Medical Waste Management during the Coronavirus 2019: A Review Study of China

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Abstract
Medical waste management is a significant aspect of public health due to its potential health risks on both the environment and humans. With the rise in of the coronavirus 2019 cases they has been an overwhelming increase of medical waste generation in hospitals. Despite been one of the most hit countries by the corona virus China has managed to handle the overwhelming medical waste by putting in place effective waste management strategies around the country. Considering the effectiveness of these medical waste management strategies put in place by China, this study explored the current measures and strategies employed. This is to enable other countries especially developing countries where the pandemic is still expanding and generating huge amount of medical waste to review effective strategies on how they can handle their medical waste.
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1. Introduction

Globally, the novel coronavirus 2019 (Covid-19) has been growing at a very speedy pace, which in turn has led to tremendous increase in quantity of medical waste generation ranging from biomedical waste to personal protective equipment (PPE) in both health care facilities and communities. The different waste been generated may have substantial impact on human health and the environment if not stored, collected, transported, disposed and treated in an appropriate and effective manner. Covid-19 was discovered in Chinas Hubei province in the city of Wuhan; in December 2019. Wuhan is considered to be the most populated city in central China with a population exceeding 11 million, as of 31st December 2019 Wuhan recorded 27 cases of pneumonia with clinical symptoms of dry cough, dyspnea and fever. Wuhan was letter quarantined on the 23rd of January together with 16 cities in Hubei province in addition to that two covid-19 hospitals were built within two weeks. These measures were put in place so as to reduce the spread of the virus (H. , C.W. , & Y, 2020).

However, on 30th January WHO declared Covid-19 as a global emergency as the virus had spread to all 31 provinces of the country and recorded 7,711 confirmed cases and a death toll of 170. By the end of that week the cases had more than doubled to 14,380 cases with a death tool of 304. The virus continued to spread throughout the country and by 16th march 2020 the country had recorded 81,000 confirmed cases according to the World Health Organization (WHO) (world, 2020). By April China started recording a decline in covid-19 cases which has continued to lessen till date; this was as a result of the strict measures and quick response that the country had put in place.

The Health sector has generally been recognized globally as one of the large waste generators. Medical waste management (MWM) is therefore a major concern owing to the potentially high risks in both human health and the environment. However, in response to Covid -19 health care facilities are producing more waste than usual, this attributes to the increased use of disposable PPE which includes surgical gloves, aprons, used testing kits, gowns, face masks and other waste from treatment facilities. The spread of the coronavirus through secondary transmission maybe increased by the inadequate waste management, highlighting poor handling conditions associated with inappropriate use of PPE and other unfavorable conditions presented mainly in developing countries (Marcos, 2020). However the potential increase in dumping, open burning and incineration could adversely impair air quality and the environment due to the exposure of dangerous toxins (World, 2020).

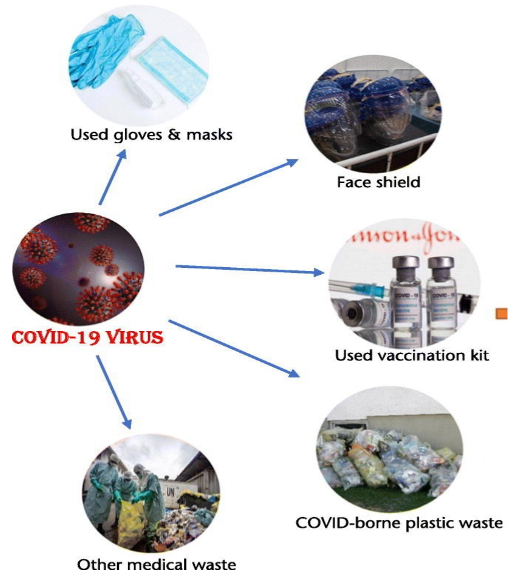

Figure 1; types of Covid -19 medical waste (Tamal Chowdhury a, 2021)

Responding to the increase in numbers of covid-19 cases in China the government did not only construct new hospitals to accommodate patients; they also built new medical waste plants (MWP) and deployed 46 mobile waste treatment facilities to handle the waste (Calma, 2020). Hospitals there generated six times as much medical waste at the peak of the outbreak as they did before the crisis began. The daily output of MW reached 240 metric tons, about the weight of an adult blue whale (Calma, 2020). However this has not been the case for most African countries who are still trying to figure out how best the increased waste can be managed. Some studies have shown that the COVID-19 virus can survive on various surfaces for as long as nine days (Kampf, 2020). Therefore, contaminated MW can be a highly risky virus reservoir that threatens public health if it is not properly disposed of and sustainably managed (Adyel, 2020). This study, aims to critically review waste generation and current medical waste management practices employed during covid-19 pandemic in China. This will help provide valuable data to policy makers, leaders, health decision makers and field engineers from other countries in decision making on how best they can handle this medical waste (MW) in the pursuit to curb the virus.

2. Research Method

This study considered currying out a qualitative unsystematic descriptive review of published work on MWM in china during the covid-19 pandemic. Data was gathered using a website search on database such as open Environmental sciences, Medline, springer, green-file, pubmed, and health sources using the subsequent keywords "hospital waste management during covid-19 in china and medical waste management systems during covid-19 in in china". The web search included articles, journals as well as other publications such as conference proceedings, newspaper articles. Over 1000 Research articles where gathered and assessed for their significance to the study, however only publications that dealt with medical/hospital waste management during covid-19 in China where selected for this review study.

3. Results and Discussion

This section reviews medical waste generated during covid-19 and the management practices during the pandemic.

