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RESEARCH ON FEASIBILITY OF DIFFERENT INCINERATION SYSTEMS FOR PAPER SLUDGE

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ABSTRACT

A large amount of paper is recycled in China, that generates a significant amount of sludge and residue during the paper production process. Energy recovery by means of combustion in Waste-to-Energy (WTE) plants can be a possible candidate for sludge elimination. Currently, two incineration methods, distinguished as either direct incineration of partially dewatered sludge (generally 80% water content) or dried sludge incineration (dried to about 40% water content), are available. Research on comparison of fixed cost, operating cost and pollutant emissions between the two systems is presented. Fixed cost and steam consumption increase for the dried sludge incineration system though this method possesses many advantages, these include the decrease in consumption of auxiliary coal, service power and flue gas purificants. Moreover, main pollutant emission, such as SO_2 and NO_x, is significantly reduced. Chinese WTE managing regulations recommend no less than a 4:1 weight ratio of waste to auxiliary fuel fed into the incinerator. For a partially dewatered sludge direct incineration system, this weight ratio is about 5:1. However it reduces to 3.6:1 in a dried sludge incineration system. This is offset by a decrease in consumption of auxiliary coal and the overall weight ratio based on the entire plant increases to 7.5:1. The result suggests not only the technical and economic feasibility of a dried sludge incineration method, but also the feasibility of adopting the weight ratio of waste to auxiliary fuel based on entire WTE plant in the future regulation in China.

1. INTRODUCTION

Paper recycling is the process of recovering waste paper and reproducing it into new paper products. More and more recycled paper has been used in China in recent years. During the recycled paper production process, significant amounts of paper sludge and residue are generated. Paper sludge and residue mainly contain plastic, adhesive tape, packing tape, steel wire, fibre, etc. The moisture content of paper sludge and residue is very high, generally 60% to 80%. Landfilling has been the most common method for paper sludge and residue disposal in China. However, adverse impacts occur because of leachate and the high content of non-biodegradable and hazardous substances in paper sludge and residue.

Waste-to-Energy (WTE) application of paper sludge and residue, such as incineration, is usually preferable to landfilling since useful energy (for example heat and electricity) is generated with significant volume, mass and toxicity reduction. Paper sludge and residue incineration with power generation and heat recovery has been used in China in recent years. In order to encourage and supervise the WTE application, a regulation named “Managed Regulation of Ratifying Resource Integrated Utilization Encouraged by state” was issued by National Development and Reform Commission of China in 2006[1]. This regulation suggests a no less than 4:1 weight ratio of waste to auxiliary fuel based on the use of a fluidized bed incinerator. WTE power plants complying with this regulation can obtain preferential tax rate and higher electricity sell price than fossil-fuel power plants.

Currently, two incineration methods, distinguished as either direct incineration of partially dewatered sludge (generally 80% water content) or dried sludge incineration (dried to about 40% water content), are available. Generally, the volume flow rate of the flue gas, auxiliary coal consumption and related operating costs associated with direct incineration of partially dewatered paper sludge method are higher than those of the dried sludge incineration method because of the high moisture content and low heating value of partially dewatered paper sludge. However additional equipment, construction and operating costs when using a

paper sludge drying system during dried sludge incineration are inevitable. This has led to a dispute about the comparative thermal efficiency and economic benefit of the two incineration methods under current regulation. Moreover, there is the doubt about the compliance with the current WTE managed regulation when using the dried paper sludge incineration method.

This paper mainly focuses on the technical and economic efficiency analysis of the two incineration systems. The comparative results of the technical system, fixed costs, operating costs and pollutant emissions between these two incineration systems are presented. The results can offer valuable suggestions for the application and management of paper sludge to energy incineration process.

2. TECHNICAL COMPARISON BETWEEN THE TWO INCINERATION SYSTEMS

2.1 Direct incineration of paper sludge and residue

One paper sludge and residue incineration project in Zhejiang province, China was selected as the subject for this study. A circulated fluidized bed (CFB) incinerator with superheated steam production of 150t/h at design temperature of 485℃ and pressure of 5.3MPa was adopted. The moisture content of partially dewatered paper sludge is 80%. One of the main components of paper residue is waste plastic and the moisture content of partially dewatered paper residue can be reduced from 56.7% to 39.7% within a few days of its arrival. According to the typical production from a paper plant, 1200t/d of partially dewatered paper sludge and 330t/d of paper residue are averagely generated based on 365 days per year. A paper sludge incineration system is usually designed for 8,000 hours (333.3 d/yr) of operating per year, which means that the maximum disposal capability of a paper sludge and residue incineration system is 1314t/d paper sludge and 361t/d paper residue for each 24 hours actual processing.

