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The Characteristics of Co-Incineration of Dewatered Sludge, Waste Oil and Waste Solvent in Commercial-Scale Fluidized Bed Incinerator

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Abstract−A commercial-scale Fluidized Bed Incinerator (FBI), which has a capacity of 60 tons per day to treat dewatered sludge and waste oil or solvent, was developed as one of the governmental R&D projects from 1990 to 1997. From the design, construction and operation of the plant, the characteristics of co-combustion and appropriate operating conditions with successful fly ash recirculation and with effluent controls have been investigated. Without adding any bed materials, sand, the co-incineration of sludge and spent-solvent can be achieved. The sludge combustion steps could be observed and confirmed, which consist of evaporation, agglomeration, devolatilization, combustion and attrition. The plant can also incinerate various types of sludge from wastewater treatment facilities with waste oil or solvent.

Key words: Fluidized Bed Incinerator, Incineration, Sludge, Waste Oil, Waste Solvent

INTRODUCTION

In 1997, domestic generation of sludge was about 7,000,000 tons/day in Korea and has increased since then. Most domestic sludge has been treated by landfill or ocean dumping. However, direct landfill of sludge was forbidden by law in 2001, and ocean dumping is to be reduced. Therefore, appropriate sludge treatment means are needed. Various domestic companies have developed technologies of sludge incineration, drying, recycling and melting.. Incineration increases the stability of the final waste by converting organic materials in the sludge into gas leaving behind a very small amount of stable inorganic residue [U. S. EPA, 1985]. In the U. S. the combustion of sludge from municipal wastewater treatment facilities has been done by two main technologies: fluidized bed and multiple hearth bed reactors. Worldwide, the recent trend is to construct more fluidized bed incinerators and to develop new methods to handle sludge such as RDF (Refuse Derived Fuel), composting, gasification, and so on [Albertson, 1992]. Even in Korea there have been many investigations for developing a proper fluidized bed technology to incinerate sludge from the beginning of the 1990s [Seo et al., 1992; Lee et al., 1994; Park, 1994; Won et al., 1997; Chung et al., 1998]. Because of high moisture content in the sludge, a dryer or auxiliary fuel is used in the sludge incineration. The fluidized bed types of sludge incinerators have the most merit, such as small scale, high stability of operation and incineration efficiency, capability of co-incineration, and low emission concentration [Lee et al., 1990, 1992; Chun et al., 1997; Chu, 1999; Jang et al., 2001]. Since there is a capability of co-incineration in fluidized bed incinerators, much utilization of co-incineration has been made. It can be used to substitute coal after this technology was used to burn coal originally in 1950s [Yaverbaum, 1977], to provide an improved option for conventional coal-fired combustion systems, that is, since it has been the capability of burning many types and grades of fuel together including municipal sludge and refuse, industrial and agricultural cellulosic waste materials, as well as waste oil or even petroleum fractions. In addition, waste oil generated at 200,000 tons/day can be used as auxiliary fuel. Then there are some research and basic studies made for co-incineration [Kim, 1997]. Since 1990, the technology of fluidized bed incineration to treat sludge by co-incineration with waste oil and solvent has been developed, and the design, construction and test operation of the plant was completed in 1998. In this paper, design outlines and operational characteristics of the commercial scale fluidized bed incinerator to treat 60 ton sludge/day by co-incinerating with waste oil and solvent are introduced [Kim, 1992, 1998]. And a potential possibility to reuse ash as bed materials in fluidized beds has been investigated, and some characteristics of sludge combustion by observing the burning steps are also studied. The plant can treat sludge from various wastewater treatment facilities with less effluent discharges.

COMMERCIAL FLUIDIZED BED INCINERATOR (FBI)

The FBI system with a capacity of 60 tons of sludge per day consists of storage, supply, incineration, waste heat recovery, flue gas treatment, ash treatment, ventilation, water supply and drain facilities [Kim, 1998; Gu et al., 2000].

1. Waste Storage and Supply Facility

A waste storage facility consists of a sludge pit and waste oil & waste solvent tank. A waste supply facility consists of piston pump

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and mono pump. The supply system of waste oil and waste solvent includes three different types of spraying nozzles according to spray degree determined by viscosity so that liquid waste is easily supplied regardless of property changes. There is a direct spray from storage tank to fluidized bed, a spray to fluidized bed after feeding to service tank and heat tracing by steam, and a spray to the fluidized bed after feeding to piston pump hopper and mixing with sludge.