3.1 Medical Waste Generation during Covid-19

According to the United States Medical Waste Tracking act of 1988 medical waste is defined as "any solid waste that is generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining there to, or in the production or testing of biological (United States Congress, 1988) . However MW generated daily due to COVID-19 is one of the major global environmental health concern currently and its critical management turn out to be a global challenge. Tones of Civid-19 contaminated wastes are been generated on a daily basis worldwide and its comprehensive management is very essential to the discontinuity of the disease transmission.

Due to the novelty of the Covid-19 pandemic, modification to existing waste facilities to control the unusual MW and its associated viral spread effects requires adequate information on the amount of medical waste generated, hot spots for waste generation and available treatment facilities. On account of potential rapid expansion volumes of medical waste, several technical knowhow on sorting, segregation, transport, storage and sustainable waste management technologies are required to maximize existing infrastructures to accommodate the emergency (Sharma,H.B,, 2020). The different forms of covid-19 related MW and its derivatives include non-hazardous waste, pathological waste, radioactive waste, infectious waste, chemical waste, cytotoxic waste, sharps waste and pharmaceutical waste. Improper management of this medical waste has the potential to expose patients, health workers and waste managers to injuries, infections, toxic consequences and air pollution (World Health Organisation, 2018).

Some studies have shown that medical waste may become a new source of infection, as the global demand for personal protective equipment led to a drastic increase in global medical waste. It is estimated that 129 billion face masks and 65 billion gloves are used globally each month (Prata, 2020). According to the Ministry of Industry and Information Technology, China produced 116 million disposable masks every day in February, which represents a 12-fold increase compared to production levels before the COVID-19 pandemic. The daily production of medical protective clothing increased from 8,700 pieces to more than 300,000 pieces. There is no doubt that most of the face masks and personal protection equipment will eventually become medical waste (China, 2020).

Fig.2 Workers of a textile company in Qingdao, Shandong province making masks in the workshop (photo taken on February 12) (China, 2020)

The Covid-19 pandemic has led to massive increase amount of medical waste all over the globe and different studies have been conducted in order to evaluate the waste generation. The estimation of MW generation differs from region to region, however, according to a study conducted in China's Hubei province it alludes that the province generally uses internationally accepted empirical formulas. Where the quantity of medical waste is calculated from the values of the variables of number of visits, bed utilization, and number of beds (Ye J, 2022) (Adu RO, 2020). Therefore, under the empirical estimation method, the study assumed that the daily MW production in Hubei Province is the same in each month under normal conditions as shown in figure 3. Based on the predicted medical waste production in the Province from January to April 2020 (M = 0.5), the medical waste production from January 23 to April 28, 2020 under normal conditions can be calculated (as shown in the Table 1). Based on the actual production value of MW from the pandemic in Hubei Province and the total normal production from Table 1, we can obtain the net production value of new MW (during the pandemic) to be 3366.99 tons, which is 16.04% higher than that under the normal conditions in the same period which was at the rate of 0.4 kg/bed/day or 0.6 kg/bed/day (Ye J, 2022).

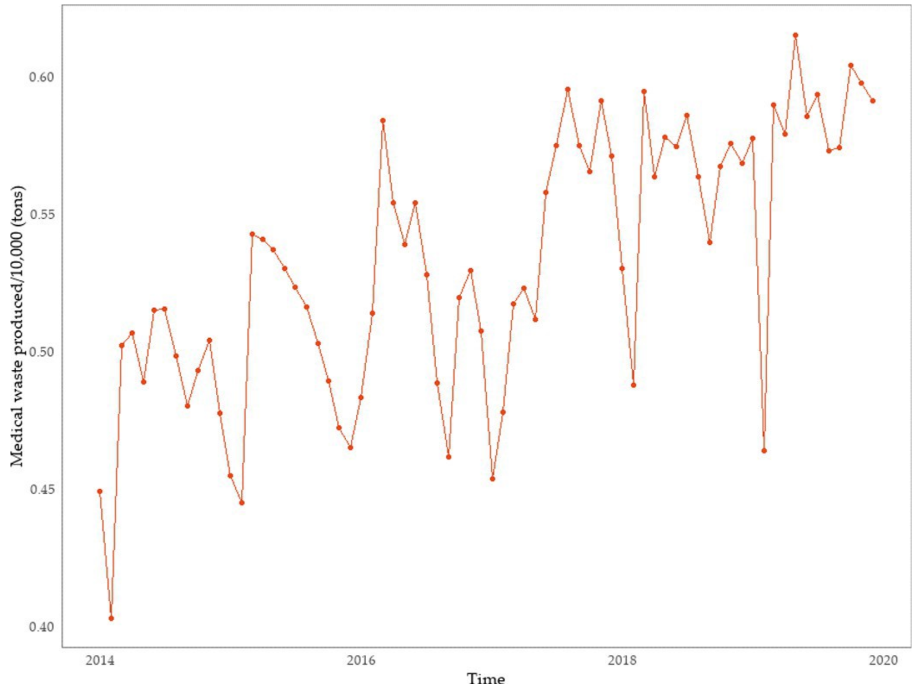

Fig 3. Plot showing the monthly production of medical waste in the Hubei Province, 2014–2019 (Ye J, 2022)

Table 1. Predicted production of medical waste under conventional conditions in the Hubei Province (Ye J, 2022)

Time	Medical waste(ton)
1/23-1/31	1964
2/1-2/29	5838
3/1-3/31	6864
4/1-4/28	6325
Sum	20991

https://doi.org/10.1371/journal.pone.0259207.t002

According to another study conducted in Wuhan, it was discovered that in 2019, MW generated in Wuhan was approximately 19,531 tones, with an average daily disposal demand of approximately 55 tones. The rapid increase in MW in such a short time far exceeded the original disposal capacity that in the most difficult time, led to a shortage in the MW disposal capacity of more than 60 tones. As shown in Fig. 3, the number of current confirmed COVID-19 cases peaked from the middle to the end of February and then gradually tapered off. However, the data analysis indicated that the peak of MW production showed a lag and occurred between late February and early March (Chang Chen a).

