Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Full length article

Emergency response to the explosive growth of health care wastes during COVID-19 pandemic in Wuhan, China

Lie Yang\(^a\), Xiao Yu\(^b\), Xiaolong Wu\(^c\), Jia Wang\(^d\), Xiaoke Yan\(^a\), Shen Jiang\(^d\), Zhuqi Chen\(^d,e,\)\(^*\)

\(^a\) Hubei Key Laboratory of Mineral Resources Processing and Environment, School of Resources and Environmental Engineering, Wuhan University of Technology, Wuhan 430070, PR China
\(^b\) Wuhan Institute of Environmental Sanitation Science, Wuhan 430000, PR China
\(^c\) Hubei Solid Waste and Chemical Pollution Prevention Center, Wuhan 430000, PR China
\(^d\) Hubei Provincial Engineering Laboratory of Solid Waste Treatment, Disposal and Recycling, Huazhong University of Science and Technology, Wuhan, 430074, PR China
\(^e\) Key Laboratory of Material Chemistry for Energy Conversion and Storage, Ministry of Education, Hubei Key Laboratory of Material Chemistry and Service Failure, School of Chemistry and Chemical Engineering, Huazhong University of Science and Technology, Wuhan, 430074, PR China

ARTICLE INFO

Keywords: Health care waste COVID-19 Incineration Emergency management Disinfection

ABSTRACT

During the Coronavirus Disease 2019 (COVID-19) as a worldwide pandemic, the security management of health care wastes (HCWs) has attracted increasing concern due to their high risk. In this paper, the integrated management of HCWs in Wuhan, the first COVID-19-outbreaking city with over ten millions of people completely locking down, was collected, investigated and analyzed. During the pandemic, municipal solid wastes (MSWs) from designated hospitals, Fangcang shelter hospitals, isolation locations and residential areas (e.g. face masks) were collected and categorized as HCWs due to the high infectiousness and strong survivability of COVID-19, and accordingly the average production of HCWs per 1000 persons in Wuhan explosively increased from 3.64 kg/d to 27.32 kg/d. Segregation, collection, storage, transportation and disposal of HCWs in Wuhan were discussed and outlined. Stationary facilities, mobile facilities, co-processing facilities (Incineration plants for MSWs) and nonlocal disposal were consecutively utilized to improve the disposal capacity, from 50 tons/d to 280.1 tons/d. Results indicated that stationary and co-processing facilities were preferential for HCWs disposal, while mobile facilities and nonlocal disposal acted as supplementary approaches. Overall, the improved system of HCWs management could meet the challenge of the explosive growth of HCWs production during COVID-19 pandemic in Wuhan. Furthermore, these practices could provide a reference for other densely populated metropolises.

1. Introduction

Coronavirus disease 2019 (COVID-19) is an emerging respiratory infectious disease caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), which was first reported in early December 2019 in Wuhan, China (Pan et al., 2020). COVID-19 can be transmitted through aerosols, large droplets, or direct contact with secretions or fomites (Shi et al., 2020). Due to its high infectiousness, which necessitates aggressive infection mitigation strategies to reduce the risk to patients and healthcare providers (Engelman et al., 2020). Therefore, a tremendous amount of personal protective equipment (PPE) is consumed through both the medical care processes and the regular human activities. Especially, a recent research reveals the strong survivability of the coronavirus, which could survive on material surfaces (e.g., metals, glass, and plastics) for up to 9 days (Nzediegwu and Chang, 2020). Thus, this survivability inevitably causes the explosive growth of health care wastes (HCWs) production in an explosive manner.

