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Industrial Wastewater Sludge Treatment in Chongqing, China

Victor Emery David Jr, Jiang Wenchao, Yasinta John, Md. Sahadat Hossain

***Abstract*—**Sludge originates from the process of treatment of wastewater. It is the byproduct of wastewater treatment containing concentrated heavy metals and poorly biodegradable trace organic compounds, as well as potentially pathogenic organisms (viruses, bacteria, etc.) which are usually difficult to treat or dispose of. China, like other countries, is no stranger to the challenges posed by increase of wastewater. Treatment and disposal of sludge has been a problem for most cities in China. However, this problem has been exacerbated by other issues such as lack of technology, funding, and other factors. Suitable methods for such climatic conditions are still unavailable for modern cities in China. Against this background, this paper seeks to describe the methods used for treatment and disposal of sludge from industries and suggest a suitable method for treatment and disposal in Chongqing/China. From the research conducted, it was discovered that the highest treatment rate of sludge in Chongqing was 10.08%. The industrial waste piping system is not separated from the domestic system. Considering the proliferation of industry and urbanization, there is a likelihood that the production of sludge in Chongqing will increase. If the sludge produced is not properly managed, this may lead to adverse health and environmental effects. Disposal costs and methods for Chongqing were also included in this paper's analysis. Research showed that incineration is the most expensive method of sludge disposal in China/Chongqing. Subsequent research therefore considered optional alternatives such as composting. Composting represents a relatively cheap waste disposal method considering the vast population, current technology and economic conditions of Chongqing, as well as China at large.

***Keywords*—**Sludge, disposal of sludge, treatment, industrial sludge, Chongqing, wastewater.

I. Introduction

INDUSTRIAL wastewater treatment has become a major issue in China. The discharge of industrial wastewater has posed a negative impact on lakes, rivers and ultimately on public health. In 2011, the Chinese government formally recognized these negative effects and their relationship to industrial wastewater effluent and issued the 12th Five Year Plan of Integrated Control of Heavy Metals to address industrial wastewater treatment. Due to vastness of land, the rich natural resources, and also the low-cost of labor, China has become famous worldwide for the establishment of factories and its rapid urbanization. This has resulted in the increase of wastewater. Sewage from industries and residential places are also increasing. The lack of adequate equipment used to drain and dispose of sewage is of concern. Harmful substances which have not been properly disposed of have been directly or indirectly deposited into rivers, causing water pollution and damage to aquatic life [1], thus creating adverse health and environmental conditions.

The number of Wastewater Treatment Plants (WWTPs) has substantially increased over recent years. There were 1856 plants in 2009 [2]. These plants were built to help solve existing environmental problems. These plants were designed to treat 907.9*106m^3 of wastewater per day. They also had the ability to treat 237.3*108m^3 of wastewater per year, including 202.9*108m^3 of domestic sewage per year. The household waste water treatment rate is 57.8%. With rapid development and economic growth, the problem faced by the increase in production of wastewater cannot be avoided. It is estimated that 536*108m^3/day of wastewater will need to be treated by 2020.

A. Discharge of Wastewater by Industries

There are 39 categories of industries, among which the paper industry produces the highest percentage of wastewater and discharge rates. The electric production factories, chemical manufacturing industries, and textile industries all produce significantly high percentages of wastewater and discharge rates. A percentage of 52.0 sewage emission rate is obtained when these industries are all combined.

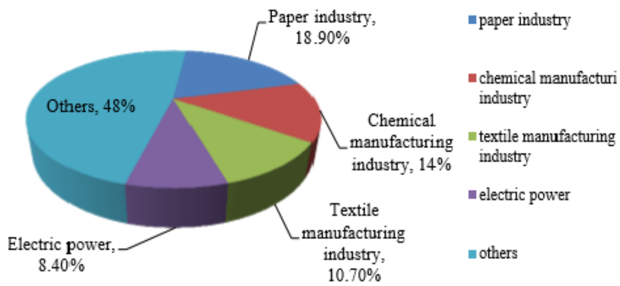

Fig. 1 Sewage Discharge Rate [1]