2. Incinerator and Waste Heat Recovery Facility

The incinerator has a tuyere type air distributor using a water-cooled dispersion disc and a bottom ignition burner. Fly ash collected at the entrance of waste heat boiler is recycled to the fluidized bed. The auto-ignition system is composed of a burner and a pre-combustor. An indirect heating method using a bottom preheating burner with precombustor is utilized. In order to recover waste heat from flue gas, a waste heat boiler and air preheater are installed. Steam production of the waste heat boiler is 2.5 ton/hr (±0.5), and the steam pressure is 7 kg/cm^2G. A two-stage air preheater system is designed to increase the efficiency of waste heat recovery. Main combustion air preheated from an air preheater is introduced into the wind box. The air preheater is connected to a secondary air duct so that secondary air can be used as preheating air.

3. Flue Gas Treatment Facility

The flue gas treatment facility consists of an attemperator for gas temperature control, a lime reactor (dry scrubber) and a bag filter for dust collection. The attemperator is used to control combustion air cooled in waste heat recovery facility to 180 °C, which is the operation temperature of dry gas reactor and filter. The attemperator is composed of two fluid nozzles and PID controller for micro-temperature control. The lime reactor of duct type dry scrubber is installed for emission control of SO_x and HCl. The feed system of hydrated lime consists of a lime silo, lime feed blower, a lime feeder and so on. The lime feeder has a flow rate controller which controls feed amount according to the incinerated amount of waste and its sulfur content.

Table 1. Analytic results of waste and auxiliary fuel

Parameters	Operation condition
Incineration rate (F)	
Waste treatment sludge cake	50 ton/day (±10)
Waste oil/Waste solvent (or Refinery oil for aux. fuel)	5-10 ton/day
Superficial gas velocity (U)	0.9-1.4 m/sec
Air to fuel ratio (m)	1.4 (±0.2)
Bed temperature (T_b)	600-750 °C
FBI outlet temperature (T_{out})	850-950 °C
1st combustion air rate (Q_1/Q_T)	0.6-0.9

4. Combustion Air Supply Facility

The combustion air supply facility is composed of primary and secondary air blowers. The design pressure of the primary air blower is 2,500 mmAq in consideration of pressure drop of orifice, air preheater, tuyere and fluidized bed height. The design flow rate is determined to feed sufficient combustion air without the secondary air blower. The primary air blower is also used for the burner at the ignition of combustion air and at the beginning of burner ignition. The exhaust pressure of secondary air blower, which controls multi-step combustion, is maintained as 370 mmAq in consideration of pressure drop of orifice and duct.

5. Ash Treatment Facility

The ash treatment facility classifies the bag filter ash of fine dust and the ash produced from waste heat boiler, air preheater and at-

Table 2. Operation parameters and conditions in commercial scale FBI Plant (60 ton/day)

Waste	HHV (db*) cal/g	Proximate analysis (wet, wt%)				Ultimate analysis (db*, wt%)					
		Moisture	Volatile matter	Fixed carbon	Ash	C	H	O	N	S	Ash
Sludge A	4627	86.84	10.04	1.61	1.51	44.30	4.88	31.36	7.50	0.49	11.47
Sludge B	3260	79.72	12.82	1.76	5.70	30.50	3.98	33.66	3.05	0.70	28.11
Sludge C	3974	91.75	5.64	0.44	2.16	35.40	4.38	35.09	3.70	0.58	20.85
Sludge D	5501	85.29	10.65	0.80	3.26	47.00	5.51	23.58	1.10	0.65	22.16
Sludge E	3989	82.01	11.78	1.91	4.30	36.40	4.24	28.21	6.58	0.65	23.90
Sludge F	2496	76.18	15.11	0.57	8.14	23.50	4.47	9.01	3.08	1.15	58.77
Sludge G	4165	91.64	6.27	0.36	1.72	35.60	4.31	32.36	6.50	0.66	20.57
Sludge H	2981	84.05	9.78	1.16	5.00	28.40	3.50	31.98	4.45	0.32	31.35
Sludge I	4445	72.00	22.85	0.71	4.44	40.60	5.39	33.88	3.90	0.37	15.86
Sludge J	2814	66.67	18.61	1.47	13.24	-	-	-	-	-	-
Sludge K	4678	56.8	-	-	-	-	-	-	-	-	-

