Sewer sludge cleaning and subsequent sludge sediments recycling reuse: A case study in PR China

Dr. Cheng YAN
Associate Professor Department of Environmental Science and Engineering, School of Environmental Studies, China University of Geosciences (Wuhan)

Country

People's Republic of China

Sectors

Sewer sludge sediments

Region

Wuyi Village, Jianshe Township, Hongshan District and Huoguan Village, Qingshan District, Wuhan, Hubei Province, PR China (Fig. 1)

Good Practice

Carbon neutrality and carbon footprint mitigation measures

Timeframe

2016-2019

CATALOGUE

Location map

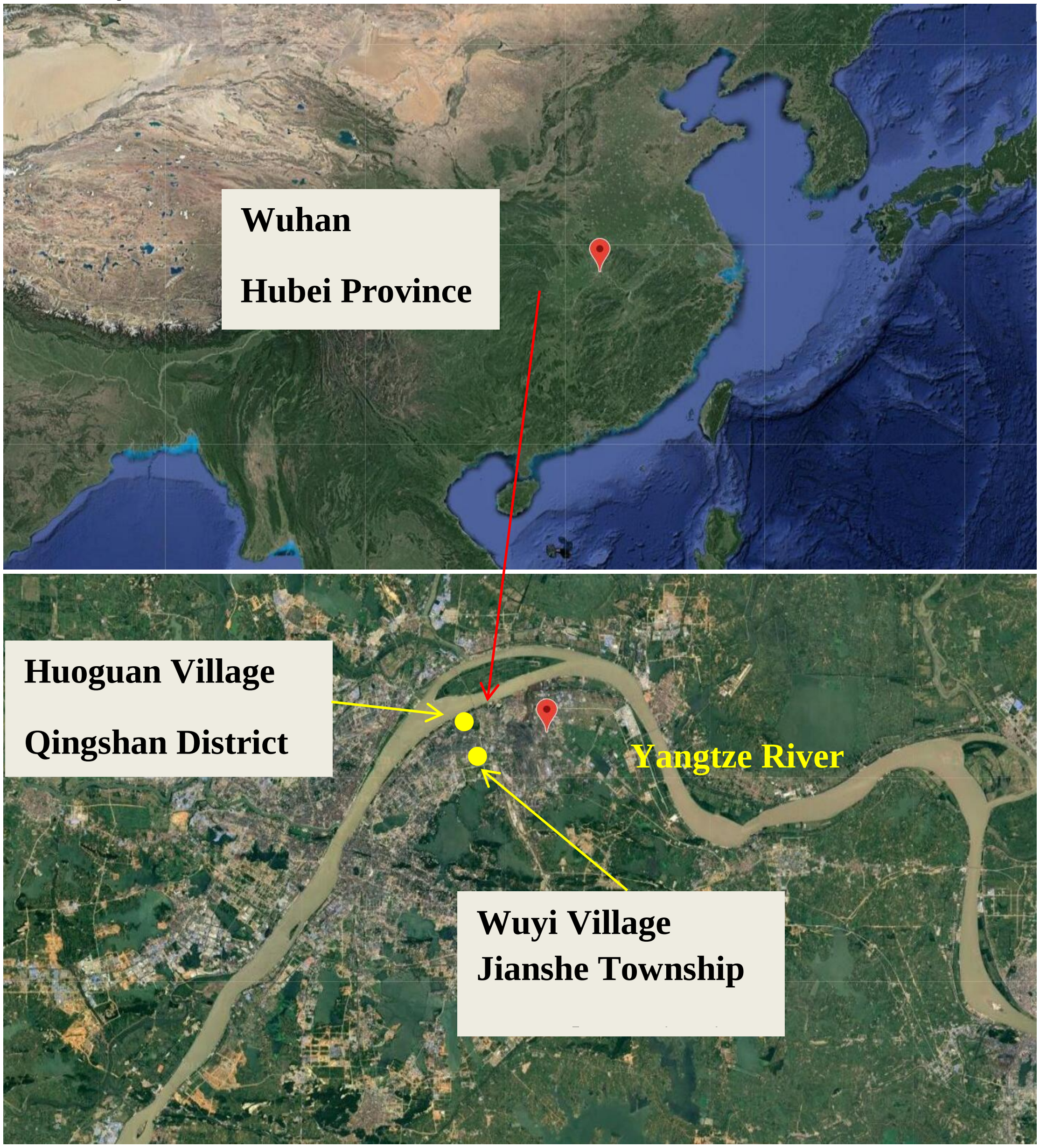

Fig.1 Geographical description of the sewer cleaning operation area, and its supporting sludge treatment and disposal center

Case study summary

Sludge sediments in the municipal sewer pipe network are a threat to the wastewater collection system since the sludge will block the pipeline and cause anaerobic environment which may increase the greenhouse gas (GHG) emission. And other negative environment effects, including H_2S and odor volatile organic chemicals (VOCs) emission, and depletes carbon sources in sewage wastewater, will incur a large cost on the wastewater treatment plant (WWTP) due to their related mitigation measures and the depreciation of assets. Furthermore, these also require energy consume and thus more GHG emission. In fact, sludge sediment in sewers has been largely ignored for decades in China by sewerage owners and operators. But with new vision of carbon neutrality to integrated operation and management of sewerage systems, moves to greater sustainability and less carbon footprint, a more efficient and effective approach to proactively manage sludge sediments is urgently required.

Nevertheless, sewer sludge cleaning is identified as a cost-effective way of dealing with sludge blockage problems, and a potentially promising method to reduce GHG emission in the sewer pipe network. But disposal of sludge sediment arising from sewer sludge cleaning is becoming more of a problem. Ultimately, it is probable that sewer cleaned sludge sediment arisings must to receive some treatments prior to reuse or landfill. And usually this treatment is recycling reuse materials and separate useless in order to meet overall carbon neutrality. Therefore, a sludge treatment and disposal center is built at Huoguan Village, Qingshan District, Wuhan, Hubei Province, PR China. It adjoins to the Wuhan Iron and Steel Corporation (WISCO). It is used to support the sewer sludge cleaning operation area at Wuyi Village, Hongshan District and Huoguan Village, Qingshan District.

An integrated perspective on wastewater treatment and transportation systems as a whole to ensure that these are operated taking due account of sustainability concepts, which would include the effects and fate of sludge deposition in, and removed from, sewer systems (Balkema et al. 1998; Ashley et al. 2000). The treatment and disposal of sludge sediments come from sewer cleaning process is the key for carbon neutrality of the whole system. This means that the sludge sediments should be recycled and beneficial reused rather than directly incineration, landfill or even laissez-faire. nevertheless, besides the environmental impacts of carbon footprint mitigation, relevant co-conflicting issues may include engineering cost, public perception, socio-economic, rules/regulations, and managerial aspects of cleaning process. They all receive excessive consideration from government authorities and stakeholders.