TABLE I
WASTEWATER DISCHARGE SITUATION (NATIONAL ENVIRONMENT STATISTICAL YEARBOOK 2008) [3]

Year	Sum	Wastewater (*10^{9}10t) Industrial	Domestic
2005	379.3	172.5	206.8
2006	412.0	180.8	231.2
2007	433.6	191.0	242.6
2008	447.3	185.3	262.0
Increase Rate (%)	17.9	7.4	26.7

Victor Emery David Jr is with the College of Urban Construction and Environmental Engineering, Chongqing University, 400044 China (corresponding author, e-mail: emerydavid2011@gmail.com).
Jiang Wenchao, Yasinta John, Md Sahadat Hossain are with the China Chongqing University of Engineering and Technology, Chongqing 400044 China (phone: +86-18725610889; e-mail: wchjiang@ cqu.edu.cn, jyasinta@ gmail.com).

According to the National Environment Statistical Yearbook 2008, from 2005 to 2008, the amount of wastewater discharge from factories near the seven key river systems increased. There was also a decrease between 2007 and 2008 in industrial emissions from factories along the key river system [3].

II. Current Wastewater Treatment Methods in China

At present, China is facing severe water shortages, resulting from both a large population and water pollution – the latter particularly caused by rapid economic development with a minimal regard for environmental impacts. Although China significantly improved its water and wastewater infrastructure (with annual water supply achieved at 549.7 billion cubic meters in 2002), there are still annual water shortages of 40 billion cubic meters. Faster urbanization and high-speed economic growth in China continue to aggravate the water shortage problem. The official municipal wastewater treatment rate was 39.9 percent at the end of 2002, a notably inadequate figure given China's serious water pollution. Over the years, effort to stem water pollution have been further undermined by a scarcity of funds for construction, renovation, or maintenance of water and wastewater facilities. Upon experiencing such conditions, the Chinese government realized the need to value water as a resource and introduced mechanisms in the water supply and wastewater treatment sector. Due to the diversity of wastewater characteristics, methods for treating sewage demand consideration [4]. Chongqing is a developing modern city with large and diverse industries. These industries are the primary producers of wastewater and, with the lack of advanced technology and specialized equipment to treat or dispose, pose threats to public health and to the environment [5]. This paper therefore seeks to investigate the current status of industrial wastewater sludge treatment in Chongqing, taking a look at treatment and disposal of sludge from industries and exploring solutions to help improve the treatment of industrial sludge. Up until present, two main treatment methods have been used for the treatment of sludge in China. They are as follows:

A. Activated Sludge

Activated sludge refers to a mass of microorganisms cultivated in the treatment process to break down organic matter into carbon dioxide, water, and other inorganic compounds. The activated sludge process has three basic components: 1) a reactor in which the microorganisms are kept in suspension, aerated, and in contact with the waste they are treating; 2) liquid-solid separation; and 3) a sludge recycling system for returning activated sludge back to the beginning of the process. This method is the artificial enhancement of water purification. Activated sludge requires the continuous operation of oxygen blowers and sludge pumps. A steady energy supply is a key requirement. The system usually needs some form of pretreatment, such as screening and primary sedimentation. This mechanism is to make suspended microbes come into contact with sewage in the aeration tanks, including the standard activated sludge process, step aeration, long time aeration, segmented aeration, restricted aeration and amended conventional activated sludge methods, such as adsorption biological (AB), anoxic oxygenic (AO), the anaerobic anoxic oxygenic (AAO) process and other, recently developed highly efficient nitrogen and phosphorus removal processes. Its advantage can be seen in the efficient removal of BOD, COD and nutrients when designed and professionally operated according to local requirements. However, its disadvantage lies in the fact that it's expensive in terms of both capital and operation and maintenance costs. It requires a constant energy supply, needs trained operators who can monitor the system and react to changes immediately, and the availability of spare parts and chemicals – all of which represent potential obstacles [6]. The activated sludge process has been widely used to treat domestic wastewater in large cities in China.