Liquid waste and aux. fuel

Waste (or Aux. fuel)	HHV(db*) cal/g	Moisture (%)	Ultimate analysis (db*, wt%)						
			C	H	O	N	S	Cl	Ash
Waste oil	11656	20	85.30	14.00	0.46	0.00	0.24	0.00	0.00
Waste solvent	10271	90	78.00	12.00	3.00	0.00	0.00	5.00	2.00
No. 2 oil	10200	0	85.00	14.10	0.30	0.10	0.50	0.00	0.00

(*db: dry basis)

temperator, and then transports, stores and treats all the ashes. The ash collected in former step of bag filter is used as raw material of brick, and the bag filter ash is transported to the landfill site.

OPERATIONAL CONDITIONS

1. Characteristics of Waste and Auxiliary Fuel

Table 1 shows the analytical results of waste and auxiliary fuel. Eleven kinds of sludge, sludge A~sludge K are used as described in Table 1, and properties and composition of waste oil and waste solvent are analyzed by using proper analytical methods. The moisture content varies from 56 to 92% and the ash content ranges from 1.5 to 8.1% in weight [Kim, 1998; Gu et al., 2000].

2. Operation Conditions

Table 2 shows a summary of operational conditions during test operation of the commercial FBI plant. Liquid feeding ranges 5-10 tons/day and solid sludge feeds around 10 tons/day. The other test operational conditions are given in Table 2 [Kim, 1998; Gu et al., 2000].

3. Characteristics of Bed Materials

Generally, fresh sands with a diameter of 0.6-1.0 mm are used for FBI. The size distribution of fresh sands used in this work is shown in Table 3. 83.3% of fresh sands range from 0.6 mm to 1.7 mm [Kim, 1992, 1998; Gu et al., 2000].

4. Characteristics of Hydrated Lime for Air Pollution Control Devices

The lime reactor of dry system type for emission control of SO_x and HCl produced by incineration of the sludge is used. Table 4 shows the characteristics of hydrated lime used for the lime reactor. 98.9% of the hydrated lime is below 325 mesh (45 μm), and CaO content is 69.1% [Kim, 1998; Gu et al., 2000; Kim and Gu, 1994].

Table 3. Size distribution of bed material (sand) in the test operation

Mesh no.	Range	Weight %
>12	>1.70 mm	0.7
20-12	0.85-1.70 mm	49.4
30-20	0.60-0.85 mm	33.9
40-30	0.425-0.600 mm	10.1
50-40	0.300-0.425 mm	5.5
70-50	0.212-0.300 mm	0.4
Total		100

Table 4. Size distribution and composition of hydrated lime in the test operation

Size distribution			
Mesh no.	Opening size (Mm)	Content (wt.%)	Analysis method
60-80	0.250-0.180	0.1	KSF 3501-95
80-140	0.180-0.106	0.2	
140-200	0.106-0.075	0.4	
200-325	0.075-0.045	0.4	
325 under	0.045 under	98.9	
	Total	100.0	

Compound analysis		
Compound	Content (Wt%)	Analysis method
CaO	69.10	KSL 9004-92
MgO	1.35	KSL 9004-92(ICP)
Total	70.45	

RESULTS OF TEST OPERATION IN COMMERCIAL FBI

1. Characteristics of Bed Pressure Drop

When wastewater sludge with high moisture content and low ash content is incinerated, the usability of fly ash as bed materials of fluidized bed without additional of fresh sand is investigated. In case of incinerating the mixture of various sludges with waste solvent except for B, F and J, of which moisture content is low and ash content is high, variations of bed pressure drop with operation time for commercial FBI operation with recycle of fly ash (a) and for commercial FBI and pilot plants without recycle of fly ash (b, c) are shown in Fig. 2. Fig. 2(a) and Fig. 2(b) show that bed pres-