In another study conducted by Singh it was established that the city of Wuhan generated nearly 247 tons of medical waste per day at the peak of the pandemic, nearly six times more than before the pandemic. The peak occurred from 15 February to15 March 2020 (Singh, N., Tang, Y., Ogunseitan, O.A.,, 2020). Before the COVID-19 outbreak, the city had about 50 tons per day of medical waste disposal capacity with an average output of 45 tons. With the rise in the cases of COVID-19 in the city, the output of the medical waste also increased to 110–150 tons per day in mid-Feb and kept increasing up to 247 tons per day at the peak of outbreak until March 15, afterward it gradually declined back to normal in mid-May (Wei, G.,, 2020).

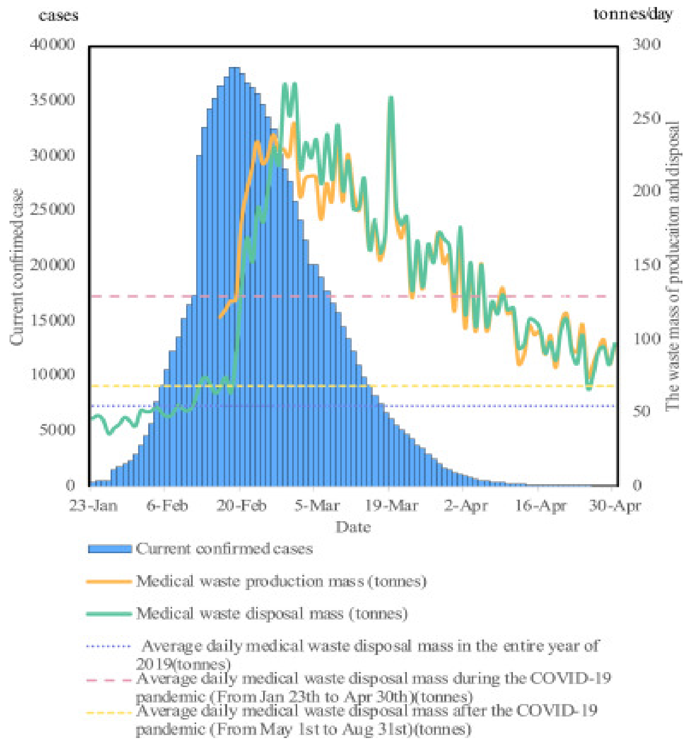

Fig. 4. Overview of medical waste production and disposal during the COVID- 19 pandemic (Chang Chen a).

3.2 Medical Waste Management during the Pandemic

The safe disposal of medical waste is a vital step in the reduction of illnesses and injuries caused through the contacting of potentially hazardous medical waste, and in the prevention of environmental contamination. The growing number of covid-19 heath facilities, hospitals and testing laboratories in China and the world at large has led to an increase in covide-19 medical waste. According to the Act 380 of "Medical Waste Management Regulations" (MWMR) publicized by the State Council of China in 2003, medical waste refers to wastes with direct or indirect Infectiousness, toxicity, and other hazards generated by medical institutions in medical treatment, prevention, health care, and other related activities (State Council of the PRC, 2004). The council further classified medical waste into 5 categories according to Regulation Act 287 as shown in table 2 (China Department of State).

Table 2. Classification of medical waste (China Department of State)

Waste category	Components
Tissues	Human or animal pathological wastes, including tissues, organs, blood, pus, and body parts and fluids
Infectious waste	Blood, blood products and objects that are contaminated with them; laboratory wastes microbiological; quarantine wastes; dialysis wastes; used surgical operating clothes; infectious organ pieces, blood and anything contaminated with these materials
Sharp objects	Needles, syringes, broken glass, blades, and other items that could cause a cut or puncture
Chemical waste	Hazardous chemicals, heavy metal containing wastes, pharmaceutical wastes, amalgam wastes, gynotoxic wastes, gentoxic wastes
Medicine waste	Common medicines that are expired or are no longer required or are discarded; other medicines discarded that could cause cancers or genetic diseases; the discarded vaccine products.

Medical waste can be a reason for human disease and may reasonably be suspected of hosting human pathogenic organisms, or may cause a significant threat or can be hazardous to human health or the environment when inappropriately treated, stored, transported, disposed of or otherwise managed. In the event that medical wastes are not carefully treated or managed by the way of the obligation of rules and legitimate methods, there are probabilities of spreading Covid-19 through the society, which may exceed the edge and average of infections and raise death rates (Ayad S Alrawi, Sahar A. Amin, Rana R. Al-Ani, 2021) .

