "anaerobic digestion-sundrying-landfilling" method was adopted for treating and disposing sludge in the Kisshoin and the Toba treatment plant. In proportion to the expansion of the sewer service area, the amount of generated sludge had increased and in 1965, the vacuum filter system was adopted in the Toba treatment plant for dewatering sludge from both plants. Dewatered sludge was landfilled in the Toba treatment plant. In 1968, a multiple-hearth furnace was constructed and part of the dewatered sludge started to be incinerated. In 1973, the Fushimi treatment plant started operation and all of the dewatered sludge from the three treatment plants was incinerated. In 1986, a stoker type furnace was constructed, and conventionally used inorganic coagulant gave place to organic one to reduce the volume of ash by using belt press filter. As the number of available years for landfilling at the disposal site owned by Kyoto city has been decreasing, landfill at a remote disposal site outside the city was consigned in 1989.

As mentioned before, the city due to the geographical and topographical features had difficulties securing final disposal sites. Therefore, the city needed to take the lead in implementing volume reductions and producing resources out of sludge for beneficial uses such as composting and ash utilization. Studies were conducted with prototypes and application tests were carried out using incinerated ash coagulated by lime in particular as soil amendments for acidified soil, and as raw materials for construction and ceramic. Moreover, utilization has been expanded to crush incinerated ash coagulated by polymer for applications such as blocks or interlocking blocks for pavement in the city walkways as shown in Figure 4.

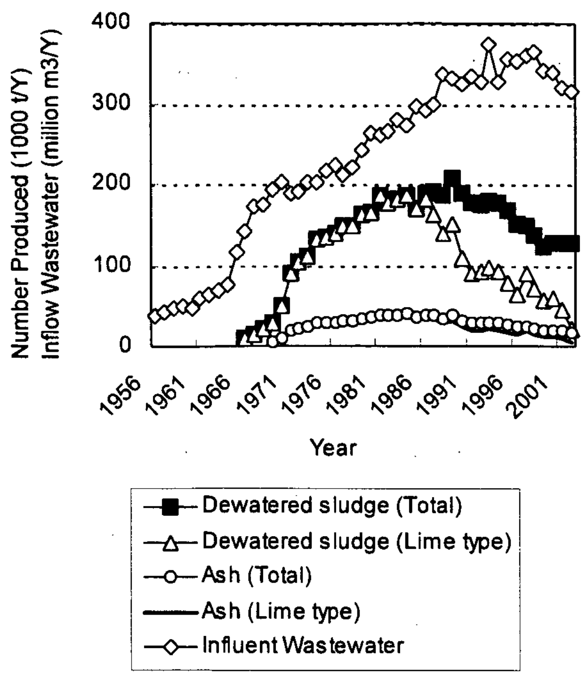


Figure 3 Change of sludge treatment

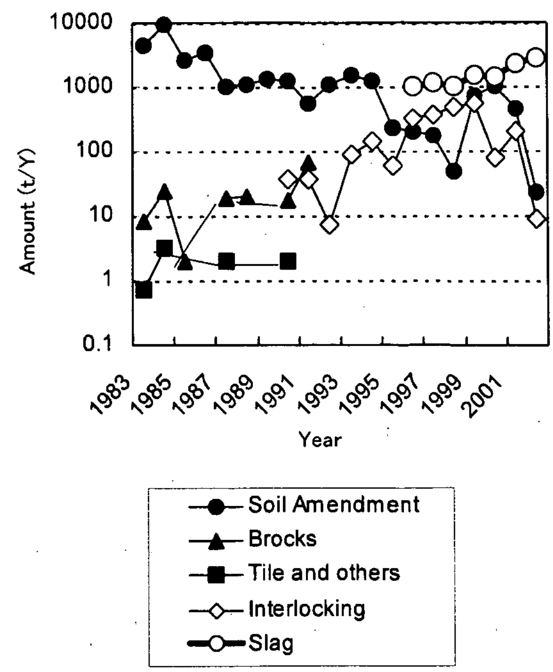


Figure 4 Change of utilization of ash and slag

Soil amendments that were once in demand, gradually decreased due to reductions of agricultural land which resulting from the progress of urbanization. And the use of incinerated ash coagulated by polymer has not been playing an active part in expanding its utilization.

Therefore, the construction of a melting furnace was determined in order to extend active use of the sludge. Melted slag can be used directly as construction materials and immobilize heavy metals. Because glass quality melted slag produced at plants operating in other cities had limited uses, the crystallization facility for improving slag quality was added to the furnace. The 150 tons/day melting and crystallization plant started operation in 1996, and the second one launched its operation in 2001.

