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Integrated drying and incineration of wet sewage sludge in combined bubbling and circulating fluidized bed units

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ABSTRACT

An original integrated drying and incineration technique is proposed to dispose of sewage sludge with moisture content of about 80% in a circulating fluidized bed. This system combines a bubbling fluidized bed dryer with a circulating fluidized bed incinerator. After drying, sewage sludge with moisture less than 20% is transported directly and continuously from the fluidized bed dryer into a circulating fluidized bed incinerator. Pilot plant results showed that integrated drying and incineration is feasible in a unique single system. A 100 t/d Sewage Sludge Incineration Demonstration Project was constructed at the Qige sewage treatment plant in Hangzhou City in China. The operational performance showed that the main operation results conformed to the design values, from which it can be concluded that the scale-up of this technique is deemed both feasible and successful.

1. Introduction

With the rapid development of the economy and society in China, the coverage rate of wastewater treatment increases every year. Statistics show that about 102.62 million m^3 of wastewater per day were treated by the end of 2010, up 13.4% over the previous year, and the sewerage treatment rate reached 76.9%. Sewage sludge is the largest byproduct by volume of wastewater treatment, and its processing and disposal may be one of the most complex environmental problems in this field (Werther and Ogada, 1999). Among the methods for sewage sludge disposal, incineration has some advantages, such as reduction, stabilization, and harmless treatment, which makes it be the most attractive method for thermal processing of sewage sludge (Fytili and Zabaniotou, 2008). The advantages of incineration can be summarized as follows (Werther and Ogada, 1999; Fytili and Zabaniotou, 2008; Otero et al., 2002; Kim and Lee, 2010; Stasta et al., 2006): (1) significant reduction of sludge volume; the final sludge volume after incineration is approximately 10% of that after mechanical dewatering; (2) thermal destruction of toxic organic constituents. The fluidized bed method has been widely studied and applied due to the sufficient blending of gas–solids, thorough incineration, and the low discharge of pollutants (Yun et al., 2007; Werle and Wilk, 2010; Murakami et al., 2009; Van de Velden et al., 2008; Shimizu and Toyono, 2007; Toraman et al., 2004). Circulating fluidized bed (CFB) combustion technology has been used for thermal destruction of sludge due to its attractive advantages of extensive fuel flexibility, strong turbulence on combustion, temperature uniformity in the furnace, and lower emissions than other incinerators (Werther and Ogada, 1999; Van Caneghem et al., 2012). The drying of sewage sludge before incineration can reduce the need for auxiliary fuel in the process of sewage sludge incineration and increase the heat efficiency of the system. Nevertheless, among most techniques for drying and incineration of sewage sludge, the drying and incineration systems are separated, and dried sludge is cooled and transported into special storage in an inert atmosphere. Therefore, the disposal system is complex, and the construction and operation cost is rather high.

We present an original integrated drying and incineration technique for sewage sludge disposal. This integrated incineration system combines a bubbling fluidized bed dryer and a circulating fluidized bed (CFB) incinerator. In this system, the dried sludge is transported directly into incineration by a screw. There is no dried sludge storage. The technique is compact and reliable as well.

2. The integrated drying and incineration technique for sewage sludge

2.1. The technique's process flow

Fig. 1 demonstrates the integrated drying and incineration technique for sewage sludge. Sewage sludge with about 80% moisture content is fed into a bubbling fluidized dryer where it is blended intensively with high temperature circulating ash and is subjected

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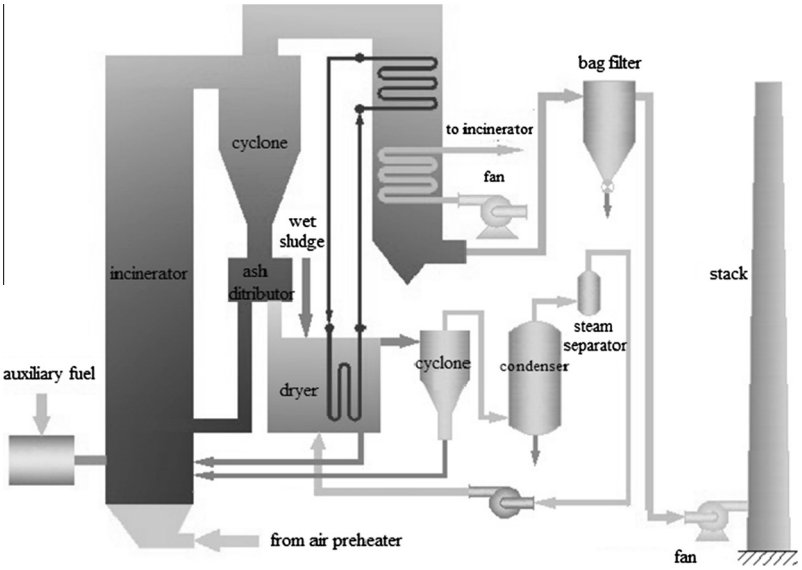