B. Conventional Activated Sludge

Another employed method is the conventional activated sludge. Conventional activated sludge systems commonly include an aeration tank and secondary clarifier. The Aerobic biomass reduces the biochemical oxygen demand (BOD) and ammonia concentrations in the aeration tank. Biomass then flows to the secondary clarifier, where it is separated into clarified water and thickened biomass by gravity sedimentation. The clarified treated water overflows at the top of the secondary clarifier, and the thickened biomass is recycled to the aeration tank or managed at sludge dewatering facilities [7]. When this method is utilized to treat sewage, the BOD removal rate usually climbs up to 95%. The conventional activated sludge treatment involves calculating and adjusting the wastewater pretreatment system in order to make the component and concentration of wastewater uniform, thus the selection of appropriate microorganism during the activated sludge process should be taken into consideration [5].

III. Materials and Method

In order to carry out this research, reports and policy documents from databases in China/Chongqing were studied. The scientific research library at Chongqing University was used for the review of documents as well. The model used to predict the wastewater sludge disposal cost was cited from the one proposed by Zhang where he described energy consumption cost, transportation cost, landfill cost and depreciation.

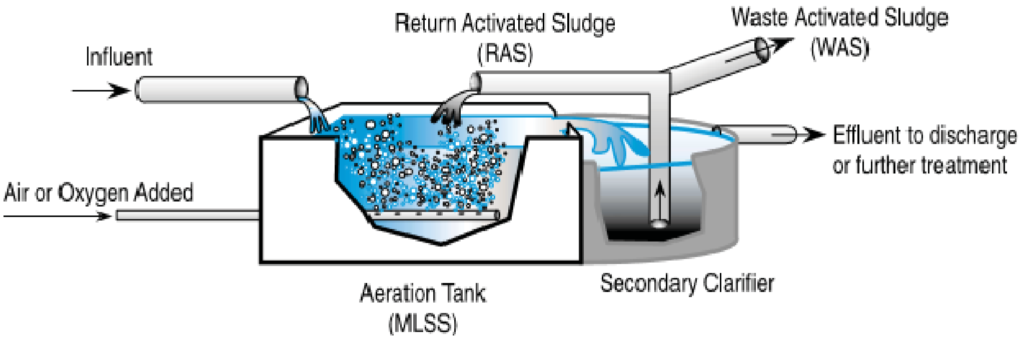

Fig. 1 Activated Sludge Process [6]

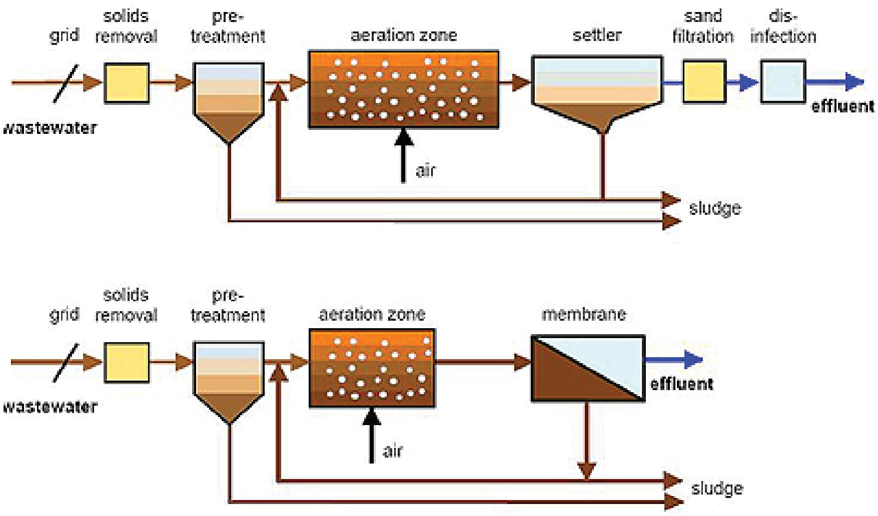

Fig. 2 Conventional Activated Sludge [7]

A. Discussions- Sludge Treatment-Management in China

The total amount of wastewater discharged in 2002 was 63.1 billion cubic meters. Industrial wastewater constituted up to 61.5 percent, and domestic wastewater 38.5 percent. The amount of municipal wastewater treated in 2002 was 13.5 billion cubic meters, with a treatment rate of 39.9 percent. A large amount of wastewater has been discharged directly into surface water bodies without treatment. The actual wastewater treatment rate in China may be less than 20 percent.