Typical HCWs are mainly collected from hospitals and can be divided into five categories: sharp waste, infectious waste, tissues waste, chemical waste and medicine waste (Yong et al., 2009). The total production of HCWs is usually stable under certain conditions (Ahmad et al., 2019). However, during the pandemic, municipal solid wastes (MSWs) from designated hospitals, Fangcang shelter hospitals, isolation locations and residential areas (e.g. face masks) are of potential infectiousness due to the high infectiousness and strong survivability of COVID-19, and need to be collected, transported, storage and treated as part of HCWs (MEE, 2005, 2006a, b). These kinds of solid wastes with potential infectiousness were defined as epidemic MSWs in this study. Thus, during COVID-19 pandemic (Engelman et al., 2020;
Li et al., 2020), the definition and scope of HCWs was obviously extended, especially for COVID-19-outbreaking cities or areas like Wuhan in China, New York in USA, Lombardia in Italy and etc., and necessitates the establishment and operation of an emergent management system.

As a mega city in the central China, Wuhan has a population of 11 million before COVID-19 outbreak, and this number decreased to approximate nine million during the lockdown period. Two emergent hospitals were urgently constructed to provide 2600 beds for confirmed cases. Additionally, 48 designated hospitals (21,722 beds) and 23 Fangcang shelter hospitals (19,757 beds) were successively applied to serve the increasing confirmed cases. Fangcang shelter hospitals were reconstructed from exhibition halls, stadia or large public facilities and used for the medical care of mild confirmed cases (Pan et al., 2020). Furthermore, a series of isolation locations to isolate presumptive cases. Tens of thousands of medical care personnels from all parts of China came to Wuhan as the support of medical treatment, and all these treatments for patients as well as activities for quarantining people in turn leads to the explosive increase of HCWs with an extended scope (e.g. face masks from non-medical regions). As far as we know, this is the first case of locking down a mega city with a population of over 10 million due to the outbreak of pandemic in human history.

As the administrative department in charge of HCWs management, and the provincial engineering laboratory of solid waste treatment, we collected and summarize tremendous data through the management of HCWs during the outbreak of pandemic. Two questions were answered, or partly answered in this paper: (1) What is the pattern of the total amount of HCWs in a locking down city with tens of millions people during the outbreak of pandemic; (2) How MSWs management system including segregation, collection, storage, transportation and treatment handle the sharp growth of HCWs generation. We believe the experience in Wuhan can be highly suggestive to audiences in the community of both scientific researchers and policy makers, especially as announced by WHO (World Health Organization) that this epidemic can easily re-ignite, and be with human-beings for a long time.

2. Methodology

The study period was from January 23, 2020 (City lockdown) to April 24, 2020 (On-care cases are less than 30), and was divided into three stages, including the first stage (Jan. 23-Feb. 12), the second stage (Feb.13-Mar. 22), and the third stage (Mar. 23-Apr. 24). The first stage was the initial period of COVID-19 pandemic and the production of HCWs began to increase. The burst growth of HCWs occurred in the second stage and then the amount decreased gradually in the third stage. The number of confirmed patients was extracted from the daily reports of Health Commission of Hubei Province and Wuhan Municipal Health Commission. A laboratory-confirmed case is defined if the patient has a positive result for SARS-CoV-2 virus by real-time reverse transcriptase-polymerase chain reaction assay or high-throughput sequencing of nasal and pharyngeal swab specimens (Pan et al., 2020). An on-care case is defined as a patient who is in the process of medical treatment in centralized hospitals or Fangcang shelter hospitals. The detailed data of health care wastes (HCWs) were provided by Hubei Solid Waste and Chemical Pollution Prevention Center. Some of the data have been reported in public by the media. The treatment capacity of HCWs means the designed limitation of treatment facilities, while the treatment amount of HCWs means the real treatment amount in treatment facilities.

3. Results and discussion

3.1. Daily treatment amount and capacity of HCWs

The schematic of HCWs management during COVID-19 pandemic in Wuhan is demonstrated in Fig. 1. Apparently, the daily treatment amount of HCWs increased slightly during the first stage. Subsequently, two emergency hospitals (2600 beds), 48 designated hospitals (21,722 beds) and 23 Fangcang shelter hospitals (19,757 beds) were successively applied. These medical facilities contributed to the burst growth of HCWs in the second stage. The peak value of daily treatment amount of HCWs was 291 tons on Mar. 1, which was nearly 6 times comparing with the routine amount of 50 tons on Jan. 23. In the third stage, the number of on-care cases decreased remarkably, on account of the large number of cured patients. It is worth mentioning that the daily treatment amount of HCWs is still notably more than that before COVID-19 outbreak, probably due to the large consumption of PPE (e.g. face masks, gloves, disinfecter). A large amount of disinfection products were consumed for virus inactivation, including chemicals (e.g., 75% alcohol solution, chlorine containing disinfectants) and UV lamps, etc. The average production of HCWs per 1000 persons in Wuhan varied from 3.64 kg/d to 27.32 kg/d after the pandemic.