Due to the low heating value and high moisture content of paper sludge and residue, about 330t/d of co-fired coal is needed in a partially dewatered sludge incineration system to achieve the necessary combustion temperature and process conditions that enable complete combustion[2]. Ultimate analysis of the auxiliary coal, partially dewatered paper sludge and residue are shown in Table 1. It is obvious that the weight ratio of paper sludge and residue to auxiliary coal for the CFB incinerator is about 5.1:1, which is the same as the weight ratio of paper sludge and residue to auxiliary coal for the entire WTE plant. This meets the criteria of current managed regulation in China.

Table 1 Ultimate analysis of paper sludge, residue and coal in partially dewatered sludge incineration system (wt %)

	C	H	O	N	S	Cl	Ash	H_2O	Q_{net}(kJ/kg)
Partially dewatered paper sludge	4.84	0.59	4.87	0.08	0.01	0.01	9.60	80.00	-274.00
Dewatered paper residue	45.94	7.82	4.13	0.17	0.08	0.13	2.06	39.66	12652.37
Coal	62.21	4.08	6.09	1.01	0.72	—	13.89	12.00	24408.00
Mixture	21.68	2.47	4.94	0.25	0.14	0.03	8.95	61.54	6115.54

Table 2 Ultimate analysis of paper sludge, residue and coal in dried sludge incineration system (wt%)

	C	H	O	N	S	Cl	Ash	H_2O	Q_{net}(kJ/kg)
Dried Paper sludge	14.52	1.77	14.61	0.25	0.03	0.02	28.80	40.00	4178.00
Dewatered paper residue	45.94	7.82	4.13	0.17	0.08	0.13	2.06	39.66	12652.37
Coal	62.21	4.08	6.09	1.01	0.72	—	13.89	12.00	24408.00
Mixture	36.02	4.41	9.05	0.39	0.20	0.05	16.10	33.78	11580.94

2.2 Dried paper sludge and residue incineration

As mentioned above, the moisture content of paper sludge after partially dewatering is as high as 80% and it can't be incinerated without the use of co-fired fuel. The sludge drying process reduces both the mass and volume and results in dried sludge having greater stability, that is easier to store, transport, package and incinerate or co-incinerate[3]. It's commonly recommended that a profitable degree of drying is to about a 30-40% moisture content for dried sludge incineration[4]. There is a variety of technical solutions for sludge drying. Indirect drying using low pressure overheated steam(180℃, 0.3MPa) is commonly used due to its convenient accessibility in WTE and paper production plants.

In this study the dried paper sludge with 40% moisture content is adopted. After the drying process the actual dried paper sludge quantity is 438t/d. Dewatered paper residue has about 40% water content and an acceptable heating value, so it doesn't need to be further dried. Therefore, about 223t/d auxiliary coal is co-fired with 438t/d dried paper sludge and 361t/d paper residue. Ultimate analysis of the auxiliary coal, dried paper sludge and residue are shown in Table 2.

As a result, the weight ratio of dried paper sludge and residue to auxiliary coal based on a CFB incinerator is about 3.6:1. However, the weight ratio for the entire plant is about 7.5:1 that is much higher compared with the partially dewatered paper sludge incineration method. It means that the weight ratio based on a CFB incinerator doesn't meet the

criteria of current managed regulation in China when using the dried sludge incineration method. This is one of the main aspects of the dispute about these two incineration methods that the WTE plant using the dried sludge incineration method can't obtain the preferential tax rate and higher electricity sell price although the actual consumption of the auxiliary coal is reduced.

Table 3 Comparison of system load between two incineration systems

Items	Partially dewatered sludge incineration		Dried sludge incineration	
Load of gas-air system				
	Flow rate(m^3/h)	Load (kW/h)	Flow rate(m^3/h)	Load (kW/h)
Primary air fan	212,341	1,360	182,380	1,120
Secondary air fan	141,560	450	121,587	380
Induced fan	870,605	2,240	661,946	1,790
Flue gas purifying system	764,832	400	584,091	290
Air compressing (Nm^3/min)	92	400	72	310
Steam consumption (t/h)	0.7	—	0.5	—
Total	—	4,850	—	3,890
Load of paper sludge drying system				
Drier	—	—	—	320
Steam consumption of Drier	—	—	13.3	—
Pumps	—	—	65	14
Total	—	—		334

2.3 Paper sludge drying system

For a dried paper sludge incineration system, the technical level and energy consumption of the sludge drying system have an important impact on the operating cost and economic efficiency of the entire plant. A multi-effect drier is adopted because of its lower steam consumption, that is about 0.3-0.4kg steam consumed per kg water evaporated from sludge, as compared with other conventional types of driers, such as paddle driers, rotary driers, etc[5,6]. For 1314t/d of partially dewatered paper sludge, about 320t/d of low pressure overheated steam is used accompanied by power consumption about 7680 kW/d. Besides the sludge drier, ancillary equipment is also necessary that include the pumps used for the low pressure steam condensate and sludge evaporated water. The low pressure steam condensate can be recycled. About 800t/d water is evaporated from paper sludge and the condensate needs to be taken away to a sewage treatment system.