All cities in China are now required by the Chinese government to construct wastewater treatment facilities. Wastewater treatment facilities include wastewater collection systems, sewer systems, wastewater treatment plants, sludge disposal systems, and other auxiliary systems. All large and medium-sized cities must construct wastewater treatment plants. The treatment rate of city municipal wastewater was estimated to increase to 45 percent by 2005, and the wastewater treatment rate in the cities with populations greater than 500,000 was estimated to increase to 60 percent. China, however, began using the conventional methods to properly manage sludge (including safe landfill disposition, reclamation and sludge incineration [8]).

The method of landfill deposition has also been employed and has proven to be effective in the prevention of leachate in landfills. However, this method requires finding a suitable location. Due to the high increase of sludge produced, it is important to have a suitable environment where the sludge can be handled properly. All landfills grow in size with time. The one characteristic that has the biggest influence on the operation of landfills and, therefore, on the need for facilities, plants and operating skills, is the deposition rate of refuse [9]. Sludge contains nutrition useful for pathogens, with degradation taking place in the environment, the sludge produces CH4, which is released in the air through the biodegradation of anaerobic bacteria. An additional problem exists with landfill leachate, which poses a threat to soil and groundwater. This method is relatively unsafe and expensive (due to high maintenance costs). Landfill disposition may not be suitable for sludge treatment.

An alternative solution to sludge treatment in China is reclamation. Reclamation is effectively the reclaiming of land from the sea. This method however, leads to the pollution of aquatic life and marine environments. Due to the pollution it causes, most countries have banned this practice [8].

Another method, incineration, requires high construction and maintenance costs and is sometimes used for the disposal of waste with almost no odor during the treatment process. It produces a non-putrescible and sterile ash, with a 70%

reduction in mass and 90% reduction in volume. Its advantage lies in the option of energy recovery to reduce cost, but the pollution it causes may cause more harm to the environment than other waste disposal methods. The incineration of waste produces the following risk factors (all of which pose serious public health and environmental concerns):

- Pollutants emission to the atmosphere,
- Contaminated waste water,
- Contaminated ash [10].

Of recent, new treatment methods have been introduced, one of which is the method of composting. Composting technologies are available in countries such as Helsinki, Finland, Estonia and others. The operations and maintenance of these technologies are relatively simple and only require a basic understanding of the biology and chemistry of composting. Composting has been increasingly recognized as a viable and economical alternative for waste management. Although composting is generally considered advantageous over landfilling and incineration due to lower investment and operation costs, less environmental pollution, and beneficial use of the end products, there are still some uncertainties about potential health hazards related to pathogens, heavy metal, and organic contaminants present in compost. Compost quality is generally based on particle size; pH; soluble salts; stability; and the presence of such undesirable components as weed seeds, heavy metals, phytotoxic compounds, and foreign objects [11]. Additional factors affecting composting, include moisture content, C/N ratio, temperature and air flow. With regard to the relationship between the optimum moisture content and the moisture content limitation for composting, Li Chen (1994) advanced the moisture content limitation concept and concluded that 60–80% of the limitation was optimal for composting [12]. Compost can be used in a number of ways, including horticultural, forestry, tree seeding, potted greenhouse crops, field- and container grown nursery plants, etc. It can also be used to maintain the organic matter, tilth and fertility of agricultural soils; to support urban landscapes; to reclaim disturbed land such as abandoned strip mines; to establish landscapes; and to cover landfills [13]. We can conclude that the convectional composting method is more suitable for treatment of sludge in Chongqing.