Background

Wuhan city overview

Wuhan enjoys a time-honoured history. According to archaeological discoveries and ancient records, more than 10,000 years ago, some human beings had already settled down in Wuhan. Furthermore, more than 100 years ago, Wuchang was the birthplace of the Revolution of 1911. Nowadays, Wuhan, the only sub-provincial city in Central China, is the capital of Hubei Province with an area of 8,494.41 square kilometers and 10,914,000 registered permanent residents. The city is located at 113°41'E to 115°05' E and 29°58'N to 31°22' N. It has a humid subtropical monsoon climate with abundant rainfall, sunshine and four distinctive seasons. The annual rainfall in the recent 30 years is 1269 mm, while most of the rainfall is in the rain season June, July, and August. The average temperature is between 15.8 and 17.5 degree centigrade. The February average temperature is 3.0 degree centigrade, while in July is 29.3 degree centigrade. The summer season lasts 135 days, the spring season lasts less 60 days, and the autumn season lasts 60 days. The frost-free period is 240 days. Nearly one quarter of the city area is covered by water body. In the city area, there are 165 rivers which are longer than 5 km. The water surface area of these rivers is 471.31 km^2. The world's 3rd longest river-the Yangtze River and its greatest branch, the Hanshui River flow across the city and divide it into three parts. In fact, Wuhan has 13 districts, among which Jiang'an, Jianghan, Qiaokou, Hanyang, Wuchang, Hongshan and Qingshan Districts are downtowns while Dongxihu, Caidian, Jiangxia, Huangpi, Xinzhou and Hannan Districts are new towns.

As Wuhan is a super megacity city which has population more than 10 million, the sewer systems are an important and integral component of urban water infrastructure. The sewer systems also highly affect the sewer systems of the city. Through collecting and transporting wastewater from residential houses or industry to waste water treatment plant (WWTP) for pollutant removal before environmental discharge or directly disposal, sewers protect our city against sewage-borne diseases, unhygienic conditions, and noxious odors (Liu et al. 2015a; Pikaar et al. 2014). Therefore, sewers are an important component of urban water infrastructure. Operationally, there are two kinds of sewer systems (i.e., fully-filled pressure sewers (rising main sewers with pump), which are anaerobic; and partially-filled gravity sewers, where re-aeration takes place) in the city.

Region overview

The sewer sludge cleaning operation area is located in the far suburb of Wuhan city adjoin to the WISCO. It includes residential area at Huoguan Village and Wuyi Village. However, the Wuyi Village is located in the Hongshan District, while the Huoguan Village and WISCO are both located in the Qingshan District. In fact, the sludge treatment and disposal center which is used to support the sewer sludge cleaning operation area is just located in the middle of Hongshan District and Qingshan District at Huoguan Village (Fig. 2).

The Huoguan Village is a small village with an area of approximately 100 square kilometers and 7433 registered permanent residents. Most parts of Huoguan Village are farmland since it is the vegetable supply base of Wuhan urban area. Almost all people live near the sludge treatment and disposal center. The Wuyi Village is the core area of Jianshe Township with an area of approximately 71 square kilometers and 3069 registered permanent residents.

WISCO is a Chinese state-owned enterprise with an area of approximately 21.17 square kilometers and approximately 100,000 workers work and live there. It started to operate in 1958, and it was merged with fellow State-owned Assets Supervision and Administration Commission of the State Council supervised steel maker Baosteel Group. The WISCO was ranked the 11th in 2015 the world ranking by production volume. But a heavy net loss is continuing since 2015.

At the north of the sludge treatment and disposal center is a power plant of WISCO, and farther is a class factory and the residential area and farmland of Huoguan Village. At the north-west, it is a sintering plant of WISCO. At the west, it is the Wuyi Village and farther is main industrial park of WISCO (Fig. 2).

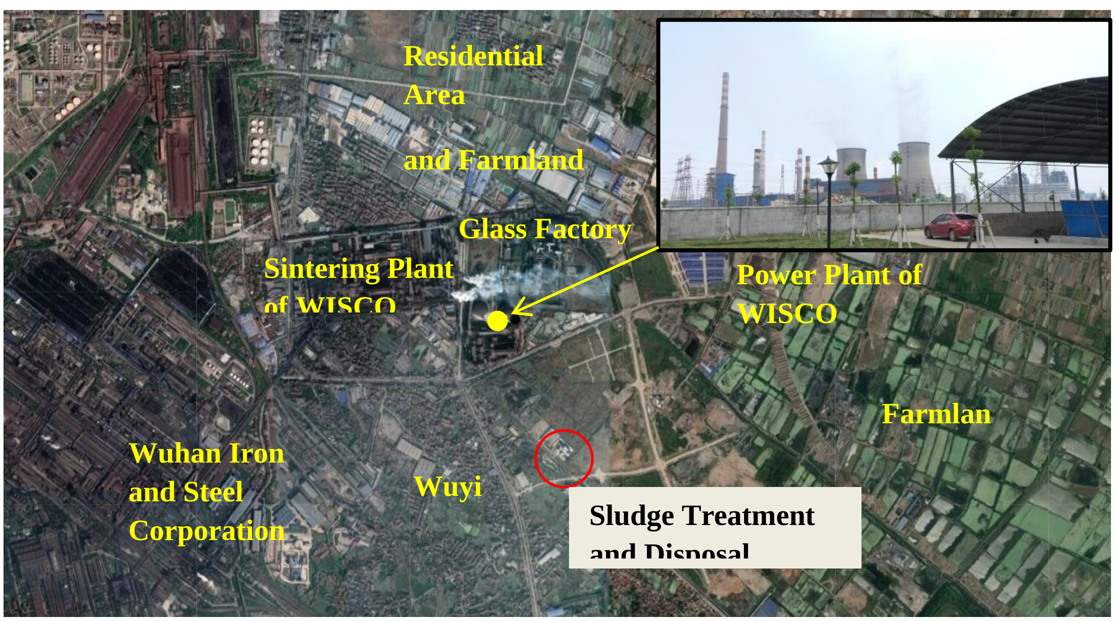

Fig.2 Geographical description of the sewer sludge cleaning operation area and its support sludge treatment and disposal center

Challenges

However, the biggest challenge here is the sewer sludge blockages always happen in sewer systems.

The raw sewer sludge amount in the Wuhan city is more than 160,000 m^3/a. Sewer sludge in the municipal pipe network is a threat to the wastewater collection system since the sludge will block the pipeline and cause anaerobic environment which may increase the GHG emission. It increases the city's carbon footprint and weak city's carbon neutrality. Nevertheless, what is its sludge blockages' origin? In fact, sewers act as a biological reactor with various microbial processes when they transport wastewater. Wastewater carries a variety of solid particles which, when hydraulic conditions do not assure their transportation, form sludge blockages. Some literature demonstrated that 30 to 500 g of physical particulate matter could deposit per each meter of sewer bottom per day under the condition of tranquil flow in sewers. The significant deposition of the particulate matter from sewage could then induce the formation of sediment (Ashley and Verbanck 1996; Ashley et al. 2003). Sludge blockage is also known as sludge sediment settling and accumulation, which are the cause of worrisome hydraulic and environmental problems in the sewer (Shahsavari et al. 2017). This sludge blockages is deposit solids, that accumulated in sewer systems can affect discharge capacity and then increasing sewer anaerobic conditions (Rodríguez et al. 2012). There are some literatures have already identified that sewer system conditions can make larger contributions to sludge blockages. In England and Wales about 75% (>23,000) of sewers derived flooding incidents per year are due to sludge blockages (Arthur et al. 2009). In Australia, sludge blockages affect almost 70,000 properties across the country every year (Marlow et al. 2011). Furthermore, 65 out of 70 water utilities recently surveyed in the USA are using sediment control in order to protect or improve sludge blockages situations (Black and Veatch 2010).

