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CHARACTERISTICS OF HIGH TEMPERATURE VISCOSITY IN SOLID WASTE INCINERATION ASH

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Abstract : High temperature viscosity of slag is measured to find the optimum operating temperature in a melting system for the treatment of sewage sludge ashes and municipal solid waste incineration ashes. Effect of calcium oxide as a flux for measurement of viscosity is also studied. Calcium oxide plays a dual role on the slag system. It reacts as an oxide donor to break apart the silicate polymers, but at the same time the calcium ortho-silicate which is formed is a higher melting point species which, for high levels of calcium oxide, eventually raises the melting temperature of the system.

Key Words : ash melting, viscosity, slag, sewage sludge, incineration ash

INTRODUCTION

The viscosity of ash slag as a function of temperature, and the dependence of the viscosity-temperature behavior on slag composition, are important parameters in the successful operation of solid wastes and coal utilization equipments, such as the direct melting furnace of solid waste, the incineration ash melting furnace, the cyclone combustor, and the slagging gasifier etc..[1~6] If these equipments are to operate successfully, the slag formed must be fluid enough to flow freely from the taphole. This information has been used primarily for design of the above devices. The viscosity of ash slag and its relationship to temperature and composition provide an evalution of the suitability of solid wastes and coals for use in such devices.

The melting behavior of ash materials is characterized by several temperatures relating to stages of deformation of cone-shaped ash samples on heating.[7] Viscosity of coal ash melts through the molten temperature range is also useful for characterization.[8] Traditionally, slag viscosity, η, is shown as a function of temperature on a semilog plot. Such curves usually have three main features. At high temperatures log η (viscosity) .vs. temperature is linear with a small negative slope. The slag is considered to have Newtonian flow characteristics in this region. At the low-temperature end of the Newtonian flow region, most curves will exhibit a pronounced change of slope. The temperature at which this slope change occurs is the temperature of critical viscosity, T_{cv}. Below T_{cv} the curve generally has a much more negative slope and may or may not be linear.

This paper describes the measurement of ash slag viscosity as a function of temperature for solid waste(sewage sludge and municipal waste) ashes. These results provide a guidance of operating condition and also a basic engineering information to design the melting system.

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EXPERIMENTAL PROCEDURES

Characterization of Sample

There were chosen three kinds of sewage sludges[①, ②, and ③] which were dewatered in the sewage treatment process and four kinds of municipal waste incineration ashes(A, B, C, and D) in Kyonggi areas. Ash samples from sewage sludges were prepared by using the standard ASTM ashing procedure.[9] The sewage sludge and MSW incineration ash samples are analyzed to determine chemical composition by XRF(X-ray fluorescence spectrometer : Bruker SRS 3400) and their results are shown in Table 1. Nine principal oxide constituents of sulfate-free ash can be divided into those that are acidic in the pyrochemical sense (SiO_2, Al_2O_3, P_2O_5, and TiO_2) and those that are basic (Fe_2O_3, CaO, MgO, K_2O, and Na_2O). The acid-base reaction as a charge transfer equation of oxygen is frequently described as follows[10];

$$O^{o} + O^{2-} = 2O^{-}$$

where, O^{o}, O^{2-}, and O^{-} are called as bridging oxygen ion, free oxygen ion, and non-bridging oxygen ion, respectively. The acidic oxide constituents are generally considered to produce high melting temperatures. Temperatures will be lowered proportionally by the relative amounts of basic oxides available in the ash for reaction. Especially, P_2O_5 content in solid waste incineration ash is higher than that of coal ash, which is in the range of 4～12%.

Viscosity Measurement

The experimental apparatus and procedures used in this study were generally similar to those used in other laboratories.[11,12] Viscosity measurements of solid waste incineration ash were conducted in an inert atmosphere with a Brookfield viscometer using rotating bob method. Fig. 1 shows the experimental apparatus of viscosity measurement, which is consisted of a high temperature electrically heated furnace, a rotational viscometer, and a system controller.