To meet the urgent treatment desire of tremendously increased production of HCWs, the treatment capacity has been promoted sharply via various approaches (Fig. 1). The treatment capacity of HCWs was significantly improved from 50 tons/d on Jan. 23 to 280.1 tons per day on Apr. 24. In the first stage, the operation loading rate of HCWs treatment facility was 93.71%, which was quite close to full loading operation conditions of treatment facilities. During the first stage of pandemic COVID-19, various approaches were employed to increase the treatment capacity of HCWs, including mobile facilities, co-processing facilities with MSWs, emergency facilities, and nonlocal treatment facilities. All of these approaches contributed the rapid enhancement of the disposal capacity of HCWs in Wuhan. Owing to the enhanced disposal capacity, the operation rate of the disposal capacity was only 36.88% on Apr. 24, 2020, which was of sufficient security during the COVID-19 period.

3.2. Collection, storage and transportation

3.2.1. Segregation and collection

Source separation is recommended based on both the segregation of infectious and non-infectious wastes from hospitals in non-epidemic periods (Lee and Huffman, 1996). The segregation practices have been reported as follows: infectious wastes were collected in yellow bags; MSWs were collected in black bags; sharps were collected in plastic containers; and cytotoxic/cytostatic drugs were collected in their original packaging (Yong et al., 2009). Nonetheless, non-infectious wastes are also potential to act as the infectious vectors due to the high risk of COVID-19. For instance, MSWs from designated hospitals, Fangcang shelter hospitals and isolation locations were packaged and collected as HCWs. Therefore, all of these HCWs were collected with strict segregation packages and managed according to the criterions of infectious wastes (MEE, 2008) during the COVID-19 epidemic in Wuhan. An investigation was conducted to evaluate the risks of the HCWs management, showing that the collection had higher importance than the temporary storage and the transportation (Eren and Tuzkaya, 2019). The specialized turnover containers (MEE, 2008) for HCWs collection have been massively supplied by the local government, from 4000 to 19,000 (Table 1). Additionally, the occupational health risk of staff cannot be ignored and the necessary protective equipment and training has been provided widely. The source management is crucial for the security of the entire system of HCWs.

3.2.2. Temporary storage and transportation

After the segregation and the collection (Figure S1), HCWs are normally delivered to temporary storage sites, which locate near/inside the hospitals (Yong et al., 2009). The storage conditions are strictly controlled based on the current regulation (e.g. areas should be easy to clean, have adequate ventilation, and be properly marked) (MEE, 2012). The waste capacity of each storage site is usually designed based on the waste production of the corresponding hospital. On
account of the severe risk of HCWs, the stored wastes should be treated within 24 h, when the temperature is higher than 5 °C (MEE, 2005). However, the storage capacities of hospitals and other medical institutions in Wuhan were not sufficient due to the burst growth of HCWs in the initial stage after COVID-19 outbreak. Apart from designated hospitals, the storage sites of Fangcang shelter hospitals and isolation locations were severely insufficient in the first stage. The amount of the stored but untreated HCWs is demonstrated in Fig. 2. It was observed that the amount of stored HCWs reached the peak value of 192 tons on Feb 25th. The high-load period of the residual stored

![Fig. 1. The schematic HCWs management during COVID-19 pandemic in Wuhan.](image)