Moreover, the CH_4 GHG emission in the sewer systems refers to sludge blockages is one of the important carbon footprint. It mightily weak city's carbon neutrality. During the wastewater transportation in a rising main over a long distance, the wastewater becomes anaerobic due to the high oxygen demand of the organic compounds and a lack of oxygenation (Zhang et al. 2009). Current data suggest that is mainly produced by methanogens in the deeper layers of sewer biofilms and sediments in both rising main and gravity sewers (Liu et al. 2015a). Wetted anaerobic biofilms feature in rising main sewers; while, in gravity sewers, both biofilms and sediments below the water surface are in partially anaerobic or fully anaerobic conditions even when oxygen is present in the bulk wastewater, due to limited penetration of the oxygen (Gutierrez et al. 2008). Sediments settled in gravity sewers are believed to be biologically active (Schmitt and Seyfried 1992), and would contribute to CH_4 production. Therefore, anaerobic fermentation using organic matter as electron acceptors can occur in deeper layers of biofilms and sediments in the sewers (Hvitved-Jacobsen 2002).

However, in contrast to sewer biofilms who typically have a depth of several hundred micrometers, sewer sediments exhibit a biologically active bacterial layer of several centimeters or even more, which contribute distinctly to CH_4 production (Schmitt and Seyfried 1992). Considering that the sediment deposition rates is 30 to 500 g per meter sewer length per day (Ashley et al. 2003, 2005), it is likely that CH_4 production from sediments is significant. At the same time, this sediment deposition rates and its characteristics are highly variable both temporally and spatially, which is expected to result in heterogeneity of CH_4 production from different sewer sediments under varied operational conditions (Ashley et al. 2005; Ashley and Verbanck 1996). Moreover, these sewer biofilms and sediments are exactly the sludge in the sewer system.

Nevertheless, wastewater in closed underground sewers is believed to be a significant source of CH_4 (Liu et al. 2015a). The liquid phase of CH_4 concentrations is up to 20-25 mg/L in rising main sewers in Australia (Guisasola et al. 2008). While, with this level of CH_4 production, CH_4 emission from these sewers even could contribute an additional GHG contribution of roughly 48–60% above that from a WWTP (Spencer et al. 2006). CH_4 is a highly potent fugitive GHG that contributes significantly to climate change since 1 ton of CH_4 will induce a warming effect equivalent to 21 tons of CO_2 (Liu et al. 2015a; IPCC 2006); i.e. an approximately 34 times global warming potential that of carbon dioxide. Therefore, the sludge in the sewers contribute to global GHG emissions since the methane production and emission from sewers which is produced by the sludge can be significant in terms of the overall carbon footprint of wastewater systems.

There are several other negative environmental effects of sludge sediments blockage. The sludge sediments accumulated in sewer systems constitute major problems in terms of reduction of sewer capacity and as a source of pollution or negative environmental effects (Ashley et al. 2000).

1) The explosion risk of CH_4 produced in sewer systems

The CH_4 production in sewer systems requires strictly control, since CH_4 is highly flammable, with a lower explosive limit of approximately 5% by volume, and thus poses a serious safety issue in confined spaces (Spencer et al. 2006).

2) H_2S and odor VOCs as a result of oxidation of sludge organic matter by sulfate reducing bacteria

Another widely reported problem in anaerobic sewers is the production of H_2S as a result of oxidation of sludge organic matter by sulfate reducing bacteria (SRB) (Boon 1995; Hvitved-Jacobsen 2002). When H_2S is released to the sewer atmosphere it may cause serious odor, corrosion and health problems. Sulfide-induced concrete corrosion causes loss of concrete mass, cracking of the sewer systems pipelines, and ultimately structural collapse. Sewer systems suffering from corrosion often require premature replacement or rehabilitation of damaged pipes, manholes, and pump stations, which involves very high costs. Furthermore, this cost is expected to increase as the aging infrastructure continues to fail. Also, H_2S released to atmosphere through manholes or pumping stations cause odor nuisance to the nearby residents. In addition, H_2S is toxic to human and animals (Zhang et al. 2008; Jiang et al. 2015). Nevertheless, the H_2S build-up in sewers is commonly found in pressure sewers as well as in gravity sewers with low slope and deposits (Nielsen et al. 1998).

Volatile organic compounds (VOCs) are produced by anaerobic reactions (such as fermentation and sulfate respiration) in thesewage, sediments, and biofilms on the sewer system (Hvitved-Jacobsen et al. 2002; Rudelle et al. 2011). These VOCs are transferred to the air in the sewer headspace by diffusive and convective mass transfer. As a result, the air in sewer headspaces contains a complex mixture of VOCs.

3) Depletes carbon sources in sewage wastewater

The methanogens depletes carbon sources in sewage wastewater, which in turn affects downstream nutrient removal processes at WWTP (Guisasola et al. 2009; Liu et al. 2015b). The CH_4 production process is the consumption process of part of the chemical oxygen demand (COD) in wastewater who is needed for biological nutrient removal in WWTP.

4) Wastewater-carrying capacity affected by sludge blockages

Sludge solids accumulated in sewer systems is sludge blockages. This sludge blockages reduce the ability to evacuate wastewater due to changes in friction and in cross sectional area of sewer (Carnacina et al. 2017). In fact, sewer sludge blockages are one of the common causes for the surcharging and subsequent unplanned release of sewage from sewer systems. This is because the accumulation of sewer sludge sediments can cause localised flooding in urban catchments even during a relatively small rainfall event, or when flow suddenly dramatically increased (Mannina et al. 2012).

5) Difficulties of disposal of sludge sediment

Disposal of sludge sediment arising from sewer sludge cleaning is becoming more of a problem. In China, this solid waste with a variety of constituents is difficult to classify, in terms of the legislation it might seem appropriate to consider it a like hazardous waste, which is flammable, toxic or corrosive, and infectious to man and other organisms, and which include substances with eco-toxic effects on animals, plants, soil, water and via the food chain on human.

As a result, the above mentioned negative effects of sewer sludge will incur a large cost on the wastewater treatment due to their related mitigation measures and the depreciation of assets (WERF 2007). Furthermore, these also require energy consume and thus more GHG emission. The ultimate disposal management of sludge sediments are also needs more attention since these sludge sediments will always become carbon footprint wherever they are. Nevertheless, with new vision of carbon neutrality to integrated operation and management of sewerage systems, moves to greater sustainability and less carbon footprint, a more efficient and effective approach to proactively manage sludge sediments is urgently required.

Activities

In order to manage the sludge blockages in sewer systems and sewer sludge sediments arising from sewer systems in Wuhan, a demonstration project about sewer sludge cleaning operation and its supporting sludge treatment and disposal center are conducted in Huoguan Village, Jianshe Township, Hongshan District.

Some existing empirical measures for sewer sludge sediment management have been shown to be useful in some circumstances. What measures can be used to manage what kind of carbon un-neutrality scenarios, why the utility choose them, and what are their disadvantages?

CH_4 control

Dosing oxygen, nitrate, iron salts, and alkali chemicals can induce inhibitory effects on methanogens in sewers, thus leading methane elimination (Ganigue and Yuan 2014; Zhang et al. 2009). A long-term addition of nitrate in a rising main sewer reactor reduced the CH_4 concentrations, since the methanogenic rates were maintained below 10% of baseline level after nitrate dosing due to the inhibitory effect on methanogenic archaea (Jiang et al. 2013).

H_2S sulfide and odor VOCs control

Sewer sludge will induce H_2S sulfide and other odor VOCs emission. While their mitigation methods and related depreciation of assets both require energy consume and these mean more GHG emission. Therefore, reduce H_2S sulfide and oodor VOCs production can significantly mitigate sewer's GHG emission in total.