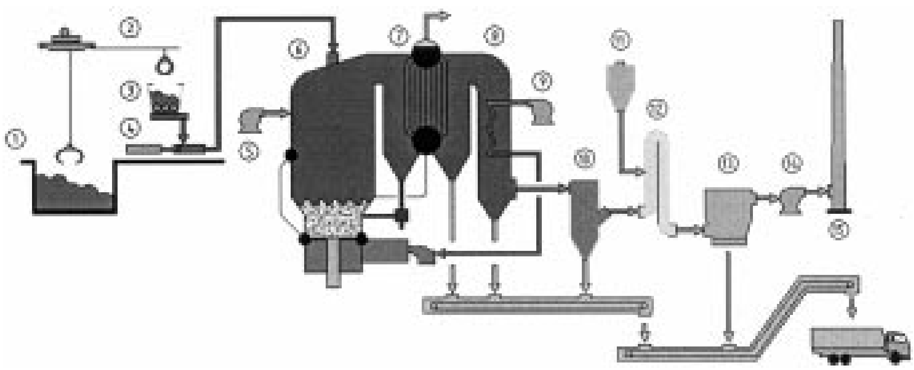
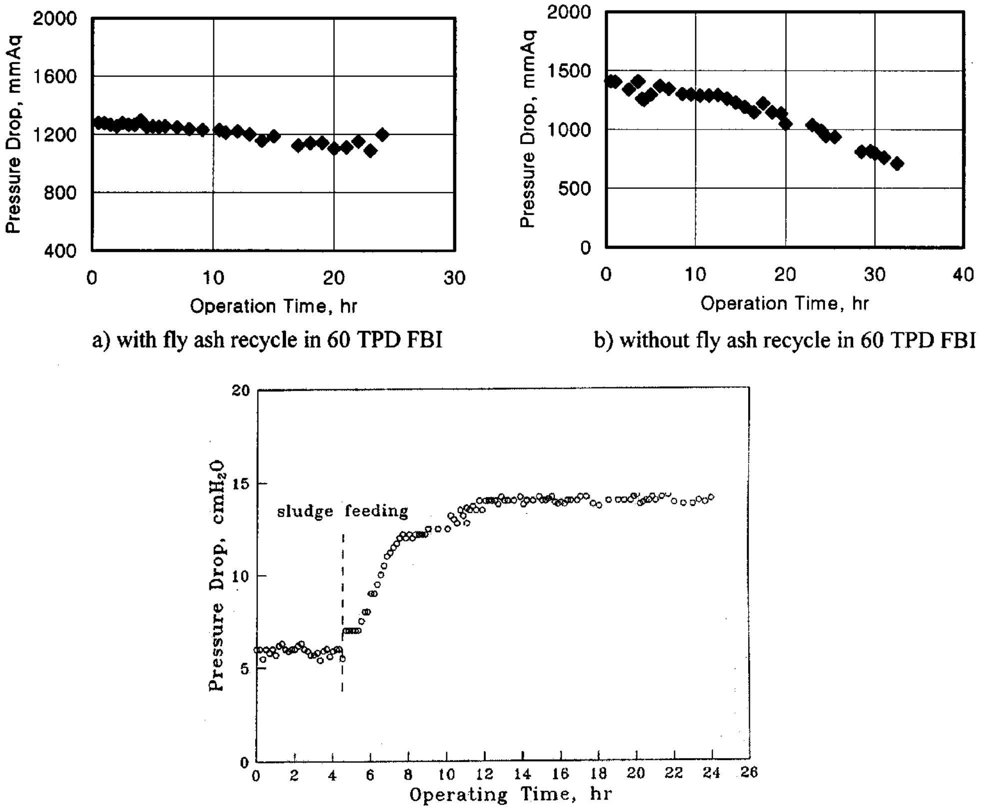


Fig. 1. Flow diagram of 60 ton/day fluidized bed incinerator system.

1. Sludge pit	5. Secondary air fan	9. Primary air blower	13. Bag filter
2. Crane	6. Fluidized bed incinerator	10. Attemperator	14. ID fan
3. Sludge service hopper	7. Waste heat boiler	11. Lime silo	15. Stack
4. Piston pump	8. Air preheater	12. Lime reactor	



a) with fly ash recycle in 60 TPD FBI

b) without fly ash recycle in 60 TPD FBI

c) without fly ash recycle in pilot plant (U : 1.1m/sec, Moisture 80.6, ash 5.6%)

Fig. 2. Variation of bed pressure drop with regard to the operation time.