2.4 Comparison of system load

In order to evaluate the technical performance of the two incineration systems, the flue gas-air system and paper sludge drying system load are presented in Table 3. Compared with a dried paper sludge incineration system, the feed rate of coal, paper sludge and residue to the CFB incinerator in partially dewatered sludge incineration system is higher. This results in higher flue gas and air flow rates and flue gas-air system load than those of a dried paper sludge incineration system. The flue gas-air system load in dried sludge incineration system is just about 80% of a partially dewatered sludge incineration system. However, extra steam and electricity consumption by the paper sludge drying system are needed in a dried sludge incineration system, that is about 8.6% of the total system electricity load.

3 FIXED AND OPERATING COSTS COMPARISON

3.1 Fixed costs comparison

The fixed cost comparison of the two incineration systems, that mainly include the instrument, installation and civil engineering costs, are presented in Table 4. The feeding rate of coal, paper sludge and residue to the CFB incinerator, flue gas and air flow rate, flue gas-air system load, as well as instrument and installation costs in a dried sludge incineration system are all lower as compared to those of a partially dewatered paper sludge incineration system. As shown in Table 4, the costs of instruments and installation for a dried sludge incineration system are just 75% of that for a partially dewatered sludge incineration system. The civil engineering cost for a dried sludge incineration system, which is mainly due to the foundation construction for the paper sludge drying system, boiler unit, boiler's ancillary equipment, air system, coal system and flue gas purifying system (desulfurization system, dedusting system, stack, etc.) is higher than that for a partially dewatered paper sludge incineration system. Instrument and construction costs for the sludge drying system are the main additional cost for a dried sludge incineration system. As a result, the fixed costs for a dried sludge incineration system increase by more than $0.33 million, which is about 1-2% of the total investment of the project.

3.2 Operating costs comparison

Besides the fixed costs, operating costs are also an important factor for the comparative economic analysis of the two incineration systems. In this paper, operating costs

discussion mainly focuses on the consumption of steam, auxiliary electricity, coal, flue gas purificants and gross pollutant emissions. Comparison results of these main operating costs are presented in Table 5.

The difference in the steam consumption between the two incineration systems mainly comes from the steam used by the sludge driers and flue gas purification system. According to Table 3, the extra steam consumption associated with a dried sludge incineration system is about 315t/d. The steam price is generally about $13-15/t. Therefore, the additional operating cost due to steam used in the dried sludge incineration system is about $1.5 million per year.

Auxiliary electricity consumption of the boiler's ancillary equipment, air-flue gas system and paper sludge drying system are taken into consideration for the auxiliary load comparison between these two incineration systems. The auxiliary electricity consumption in a partially dewatered sludge incineration system is about 640kW/h higher than that in a dried sludge incineration system despite the additional electricity consumption by the sludge driers. This results in a considerable decrease in the auxiliary electricity consumption of about 5,120MW and a net operating cost reduction of about $0.35 million per year for a dried paper sludge incineration system.

Table 4 Comparison of fixed costs between two incineration systems

Items	Partially dewatered sludge incineration	Dried sludge incineration
Instrument Cost and Installation Cost ($ million)		
Sludge drying system	0	2.16
Boiler unit	3.16	2.40
Boiler wall	0.37	0.24
Insulation material and paint	0.28	0.18
Flue gas, air and coal ducts	0.31	0.26
Fans	0.38	0.31
Flue gas purifying system	3.35	2.54
Total	7.85	8.09
Civil Engineering Cost ($ million)		
Sludge drying system foundation	0.50	0.76
Boiler foundation	0.09	0.04
Boiler's ancillary equipment foundation	0.04	0.04
Flue gas purifying system foundation	0.46	0.32
Total	1.09	1.18