Chemical dosing to control H_2S sulfide in sewers

Various chemical dosing methods for H_2S sulfide control have been utilized by the water industry (Ganigue et al. 2011). The most commonly used chemicals include oxygen and nitrate for sulfide oxidation, iron salts for sulfide precipitation, and alkali for pH elevation to minimize liquid to gas mass transfer of H_2S (Ganigue et al. 2011; Zhang et al. 2008; Jiang et al. 2015).

Oxygen or nitrate is always dosing to control sulfide H_2S production in sewer systems' pipelines. But it should be added shortly only before the point of sulfide control with an hydraulic retention time of 1-2 h

(Jiang et al. 2015). This is because oxygen is an important chemical for sulfide control, but it only has short-lasting inhibitory effects on sulfide production since the SRB activity will resume immediately after oxygen depletion (Gutierrez et al. 2008). Furthermore, oxygen injection stimulates SRB growth and activity in downstream pipeline systems since it increased availability of sulfate in sewer. Nitrate behaves similarly (Mohanakrishnan et al. 2009; Jiang et al. 2010; Jiang et al. 2009).

For iron salts, in addition to precipitating sulfide in sewage, Fe^{3+} can significantly inhibit sulfide H_2S and CH_4 production by sewer biofilms, leading to reduced demand for iron salts (Zhang et al. 2009; Firer et al. 2008; Zhang et al. 2010). Fe^{3+} is effective in reducing dissolved sulfide in the wastewater since Fe^{3+} can oxidize sulfide H_2S to elemental sulfur while itself being reduced into Fe^{2+}, which precipitates with sulfide to form ferrous sulfide precipitants (Dohnalek and Fitzpatrick 1983; Nielsen et al. 2005). And it should be noted that, the typical municipal sewage pH is 6.5-8.5. At this pH environment, Fe^{3+} will hydrolyze rapidly to form amorphous $Fe(OH)_{3(S)}$. But this ferric hydroxide can also remove H_2S from aqueous systems through oxidation and precipitation reactions in a similar way (Davydov et al. 1998). Therefore, Fe^{3+} iron salts should be added at sewer systems' upstream locations (Sun et al. 2015). Nevertheless, the $Mg(OH)_2$ is commonly used to elevate sewage pH to maintain between 8.5 and 9.0 to minimize H_2S transfer from wastewater liquid to sewer upper air gas phase. Furthermore, the pH in this range also can reduce SRB activity in sewer biofilms, while suppressing methane production to a certain extent (Gutierrez et al. 2009). Therefore, $Mg(OH)_2$ should also be added at upstream locations in practical applications like oxygen or nitrate. Furthermore, the method of addition of metal salts including zinc, lead and copper salts to precipitate sulfide by forming highly insoluble metallic sulfide precipitates (Poulton et al. 2002).

Nevertheless, intermittent dosing of alkali is often used to raise sewage pH to above 11.0 in order to inactivate sewer biofilms. However, this inactivating process can not last long time, and therefore weekly or even more frequent dosing is needed (Gutierrez et al. 2014).

The addition of ozone, hydrogen peroxide, hypochlorites, chlorine, and potassium permanganate can also chemically oxidize sulfide (Charron et al. 2004).

However the main limitations of these approaches are that the H_2S restrain conditions must be continuously kept through the whole pipe, otherwise H_2S build-up resumes immediately after the depletion of the dosing chemicals. This means that a dramatically high cost in chemicals (Mohanakrishnan et al. 2009).

Electrochemical method to control H_2S sulfide in sewers

Electrochemical oxidation of sulfide can remove H_2S from wastewater (Jiang et al. 2015; Pikaar et al. 2012; 2011). While the electrochemical method also is able to produce NaOH which can inactivate sewer biofilm

(Pikaar et al. 2013). However, it consumes a lot of electricity since electrochemical method is apparently energy-extensive consumption.

Gas phase H_2S sulfide and odor VOCs treatment for abatement

Fugitive emission of H_2S sulfide and odor VOCs can be collected and treated. Gas phase odor treatment technologies currently applied primarily include chemical scrubbing, activated carbon adsorption, biofiltration and biotrickling filtration (Apgar and Witherspoon 2008). However, activated carbon adsorption and chemical scrubbing present higher environmental impacts and operation cost than biofiltration and biotrickling filtration (Estrada et al. 2011). Furthermore, the traditional H_2S-based method to assess the performance of sewer odor treatment units was found to be not always effective, as some non-H_2S odorants VOCs, but less efficiently removed by the treatment units (Wang et al. 2014).

Clean sewage sludge blockages by using storage overflows

Improvement to some unsatisfactory Combined Sewer Overflows (CSO) and the utilisation of technologies such as Real-Time Control (RTC) increase the potential for greater solids retention in sewage systems and problems of sludge sediment accumulation in storage pipes, chambers, pumping station sumps and sewage treatment works' inlets **(**Ashley et al. 2000; Chubb 1998). The effect of sediment on CSO controls causes failure to meet discharge standards through partial blockage, leading to reduced settings, premature operation and complete blockage, often with operation in dry weather.

While, the process of clearing blockages at storage overflows may also cause overloading of treatment plant inlets and pump station. This will highly affect the WWTPs effluents. In addition to the effect on CSO controls, the presence of sediments may also affect the performance of CSO screens and impact the treatment process where large storage tanks are constructed. For increasing reliance on pumping, with consequent impeller abrasion by sediment, also makes sludge sediment clean in the upstream of pumping stations very risk.

Clean sewage sludge blockages by using artificial flushing

Generating artificial flushing waves is a technique for the removal of sludge sediments deposited in sewage system. The artificial flushing waves can scour sediments accumulated over the sewage channel invert and to transport them downstream through sections that endow sufficient self-cleaning conditions (Shahsavari et al. 2017).

However, the disadvantage of the flushing is that due to the high initial energy of the flush, erosional effects were observed in the sewage channel bed downstream of the gate section. Therefore, the maintenance fee of this sewage channel will count as GHG emission of the whole wastewater treatment system.

The above mentioned semi-empirical methods for sewer sludge sediment deposition management have been shown to be useful in specific localized case studies. However, a universally applicable approach of management which is overall consideration (especially for the ultimate disposal of sludge sediments arising from sewer sludge cleaning) is still urgently needed. Nevertheless, this applicable management need to be developed which are robust and deal with whole-life and sustainable carbon neutral perspectives.

Sewer sludge cleaning and subsequent sludge sediments recycling reuse is a once for all program to manage the sludge blockages, as well as its pollution and negative environmental effects. Some have identified that sewer sludge cleaning as a cost-effective way of dealing with sludge blockage problems (e.g. Ashley et al. 2000; ten Veldhuis et al. 2009; Caradot et al. 2011; ten Veldhuis and Clemens 2011), since the complex physical mechanisms of sludge sediment deposition, and the number of factors that may contribute to a sediment-related sludge blockage, make sewer sludge cleaning a potentially promising method to reduce GHG emission.

Therefore, a sludge treatment and disposal center is built at Huoguan Village, Jianshe Township, Hongshan District, Wuhan, Hubei Province, PR China. It is used to support the sewer sludge cleaning operation area at Huoguan Village and Wuyi Village.

Sewer sludge cleaning field operation

A mobile pumping truck is used for the sewer sludge cleaning field operation (Fig. 3). It pumps sewer sludge from the sewage manhole and sends them to a transport vehicle. Then, the transport vehicle will immediately convey sewer sludge to the sludge treatment and disposal center. The mobile pumping truck and the transport vehicle are both patented product that independent researched and developed by SafeCleen Technologies Co. Ltd. PR China. The situation inside the sewage pipeline system can be found in Fig. 4.

