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Application Status of Co-Processing Municipal Sewage Sludge in Cement Kilns in China

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Abstract: Municipal sewage sludge (MSS) disposal is an urgent issue in China with the continuous growth of sewage treatment capacity. Among various disposal methods, co-processing of MSS in cement kilns has been one of the most promising disposal methods in recent years. The present situation of sewage treatment and sludge disposal, the development of co-processing MSS in a cement kiln, and main disposal routes in China were discussed in this study. The results indicated that China had paid considerable attention to the technology and released correlative policies in the past few years. There were about 35 co-processing projects built in China, all of which were limited by construction scale and pollutant emissions. Due to differences in construction methods and economic conditions, China's co-processing projects mainly employed three routes—direct addition to a transition chamber, addition to a precalciner after direct thermal drying, and addition to a precalciner after indirect drying. Summarizing and analyzing the characteristics of MSS co-processing would facilitate its development in China and similar regions.

Keywords: municipal sewage sludge; cement kilns; co-processing; application status

1. Introduction

The domestic wastewater treatment capacity in China has grown rapidly in recent years. As the byproduct of wastewater treatment, the weight of municipal sewage sludge (MSS, with 80% moisture content unless otherwise noted) has increased considerably [1]. MSS treatment and disposal have seriously challenged environmental protection in China [2]. Landfilling, incineration, agricultural use, and composting have been the most common sludge disposal methods, with landfilling the most widely applied [3,4]. However, odors and landfill leachates have resulted in the adoption of increasingly strict standards. Accordingly, incineration has attracted increasing attention as a potential alternative. In China, the landfilling disposal rate has been on the decline, while incineration increased in the past few years [5]. Sludge incineration technologies can be grouped into two categories: Mono-incineration and co-processing. Among the latter, one of the most common methods is co-processing MSS in cement kilns, which has been gaining popularity due to its lower energy consumption and greenhouse gas emissions [6,7]. Compared with other disposal methods, co-processing MSS in cement kilns is more environmentally friendly. High kiln temperatures destroy dioxins or furans produced during combustion, acidic gaseous pollutants can be effectively removed by the suspended fine limestone particles, and heavy metals from the sludge are adsorbed onto the particles or solidified in clinkers [8,9]. Furthermore, organics in MSS can contribute extra heating value to the cement kiln, resulting in their serving as alternative fuels for the kiln. Currently, co-processing of MSS in cement kilns is widely applied in the United States, Japan, Germany, France and other developed countries [10–12]. As a result, management policies and regulations exist for this method; however, the properties of China's MSS are significantly different from those of developed countries. Specifically, MSS in China contains 30–50% organic matter, while that in developed countries contains 60–70% organic matter. In addition, Chinese MSS has higher moisture and more heavy metal than that of developed countries [13,14]. These characteristics necessitate that unique sludge co-processing techniques should be developed for China.

Summarizing and analyzing this technique would facilitate its development in China and similar areas. However, few systematic investigations of the current state of co-processing MSS in cement kilns have been conducted to date. Therefore, this study was conducted to investigate and analyze the MSS generation, geographical distribution, and characteristics of different co-processing routes in China.

2. MSS Generation in China

According to the data released by the Ministry of Housing and Urban-Rural Development of the People's Republic of China, Chinese municipal sewage treatment rate increased rapidly and consistently in the past fifteen years (Figure 1) [15]. By 2017, there were 3781 wastewater treatment plants (WWTPs) meanwhile the sewage treatment rate was also close to the target value of 2020 [16,17]. Additionally, the rapid development of the economy, growing environmental awareness of the government and citizens and extension of the drainage pipeline system suggested that the sewage treatment capacity of China must be established quickly, which has also resulted in MSS production increasing rapidly [18].

As shown in Figure 1, the harmless treatment rate of China's MSS in 2010 was only 25.1%, which was obviously insufficient compared with the scale of sewage treatment. In response to this situation, China has successively issued plans for the construction of municipal sewage treatment and recycling facilities in the 12th and 13th Five-Year Plan, including investing a total of approximately 9 billion US dollars in new or modified MSS disposal facilities. The results demonstrated that since 2015, MSS harmless treatment rate has increased to more than 50%, and it was expected to rise to 75% by 2020, narrowing the gap with the sewage treatment rate gradually [17]. Despite the efforts already made, China's MSS treatment, disposal, and resource utilization are still an urgent problem.