3. ADOPTION OF MELTING AND CRYSTALLIZATION PLANT

3.1 Melting and crystallization technology

The technology improves the glass quality of melted slag into a quality equal to natural stones. In the case of sewage sludge, the main inorganic components are SiO_2, Al_2O_3, Fe_2O_3, and P_2O_5, as shown in Table 2. Under the components ratio in the table, the crystallization of slag is hardly progressed due to the shortage of basicity. And as shown in Figure 5, when 10% of limestone is added to ash as a conditioning reagent, the CaO ratio comes to be 25 to 30% and forms anorthite crystals (2 SiO_2-CaO-Al_2O_3).

Table 2 Properties of Dewatered Sludge

Moisture content		wt%	79.3
Solid Combustibles		wt%	74.3
Ash content		wt%	25.7
Calorific value(high)		kJ/kg-ds	16,783
		(kcal/kg-ds)	(4,009)
Ash content (Ash base)	SiO_2	wt%	56.3
	Al_2O_3	wt%	22.7
	CaO	wt%	8.2
	Fe_2O_3	wt%	6.6
	MgO	wt%	2.4
	Na_2O	wt%	1.4
	K_2O	wt%	2.3
	P_2O_5	wt%	1.5
Basicity (CaO/SiO_2)			0.15

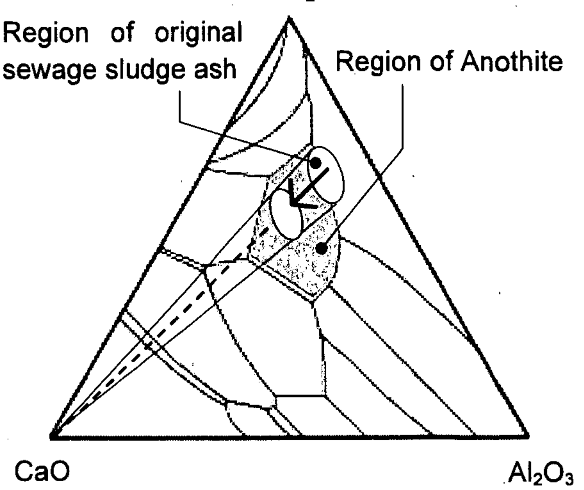


Figure 5 Phase equilibrium diagram of SiO_2-CaO-Al_2O_3

Anorthite exhibits a needle type crystal structure and maintains a somewhat glass quality while holding the characteristics of a crystal. And it shows superior strength, heat and chemical resistance. Generally, crystal core is necessary to precipitate crystal homogeneously in glass quality slag, but in the case of sewage sludge, metal components in the sludge such as iron, etc. play the role of the core.

The physicochemical characteristics of crystallized slag are shown in Table 3. It turns into a luster like obsidian by polishing it and is a good substitute for natural stones in application as aggregates of construction materials.

Table 3 Physico-Chemical Qualities of Crystallized Slag

Items for Measurement		Crystallized Slag	Natural Stone
Compressive strength	kg/cm^2	1,400 ~ 1,670	1,265 ~1,770
Acid resistance [1]	%	0.1 ~ 0.2	1.1 ~ 1.2
Alkali resistance [2]	%	0.16 ~ 0.2	0
Water absorption	%	0.0	0.2
Specific gravity	-	2.95 ~ 3.05	2.6 ~ 2.7
Moh's hardness	-	6 ~ 7	7

1) Weight reduction(%) after immersing 15x15x10 samples in 5% H_2SO_4 at 25°C for 250 hours

2) Weight reduction(%) after immersing 15x15x10 samples in 5% NaOH at 25°C for 250 hours

3.2 Outline of the melting and crystallization plant

The plant is composed of the drying facility, the melting facility, the crystallization facility and the flue gas treatment facilities. Figure 6 shows the total flow sheet. Table 4 indicates the outline of the melting and crystallization plant, and the specifications of the main equipment. The vortex melting system incinerates sludge while circulating fine dried sludge particles in the furnace. In order to supply dry solids with a diameter of 1mm or less with solids content of higher than 90%, a circulation type fluidized drying system, which dry and produce fine particles at the same time, is adopted.

Dewatered sludge mixed with fine dried sludge particles is supplied to the fluidized zone. Moisture is evaporated with the heat exchanger installed on the upper part of the dryer, then dried sludge flying out from the dryer is caught in the bag filter and used circularly.