B. Sludge Treatment in Chongqing

Chongqing is one of four municipalities directly under the Chinese central government. It is located at the confluence of the Yangtze and Jialing Rivers. Today it is known as a large industrial city with proximity to oil fields and iron mines. The city benefits from the supply of cheap electricity provided by the newly opened Three Gorges Dam nearby, which is designed to produce power equivalent to 15 nuclear power plants. Chongqing's economy is largely represented (among others) by a large shipbuilding, automobile, and chemical industry [14].

By the beginning of June 2006, Chongqing's wastewater project had gained both greater urgency with the early completion of the construction phase of the controversial Three Gorges Dam and a boost from the signing of a new agreement between the city of Chongqing and The Suez. The total number of plants at the time were 36. Building on their earlier strategic partnership established in 2005, a 50/50 joint venture was set up between the Water Company of Chongqing and the Suez subsidiary, Sino-French Water Development, to implement a new major wastewater treatment initiative in the region. This initiative involved the construction of a new 300,000 m³/day WWTP at Tangjiatuo and the provision of wastewater services in the Jiang Bei and Yubei sectors of the city over a 25 year period -- all costing US$72.5 million [15]. There are nine factories located in the city center, with 24 plants sitting near the Three Gorges Dam of the Yangtze river. The remaining three plants are situated in the affected zone. The production rates of sludge per day were 950t/day, 160t/day and 52.5t/day. These numbers are relatively small in comparison to plants in the city center and plants situated around the dam. The disposal of sludge in Chongqing is usually completed through landscaping, building materials, land use reclamation and landfill. All the sludge contains 80% moisture content.

TABLE II
CURRENT SITUATION AND PREDICTION OF SLUDGE PRODUCTION IN CHONGQING [16]

Districts	Index	Year 2006	Year 2010	Year 2020
City Center	Sewage treating Amount (*$10^4 m^2$/day)	75.3	185.3	405.4
	Production of sludge (*t/day)	947.9	1738.3	3401.4
Three Georges of Yangtze River	Sewage Treating Amount (*$10^4 m^2$/day)	16.83	80	118.5
	Production of sludge	158.73	829.2	1224.45
Affected Zone	Sewage Treating Amount (*$10^4 m^2$/day)	6.85	64.7	64.7
	Production of sludge (*t/day)	52.5	706.7	706.7
Total	Sewage Treating Amount (*$10^4 m^2$/day)	98.98	330	588.67
	Production of sludge (*t/day)	871.53	3274.2	5332.55

TABLE III
SLUDGE DISPOSAL IN CHONGQING [17]

Disposal ways	**Disposal amount (*10^4t/year)**	**Disposal amount (*t/day)**
Building materials		
Cement	108.84	2982
Brick Making	23	630
Fertilizer	0.02	0.61
Landscaping		
Soil Medium	100.23	2747.6
Potting Soil	0.03	8.22
Land Use		
Agriculture	159.51	4370
Woodland	1153.4	31600
Reclamation	593.67	16265
Landfill	67.45	1848
Total	2206.42	60451.43

In order to get a clear picture of the sludge content in Chongqing, ten waste water treatment plant were researched, as seen in Table IV.

TABLE IV
NUTRIENT CONTENT OF SEWAGE IN WASTEWATER PLANTS IN CHONGQING [17]

Wastewater Plants	Moisture Rate (%)	pH Value	Organic Matter (g/kg)	TN (G/Kg)	TP (G/Kg)	TK (G/Kg)
Tangjiaqiao	69.8	6.51	195.4	46.2	10.9	14.8
Jijang	82.8	7.35	284.47	48.69	20.39	12.44
Degan	75.9	6.93	244.89	35.11	26.07	13.06
Yunyang	78.7	7.24	321.58	44.92	18.44	17.42
Wanzhou	70.1	7.63	272.1	35.86	26.56	12.44
Fueling	80.9	7.73	324.05	55.49	7.76	11.2
Miaozui	85.4	7.73	410.63	72.48	22.48	8.71
Kouqian	82.8	7.36	256.02	54.73	8.88	18.66
Tanjiagou	79.9	7.33	393.31	45.67	23.78	16.17
Shizhu	71.2	5.95	265.92	44.16	24.17	14.17
Mean Value	77.8	7.17	296.84	48.33	18.94	14.17
Pig Manure	-	-	302	9.4	4.7	9.5