### Table 1
The comparison of collection and storage facilities before and after COVID-19 outbreak.

| Items                | Before COVID-19 outbreak | After COVID-19 outbreak | Growth rate (%) |
|----------------------|--------------------------|-------------------------|-----------------|
| Turnover containers  | 4000                     | 19,000                  | 475             |
| Emergency storage sites | –                        | 17 (1118.6 tons)        | –               |
| Transport vehicles   | 24                       | 82                      | 342             |
According to the current regulations in China (MEE, 2003), the off-site transportation of HCWs to the final disposal site should be handled by authorized disposal companies. HCWs are transported through pre-established routes (Yong et al., 2009). At all times, the place of origin and collection date, and place of destination of transport vehicles should be strictly monitored and noted (Insa et al., 2010). Before COVID-19 outbreak, there were 24 licensed transport vehicles available for HCWs transportation in Wuhan. This number rapidly increased to 82 via emergency dispatching. The improved transportation capacity was confirmed to be sufficient for the daily operation of HCWs management in Wuhan.

3.3. Emergency management of treatment facilities

The dynamic distribution of various local treatment capacities is presented in Fig. 3. The total capacity of local HCWs treatment is significantly improved to meet the challenge of COVID-19 spread. The majority (97.38%) of HCWs was treated in local facilities, including stationary facilities, mobile facilities and co-processing facilities. During the peak period, some HCWs were delivered to three nearby cities for harmless treatment, accounting for 2.62% of the total treatment amount during the study period.

3.3.1. Stationary facilities

Before COVID-19 outbreak, the local treatment capacity of HCWs in Wuhan was 50 tons/d by an active centralized incineration plant for HCWs. The incineration plant is well equipped with incinerator feeding system, incinerator, thermal energy utilization system, flue gas purification system, residue treatment system, etc. After the lockdown of Wuhan, a brand new incineration plant was established on Jan. 24, with a capacity of 10 tons/d. In addition, an emergency treatment center (Qianzishan) using steam-based centralized treatment was constructed with two phases (each phase with the capacity of 30 tons/d) (Figure S4). Incineration and steam disinfection are both widely utilized technologies (Ababneh et al., 2020; Dursun et al., 2011; Kaur et al., 2019), and can meet the requirements of current regulations under standardized management (MEE, 2005, 2006b). Until Apr. 23, the capacity of stationary facilities for HCWs reached 120 tons/d, accounting for 42.84% of the total capacity. It was worth mentioning that the three stationary facilities were operated at high loading rates, nearly covering the entire study period. For instance, 59.86 tons of HCWs were treated in the three stationary facilities, which took up 87.90% of HCWs from hospitals and isolation locations on Mar. 21. Evidently, the stationary facilities played a leading role in the treatment of HCWs from various hospitals and isolation locations.

3.3.2. Mobile facilities

34 mobile facilities using various technologies were rapidly built in designated hospitals (Figure S5), Fangcang shelter hospitals, and temporary storage sites during the COVID-19 period, from procurement (18, 52.94%), social donation (10, 29.41%) and allocation by the Ministry of Ecology and Environment of China (MEE) (6, 17.65%). It was worth mentioning that social donation played an important role in the rapid growth of mobile treatment capacity. Most facilities were small-scale, with the daily treatment capacity below 5 tons/d. As illustrated in Fig. 4, microwave disinfection facilities contributed the largest share (55.88%) of mobile facilities, followed by incineration (32.35%). The capacity of mobile facilities reached 75.6 tons/d on Mar. 21. Nevertheless, only some of these mobile facilities (10 of 34) remained in service during the COVID-19 period. The treatment capacity of mobile facilities in service was 23.10 tons/d, which was notably lower than that of the stationary facilities. The majority of mobile facilities were standby during the COVID-19 period. The phenomenon could be probably attributed to the lower stability of mobile facilities, comparing to stationary facilities.