The average amount of raw sewer sludge is 20 m^3/d in the operation area of Huoguan Village and Wuyi Village. The cleaning operation is conducted every 30-60 day depends on the sewage condition. For the characteristics of sewer sludge, the moisture content is 40%-60%, organic content is 10%-40%, Pb is 80-460 mg/kg, Cd is 0.30-1.30 mg/kg, Cr is 20-125 mg/kg, Hg is 0.5-2.10 mg/kg, As is 0.95-4.50 mg/kg, volatile phenol is 0.40-6.50 mg/kg, and the amount of Coliform bacteria is higher 160,000 per gram.

Fig.3 Sewer sludge cleaning field operation

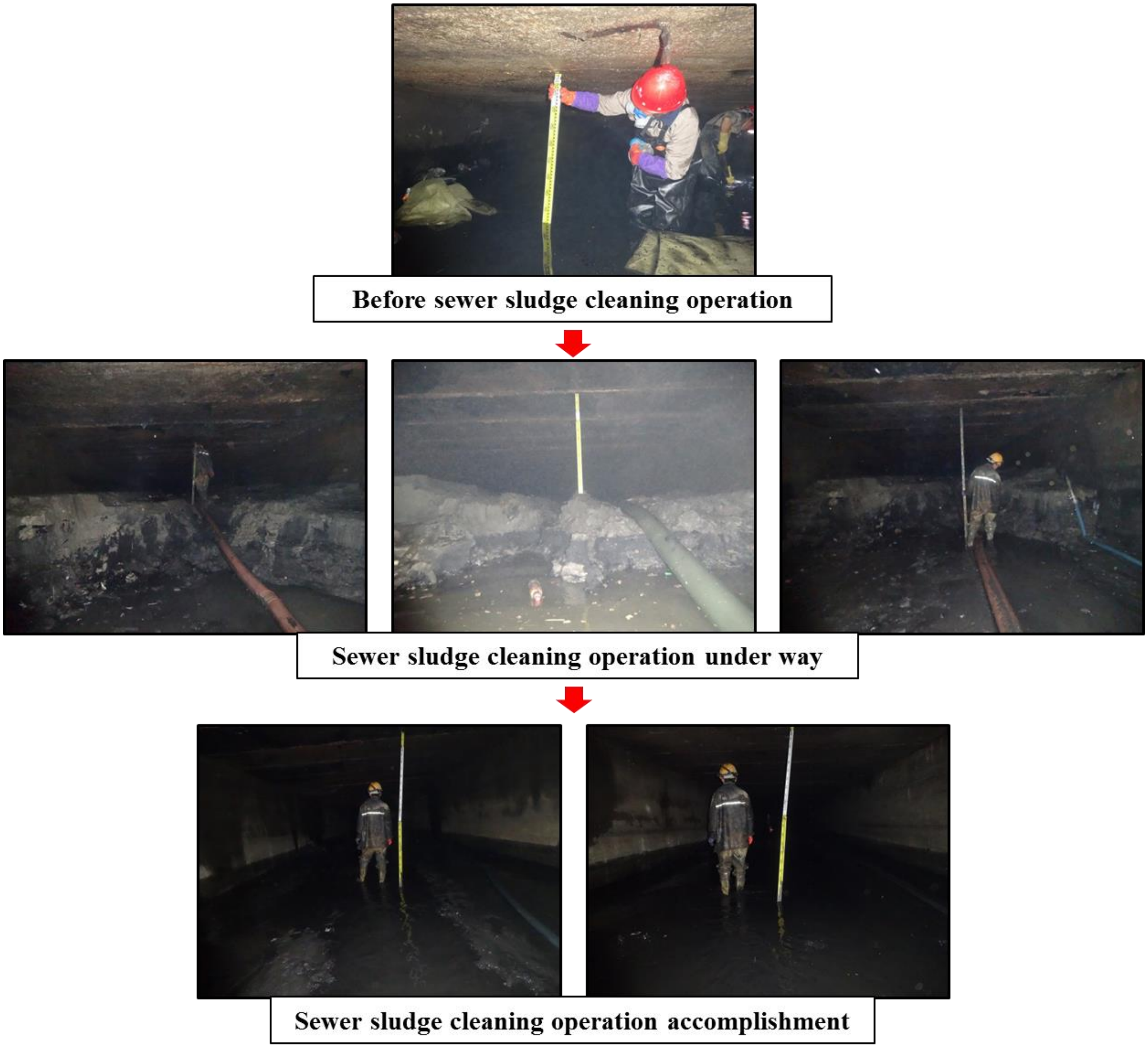

Fig. 4 Situation inside the sewage pipeline system when sewer sludge cleaning operation going on

Sewer sludge sediments recycling reuse

A sludge treatment and disposal center was built to achieve the goal of sewer sludge sediments recycling reuse. This center is designed to adopt 160 m^3/d raw sewer sludge. However, not only sludge, but also incidental wastewater and odor are all treated in the center (Fig. 5). For the sewer sludge, the feeding and pretreatment parts of recycling reuse treatment process are demonstrated in the Fig. 6 and 7. The transport vehicle conveys sewer sludge from the cleaning field operation site to the sludge stock dump. Then, a sludge grab bucket sends sewer sludge to the sludge balance pools, after coarse screen and fine screen treatments, the sewer sludge goes into the feed port of sludge treatment workshop (Fig. 5). After washing and separation, sludge separation, and hydrocyclone, the sewer sludge is divided into waste, organic matter, gravel, and sand. The waste has to be send into incineration in cement plant. The organic matter can be used for landscaping nearby. The gravel and sand can be used as raw material in cement plant.

A wastewater treatment system is an indispensable part since the raw sewer sludge's moisture content is 40%-60%. This means a lot of wastewater will be produced during the sludge treatment process. Fig.8 demonstrated the wastewater treatment system. Wastewaters come from raw sewer sludge or sludge treatment process all go to the sewage pool. After adding chemical agents, a membrane bioreactor (MBR) is utilized to treat the wastewater. The effluents are used for landscaping nearby, while the residual sludge goes into the sludge solidification system and finally be used as fertilizer for landscaping nearby.

Odor is always an annoying problem the affects the sewer sludge treatment successfully developing. Therefore, an odor treatment system is built to achieve odor abatement (Fig. 9). All the odors that produced in the sludge treatment workshop are collected by using ventilation system and treated in a UV treatment system and an active carbon treatment system, and finally organized emission into the ambient atmosphere.