IV. CHALLENGES TO WASTEWATER TREATMENT IN CHONGQING

There are number of challenges for waste water treatment in Chongqing:

Geographical challenges and Chongqing's wastewater treatment infrastructure. Chongqing is a mountainous terrain with numerous rivers and lakes, all of which make it particularly difficult for Chongqing to build a centralized wastewater collection system. Construction of water treatment facilities in different parts of the region has been staggered, leading to infrastructure inconsistencies. Thus, treatment efficacy in the large and populous city has been fairly small.

- Low collection rates of wastewater and slow construction of new water treatment plants- the collection rate of wastewater is estimated to be as low as 79%. In many districts, low-quality wastewater drainage networks and poor maintenance have resulted in broken pipes and sewage leaks, leading to contamination and a lowering of the collection rate of wastewater.
- Low collection rate of wastewater in the outskirts of downtown and urban-rural fringe areas, and shortage of finances for infrastructure and operating expenses- Fewer wastewater treatment projects have been constructed because of a lack of funding (especially in industrial zones on the outskirts of town).
- Difficulties paying for wastewater treatment- Authorities have found it almost impossible to cover the high costs of water treatment by means of wastewater treatment fees collected from residents. Chongqing has developed rapidly since it became a municipality, but the city has had difficulty reforming and modernizing its social services and physical infrastructure fast enough to keep up with the growth of the city.

The wastewater needs of Chongqing are growing at a faster pace than its wastewater treatment capabilities. With regards to rapid economic development in Chongqing, both environmental protection planning and supporting facilities in several industrial and new-developing zones are not up to speed. The quality of the wastewater collection pipe network is poor, resulting in pollution, accidents (such as broken pipes) and wastewater leakages. The growth of private enterprises in Chongqing has been rapid, and most are not properly disposing of their wastewater [18].

A. Industrial Wastewater Sludge Disposal Cost

It's basically rare to investigate the cost of industrial wastewater sludge disposal. However, landscaping, land use and fertilizing are categorized as compost.

The cost of reclamation is derived by energy consuming cost, transportation cost, landfill cost and depreciation. Thus: [19]

$$A= [1/ (1-\eta 0)-1/ (1-\eta e)]*150*\alpha*Pele+0.65*L/ (1-\eta e) +\beta Pf/(1-\eta e)+ [1/ (1-\eta 0)-1/ (1-\eta e)]*180*\alpha*0.17*104/8000$$

where; A equals the reclamation cost, RMB/t, $\eta 0$ equals the moisture content of sludge before treatment, ηe equals the moisture content of sludge after treatment, P_{ele} equals the electricity price, RMB/(kw*h), α equals the labor cost index, L equals the transportation distance, β equals the volume coefficient of sludge, Pf equals the landfill cost of the landfill site, RMB/t, α is 1.3. β is 1.5, when the moisture content of treated sludge equals or is above 68% β is 1, and when the moisture content of treated sludge is below 68% the average of Pf is 52 RMB/t.,

Incineration Cost- Incineration cost is derived by energy consuming cost, transportation cost (including the cost that transports the ash to the landfill site) and depreciation (including the materials used in the facilities).

$$Ai= [1/ (1-\eta 0)-1/ (1-\eta e)]*150*\alpha*Pele+0.65*L/(1-\eta e) +\beta Pf/(1-\eta e)+[1/(1-\eta 0)-1/(1-\eta e)]*180*\alpha*0.17*104/8000+2317$$

where; Ai equals the incineration cost, RMB/t, $\eta 0$ equals the moisture content of sludge before treatment, ηe equals the moisture content of sludge after treatment, P_{ele} equals the electricity price, RMB/(kw*h), α equals the labor cost index, L equals the transportation distance, β equals the volume coefficient of sludge, Pf equals the landfill cost of the landfill site, RMB/t.