According to Fig. 4, microwave disinfection, steam disinfection and incineration were applied in these mobile facilities in service. Although these mobile facilities were designed and built based on the current regulations and laws, the preferential treatment approaches of HCWs are still the stationary facilities due to the actual treatment efficiency.
and secondary environmental risks (Liu et al., 2009; Tiller and Linscott, 2004; Wu et al., 2011). Microwave disinfection and steam disinfection are both effective technologies for the disinfection of HCWs (Hong et al., 2018; Oliveira et al., 2010; Wang et al., 2020). The disinfected HCWs should be further treated according to the regulations (MEE, 2006a, b). The licensed transportation from these mobile facilities to ultimate disposal sites is necessary for the security treatment of HCWs. Regarding mobile incineration facilities, the secondary environmental risk cannot be ignored in the absence of ancillary facilities (MEE, 2005), including thermal energy utilization system, flue gas purification system, residue treatment system, etc. In China, the waste-to-energy incineration has been increasingly adopted for waste treatment (Hu et al., 2018; Makarichi et al., 2018; Yatsunthea and Chaiyat, 2020). Moreover, the severe ecological risk would occur without specialized flue gas purification and fly ash treatment (Kaur et al., 2019; Wu et al., 2011). These disadvantages of mobile facilities could reasonably explain that 6 mobile facilities were closed, when the second stage (Capacity: 30 tons/d) of Qianzishan emergency treatment center came into operation on Apr. 23.

3.3.3. Co-processing facilities

Co-processing of HCWs with MSWs is an emergency choice, when the generation of HCWs exceeds the capacity of existing treatment facilities. In fact, the generation of MSWs decreased significantly in the first stage (Jan. 23–Feb. 12), and then increased slowly in the second stage (Feb. 13–Mar. 22) and the third stage (Mar. 23–Apr. 24) (Fig. 5).

Fig. 3. The dynamic variation of local treatment capacities during COVID-19 pandemic in Wuhan.

Fig. 4. The technologies and status of the mobile facilities during COVID-19 pandemic in Wuhan.
The generation decline of MSWs provided a sufficient treatment capacity for the co-processing of HCWs. In addition to various sterilization treatments, landfill and incineration are frequently-used for the ultimate treatment of HCWs (Aung et al., 2019; Chen et al., 2013; Lee and Huffman, 1996). There are five waste-to-energy incineration plants and two sanitary landfills in service for MSWs treatment in Wuhan. Although landfill is still applied for the treatment of HCWs in some developing countries (Khan et al., 2019; Niyongabo et al., 2019), it is not secure for the ultimate disposal of HCWs due to the high risk of COVID-19. In contrast, waste-to-energy incineration is a considerable option for simultaneous treatment and energy utilization of HCWs. It is widely known that various pollutants would be generated along with the generation of flue gases and fly ashes during the incineration process of HCWs (Xie et al., 2009), especially for PCDD/Fs (Wu et al., 2011), PAHs (Wang et al., 2020) and heavy metals (Li et al., 2017; Liu et al., 2009). Therefore, secondary pollution control is the vital factor for evaluating incineration types.

According to the regulations for hazardous waste incineration (MEE, 2001, 2005), the burning temperature of the incinerator used for medical waste should be higher than 850 °C. Only two waste-to-energy incineration plants (Xinghuo MSWI and Xingou MSWI) (Figure S6) were available for HCWs treatment in Wuhan due to the burning temperature (> 850 °C). Two selected incineration plants are equipped with grate furnaces, which are beneficial for the removal of persistent organic pollutants (e.g. PCDD/Fs) (Vandecasteele et al., 2007). Nevertheless, the other three incineration plants are equipped with fluidized bed furnaces, which may cause air pollution due to the lower heat transfer rate between the bed material and medical wastes (Wang et al., 2020). Therefore, grate-furnace incineration plants are more suitable for the co-processing of HCWs, rather than fluidized-bed incineration plants.

According to the emergency regulation of MEE (MEE, 2020), the maximum loading amount of HCWs in MSW incineration plants is only 5% of the for the co-processing. Consequently, the co-processing capacity of the two selected incineration plants (2000 tons/d for MSWs) was 100 tons/d. The co-processing amount and percentage of HCWs during COVID-19 pandemic in Wuhan are demonstrated in Fig. 5. It was observed that co-processing played a crucial role in the treatment of HCWs in Wuhan. The total amount of co-processed HCWs reached 5806.4 tons, accounting for 46.09% of the total treatment amount of HCWs during the study period. The co-processing with MSWs could notably raise the treatment capacity of HCWs based on existing treatment facilities, which could provide a reference for the emergency management of other regions and cities.