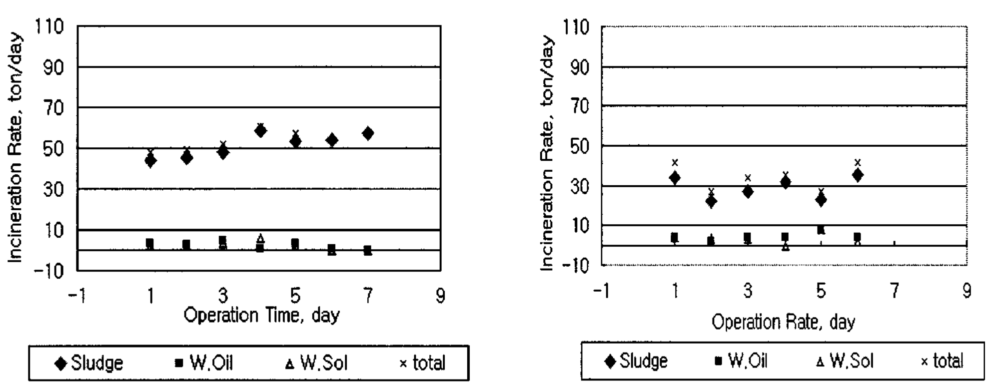
sure drop decreases with increasing operation time regardless of recycle of fly ash. Therefore, it is found that the amount of the recycled ash is not sufficient to maintain the proper bed height without adding fresh sand as bed material for both cases. However, by comparison of bed pressure drop with time, in case of recycle of fly ash, the time to decrease up to a certain pressure drop that is required is four times more than that for no recycle of fly ash. In (c) of Fig. 2, which is the result from the operation of a pilot plant, because ash content is higher than that in the commercial operation and residence time is sufficient,it is enough to maintain the bed pressure. From such results it is found that the ash is usable as bed material in a fluidized bed.

2. Effect of Fly Ash Recirculation

Fig. 3 shows incineration rate for commercial FBI operation with recycle of fly ash and without recycle of fly ash. Recycle of fly ash increased 40% of incineration rate. It means that recycle of fly ash leads to increase of gas flow rate in free board. Consequently, the size of the incinerator could be smaller, and heat loading could be increased by recycle of fly ash.

3. Combustion Behavior of Sludge Clusters

Combustion procedure of sludge cake in a fluidized bed incinerator has been observed. Combustion steps of sludge are investigated



a) with fly ash recycle in 60 TPD FBI

b) without fly ash recycle in 60 TPD FBI

Fig. 3. The results of incineration rate with or without fly ash recycle.

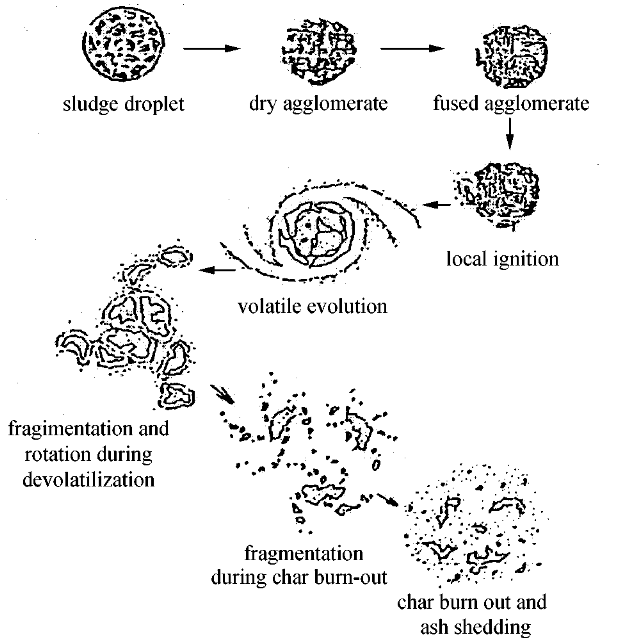


Fig. 4. Conceptual diagram of combustion steps for sludge cluster.