Consequently, safe handling and managing methods are necessary whenever medical wastes are produced. Therefore, safe management of medical care waste is a critical part of environmental health safety, for sure that the more the pandemic expands, the more waste produced will increase. Thus, the challenge of treating and managing infectious medical wastes will keep on until the crisis ends. (World Health Organisation (WHO), 2020). It is for this reason that the chines government come up with strategies of managing the increased levels of medical waste produced during the pandemic. After the third weeks of January 2020, when the pandemic was moving towards its peak, the local authority realized that the medical waste was running out of the existing capacity to safely disposed of the rising amount of medical waste, they searched for the strategies from different levels of experts and decided to involve four companies specialized in solid waste management including Gient, which claimed to have built a 30 tons/day capacity emergency treatment plant by February 22 to treat around 25% of total medical wastes generated in the city during the COVID-19 pandemic (Wei, G.,, 2020) .

3.2.1 Segregation and Storage

China, similar to many countries with developing economies and those in transition, has shown effective and successful measures against the COVID-19-led medical waste management. Since 2003, after the Severe Acute Respiratory Syndrome (SARS) breakout in the region, more than 30 legislative orders and emergency management orders on environmentally sound management of medical waste have been implemented. According to the legislative Act 380, medical waste has been divided into five categories: sharp waste, infectious waste, tissues waste, chemical waste and medicine waste. The medical waste should be segregated for collection by using colored bags and containers (plastic, metal or paper) as stated in the current legislation (State Council of the PRC, 2004). 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, Z., Gang, X., Guanxing, W., Tao, Z., Dawei,, 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, 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 during the COVID-19 epidemic in China (Lie Yanga, Xiao Yub, Xiaolong Wuc, Jia Wangd, Xiao).

After segregation medical waste are normally delivered to temporary storage sites, which are located near/inside the hospitals. The medical waste generated in potentially contaminated areas are sprayed and disinfected on the surface of the packaging bag or covered with a layer of medical waste packaging bag before leaving the contaminated area. Medical waste buckets from fever clinics, observation wards, isolation wards, and nucleic acid testing laboratories were put into this area to avoid mixing them with other waste from common wards. The temporary storage time for COVID-19 related medical waste in the hospital should not exceed 24hours (Su, M.;Wang, Q.; Li, R.).

3.2.2 Collection and Transportation

Medical waste transportation refers to the haulage and handling of waste from inside healthcare facilities to treatment sites, which can either exist on-site at a hospital or be a central off-site facility (Windfeld, E.S., Brooks, M.S.-L.,, 2015). According to the current regulations in China, the off-site transportation of HCWs to the final disposal site should be handled by authorized disposal companies through pre-established routes that are not crowded (State Council of the PRC, 2004). Before COVID-19 outbreak, there were 24 licensed transport vehicles available for medical waste transportation in Wuhan. This number rapidly increased to 82 through emergency dispatching. The improved transportation capacity was confirmed to be sufficient for the daily operation of medical waste management in Wuhan. Furthermore the vehicles for medical waste should be installed with closed loading box and maintained at 4℃ when transporting the medical waste storage from hospitals (Lie Yanga, Xiao Yub, Xiaolong Wuc, Jia Wangd, Xiao).

At hospital level, for more effective medical waste management, smart medical waste transfer vehicles are being used to automatically collect and transfer medical waste from hospitals, which could reduce the operator’s contact with medical waste, thereby reducing the related risks (People.cn,, 2020). A smart software system has been established to promote dynamic medical waste monitoring and transfer scheduling. A warning will be sent by the system to the waste management department that a transfer is required, thus reducing the risk (People.cn,, 2020)

Fig 5. Smart medical waste transfer vehicle (left) and the traditional medical waste car (right) (People.cn,, 2020)

According to a study by Kannan et al a new mixed-integer linear programming (MILP) model was introduced with the purpose of MSW management considering risks related to the population exposed to pollution, location-allocation, and green VRP. Multiple vehicles of different types are supposed to start their tour from separation centers and return in time after collecting MSWs from waste-generating nodes. In separation centers, collected MSWs will be separated and sorted before moving into recycling, compost, incineration, or landfill centers. In addition, the vehicles' fuel consumption with respect to the extra weight of MSWs are considered as a part of the total cost of the supply chain. This has an indirect impact on reducing the pollution generated by vehicles while collecting MSWs. The study formulated a novel multi-product, multi-period and bi-objective MILP model for MSW management with location-allocation, time window-based green VRP, population risks, vehicles scheduling and failure, split delivery, and load-dependent fuel consumption minimization (Kannan Govindan, Hassan Mina,, 2021).

The study developed a model that is a multi-product, multi-period and one including waste production nodes and potential collection centers; total cost and pollution risk are simultaneously minimized in this model. Waste production nodes include laboratories, hospitals, temporary hospitals, clinics, and health centers, which fall into two categories, namely nodes that produce COVID-19 wastes and are considered hazardous wastes and nodes that produce both infectious (hazardous) and non-infectious wastes. Vehicles move from collection centers to waste generation nodes and return to collection centers before the allowed time window following the collection of wastes. In Fig. 6, illustrates the overall structure of the network developed (Kannan Govindan, Hassan Mina,, 2021).