3.3.4. Nonlocal treatment

Besides local treatment, some HCWs were transported to nearby cities for nonlocal treatment in the second stage (Feb.13–Mar. 22) (Fig. 6). Three cities, including Xiangyang, Huangshi and Xianning, provided the emergency treatment of HCWs from Wuhan. Licensed vehicles (MEE, 2003) were used for the trans-regional transportation of HCWs. The transportation process was strictly monitored for security reasons. The accumulated nonlocal treatment amount of HCWs reached...
330.3 tons, accounting for 2.62% of the total treatment amount during the studied period. Although the amount was significantly lower than those of the stationary and co-processing facilities, the contribution of nonlocal treatment could not be ignored in the emergency management of HCWs in Wuhan. Overall, nonlocal treatment could act as an alternative option for other cities and regions during COVID-19 pandemic.

4. Implications from the practices of HCWs management in Wuhan

On the whole, the emergency management of HCWs during COVID-19 pandemic in Wuhan is a successful case, especially considering the fact that this outbreak of pandemic was a sudden case. The efficient and secure management of HCWs is believed to contribute remarkably to the effective control of COVID-19 spread in Wuhan. Therefore, several implications are drawn from the actual practices of HCWs management in Wuhan as indicated above.

(a) The implementation of national and local emergency policies could provide operable guidelines for the management of HCWs during COVID-19 pandemic. MEE promulgated a national guideline for the emergency management of HCWs (MEE, 2020). In addition, Wuhan Municipal Administration and Law Enforcement Committee announced an emergency policy on Feb. 12, 2020, which decided to adopt two grate-furnace incineration plants as co-processing facilities.

(b) MSWs of potential infectiousness were defined as HCWs during COVID-19 pandemic. Besides typical HCWs, infectious MSWs in designated hospitals, Fangcang shelter hospitals, isolation locations and residential areas were also collected and treated as HCWs.

(c) The integrated management of HCWs, including segregation, collection, storage, transportation and treatment, was significantly enhanced during COVID-19 pandemic. The entire process should be monitored to guarantee the secure management of HCWs at all time.

(d) The co-processing facilities contributed significantly to the efficient and secure treatment of HCWs as an emergency approach. Especially for those grate-furnace incineration plants, the total treatment capacity of HCWs could be rapidly improved even with a co-processing rate of 5%. The high operation temperature (>850 °C) and ancillary facilities effectively prevent the emission of various pollutants.

(e) Social participation played an important role in the rapid improvement of treatment capacity of HCWs. It was noticed that 10 mobile facilities were donated from various companies for corporate social responsibility, accounting for 29.41% of mobile facilities in Wuhan.

(f) Nonlocal treatment could act as an effective supplement during which the trans-regional transportation of HCWs should be strictly monitored for risk control.

5. Conclusions

The detailed emergency management of HCWs during COVID-19 pandemic in Wuhan was investigated in this study. Infectious MSWs in designated hospitals, Fangcang shelter hospitals, isolation locations and residential areas were also collected and treated as HCWs, and led to the increase of total production of HCWs in an explosive manner from 3.64 kg/d to 27.32 kg/d per 1000 persons. The capacities of collection, storage, transportation and treatment facilities were all massively increased to guarantee the safe management of HCWs. Stationary and co-processing facilities played a crucial role for the efficient treatment of HCWs. When the daily production of HCWs was close to the acceptable limitation of local treatment facilities, the trans-regional management were applied. The practical experience of emergency management of HCWs in Wuhan can be highly suggestive to other countries and regions to combat the global pandemic of COVID-19, and other respiratory infectious diseases.