Fig. 1. Process diagram of the integrated drying and incineration technique for sewage sludge in a circulating fluidized bed.

to direct heat transfer. Sewage sludge is dried and broken into small particles while the water is evaporated. In order to reduce the moisture content of sewage sludge to below 20%, extra heat recovered from the flue gas generated by sludge incineration provides energy for further drying of sludge via indirect heat transfer. Dried sludge with moisture content below 20% is released from the dryer bottom and flows directly into the CFB incinerator to be continuously incinerated. Steam, fluidization gas, and elutriated fine powder from the dryer are first dispersed into a cyclone. The fine powder captured from the cyclone is delivered into the CFB incinerator for incineration. Next, fluidization gas with steam enters the condenser. The condensate water at the inlet comes from the reclaimed water treatment system, and the condensate water in the outlet is pumped into the sewage treatment plant to be treated as waste water. Then the fluidization gas flows into the steam separator. Lastly, the remaining fluidization gas, as recycled bubbling fluidized air, is blown into the fluidized dryer by a fan. The high temperature flue gas generated by the CFB incinerator with bed material flows into the high-temperature cyclone separator. After being separated, the high temperature circulating bed material enters a dual-exit ash distributor that can regulate the ash flow ratio into the incinerator and dryer. The high temperature flue gas out of the high-temperature cyclone separator flows into a heat exchanger for a convection back pass in which oil-tube heaters and air preheaters are adopted, and then through a flue-gas cleaner and a bag filter. Finally, the flue gas is released from the stack by an induced draft fan into the air.

The dual-exit ash distributor mentioned here is a dual-exit loop-seal which has two supply chambers, recycle chambers, and delivery pipes. The operational principle is similar to the twin-exit loop-seal reported in Basu et al. (2009). According to the design values, the flow ratio on the fluidized bed dryer side is less than 30%. The ash flow rate entering the dryer is controlled by the gas supplied into the dual-exit ash distributor. The amount of ash introduced into the dryer affects the bed temperatures of the dryer. The flow rate of the bed material entering the incinerator from the dryer is regulated by keeping the pressure drop almost constant across the bed.

2.2. Major characteristics of the technique

- *Integrated incineration technology.* This integrated incineration system combines a bubbling fluidized bed dryer and a circulating fluidized bed incinerator. The technical process is simple and reliable. Sewage sludge is dried and incinerated in only one system, thereby enabling its reduction, stabilization, and harmless treatment.
- *Direct–indirect combined drying.* Direct–indirect combined drying technology is applied in the fluidized bed dryer with intensive drying capability. A dual-exit ash distributor is used to control the ash flow ratio into the incinerator and fluidized dryer according to actual need. The high temperature circulating ash blends directly and intensively with sewage sludge, which not only increases the sludge drying rate, but also facilitates the fluidization of sewage sludge. A heat medium, such as heat conducting oil recycling heat from the flue gas, exchanges heat with the sludge for indirect drying.
- *Combustion with high efficiency and low emission of pollutants.* The CFB combustion technology is used to incinerate sludge due to its attractive advantages of extensive fuel flexibility, strong turbulence on combustion, and temperature uniformity in the furnace. The combustion efficiency is over 98%. Limestone is injected into the CFB incinerator for desulfurization. NO_x emissions are reduced by staged combustion. The residence time of flue gas in the incinerator is longer than 2 s, while the temperature at the outlet of the furnace is greater than or equal to 850 °C. The pollutant emissions in the flue gas can sufficiently meet the national emission standards.
- *Safe and reliable operation.* CFB combustion technology is mature, and sludge is dried in an enclosed system. Dried sludge is transported directly into the CFB incinerator. The transportation route is short, and there are lots of inert sand particles in the dryer which leads that dry sewage sludge particles reduces, and the explosion temperature increases. On this account, the dust explosion risk is effectively reduced.

3. The experiment and discussion of a pilot plant

3.1. Material and methods

An integrated CFB sewage sludge incineration pilot plant with a capacity of 1.0 t/d was established at the Institute of Engineering Thermophysics, Chinese Academy of Sciences (IET, CAS). The process flow of the test system is the same as that in Fig. 1. The experimental system includes an incinerator with an internal diameter of 0.3 m and a height of 7.5 m, and a bubbling fluidized bed dryer