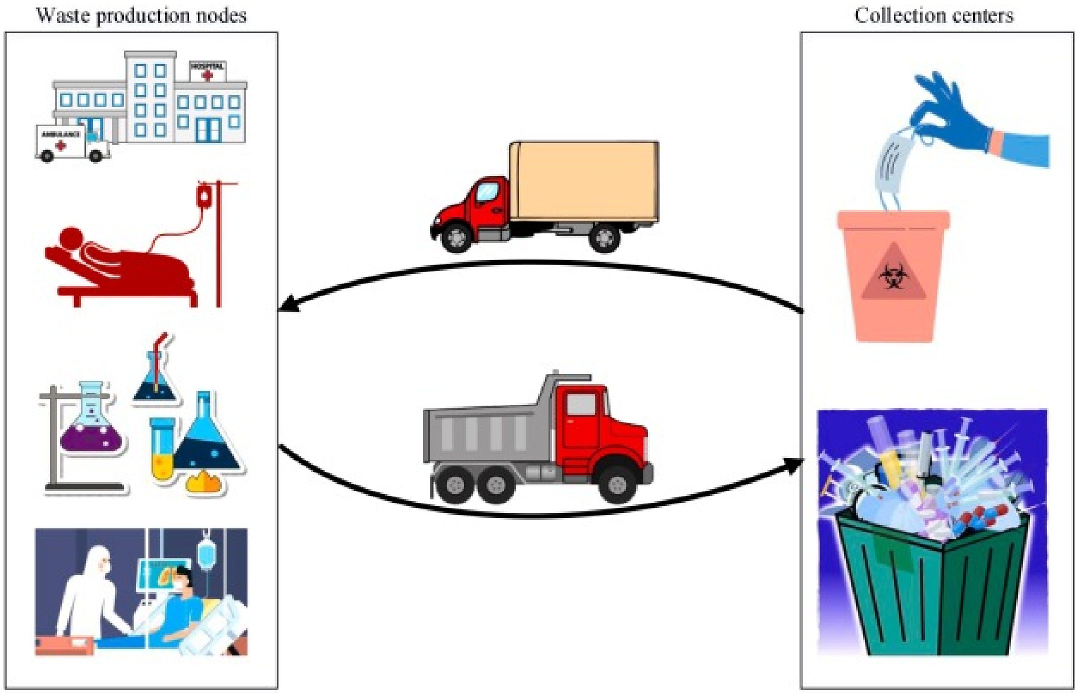

Fig 6. Structure of mixed-integer linear programming (MILP) model network.

3.2.3 Disposal

During the COVID-19 epidemic, the daily generation of China's medical waste has increased significantly, placing a severe test on China's medical waste disposal system. Faced with difficulties, the Chinese government has formulated a policy for medical waste management and a response plan for the epidemic, which provides policy guarantee for the standardized disposal of epidemic medical waste In addition, the government and medical institutions at all levels have formed a comprehensive, refined, and standardized medical treatment process system during research and practice. China has increased the capacity of medical waste disposal in various places by constructing new centralized disposal centers and adding mobile disposal facilities. Therefore, effective response measures across the country ensure the proper disposal of medical waste (Wang, Q.; Su, M., 2021) .

Similar to many other countries before the pandemic china had numerous medical waste disposal methods, that include incineration, autoclave, steam sterilization, chemical disinfection, microwave sanitation, dry heat disinfection, and disinfection with superheated steam temperature. However despite all the above mentioned technology the country was overwhelmed and over loaded with increase in medical waste generation during the pandemic. This situation led to the introduction of emergency technologies that could respond to the increased pressure on medical waste disposal by hospitals around the country. The Ministry of Ecology and Environment of the People's Republic of China issued "COVID-19 Infected Pneumonia Medical Waste Emergency Disposal Management and Technical Guide (Trial)," proposed and approved the use of hazardous waste incinerators, municipal solid waste incinerators, industrial furnaces, and other technologies such as movable disposal (e.g. movable incineration equipment, movable steam sterilization cabin, movable microwave sterilization equipment) and co-disposal (i.e. MSW grate incinerator, hazardous waste incinerator, and cement kiln) for pneumonia medical waste treatment to meet epidemic prevention needs (Ministry of Ecology and Environment, Management and Technical Guidelines for Emergency Disposal of Medical Waste Infected by the Novel Coronavirus Pneumonia (Trial) in Chinese, 2020).

According to a study conducted in Wuhan the unexpected pandemic made administrators aware of the shortcomings of medical waste management. Therefore, after the overall situation returned to normal, Wuhan improved its medical waste management system by increasing disposal capacity, the pandemic led to a significant increase in Wuhan's medical waste disposal and emergency response capabilities. After the pandemic the increase in the medical waste disposal capacity was 60 tonnes/day, but the emergency disposal capacity was 30 tonnes/day. Furthermore, Wuhan had 180 tonnes/day of back-up emergency disposal capacity (including 80 tonnes/day of hazardous waste incineration disposal capacity and 100 tonnes/day of municipal waste incineration disposal capacity) (Lie Yanga, Xiao Yub, Xiaolong Wuc, Jia Wangd, Xiao).

Hazardous medical waste incinerators

Incineration is an engineered process that employs thermal decomposition through thermal oxidation at high temperature (usually 900°C or greater) to destroy the organic fraction of the waste and reduce volume. Generally, combustible wastes or wastes with significant organic content are considered most appropriate for incineration. However, technically speaking, any waste with a hazardous organic fraction, no matter how small, is at least a functional candidate for incineration (Timothy Oppelt E , 1987). Different incineration technologies have been developed for treating the various types and physical forms of hazardous waste which includes hazardous medical waste. During covid-19 china adopted several types of these technologies which include the following;