The speed of bob rotation was 6 rpm to get the stable movement of sample. The inert gas (Ar) was injected into the furnace from the bottom through an alumina tube at a flow rate of approximately 2 L/min. Each sample was pulverized to -60 mesh(250 μm) and ashed

Table 1. Composition of sewage sludge, MSW incineration and coal ashes

(unit: wt%)

Sample / Comp.	sewage sludge ash			MSW incineration ash								coal ash
				A		B		C		D		
	①	②	③	bottom ash	fly ash	bottom ash	fly ash	bottom ash	fly ash	bottom ash	fly ash	
SiO_2	51.47	43.94	45.28	18.62	9.17	20.39	2.91	19.87	5.90	12.5	6.7	44.9
Al_2O_3	24.2	22.84	20.67	8.47	3.81	9.21	0.74	9.72	2.83	14.0	3.49	21.0
TiO_2	0.87	0.88	0.8	2.3	1.28	2.85	0.34	2.24	0.76	1.75	1.18	1.12
Fe_2O_3	8.62	7.73	9.93	4.8	1.13	5.28	0.50	2.7	0.67	1.99	0.7	6.01
CaO	3.87	6.56	8.0	43.08	38.58	41.79	43.7	42.35	29.88	42.4	35.11	21.4
MgO	1.87	2.60	2.44	4.64	3.30	4.45	0.94	4.95	2.19	3.41	3.32	5.4
Na_2O	0.86	0.90	0.7	3.01	7.41	2.26	3.94	2.63	10.23	4.60	8.87	0.23
K_2O	2.62	2.46	2.91	1.27	5.87	0.79	2.83	1.25	8.52	1.38	6.49	0.6
MnO	0.3	0.12	0.29	0.42	0.12	0.78	0.06	0.21	0.06	0.21	0.07	N.A.(1)
P_2O_5	5.32	11.97	8.98	5.81	1.14	3.5	0.13	6.29	1.42	7.82	2.76	N.A.(1)
B/A(2)	0.22	0.25	0.32	1.65	3.66	1.52	12.80	1.41	4.72	1.49	3.86	0.5
Basicity(3)	0.08	0.15	0.18	2.31	4.21	2.05	15.07	2.13	5.06	3.39	5.24	0.48

* N.A.(1) : not analyzed

B/A(2) : Fe_2O_3+CaO+MgO+Na_2O+K_2O/SiO_2+Al_2O_3+TiO_2+P_2O_5

Basicity(3) : CaO/SiO_2

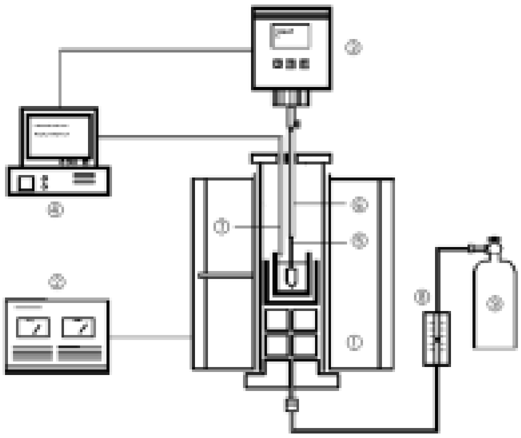

Figure 1. Experimental apparatus of viscosity measurement.

① Electric Furnace ② Furnace Controller
③ Viscometer ④ Data Acquisition System
⑤ Graphite Bob ⑥ Alumina Tube
⑦ B-Type Thermocouple ⑧ Flowmeter
⑨ Ar Gas

according to the ASTM ashing procedures.[9] The resulting ash was compressed into 10 mm diameter, 10 mm long pellets weighing about 1.2 g each. The ash pellets were dropped into a heated sample crucible. A typical sample ash charge was about 70-80 g.