The sewage treatment rate and MSS harmless disposal rate of different parts of China in 2010 are shown in Figure 1 [15]. Treatment rate varied greatly among geographical regions and areas with different levels of economic development. In general, coastal areas and economically developed areas have higher rates of sewage treatment and MSS disposal (e.g., Jiangsu 87.6% and 54.6%, respectively) and Shandong (91.1% and 45.5%, respectively). In these areas with relatively better economic development, local governments paid more attention to the MSS disposal. However, more than half of the regions in China had less than 20% MSS harmless treatment rate in 2010, suggesting that the corresponding sludge disposal methods had great promotion potential. Additionally, treatment rates were comparatively lower in the less developed areas in Northwest China, such as Tibet and Qinghai. Sludge treatment and disposal also demand to be combined with regional needs and economic conditions.

Measures such as constructing and expanding the pipe network and upgrading and retrofitting existing WWTPs should be taken to improve the sewage treatment rate. For MSS treatment and disposal, thickening-coagulation-mechanical dehydration is the basic treatment route, but for subsequent sludge disposal, there are no generally accepted routes. In recent years, co-processing of MSS in cement kilns has been selected by China's WWTPs as a highly effective and exhaustive technology and has attracted much attention [19].

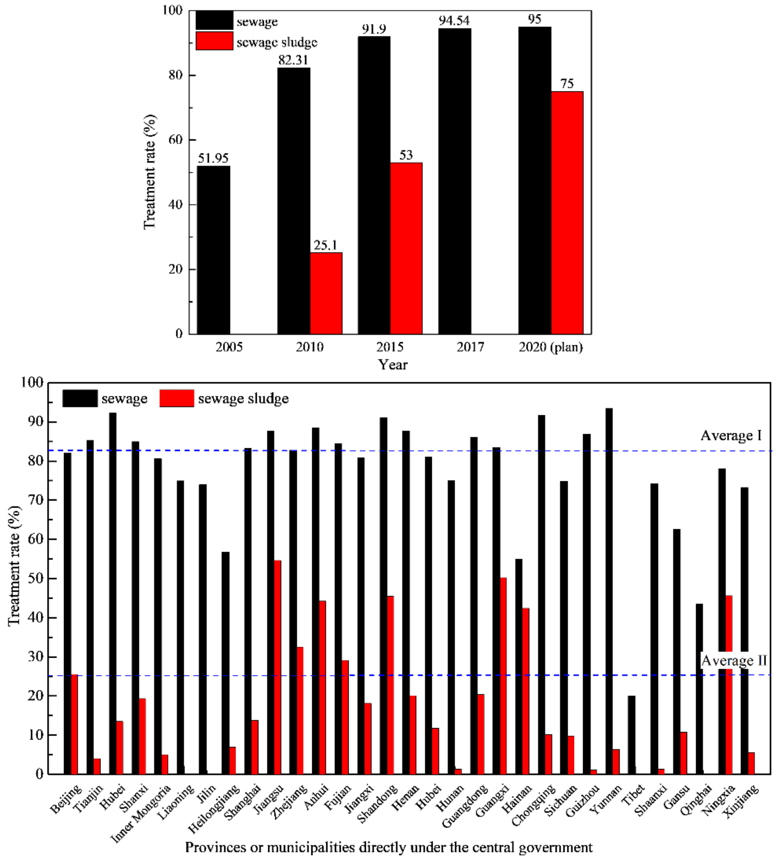

Figure 1. Sewage treatment rate and sewage sludge harmless disposal rate of China [15]. The figure above shows these treatment and disposal rates of China during different years. The following figure displays the rates of provinces or municipalities directly under the central government.

3. Application Status

During the past few years, the Chinese government has introduced various policies and national standards to encourage and support the application of this co-processing technology. In the first stage (before 2009), the policies mainly consisted of advocating and suggestions. Typically, the cement industry development policies issued by the national development and reform commission stated that governments encourage and support large-scale new dry process kilns and construct sludge co-processing projects. The Ministry of Housing and Urban-rural Development (MOHURD) and the Ministry of Industry and Information Technology also implemented correlative policies. In the second stage (from 2009), numerous national projects and standards were constructed released to support this technology, the most well-known being the National Major Science and Technology Project of Water Pollution Control and Management. The core standards developed are the code for design of sludge co-processing in cement kilns (GB 50757-2012) and the standard for pollution control on co-processing of solid wastes in cement kilns (GB 30485-2013). The standards expressly provide series codes for co-processing sludge in cement kilns (Table 1). With the release of relative policies and national standards, increasing numbers of cement plants have constructed co-processing projects.