Table 5 Operating costs comparison between two incineration systems

Operating cost item	Partially dewatered sludge incineration		Dried sludge incineration		Difference	
	Quantity	Cost $ m/yr	Quantity	Cost $ m/yr	Quantity	Cost $ m/yr
Steam	5,600	0.07	110,656	1.51	105,056	-1.44
Auxiliary Electricity	38,800MW/yr	2.66	33,680 MW/yr	2.31	5,120 MW/yr	0.35
Coal	109,989t/yr	9.71	74,326	6.56	35,663	3.15
Desulfurizer	4,880t/yr	0.09	3,360t/yr	0.06	1,520t/yr	0.03
activated carbon	12.8t/yr	0.01	9.6t/yr	0.01	3.2t/yr	3×10^{-3}
SO_2 emission	312 t/yr	0.03	217 t/yr	0.02	95 t/yr	0.01
NO_x emission	1,316 t/yr	0.12	1,000 t/yr	0.09	316 t/yr	0.03
Total	—	12.69	—	10.56	—	2.13

As mentioned above, the consumption of co-fired coal in a dried paper sludge incineration system can be significantly reduced by about 32.4%, 107t/d, due to the increase in heating value of the dried paper sludge. Therefore, the operating cost due to the coal consumption in a dried sludge incineration system is much lower. Since the current coal price is about $90/t in China, the reduction in operating costs due to decreased coal consumption can results in a net saving of about $3.15 million per year.

The main flue gas purificants used in a paper sludge incineration system are the desulfurizer and activated carbon adsorbent. Because of the decreased coal consumption and flue gas flow rates in a dried sludge incineration system, the consumption of the desulfurizer and activated carbon are

correspondingly lower than in a partially dewatered sludge incineration system. $Ca(OH)_2$ is generally used for flue gas desulfurization in sludge incineration systems. Under conditions of a 2.2 Ca/S ratio and an 80% desulfurizing efficiency, the consumption of sulfurizer in a dried paper sludge incineration system can be reduced by about 31%. Consumption of activated carbon can be reduced by about 25%. The decrease of flue gas purificants consumption can save about $ 0.03 million per year.

3.3 Main pollutant emission

In this project the efficiency of desulfurizing equipment and bag filters are 80% and 99.9% respectively. The reduced coal consumption and lower flue gas flow rates in a dried sludge incineration system leads to lower emissions of the main pollutants. For example, SO_2 emission decreases by about 30%, NOx by about 24% and dust by about 6%. So far the pollution discharge fees for SO_2 and NO_x are both about $90/t in China. Therefore, nearly $0.04 million per year can be saved using a dried sludge incineration method. Further economic benefit can be reached when considering the reductions in CO_2 and dust emissions.

3.4 Economic feasibility analysis of two systems

From the discussions above, it can be seen that the principal operating costs for the partially dewatered and dried incineration systems are about $12.7 million and $10.6 million per year, respectively. Significant savings in operating costs can be achieved when using dried sludge incineration system, nearly $2.13 million per year, that represents about 16.8% of the operating costs using a partially dewatered paper sludge incineration system. Although there are extra fixed costs associated with the use of paper sludge drying instruments and the ancillary equipment in a dried paper sludge incineration system, these costs can be recovered in several months due to the operating cost savings. From an economical perspective, it is feasible to choose the dried paper sludge incineration method.

CONCLUSION

The heating value of paper sludge after undergoing the drying process can be dramatically increased to a level that make it suitable for use as a co-fired fuel in Waste-to-Energy plants. Based on the comparative technical and economic analysis of these two different incineration systems in this study, the dried paper sludge incineration method is a reasonable approach to reduce the consumption of co-fired coal, decrease the flue gas and air system load and flow rates and drop the operating costs. The increased fixed costs can be easily recovered due to the reduced operating costs for a dried sludge incineration system. With the successful experience in municipal solid waste (MSW) and washed coal residue incineration plants in China, the application of converting dried paper sludge and residue to energy can gain further technical support and development.

One point to note is that the weight ratio of dried paper sludge and residue to auxiliary coal based on the use of a CFB incinerator is just about 3.6:1 in a dried sludge incineration system, that is less than 4:1. This results in an awkward situation since the application of a dried paper sludge incineration does not comply with the current managed regulation for WTE plant in China. However, the weight ratio of paper sludge and residue to auxiliary coal based on the entire WTE plant is 7.5:1 in a dried sludge incineration system and the actual co-fired coal consumption is less than that in a partially dewatered paper sludge incineration system. It is therefore considered that the adoption of the weight ratio of paper sludge to coal based on the entire WTE plant is a more suitable managed resource utilization criteria. Nevertheless, the weight ratio for a partially dewatered paper sludge incineration system (80% water content) using a CFB incinerator having a value of about 5.1:1 is in compliance and is a reasonable option so far for the use of paper sludge resources in an integrated utilization plant.

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