Rotary Kiln Incineration

The Rotary Kiln incinerator is widely used in China for treating their medical hazardous waste. The equipment consists of a rotating oven and a post- combustion chamber. Rotary kiln does not only help in the mixing of wastes thoroughly but also exhibits efficient incineration. The kiln is loaded with the wastes on the top and rotates 2 to 5 times per minute. The incineration temperature could be as high as 1200-1600 ^{0}C, which could efficiently destroy the hazardous materials that are carried by COVID-19 waste (Ma, P., Ma, Z., Yan, J., Chi, Y., Ni, K., Cen, M., 2011). The new coronavirus is heat sensitive, and the virus can be effectively inactivated at a temperature of 56 °C for 30min (Ministry of Ecology and Environment, Management and Technical Guidelines for Emergency Disposal of Medical Waste Infected by the Novel Coronavirus Pneumonia (Trial) in Chinese, 2020) thorough incineration. At present, the most commonly used rotary kiln incinerator is the ash-type rotary kiln incinerator, followed by the slag-type rotary kiln incinerator. The development trend is of pyrolytic. The rotary kiln incinerator has the advantages of wide adaptability, reliable operation, and rotary kiln incinerators, which uses a combination of pyrolysis and rotary kiln technology. At present, the general process of hazardous waste incineration system mainly includes the feeding system, combustion system, and air pollution control devices (Yufeng Ma · Xiaoqing Lin · Angjian Wu · Qunxing & Huang · Xiaodong Li · Jianhua Yan, 2020) as shown in Fig. 6.

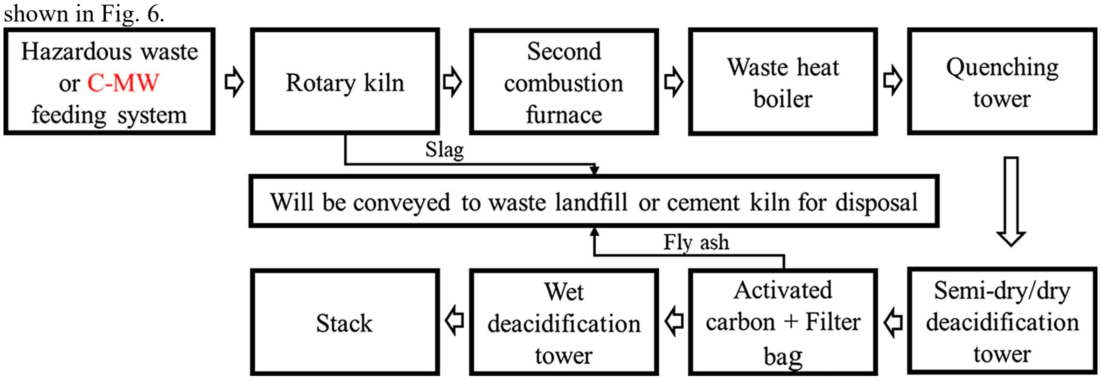

Fig.7 Systemic diagram of the hazardous waste incinerator (Yufeng Ma · Xiaoqing Lin · Angjian Wu · Qunxing & Huang · Xiaodong Li · Jianhua Yan, 2020).

The kiln incinerator produces gases as it evolves, these gases are forced to pass through the combustion chamber, where the organic compounds are burned and the ash remains are collected at the bottom. The exhaust gases and ashes that are produced upon incineration of medical waste, which may still carry some toxic substances and has to be treated again. Generally, the equipment and operation costs are high due to its excess energy consumption, and the by-products so formed are highly corrosive, which causes the kiln to get often repaired or replaced (Dorn, T., Flamme, S., Nelles, M., 2012). In order to break through the technical bottleneck that has seriously affected continuous and stable operation due to the slagging of the rotary kiln, achieving efficient control and reduction of pollutants emission especially dioxins. Zhejiang University has innovatively developed new rotary multi-stage pyrolysis self-melting incineration technology (Ma P, Ma Z, Yan J,). This technology has been applied to 49 hazardous waste pyrolysis incineration treatment projects in 38 cities in 21 provinces of China, with an annual disposal of more than 800,000 tons of hazardous waste (Chen T, Zhan M, Yan M, et al).

Municipal solid waste incineration

Municipal solid waste incineration technology uses the Grate furnace incineration as the mainstream method, it has the advantages of mature technology, stable and reliable operation, wide adaptability, and adaptability to most solid waste and medical waste, which can be directly fed into the furnace without any pretreatment. The Grant furnace has a temperature of above 850 °C, and the residence time of MSW in the furnace is generally 1 to 1.5 h for complete inactivation of the novel coronavirus making is feasible to dispose medical waste using municipal solid waste incineration (Zhao, H., Liu, F., Liu, H., Wang, L., Zhang, R., H). The over-all process of municipal solid waste incineration systems mainly includes the feeding system, combustion system, and air pollution control devices. The temperature of the grate furnace is controlled above 850 °C, and the residence time of the waste is 60–90 min, which ensures that combustibles and toxic substances are completely decomposed at a high temperature; the loss on ignition is < 5%. Figure 7 show a detailed process of municipal solid waste incarnation (Yufeng Ma · Xiaoqing Lin · Angjian Wu · Qunxing & Huang · Xiaodong Li · Jianhua Yan, 2020).

China has successfully applied the use of municipal solid waste incineration as an emergency medical waste disposal technique as their working process are similar. However, the content of hydrogen chloride and dioxins in the flue gas increase due to high plastic content in medical waste

Hence, Shanghai stipulated that medical waste (except chemical waste) must be less than 5 wt% (total mass of the mixed waste) when co-incinerated with municipal solid waste. (Ministry of Ecology and Environment, National Annual Report on Prevention and Control of Environmental Pollution by SolidWaste in Large and Medium Sized Cities in China, 2020).