Compared to the standard (Table 1), the content of heavy metals in dried sludge is much lower than the national limits according to previous studies [20]. With the drying process of sludge, the content of heavy metals in the exchangeable state and carbonate binding state in the sludge decreased significantly, reducing the release of heavy metals in the collaborative disposal process of sludge [21]. However, when MSS and heavy metal-rich waste were treated simultaneously, the fixed ratio of heavy metal declined due to the trace element composition of MSS [9]. Therefore, attention should be paid to pollutant emission when cement kilns are used to coordinate the disposal of various wastes.

Furthermore, adding the right amount of sludge would improve the burnability of cement clinker without breaking the normal operation of the cement production [22,23].

Table 1. Parameter limits for cement co-processing plants [24,25].

Parameters Types	Parameters	Maximum Acceptable Value for Different Parameters
Sludge co-processing quantity	Sludge co-processing ability	300 t/d (capacity of 1000–2500 t/d clink) 600 t/d (capacity of 2500–3000 t/d clink) 800 t/d (capacity of 3000–5000 t/d clink)
Volatile heavy metals in sludge	Hg Pb Cd Zn Cr	15 mg/kgDS 1200 mg/kgDS 45 mg/kgDS 10,000 mg/kgDS 1500 mg/kgDS
Polluting substances in exhaust gases	HCl HF Hg Tl + Cd + Pb + As Be + Cr + Sn + Sb + Cu +Co + Mn + Ni + V Dioxins	10 mg/m^3 1 mg/m^3 0.05 mg/m^3 1.0 mg/m^3 0.5 mg/m^3 0.1 ng TEQ/m^3 (TEQ: Toxic Equivalent Quantity)

At present, there are approximately 35 cement plants with co-processing projects [26]. The major and relatively large-scale projects are presented in Figure 2. The capacity of the projects range from 150–1500 t/d, and they were mainly constructed from in the past ten years. Additionally, the construction of the facilities has obvious regional distribution characteristics. Most projects were constructed in areas of eastern and southern China, such as Jiangsu, Hubei, and Guangdong, which have higher GDP. There were large-scale cement plants in Beijing, Hubei, Guangdong and Guangxi, thus the amount of co-processing sludge is larger. Moreover, the investment of each project is varied from different co-processing technique routes.