After incinerating the sludge while circulating in the preliminary combustion furnace, the dried sludge is melted in the main melting furnace. As the furnace is inclined 15 degrees, melted slag flows down to the refining furnace spontaneously. Melted slag is kept in the refining furnace for two hours at around 1,400℃ for homogenization, then molded in the molder, cooled and formed into a small clot of glass quality slag. The molder is designed to produce water-cooled slag of less than 5mm, or to produce air-cooled slag of 5-20mm. The cooled slag is reheated in a rotary kiln type crystallization furnace at approximately 1,100℃ to precipitate crystals. Figure 7 is the crystallized slag used of air-cooled and water-cooled slag. Crystallized slag is separated into fine and rough particles with a 5mm screen, and is stored.

In order to heat the crystallization furnace, flue gas from the refining furnace is used. The heat in the flue gas from the melting process is recovered by the air pre-heater and the waste heat boiler. Hazardous matters in the flue gas are removed in the scrubber and dust is removed by the wet electrostatic precipitator. Preheated air is used for combustion in the melting furnace and the recovered steam is used for the dryer.

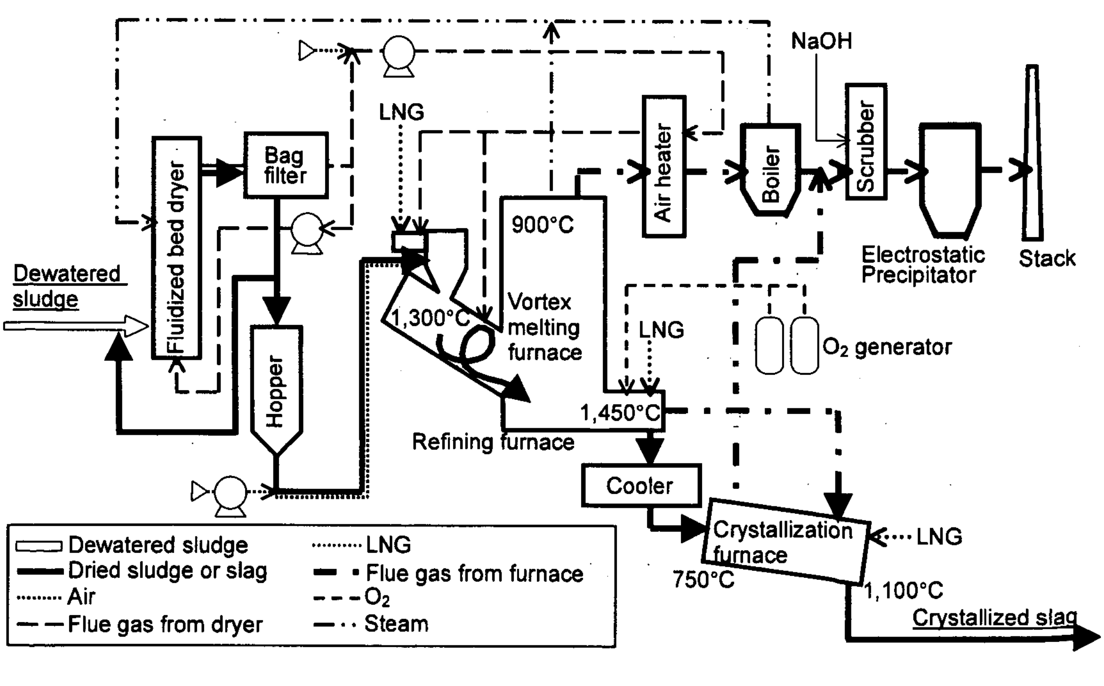


Figure 6 Flow sheet of melting and crystallization plant

Table 4 Specifications for Main Equipment of the Melting and Crystallization Plant