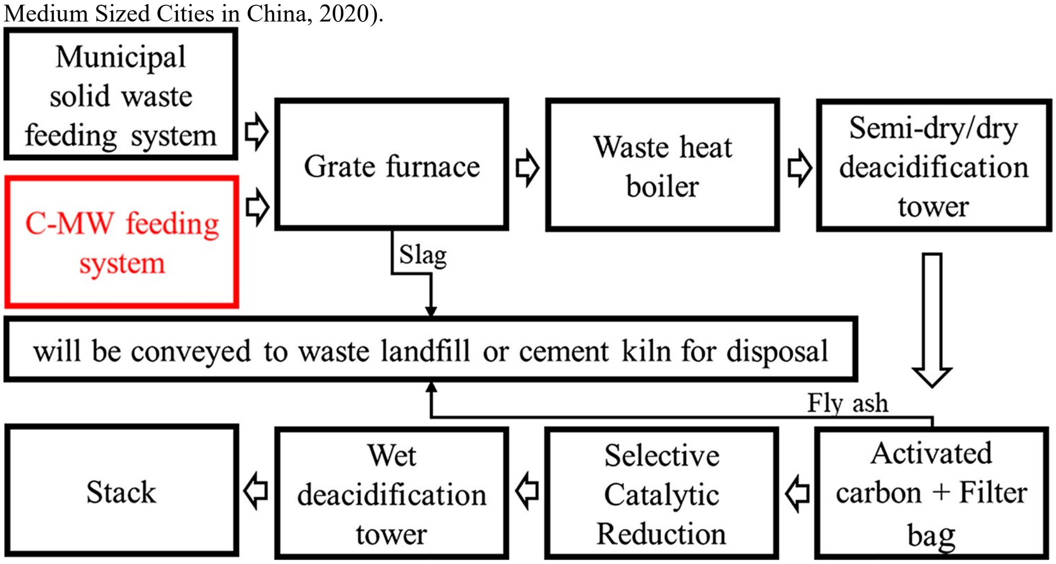

Fig 8.Systemic diagram of the municipal solid waste incinerator (Yufeng Ma · Xiaoqing Lin · Angjian Wu · Qunxing & Huang · Xiaodong Li · Jianhua Yan, 2020).

Cement kiln co-incineration technology

The cement industry is one of Chinas largest and leading industry in building material with unique characteristics such as processing on over 1500 ^{0}C high temperature and a strong alkaline atmosphere that can instantly kill viruses and germs. This unique property allows it to kill the coronavirus when the technology is used for waste disposal. Cement kiln co-incineration technology is a process where solid waste met requirements are put into the cement kiln for disposal, and cement clinker is produced simultaneously (Jin, H., 2020). On the 16th of March, 2020, the Chinese government issued a standardized guide co-disposal of medical waste in cement kilns as an emergency disposal of covi-19 medical wastes (Federation, China Building Materials, 2020). Co- disposal of medical waste in cement kiln is a practice that has been proven to be safe, free from secondary pollution and eliminates any risk of infection from covid-19 waste.

Movable pyrolysis equipment

This method of disposal utilizes a movable pyrolysis disposal vehicle that is assembled with disposal equipment's. Pyrolysis disposal vehicle is mainly composed of chassis, carriage, pyrolysis furnace system, shaft power generation system and other ancillary equipment. The chassis of EQ2102 off-road vehicle was nominated as the loading platform, and the overall structural arrangement and appearance of the vehicle is shown in figure 8 (Han, J., Ren, X., Meng, L., Su, C., , 2018). From top to bottom, the pyrolysis furnace is composed of a pyrolysis chamber, combustion chamber and melting chamber. The medical waste is sent into the pyrolysis chamber by the feeding mechanism on top of pyrolysis furnace. The organic components in medical waste are initially pyrolyzed in the pyrolysis chamber to produce combustible gas such as carbon monoxide, hydrogen, methane and other alkanes, which are sent to the combustion chamber for combustion to provide the heat for pyrolysis and coil pipe heating (Wang, Z., Han, J., Wu, L., Liu, Y.,, 2015). Thermal calculations on the energy requirements and supply of pyrolysis equipment show that the 9×10^5 kcal heat energy produced by Medical waste per tonne is sufficient for self-use. The vehicle uses about 20 L diesel (or other high calorific value fuel) is needed for the first ignition, and then the gas produced by the pyrolysis can supply heat to the system for continuous pyrolysis, which can effectively save energy and reduce operating costs (Han, J., Ren, X., Meng, L., Su, C., , 2018).

The residue is melted in the melting chamber and discharged outside the furnace for landfill. The flue gas from the combustion chamber passes through the lye spray water tank (de-acidification and dust removal), the flue gas coil pipe and the quench water tank and finally discharged into the atmosphere (Han et al., 2018). The flue gas stay in the coil pipe for more than 2s, and the temperature is controlled above 850 °C for the dioxins decomposition, and then enter the quench water tank for quenching to 250 °C to avoid the de novo reaction of dioxins. In the pyrolysis disposal vehicle, medical waste is heated and distilled under high temperature of about 800–1000 °C, in anaerobic or anoxic conditions (Han, J., Ren, X., Meng, L., Su, C., , 2018).