Fig.5 Situation plan of the sludge treatment and disposal center

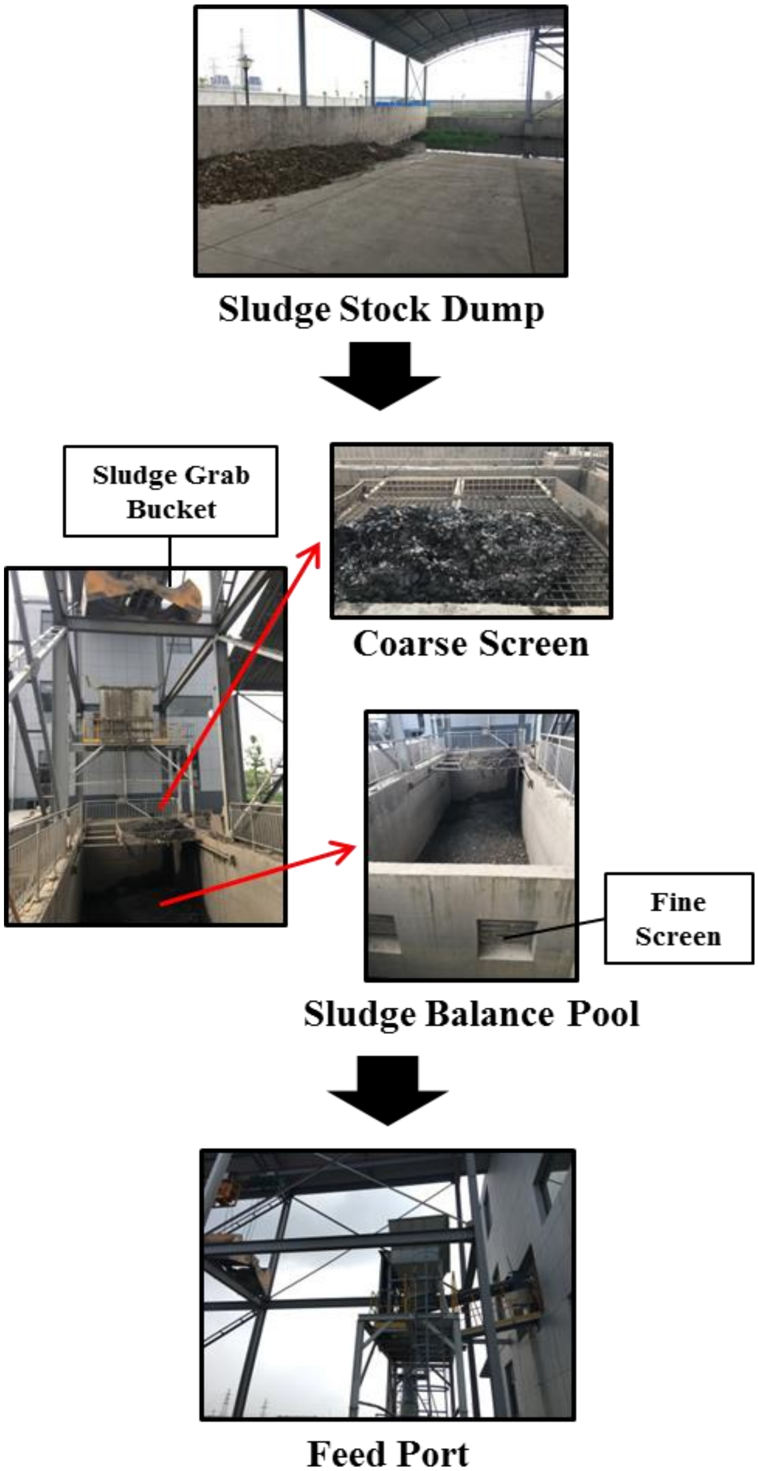

Fig.6 Feeding and pretreatment parts of the sludge treatment and disposal center

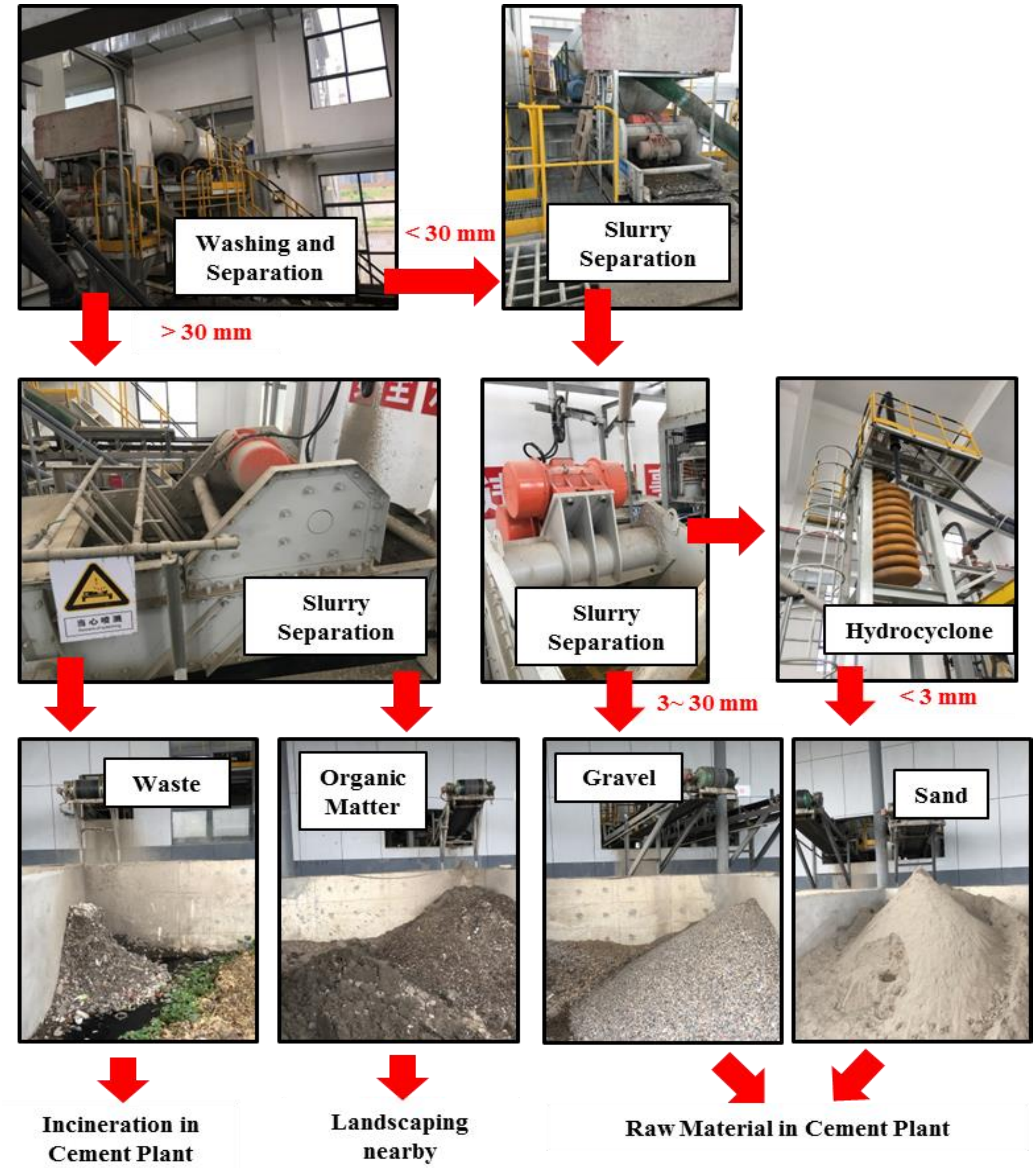

Fig.7 Sludge treatment system

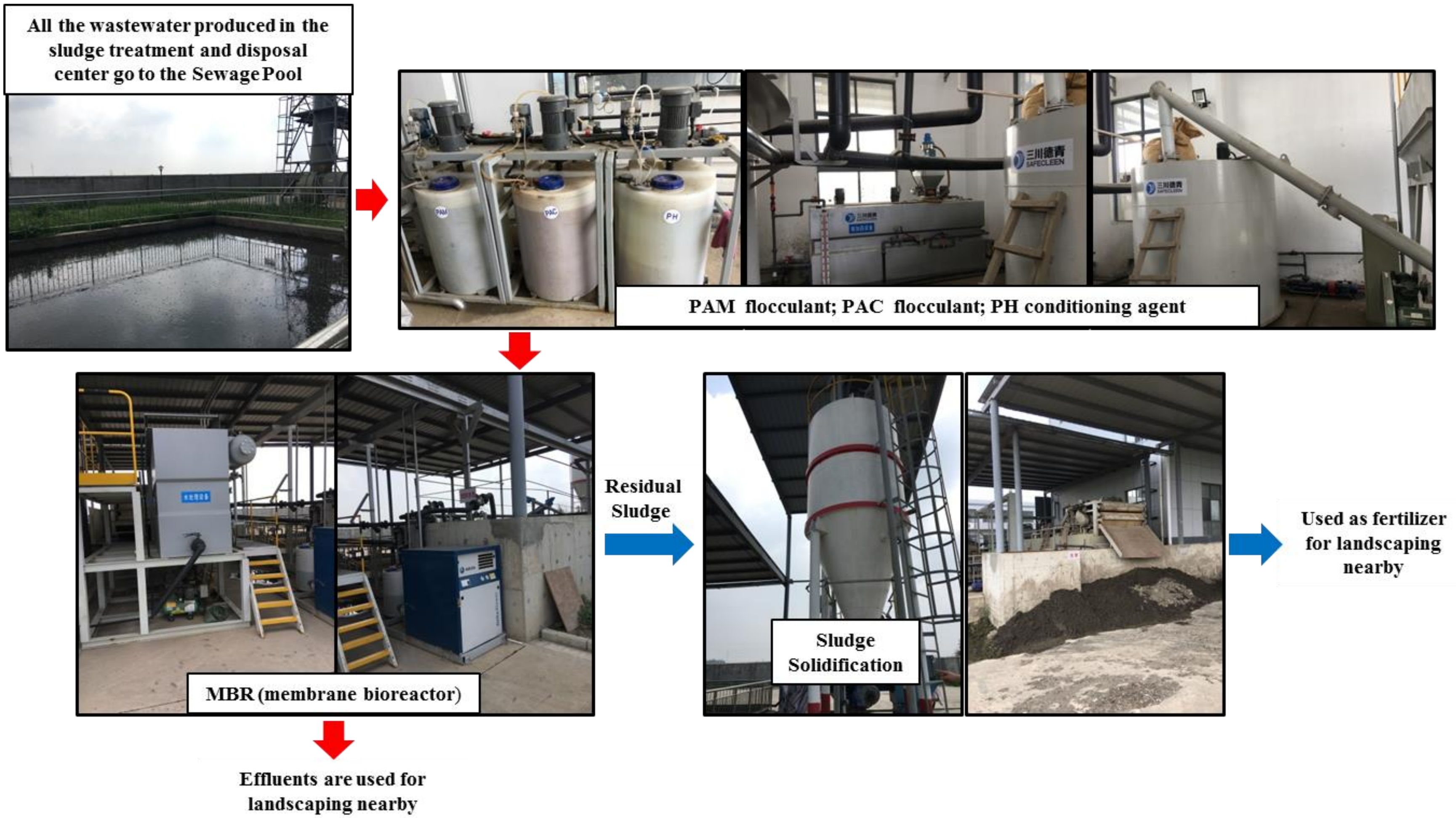

Fig.8 Wastewater treatment system

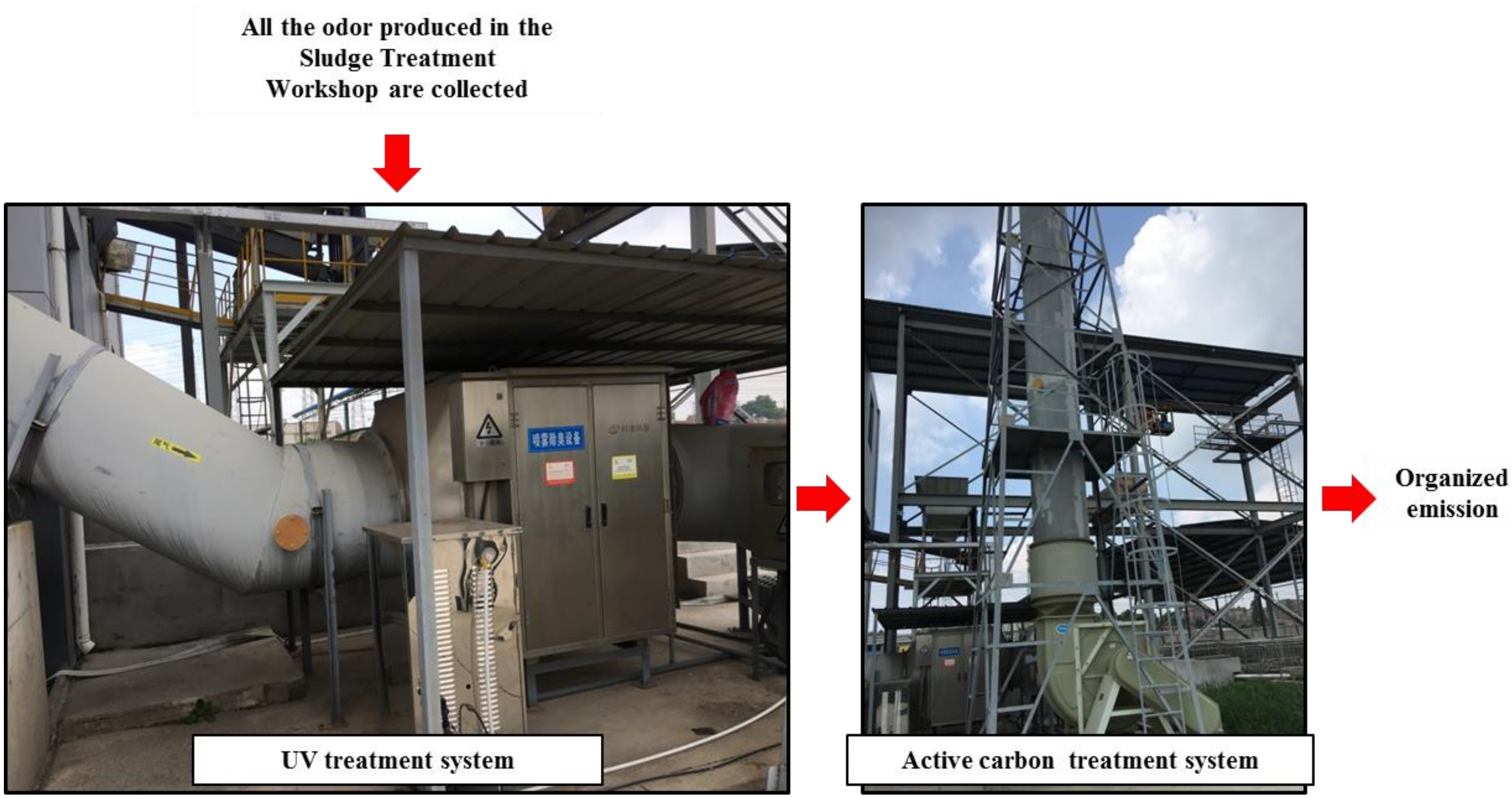

Fig.9 Odor treatment system

Institutions Involved

Wuhan City Water Affairs Bureau is the owner of the utility. The SafeCleen Technologies Co. Ltd takes charge of design and construction. Considering the cost of maintenance and operation, a joint venture company (Water Affairs Bureau and SafeCleen Technologies) may establish to handle the daily routine work in the sludge treatment and disposal center. And parts of work that refers to sewer sludge cleaning field operation will also outsource to a professional environmental company. However, this is neither a build-operate-transfer (BOT) or Public-Private Partnership (PPP) project.