CRediT authorship contribution statement

Lie Yang: Conceptualization, Methodology, Writing - original draft, Funding acquisition. Xiao Yu: Methodology, Data curation. Xiaolong Wu: Data curation. Jia Wang: Writing - original draft. Xiaoke Yan: Data curation. Shen Jiang: Writing - review & editing. Zhuqi Chen: Conceptualization, Writing - review & editing, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was financially supported by the National Key R&D Program of China (No. 2018YFC1901403), the Fundamental Research Funds for the Central Universities (No. 2019kyRCPY058), and Chutian Scholar Foundation from Hubei province.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.resconrec.2020.105074.

References

Abalbeh, A., Al-Rousan, R., Gharibeh, W., Abu-Dalo, M., 2020. Recycling of pre-treated medical waste fly ash in mortar mixtures. J. Mater. Cycles Waste 22 (1), 207–225.
Ahmad, R., Liu, G.Y., Santagata, R., Caussa, M., Xue, J.Y., Khan, R., Nawab, J., Ungiati, S., Lega, M., 2019. LCA of hospital solid waste treatment alternatives in a developing country: the case of District Swat, Pakistan. Sustainability 11 (13), 3501.
Aung, T.S., Luan, S.J., Xu, Q.Y., 2019. Application of multi-criteria-decision approach for the analysis of medical waste management systems in Myanmar. J. Clean. Prod. 222, 733–745.
Chen, Y., Zhao, R., Xue, J., Li, J., 2013. Generation and distribution of PAHs in the process of medical waste incineration. Waste Manage. 33 (5), 1165–1173.
Dursun, M., Karak, E.E., Karadany, M.A., 2011. Assessment of health-care waste treatment alternatives using fuzzy multi-criteria decision making approaches. Resour. Conserv. Recycl. 57, 98–107.
Engelman, D.T., Loiber, S., George, I., Funk, D.J., Ailawadi, G., Ailfuri, P., Grant, M.C., Haft, J.W., Hassam, A., Legare, J.-P., Whitman, G., Arora, R.C., 2020. Adult cardiac surgery and the COVID-19 pandemic: aggressive infection mitigation strategies are necessary in the operating room and surgical recovery. J. Thorac. Cardiovasc. Surg In Press.
Eren, E., Tuzkaya, U.R., 2019. Occupational health and safety-oriented medical waste management: a case study of Istanbul. Waste Manage. Res. 37 (9), 876–884.
Hong, J., Zhan, S., Yu, Z., Hong, J., Qi, C., 2018. Life-cycle environmental and economic assessment of medical waste treatment. J. Clean. Prod. 174, 65–73.
Hu, Y., Cheng, H., Tao, S., 2018. The growing importance of waste-to-energy (WTE) incineration in China’s anthropogenic mercury emissions: emission inventories and reduction strategies. Renewable Sustainable Energy Rev. 97, 119–137.
Insa, E., Zamorano, M., Lopez, R., 2010. Critical review of medical waste legislation in Spain. Resour. Conserv. Recycl. 54 (12), 1048–1059.
Kaur, H., Siddique, R., Rajor, A., 2019. Influence of incinerated biomedical waste ash on the properties of concrete. Constr. Build. Mater. 226, 628–411.
Khan, B.A., Cheng, L.S., Khan, A.A., Ahmed, H., 2019. Healthcare waste management in Asian developing countries: a mini review. Waste Manage. Res. 37 (9), 863–875.
Lee, C.C., Huffman, G.L., 1996. Medical waste management/incineration. J. Hazard Mater. 48 (1), 1–30.
Li, G., Hu, R., Gu, X., 2020. A close-up on COVID-19 and cardiovascular diseases. Nutr. Metab. Cardiovasc. Dis In press.
Li, Y., Zhang, H., Shao, L.-M., He, P.-J., 2017. Tracing source and migration of Pb during waste incineration using stable Pb isotopes. J. Hazard Mater. 327, 28–34.
Liu, Y., Zhan, Z., Du, F., Kong, S., Liu, Y., 2009. Indoor air concentrations of mercury ( >850 °C) and ancillary facilities effectively prevent the emission of various pollutants.