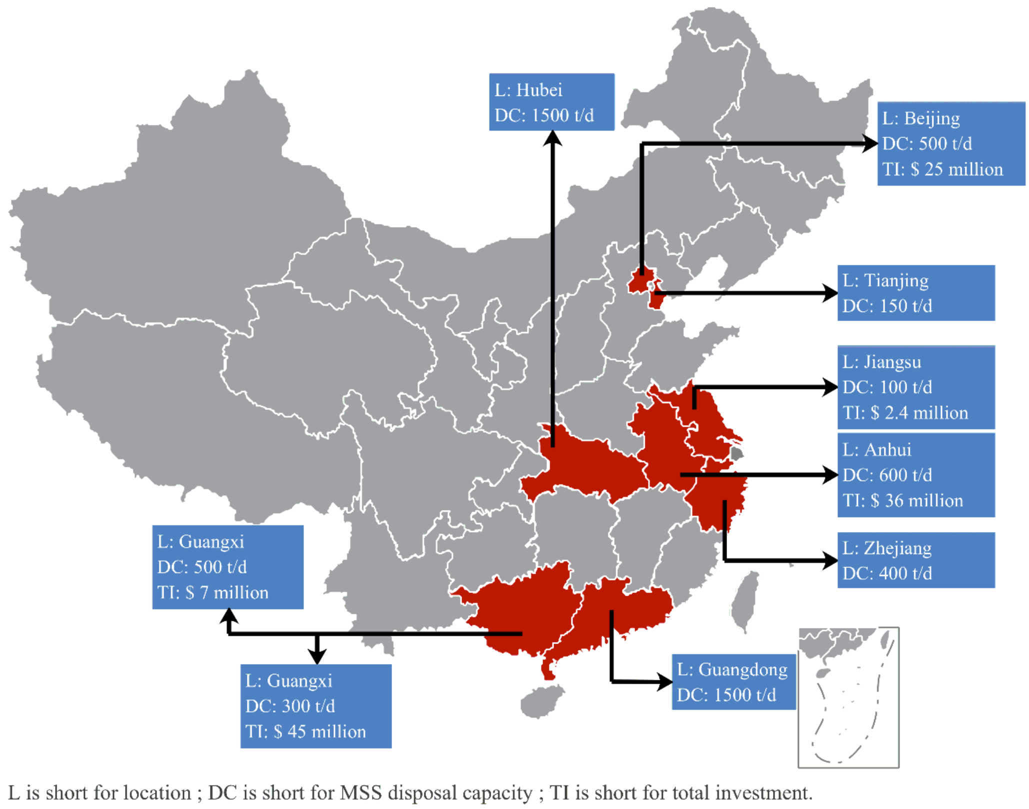

Figure 2. Major sludge co-processing projects in China.

4. Mainstream Co-Processing Technique Routes

There are many factors that affect the selection of co-processing technique routes of cement plants, such as distinct features of different processes, MSS properties, and social situations [6,9]. The primary routes used in mainland China can be summarized as follows: In the first route, MSS is added to a cement kiln from a transition chamber using special pumps (Route 1), and the typical case is the co-processing project in a cement plant in Guangxi; In the second route, MSS is dewatered by direct thermal drying, and after that it is added to the cement kiln from a precalciner via a plate chain conveyor (Route 2) and the typical application case is the co-processing project in Guangdong; In the third route, after indirect drying pretreatment, MSS is added to the cement kiln from a precalciner via a plate chain conveyor (Route 3), and Beijing Cement Plant adopted this route.

The characteristics of the different routes are shown in Table 2. Route 1 has the simplest operation and lowest investment, but the addition of wet sludge lowers the temperature in the kiln, leading to extra energy consumption. Wet sludge would cause a large volume of vapor as well, which could overload existing devices for off-gas cleaning and capacity of fans. Route 2 uses the surplus heat of the cement plant to dry sludge effectively, which can reduce the amount of fuel, but direct contact between sludge and hot air increases the difficulty of waste gas treatment and aggravates odor pollution. Route 3 has the most difficult operation requirements and the highest investment due to its relatively complex systems and condensate treatment, but it has a large disposal capacity and is environmentally friendly. In summary, each co-processing route has advantages and disadvantages. Thus, the selection of co-processing routes should be based on operating parameters, economical parameters, and environmental impact.

Table 2. Typical routes of co-processing MSS in cement kilns in China [27–29].

Items	Route 1	Route 2	Route 3
Operating Parameters			
MSS pretreatment processes	no	direct thermal drying	indirect thermal drying
Heat source and temperature	no	exhaust gases from preheater, 350 °C	exhaust gases from preheater, 350 °C, or hot gases from precalciner, 80 °C
Inlet moisture content	<80%	<30%	<35% or <10%
Adding methods	special pumps	plate chain conveyor	plate chain conveyor
Adding points and temperatures	transition chamber, bout 1000 °C	precalciner, about 880 °C	precalciner, about 880 °C
Economic parameters			
Disposal capacities	about 5% of clinker production	about 10% of clinker production	about 15% of clinker production
Total construction investment	about 13 thousand US dollars/(t MSS /d)	about 17 thousand US dollars/(t MSS /d)	about 50 thousand US dollars/(t MSS /d)
Environmental impact			
Polluting substances	adding MSS increases NOx emission	SO_2, NOx, CO because the large air volume makes it difficult to collect and treat these substances effectively	Macromolecule organic compounds, if operating improperly organic compounds in MSS will volatilize

5. Conclusions

In the past few years, the harmless disposal rate of sludge in China has increased from 25% to more than 50% due to the expansion of the sludge treatment scale. With the gradual standardization of sludge disposal management, the advantages of co-processing MSS in cement kilns will be more obvious. In order to encourage and support this technology, several policies and national standards have been released. The MSS disposal capacities accounting for clinker production of three routes mainly employed in China are 5%, 10%, and 15%, and their required investments are 13, 17, and 50 thousand US dollars per processing size (t MSS /d), respectively. Sludge characteristics and regional characteristics should be combined to select an appropriate route in the promotion process. With the deepening of application research, comprehensive economic evaluation should be carried out on the MSS co-processing to optimize the economic modes of different MSS disposal methods. Moreover, considering the high carbon emissions of the cement industry, it is necessary to study the carbon emissions of co-processing projects and the reduction benefits from energy and resource conservation.

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