2317 represents the cost of materials used in facilities and operation fee is in calculated in RMB/t.

α is 1.3. β is 1.5, when the moisture content of treated sludge equals or is above 68% β is 1, and when the moisture content of treated sludge is below 68%. The average of Pf is 52 RMB/t [19].

Composting does not require electricity and transportation cost. This is due to the fact that most landfill are usually situated close to the wastewater treatment plant. The equation as given by Zhang is seen as

$$Ac=\beta Pf/(1-\eta e)+[1/(1-\eta 0)-1/(1-\eta e)]$$
$$*180*\alpha*0.17*104/8000+200$$

where; Ai equals the incineration cost, RMB/t, $\eta 0$ equals the moisture content of sludge before treatment, ηe equals the moisture content of sludge after treatment, α equals the labor cost index, β equals the volume coefficient of sludge, Pf equals the landfill cost of the landfill site, RMB/t [19].

B. Industrial Wastewater Sludge Disposal Cost in Chongqing

In Chongqing, the distance between the wastewater treatment plants and the landfill is 10km to 30km [20]. The maximum price of electricity is 0.765kw*h while the minimum price is 0.710kw*h [21]. After the wastewater treatment plants treats the sludge, the moisture content of sludge is approximately 30%. Therefore, β is 1. Moreover, the $\eta 0$ is 80% [22].

TABLE V
ESTIMATED RECLAMATION COST OF INDUSTRIAL WASTEWATER SLUDGE IN CHONGQING [23]

Transportation Distance (Km)	Electricity Price (Kw*h)	Total Cost (RmB/t)
10	0.765	793.93
10	0.71	755.63
30	0.765	812.5
30	0.71	774.2

Ash produced during the incineration process are usually transported 50 km away from the wastewater treatment plants. Usually, incineration requires low moisture content in sludge. Otherwise, the incineration will stop due to the existence of high content of water. As seen in Table VI where $\eta 0$=60% or 10% in China. ηe=0%. β is 1, when the moisture content of sludge is below 68%.

TABLE VI
ESTIMATED INCINERATION COST OF INDUSTRIAL WASTEWATER SLUDGE IN CHONGQING [23]

Moisture Content (%)	Transportation Distance (Km)	Electricity Price (Kw*h)	Total Cost (RmB/t)
60	50	0.765	3148.07
10	50	0.71	3109.77

V. CONCLUSION

Solid waste (MSW and sewage sludge) production in Chongqing is increasing rapidly (in terms of volume as well as composition). This is due to urbanization of the city and the expansion of industries. Chongqing has the biggest car industry in the west of China, with a high percentage of sludge produced but with a low treatment rate. The sewage sludge quality in Chongqing is lower than the requirements of China's control standards. Heavy metals and persistent organic pollutants are main factors affecting sludge quality. More effort should be made to ensure the quality of wastewater by enforcing strict discharge standards for industrial wastewater. Considering the rapid urbanization of Chongqing and its vast industries, there is a likelihood that more sludge will be produced over the years. However, the disposal cost is of importance. Of the three aforementioned methods of sludge disposal i.e. reclamation, incineration and composting, it can be concluded that composting is the cheapest in comparison to the other two treatment methods. Although sanitary landfilling is and will likely remain the primary method for MSW disposal, composting should be extensively applied in MSW treatment after source separated collection is carried out in Chongqing. Composting is suited for mid-scale and small-scale municipal sewage treatment plants. It is further expected that this practice will play a bigger role in the sewage sludge treatment in the future due to the influence of heavy metals and pathogens on sewage sludge land application. Composting technology is suited for Chongqing's conditions, and more effort should be made to study and develop low-cost and highly efficient composting technology.

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