Name of Equipment	No	Spec.(Capacity, Type, etc.)	
1) Dewatered sludge drying facility			
•Fluidized bed dryer	2	Wet cake 5 ton/hr	Circulating Fluidizing Indirect heating
•Dried sludge recovery & distributor	2	540 m^3/hr	Bag filter
•Dried sludge hopper	2	17 m^3	Vertical tubular tank
2) Melting facility			
•Vortex melting furnace	1	Wet cake 150 ton/d	Inclined vortex furnace
•Air preheater	1	540,000 kcal/hr	Radiation heat transfer
•Waste heat boiler	1	Area of heat-transfer 200 m^2	Water tube
3) Crystallization facility			
•Refining furnace	1	1,000 kg/hr	Oxygen enriched burner
•Molding cooler	1	1,000 kg/hr	Water-cooled turntable
•Crystallization furnace	1	1,000 kg/hr	Rotary kiln
•Oxygen generator	1	120 Nm^3/hr	Absorption type
4) Flue gas treatment facility			
•Scrubber	1	18,000 m^3/hr	3 stage spray tower
•Electric precipitator	1	15,000 m^3/hr	Wet electrostatic precipitator

Figure 7 Crystallized slag

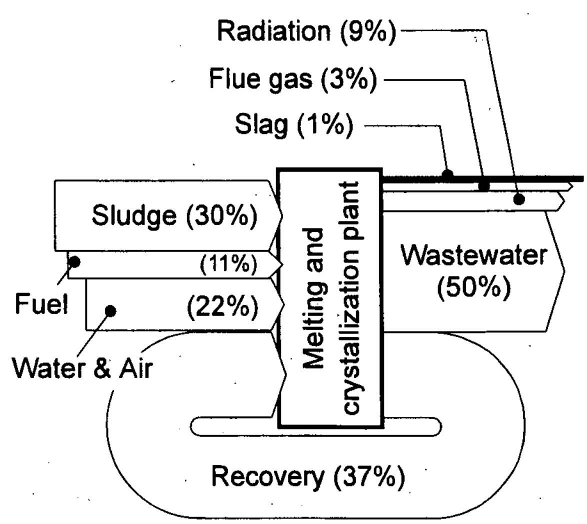


Figure 8 Energy balance

3.3 Energy balance

Figure 8 illustrates the energy balance of the melting crystallization facility. Around 30% of the thermal capacity in the facility is that of the sludge itself. Around 37% of the capacity is recovered and recycled by the steam or by the air preheats. And the thermal capacity required by the supplemental fuel is only 11%.

4. OPERATIONAL CONDITION OF THE MELTING FURNACE

Table 5 shows the operational condition in the 2002 fiscal year. Around 2,800 tons of crystallized slag was produced by dosing around 42,000 tons of sludge cake. The table also shows the utility of the melting furnace.

Figure 9 indicates the maintenance cost of each furnace in 2002. The running costs per dewatered sludge are about 10,000 yen. Because the treatment and disposal cost of the treatment sludge generated from treatment plants is much higher in Japan, the melting furnace is considered effective for reducing dumping site and utilizing resources in the long-term viewpoint.

Table 5 Amount of treated sludge and utility consumption

Amount of treated sludge (Annual)		
Dewatered sludge	42,409	ton
Dried sludge	9,421	ton
Crystallized slag (Generation)	2,795	ton
Utility consumption (Annual)		
LNG	1,672,700	N m^3
Heavy oil A	1,245	kℓ
Caustic soda	288	ton
Lime	767	ton
Drinking water	4,573	m^3
Electric power	10,981,230	kWh

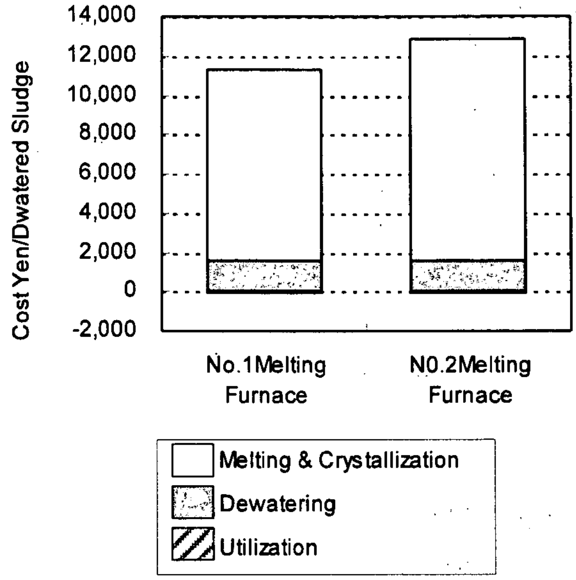


Figure 9 Sludge treatment cost of melting furnace

For the second melting furnace, gas is used as spare fuel in order to reduce exhausted air pollution substances such as carbon dioxide or sulfur oxide, based on the municipal policy that the energy of low greenhouse gas emission is the first priority.