MEE, 2001. Pollution control standard for hazardous wastes incineration.
MEE, 2003. Technical specifications for medical waste transfer vehicles.
MEE, 2005. Technical specifications for centralized incineration facility construction on medical waste.
MEE, 2006. Technical specifications for microwave disinfection centralized treatment engineering on medical waste (on trial).
MEE, 2006. Technical specifications for steam-based centralized treatment engineering on medical waste (on trial).
MEE, 2008. Standard of packaging bags, containers and warning symbols specific to medical waste.
MEE, 2012. Technical specifications for collection, storage, transportation of hazardous waste.
MEE, 2020. Emergency management and technical Guidelines for medical wastes during COVID-19 pandemic (on trial).
Niyongabo, E., Jang, Y.C., Kang, D., Sung, K., 2019. Current treatment and disposal practices for medical wastes in Bujumbura, Burundi. Environ. Eng. Res. 24 (2), 211–219.
Nzediegwu, C., Chang, S.X., 2020. Improper solid waste management increases potential for COVID-19 spread in developing countries. Resour. Conserv. Recycl., 104947.
Oliveira, E.A., Nogueira, N.G.P., Innocentini, M.D.M., Pisani, R., 2010. Microwave inactivation of Bacillus atrophaeus spores in healthcare waste. Waste Manage. 30 (11), 2327–2335.
Pan, A., Liu, L., Wang, C., Guo, H., Hao, X., Wang, Q., Huang, J., He, N., Yu, H., Lin, X., Wei, S., Wu, T., 2020. Association of public health interventions with the epidemiology of the COVID-19 outbreak in Wuhan, China. JAMA 323 (19), 1915–1923.
Shi, P., Dong, Y., Yan, H., Zhao, C., Li, X., Liu, W., He, M., Tang, S., Xi, S., 2020. Impact of temperature on the dynamics of the COVID-19 outbreak in China. Sci. Total Environ. 728, 138880.
Tiller, T., Lisscott, A., 2004. Evaluation of a steam autoclave for sterilizing medical waste at a university health center. Am. J. Infect. Control. 32 (3), E9.
Vandecasteele, C., Wauters, G., Aricks, S., Jaspers, M., Van Gerven, T., 2007. Integrated municipal solid waste treatment using a grate furnace incinerator: the Indaver case. Waste Manage. 27 (10), 1366–1375.
Wang, H., Qin, L., Xu, Z., Zhao, B., Wang, Y., Han, J., 2020a. The suppression mechanism of PAHs formation by coarser-sized bed material during medical waste fluidized bed incineration. J. Energy Inst. 93 (3), 1138–1147.
Wang, J., Shen, J., Ye, D., Yan, X., Zhang, Y., Yang, W., Li, X., Wang, J., Zhang, L., Pan, L., 2020b. Disinfection technology of hospital wastes and wastewater: suggestions for disinfection strategy during coronavirus disease 2019 (COVID-19) pandemic in China. Environ. Pollut. 262, 114665.
Windfeld, E.S., Brooks, M.S.-L., 2015. Medical waste management – a review. J. Environ. Manage. 163, 98–108.
Wu, H.-l., Lu, S.-y., Yan, J.-h., Li, X.-d., Chen, T., 2011. Thermal removal of PCDD/Fs from medical waste incineration fly ash - Effect of temperature and nitrogen flow rate. Chemosphere 84 (3), 361–367.
Xie, R., Li, W.-j., Li, J., Wu, B.-l., Yi, J.-q., 2009. Emissions investigation for a novel medical waste incinerator. J. Hazard. Mater. 166 (1), 365–371.
Yatsunthea, T., Chaiyat, N., 2020. A very small power plant – municipal waste of the organic Rankine cycle and incinerator from medical and municipal wastes. Therm. Sci. Eng. Progress 18, 100555.
Yong, Z., Gang, X., Guanxing, W., Tao, Z., Dawei, J., 2009. Medical waste management in China: a case study of Nanjing. Waste Manage. 29 (4), 1376–1382.