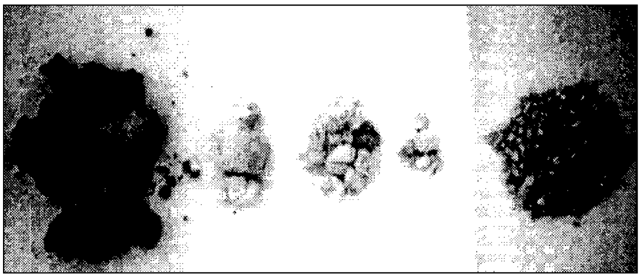


Fig. 5. Picture of sludge cluster combustion steps in 60 TPD FBI.

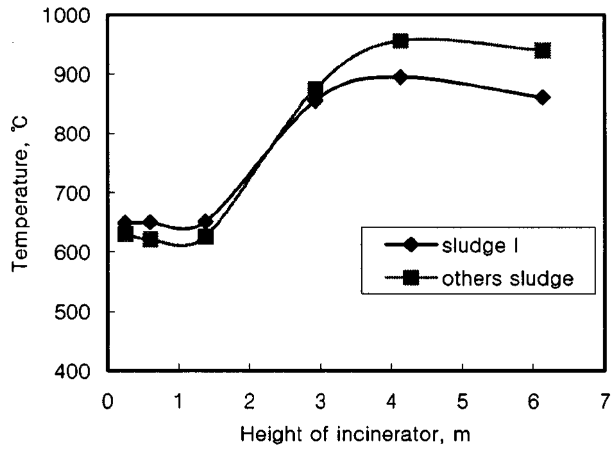


Fig. 6. Axial temperature profiles with the variation of sludge type.

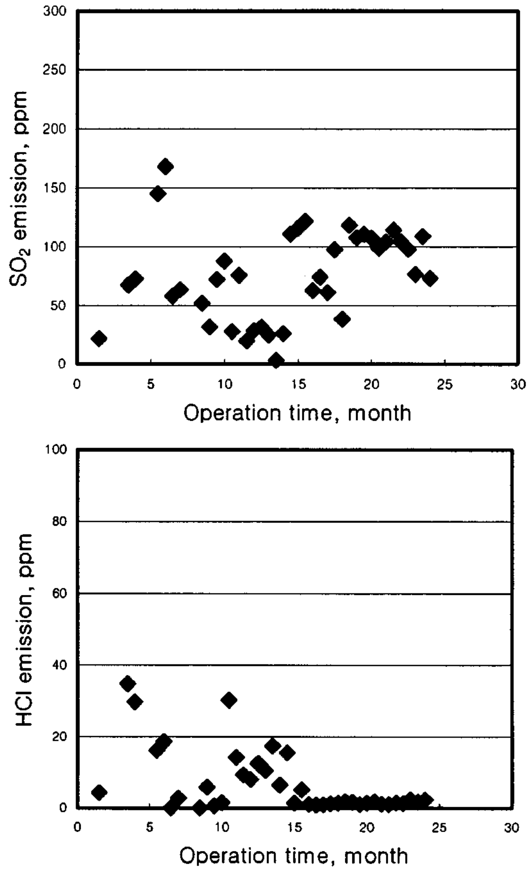


Fig. 7. Variation of SO_2 and HCl emission with regard to the operation time.

by sampling materials in the bed from the drain during incineration. Fig. 4 shows combustion steps of sludge as the same as those in combustion of CWM (Coal Water Mixture). Fig. 5 shows sludge samples in 60 TPD FBI during incineration of the mixture of sludge and waste solvent (or waste oil). As a sludge cluster enters into a fluidized bed incinerator, it is heated and moisture is evaporated. Then, agglomeration of particles is proceeded by surface forces as other investigator suggested [Ohman, 1997]. In case of above 750 °C of cluster surface temperature, the cluster is not only divided by devolatilization and combustion of volatile matter, but changed to fine ashes according to attrition by bed materials as shown in Figs. 4 and 5 [Gu, 1994].