Table 6 Analysis Result of Flue Gas (2002)

Item		Measured	Standard
Gas vol. Dry gas	Nm^3/hr	29,600	-
Wet gas	Nm^3/hr	28,100	-
Temperature	°C	58	-
Moisture content	Vol.%	4.9	-
CO_2	Vol.%	6.0	-
O_2	Vol.%	13.6	-
CO	Vol.%	<0.1	-
N_2	Vol.%	80.4	-
Dust density	g/Nm^3	0.005	0.08
Sulfur oxide	ppm	0.14	2.34
Nitrogen oxide	ppm	149	250
Hydrogen chloride	mg/Nm^3	3	700
Dioxins	$ng\text{-}TEQ/m^3N$	0	0.1

Table 6 shows the exhaust gas composition of the melting furnace. The generation of nitrogen oxides is controlled by the reduction condition in the first combustion chamber which is brought by the gradual supply of the air, and by the complete combustion in the secondary chamber. The concentration of the dioxins is extremely lower than the standard as shown in the table.

5. CHARACTERISTICS AND UTILLIZATION OF THE MELTED SLAG

The crystallized slag has a similar quality to the natural stone and it can be used in various ways such as construction materials. The utilization of the crystallized melted slag has been experimented in various ways.

5.1 The characteristics of melted slag

The inorganic matter contained in the sludge is converted to slag. The main components of the slag are SiO_2, Al_2O_3, Fe_2O_3, P_2O_5, and CaO. The components adjustment is carried out by dosing CaO in order to keep the ratio of SiO_2, Al_2O_3 and CaO in a certain range, so the crystal in the slag composed mainly by those three elements is produced.

This crystal belongs to the Feldspar, which is one of the natural ores, and the crystallized slag has similar characteristics to the natural pebble stone.

(1) Safety of crystallized slag
As the result of the leachate test based on the authorized method by the Ministry of Environment, every experimented value is below the minimum determination limit and satisfies the environmental quality standard for soil.

(2) Physical characteristics
As shown in Table 7, both of crystallized slag larger than 5mm and that of smaller than 5mm satisfies the standard for the aggregate. In the case of the utilization of the melted slag for the asphalt and concrete aggregate and the sub-base course material, the glass-quality slag does not have the required strength and hardness and the usage is restricted. On the other hand, the loss in quantity of crystallized slag is around 15%. This value is almost the same as the natural crushed stone.

Table 7 Aggregate test result of crystallized slag

Item	5mm<			<5mm	
	Result	Standard (for asphalt)	Standard (for concrete)	Result	Standard (for concrete)
specific gravity (−)	2.94	2.45<	2.5<	2.82	2.5<
water absorption (%)	0.22	<3.0	<3.0	0.68	<3.0
abrasion loss (%)	14.8	<30	<40	-	-
soundness test (%)	0.0	<12	<12	0.2	<10
washing test (%)	0.053	-	<1.0	0.080	<7.0
unit weight (kg/ℓ)	1.78	-	1.35<	1.42	1.35<

(3) Distribution of particle size

Figure 10 shows the distribution of particle size of the crystallized slag larger than 5mm and smaller than 5mm. The distribution of the slag larger than 5mm is within the range of the crushed stone No.6. The distribution of the slag smaller than 5mm shows that the ratio of smaller than 2.5mm is lower than that of the range of the crushed sand.