Crucible and bob were made of graphite. The sample crucible is composed of graphite measuring 25 × 50 mm. It is contained in a larger graphite guard crucible (which serves to protect the furnace lining and heating elements in the event that the sample crucible cracked or overflowed), with the annular space between the two crucibles packed with glass fiber.

The viscometer bob was fabricated from 12.5 mm graphite bar stock. The bob was approximately 23 mm long with a 30° angle taper machined on both ends. The top of the bob terminates in a 15 mm long × 4 mm diameter shaft which is taped to accommodate a 5 mm diameter × 421 mm long alumina tube. The top of the alumina tube was connected with a 3 mm diameter, 15 mm long steel shaft. The bob was attached to the viscometer measuring head by a rigid shaft containing a set screw to hold the stem. During a viscosity test, the bob is immersed until the slag just covers its top.

During a viscosity test, the sample was held for 30 min. at the desired temperature long enough to demonstrate constant viscosity before the viscosity measurements were started. Measurements were normally started at the highest temperature considering the melting temperature of sample. The temperature was then decreased slowly until the next temperature was reached for which a measurement was desired. This procedure was repeated over a decreasing sequence of temperatures until the viscosity of melt was too high to obtain reliable data.

In this study, the instrument factor was determined by testing National Bureau of Standards glass viscosity standard No. 711 to calibrate the viscometer, the viscosities of which are precisely defined over the temperature range of interest. The instrument factor is related to the viscosity by the equation as follows.[13] Using this equation, the viscosity of sample was measured.

$$\text{Viscosity} = (\text{Instrument Factor} \times \text{Torque Reading})/\text{Bob Speed}$$

RESULTS AND DISCUSSION

Viscosity of Sewage Sludge Ash Slag

The viscosity of slag in the complete liquid phase from each sewage sludge ash (①, ②, and ③) was measured over the ranges of 1350-1550°C in an inert atmosphere and the results are shown in Fig. 2. The ash sample that was melted to produce the slag was prepared by the standard ASTM ashing method. The slag removal temperature is the temperature corresponding to the maximum viscosity at which slag can be tapped from the melting system. This upper limit for fluidity of slag is approximately 25 Ns/m^2 (250 poise). But the temperature of normal slag removal is defined as the recommended temperature for easy slag tapping from a furnace. Usually, it corresponds to a slag

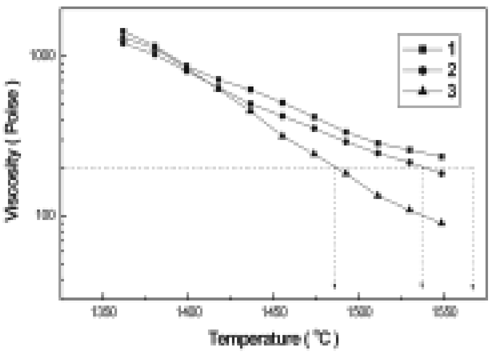

Figure 2. Viscosity of sewage sludge ash slag.

viscosity of 20 Ns/m^2 (200 poise). The flow temperature is also defined as the temperature at which slag has sufficient fluidity to allow free flow without difficulty. Normally the flow temperature corresponds to a slag viscosity of approximately 8 Ns/m^2 (80 poise).

As shown in Fig. 2, the temperature of normal slag removal corrsponding the 20 Ns/m^2 (200 poise) in the viscosity of each sewage sludge ash slag, ①, ②, and ③ is about 1560°C, 1540°C and 1480°C, respectively. The decreasing order of viscosity of each sewage sludge ash slag in the Newtonian region is ①, ②, and ③ in series in the whole ranges of temperature measured the slag viscosity. Viscosities of the ② and ③ sewage sludge ash slags having lower acidic oxide contents are lower than those of ① sewage sludge having higher acidic oxide content in the complete liquid phase. Differences of viscosity are due to those of each sewage sludge ash slag composition. Viscosity behavior is normally determined by the structures of aluminosilicate polymers present in the melt11). Acidic oxides, such as SiO_2 and Al_2O_3 etc., form strong bonds to oxygen, acting as polymer builders and thus increasing concentration of polymer builders acts to increase viscosity. Alkali or alkaline earth species donate oxide ions to the aluminosilicates, acting as polymer breakers. The higher the alkali or alkaline earth content, the lower the viscosity at a given temperature.