Financing

Municipal construction fund that comes from government's annual budget are used for this sewer sludge cleaning project and sludge treatment and disposal center build. The sludge treatment and disposal center costs approximately 9,000,000 CNY (approximately 1,316,000 USD). Nevertheless, the sludge cleaning field operation's cost depends on employee wages and price of the mobile pumping truck and the transport vehicle.

Impacts

CH_4 GHG emission in the sewer systems refers to sludge blockages can be reduced after sewer sludge cleaning field operation.

Other negative effects of sewer sludge (including explosion risk of CH_4 produced in sewer systems, H_2S and odor VOCs emission, depletes carbon sources in sewage wastewater, and wastewater-carrying capacity loss) will also be mitigated after sewer sludge cleaning field operation. Then, their related mitigation measures which planned to consume energy can be replaced by this sewer sludge cleaning. Therefore, the depreciation of assets and related GHG emission leave out.

Sewer sludge sediments are recycling reuse in a sludge treatment and disposal center. Then, greater sustainability and less carbon footprint are achieved.

Success Factors

Wuhan City Water Affairs Bureau gives full autonomy to SafeCleen Technologies. So, the SafeCleen Technologies can design and build sewer sludge cleaning field operation process and sewer sludge treatment and disposal center independently. The SafeCleen Technologies only consider technology issues.

The disposal of sludge sediment arising from sewer sludge cleaning is considered. The sewer sludge sediment is separated into recycling reuse materials and useless in the sewer sludge treatment and disposal center in order to meet overall carbon neutrality.

This demonstration project about sewer sludge cleaning operation and its supporting sludge treatment and disposal center are conducted in outer suburb rather than downtown. So, the traffic jams during cleaning field operation is avoided. The site selection of the center has few restrictions since the outer suburb is vast and sparsely populated.

Obstacles Overcome

After recycling reuse treatment, the sewer sludge is divided into waste, organic matter, gravel, and sand. They all can find a proper disposal way in this project. However, usually it is hard to let the consumers buy products that come from solid waste. Therefore, the public subsidies and publicity guide are needed to help this solid waste products marketization.

Lessons Learned

(1) Sludge sediment in sewers has been largely ignored for most of the last decades in China

Sewerage owners and operators both consider that as the management authorities and regulatory agency cannot see what is happening underground, they are not particularly concerned about in-sewer processes and deposition. Furthermore, differentiated incentives to invest in capital rather than operations also militates against interest in better sewer operational management (Ashley and Hopkinson 2000). With new vision of carbon neutrality to integrated operation and management of sewerage systems, moves to greater sustainability and less carbon footprint, a more efficient and effective approach to proactively manage sludge sediments is urgently required.

(2) The blockage problems caused by in-sewer sludge solids are often unacknowledged

Since the early development of sewerage management in China before 2000s only modest advances have been made in sewer sludge cleaning, sewer system performance understanding has advanced mostly in terms of the hydrology and hydraulics of the inputs, and the hydraulics of the flows in the sewer (Ashley et al. 2000). The blockage problems caused by in-sewer sludge solids are often unacknowledged, even today, and differentiated investment policies, which favor capital rather than operational expenditure, often discriminate against an honest look at these blockage problems. Therefore, many management authorities, regulatory agency, and even utilities preferring not to be aware of in-sewer sludge solids blockage problems, although they are often confronted with process problems due to GHG emission, reduction of sewer capacity, H_2S and odor VOCs production, depletes carbon sources in wastewater downstream nutrient removal processes at WWTP.

However, in the recent ten years, management authorities, regulatory agency, and utilities of sewerage system are becoming more aware of the costs of maintaining their sewerage infrastructure and are beginning to try to incorporate sustainability concepts of carbon footprint reduction into the way in which maintenance and operation is undertaken (Ashley et al. 2000).

Furthermore, in many event databases of the local sewer management authorities, the majority of operational incidents are only recorded simply as "blockage". This is really misleading since most of these blockages often re-occur, indicating that current sewer maintenance practices are tackling the symptoms of the problem and not the cause (Fenner and Sweeting 1999).

(3) An integrated perspective

There are a number of initiatives underway relevant to sludge deposition and effects. An integrated perspective on wastewater treatment and transportation systems as a whole to ensure that these are operated taking due account of sustainability concepts, which would include the effects and fate of sludge deposition in, and removed from, sewer systems (Balkema et al. 1998; Ashley et al. 2000).

The treatment and disposal of sludge sediments come from sewer cleaning process is the key for carbon neutrality of the whole system. This means that the sludge sediments should be recycled and beneficial reused rather than directly incineration, landfill or even laissez-faire. nevertheless, besides the environmental impacts of carbon footprint mitigation, relevant co-conflicting issues may include engineering cost, public perception, socio-economic, rules/regulations, and managerial aspects of cleaning process. They all receive excessive consideration from government authorities and stakeholders.

(4) Sediment management

Ideally sludge (sediments and other solids) should be kept out of wastewater systems. Failing this option, it can presume that sediment solids transferred into the sewer system are most economically managed by their conveyance to a downstream facility (Butler and Clark 1995). However, most of the sediment solids and associated pollutants arise from human activity, with domestic, construction and highway sources typically comprising the largest amounts. Therefore, controls thus relate to: education and behavior at the level of the individual as to the type and amounts of sediment solids introduced to wastewater systems; sediment solids control via street sweeping; runoff management from construction sites; design and operation of devices and structures at inlets to sewer systems.

Not in China but in the US and certain other western countries, kitchen sink grinders are widely used. It allows the introduction of more organic solids into the sewer system. Then, higher risk of blockage happened.

Frequent maintenance of the sewage systems requires significant manual labor and is hence very expensive. Consequently, many workers undertake only reactive rather than pro-active maintenance, when sludge blockages necessitate. Furthermore, traditionally, sewage utilities have addressed the maintenance and operation of sewer systems with a reactive approach, do not get around the problems only after they cause a significant failure. However, the cost of representative sewer failure: service disruptions, adverse public relations, and health & safety concerns, can be significantly higher than the cost of implementing proactive maintenance.

In conclusion, a regular sewer cleaning as a cost-effective way of dealing with sludge blockages and a move away from reactive maintenance to a more proactive approach is encouraged, and may meet the carbon neutral. However, the major reason for using reactive approaches is lack of record and monitoring keeping, so that a sewer system's deterioration is even not evident until major failures occur. Lack of data on the condition of sewers also hinders the development of predictive models and the evaluation of effects of changes in the maintenance policy

(5) Coordinate all stakeholders and holistic analyses

Different types of decision makers including politicians, utility owners, construction organization, idealists or environmentalists can significantly influence decision making processes, and often, contradictory views are expressed during investigations or negotiations. Then coordinate all stakeholders and holistic analyses are needed in order to achieve a balanced and sustainable decision.

Replication

This case study is replicable when there is appropriate location in outer suburb rather than downtown. And the wastes arising from recycling reuse treatment should have a short cut to reuse them nearby.

Fig.10 Mobile sewer sludge pretreatment unit

Best Practice

This is a best practice case study example since the sewer sludge cleaning field operation and the sludge treatment and disposal centre both approach to achieve carbon footprint reduction results. And they are now moving the utility towards energy and carbon neutrality.

Next Steps

A mobile sewer sludge pre-treatment unit is utilized on site to reduce the raw sewer sludge's moisture content (Fig. 10). Then, the sludge transportation and storage will be more convenient.

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