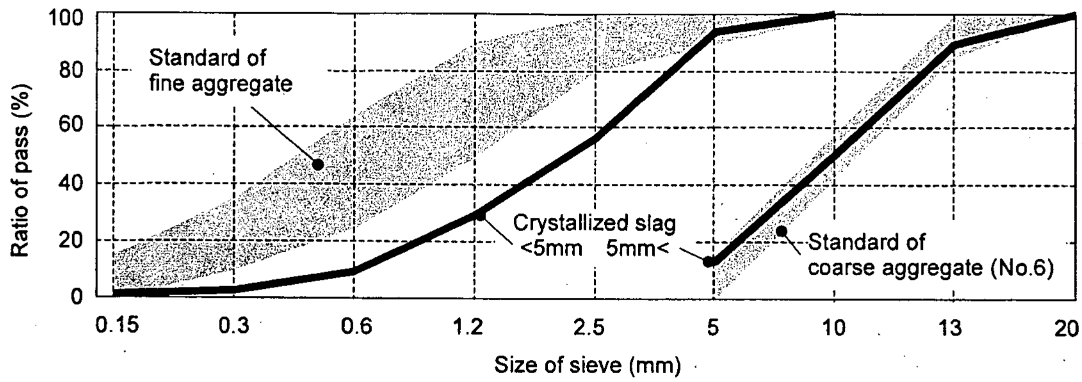


Figure 10 Sieving test result of crystallized slag

5.2 Sales results and utilization examples of the crystallized slag

During the first two years after the launch of operation of the melting-crystallization furnace in 1996, research, experiments and trial producing had been pursued for developing the utilization of the crystallized slag. In those two years, the slag was used experimentally for the sub-base course material and the asphalt aggregate of the inner roads of the Toba treatment plant. Application test of the crystallized slag for the concrete aggregate is now carried out.

As shown in Table 8, the sale of the crystallized slag was commenced in 1999 and 2000 ton of the slag was sold in 2002. The price of the slag is referred to the natural crushed stone and is determined to be 1,100 yen/ton considering the carriage. In 1999 the crystallized slag was named "MIYAKO ISHI", i.e. "stone of the capital city", in order to encourage people to use it. The Home Page is also used effectively to promote the utilization of the "MIYAKO ISHI".

Many products made of the water-cooled "MIYAKO ISHI" are manufactured and marketed by tile companies. The main products are the outer wall tiles and the permeable ceramic blocks. Those products are qualified as Eco-Mark Goods, and are used mainly for the public works by means of the prior supply policy of the "Eco-Mark Goods". The utilization instances of those products are as follows:

Table 8 Selling amount of "MIYAKO ISHI"

Year(Apr.-Mar.) / Application	1999	2000	2001	2002	Remark
Outer wall tile	500				
Permeable ceramic block	500	1,100	1,200	2,000	
Selling amount	1,000	1,100	1,200	2,000	
Production of crystallized slag	1,474	1,445	2,305	2,795	Two plants were operated since 2001

Unit price for selling: 1,100 yen/ton (excl. tax)

(1) Outer wall tile

The quality standard of tile is fixed for each works site, such as standard for outer wall, flooring and inner wall. Among them, the water absorption rate standard for outer walls is the strictest in order to avert tiles from damage by repeated freezing and melting. For material in outer wall tiles, 50% of the crystallized slag, "MIYAKO ISHI" can be mingled. The outer wall tiles mingled with "MIYAKO ISHI" have been used in a total of 15000m^2 in areas such as the Johhana Tunnel of the Tokai-Hokuriku Highway (Figure 11).

(2) Permeable ceramic blocks

Permeable ceramic blocks are used in pavements, parks and open spaces similar to permeable interlocking block made of concrete. As the permeable ceramic blocks are produced in furnaces at high temperatures, it is harder in strength and resists discoloring more than the concrete products. Crushed waste ceramic has been used as the material of the permeable ceramic blocks, though, when the water-cooled crystallized slag smaller than 5mm is used, more than 50% of the material can be alternated with the slag. Up to 2002, permeable ceramic blocks have been used in a total of 7000m^2 in areas including at Dangohzaka Service Area of the Chuou Highway (Figure 12).

In addition to those uses of "MIYAKO ISHI", it is used for backfilling and mulching material in wastewater treatment plants and all the crystallized slag is utilized. The storage facility is now under construction and a stable supply of "MIYAKO ISHI" is promoted.

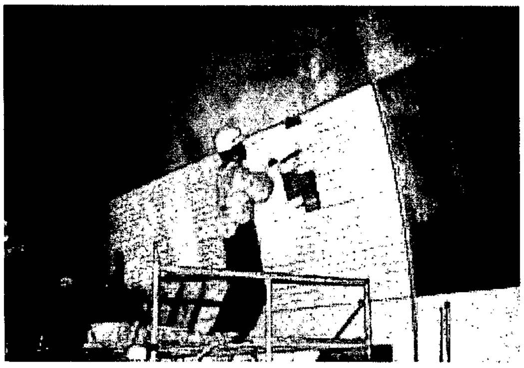


Figure 11 Construction example of outer wall tile

Figure 12 Construction example of permeable ceramic block

6. CONCLUSIONS

The sludge utilization by producing the crystallized slag performed by the sewerage works bureau was awarded the "Iki-Iki Gesuido Prize", i.e. "vivid sewerage works prize" by the Ministry of Land, Infrastructure and Transport in 2002.

The cost reduction and the quality control have to be carried out by pursuing an efficient operation control. And also, the stable sludge treatment and the crystallized slag production have to be proceeded.

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