As shown in Fig. 2, because the temperature of normal slag removal in sewage sludge ash

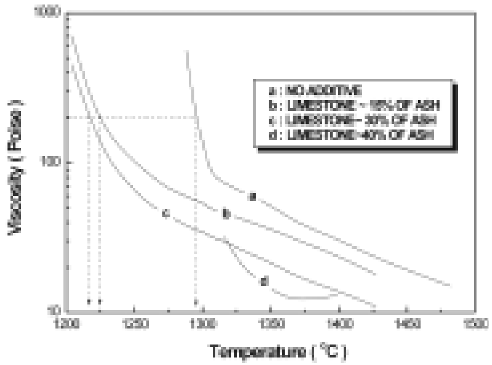

Figure 3. Effect of limestone addition on viscosity of subbituminous coal ash slag(ref. 5).

slags is above 1480°C, ash melting system needs an improved method to lower the operation temperature of the system. For this, a relatively inexpensive fluxing agent, such as limestone, would be advantageous. The use of limestone as a flux for measurement of viscosity in the subbituminous coal ash slag has been studied by Ford and co-workers,[5)] as shown in Fig. 3. At concentrations to approximately 30%, limestone addition decreases the viscosity of the slag melts and increases the temperature range over which the slag exists as a fluid. However, at concentrations somewhat greater than 30% there is a decrease in fluid temperature range.

The effect of limestone addition in amounts of up to 30% is to break down the more complex silicate structures in favor of simpler ones. These results agree well with Vorres' discussion[14)], that the effect of addition of a base, such as CaO, is to reduce silicate polymer size and thus to decrease viscosity. Beyond 30% limestone addition no additional disruption of silicate structures occurs. Indeed a slight trend is indicated for repolymerization. Thus, the calcium oxide plays a dual role on the slag system.[15)] It reacts as an oxide donor to break apart the silicate polymers, but at the same time the calcium ortho-silicate which is formed is a higher melting point species which, for high levels of limestone addition, eventually raises the melting temperature of the system.

To lower the operation temperature of the sewage sludge ash melting system, calcium

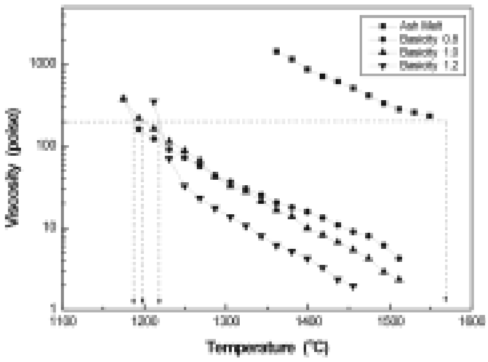

Figure 4. Effect of CaO on viscosity of ① sewage sludge ash slag.

oxide additions having the basicity(expressed as the ratio of CaO/SiO_2) of 0.8, 1.0, and 1.2 were given to the system for finding out the viscosity behavior, as shown in Fig. 4. In the case of calcium oxide addition, Fig. 4 shows low viscosities than the observed values for the viscosity of sewage sludge ash slag without addition of lime. The effect of calcium oxide addition is to break down the more complex silicate structures and thus to decrease viscosity.