4. Incineration Characteristics in 60 TPD FBI

Operation data such as vertical temperature distribution at the incinerator and concentrations of SO_2, HCl and trace heavy metals in flue gas emitted from stack could be obtained during commercial operation. Results measured twice a month for 24 month of operating time have been recorded. Fig. 6 shows vertical temperature distributions in the incinerator for various kinds of sludge. Fig. 7 shows SO_2 and HCl concentrations emitted from stack. Fig. 8 shows concentrations of trace heavy metals such as Cr, Hg, Cu, Pb and Cd at the stack. As shown in Fig. 6, in case of sludge I, for which heating value is high and moisture content is low, it can be incinerated without mixing waste oil and waste solvent. As a result, the incinerator can be operated at about 860 °C in stable state by the combustion of combustible matter in sludge. Since most of the other sludges besides sludge I have high moisture content and low heat capacity, it is very difficult to operate continuously without co-incineration with auxiliary fuel such as waste oil or waste solvent. As a result, the temperature at the free board of the incinerator is maintained about 950 °C. From Fig. 7, SO_x emission is lower than

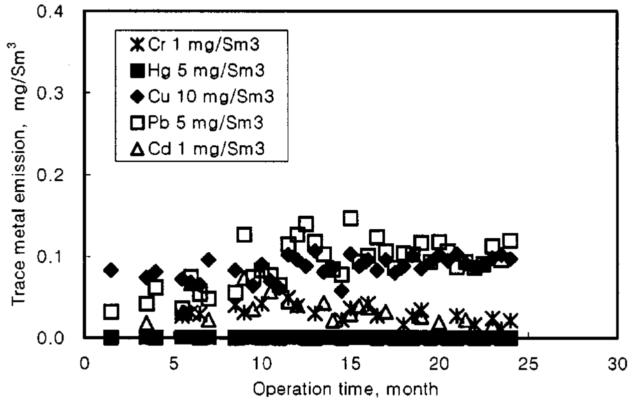


Fig. 8. Trace heavy metal emission as a function of operation time.

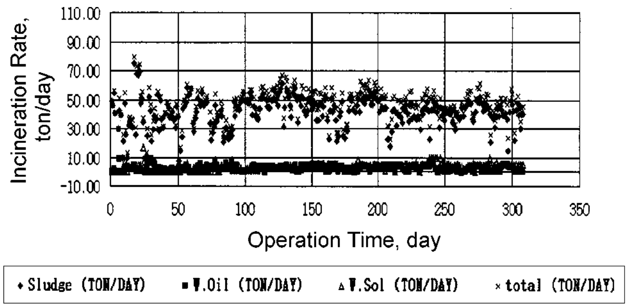


Fig. 9. Incineration rate of 60TPD FBI during 14 months.

175 ppm during operation period, and HCl emission is about 40 ppm at the beginning, but the concentration becomes lower than 5 ppm after 15 months. As shown in Fig. 8, the emission of heavy metals (Cr, Hg, Cu, Pb, Cd) at the stack is lower than the regulatory level. Although Pb content in sludge is a little bit high, it can be controlled by incineration process and flue gas treatment system. The results of leaching test of such heavy metals in ashes were very low and not detected.

5. Characteristics of Incineration Rate during 14 Months

Eleven kinds of dewatered sludges are incinerated with waste oil and waste solvent in the FBI plant. Fig. 9 shows incineration rate data acquired from continuous operation during 14 months. As shown in Fig. 9, average incineration rate of sludge ranges from 40 tons/day to 70 tons/day; FBI is operated in the zone of turn up/turn down. It can be explained in terms of the effect of moisture content in the bed and heating value of sludges on the capacity of FBI. In case of waste oil and waste solvent, a combustion zone forms in the top because of high volatile matter content, and effect of moisture content is high. In addition, high viscosity waste oil shows proper combustion characteristics according to mixing with sludge on feeding line.

CONCLUSION

A pilot plant of FBI for sludge treatment has been developed by the company since 1990 and a commercial scale plant with a capacity of 60 tons/day was completed in 1998. The plant has been in commercial operation since then, and it has been upgraded in design and installation by a continuous trial operation. Also, the trial operation data was fedback to the design factor so as to minimize trouble and the plant has been in successful operation for more than 2 years. From the operation results of the commercial FBI, the following conclusions can be derived.

1. The recycling of fly ash could be used instead of fresh sand adjustment for some sludges having enough ash content. Also, the recycling of ash results in the increase of incineration capacity because of higher heating load and gas flow rate in the free board.
2. The combustion steps of sludge are similar to those of CWM, which consist of evaporation, agglomeration, devolatilization, combustion and attrition to become fine ash.
3. The incineration for all the tested sludges could be successfully operated, either mixing with waste oil and solvent or not at a designed capacity of 40 to 70 tons/day, when the flue gas emission is under regulatory limits.

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