Viscosity of Incineration Ash from Municipal Solid Waste

The viscosity of slag in the complete liquid phase from each municipal solid waste incineration bottom ash (A, B, C, and D) was measured over the ranges of 1100-1400°C and the results are shown in Fig. 5. The bottom ashes which were collected from four different incineration plants were melted to produce the slag. The basicity ranges of MSW incineration bottom ashes and sewage sludge ashes are 2.05-3.39 and 0.08-0.18, respectively. The values of bottom ash are approximately twenty times higher than those of sewage sludge ash, In other words, the higher the basicity value is, the lower the viscosity at a given temperature.

As shown in Fig. 5, the temperature ranges of normal slag removal corrsponding the 20 Ns/m^2 (200 poise) in the viscosity of MSW incineration bottom ash slags, A, B, C, and D are about 1200-1310°C. The temperature of normal slag removal in the MSW incineration bottom ash

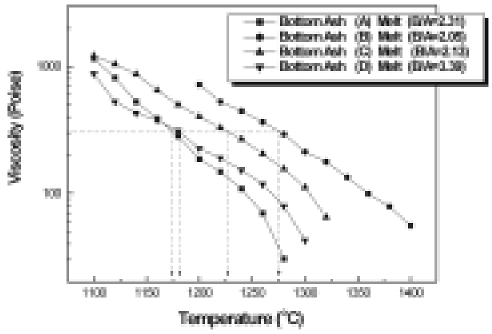

Figure 5. Viscosity of incineration bottom ash slag from municipal solid waste.

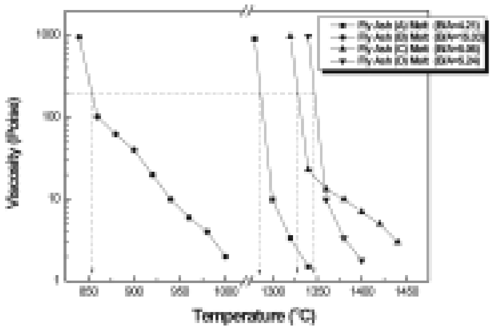

Figure 6. Viscosity of incineration fly ash slag from municipal solid waste.

slag is low in comparison with that of sewage sludge ash slag because calcium oxide reacts as an oxide donor to break apart the silicate polymers and thus to decrease viscosity.

The viscosity of each MSW incineration fly ash(A, B, C, and D) was measured as the same procedures of MSW incineration bottom ash and the results are shown in Fig. 6. As shown in Fig. 6, the temperature ranges of normal slag removal corrsponding the 20 Ns/m^2 (200 poise) in the viscosity of each MSW incineration fly ash slag, A, C, and D are about 1300-1350°C except abnormal samples of B. But the temperature ranges corrsponding the 20 Ns/m^2 (200 poise) in the viscosity of samples are very critical because the slag melts are in the Non-Newtonian region consisting of partial liquid phase. So the operation temperature of MSW fly ash melting system should be decided at the Newtonian region consisting of complete liquid phase. The basicity ranges of MSW incineration fly ashes are 4.21-5.24, except that of B. The values of fly ash are higher than those of bottom ash. The relationship between log viscosity and temperature in the MSW incineration fly ash slag represents the slag with rapid crystallization and freezing characteristics below the temperature of critical viscosity. This may be due to the high levels of basicity in comparison with that of bottom ash, and this eventually raises the melting temperature of the system.

CONCLUSIONS

The major conclusions of this study are as follows;

(1) Viscosity is closely related with composition of solid waste incineration ash slag. The higher the alkali or alkaline earth content, the lower the viscosity at a given temperature.

(2) Effect of calcium oxide addition is to break down the more complex silicate structures and thus to decrease viscosity in sewage sludge ash slag.

(3) Municipal solid waste incineration bottom ash can be easily melted because calcium oxide reacts as an oxide donor to break apart the silicate polymers and thus to decrease viscosity.

(4) Temperature ranges corrsponding the 20 Ns/m^2(200 poise) in the viscosity of municipal solid waste incineration fly ash are very critical because the slag melts are existed as partial liquid phases. So the operation temperature should be decided at the complete liquid phase.

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