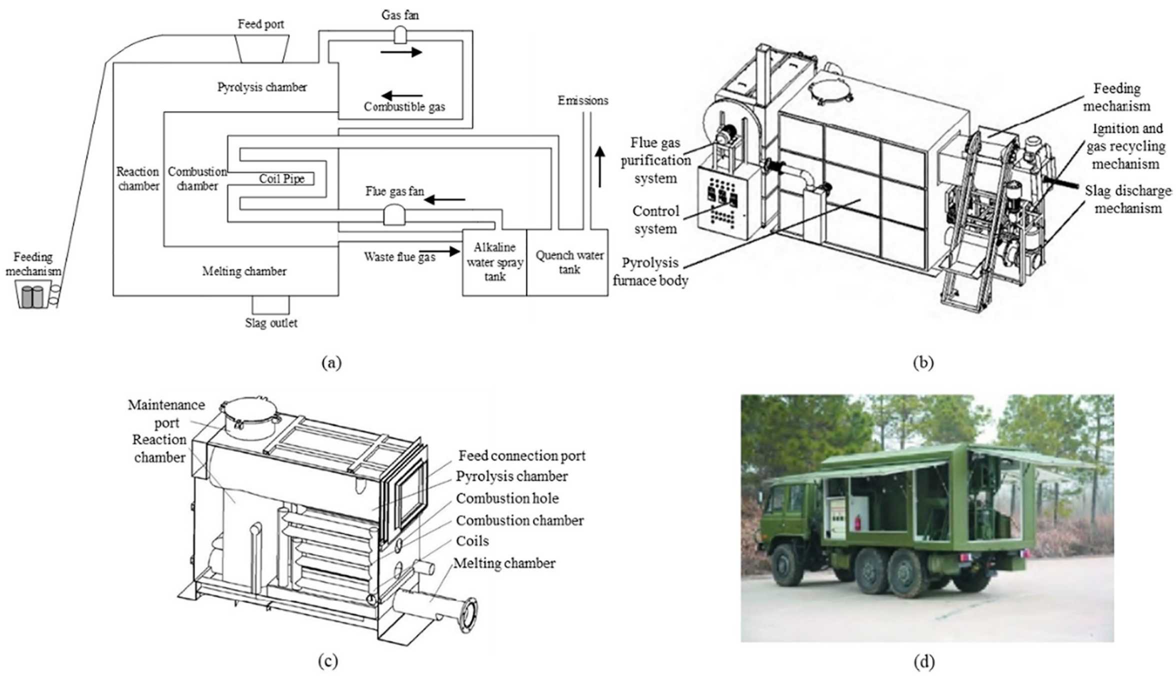

Fig. 9. Pyrolysis disposal vehicle. (a) pyrolysis technique process; (b) the composition of the pyrolysis system; (c) pyrolysis furnace structure; (d) appearance (Han, J., Ren, X., Meng, L., Su, C., , 2018) (Wang, Z., Han, J., Wu, L., Liu, Y.,, 2015).

Movable Steam Sterilization

It is a disposal method that utilizes a wet heat process of steam sterilization, which is suitable for the treatment of infectious and sharps medical waste but not for pharmaceutical and chemical waste. Microorganisms on the transmission medium are killed by saturated water vapor with temperature higher than 100 °C (Wang, J., Shen, J., Ye, D., Yan, X., Zhang, Y.,, 2020). The equipment is equipped with the safety valve, pressure controller for overpressure protection, to prevent the boiler from explosion accidents due to excessive pressure. When the water supply stops, the boiler can stop working automatically to prevent the electric heating elements from being damaged or even burnt out. The movable steam sterilization cabin is designed by Aerospace Shenhe (Beijing) Environmental Protection Co., Ltd., and the Medical waste treatment capacity of each equipment is 2.8 TPD. The equipment is mainly composed of several systems, i.e. feeding, steam generation and disinfection, crushing, waste gas and wastewater treatment (Aerospace Shenhe(Beijing) Environmental Protection, 2020).during this process medical waste is disinfected by saturated steam at above 134 °C for 45 min and broken, packed for landfill or incineration. The equipment is equipped with flue gas and water vapor purification system to ensure that the emissions meet the acceptable standards. Installation and operation of the equipment only need the necessary water and high voltage electricity (or diesel), and the voltage needs 380 V (three-phase power supply) (Aerospace Shenhe(Beijing) Environmental Protection, 2020). The latent heat released by the water vapor leads to protein denaturation and coagulation of microorganisms and the death of microorganisms (Wang, J., Shen, J., Ye, D., Yan, X., Zhang, Y.,, 2020).

Movable Microwave Sterilization

The movable microwave sterilization disposal equipment is able to dispose of infectious, damaging, pathological medical waste except for human limbs and organs. The microwave disinfection technology is characterized with short time, rapid action, energy saving, strong penetration, slow heat loss and low environmental pollution with no dioxins and malodorous gas, and wastewater (Ohtsu, Y., Onoda, K., Kawashita, H., Urasaki, H.,, 2011). The equipment adopts an automatic disposal system of hydraulic lifting, material crushing, microwave disinfection, and spiral discharge. Medical waste treatment capacity is 3–10 TPD, and the sterilization rate is above 99.99%. The automatic feeding device lifts the MW to the feeding bin and enters the crushing system, where Medical waste is crushed (Henan Liying Environmental Protection Technology , 2020). During this process of high certain intensity, the bacteria heat up due to the absorption of microwave energy, the protein is deformed and loses biological activity Microwave sterilization is the result of the combined effect of microwave heating and biological effects, which can make microwave energy directly interact with microorganisms and kill them quickly (Wang, J., Shen, J., Ye, D., Yan, X., Zhang, Y.,, 2020).

Conclusion and future research directions

The experience and effective measures in Hubei and other parts of China gained from COVID-19 led medical waste management systems may possibly be a piece of valuable information for most of the developing countries coping with a unexpected increase in the medical waste during the pandemic. This study reviews the successful measures put in place by china due to the fact that among other countries, China was one of the first country to successfully employ effective medical waste disposal measures which directly or indirectly helped in the reduction of covid-19 cases. Apart from the already existing medical waste disposal systems in the facilities which were overwhelmed at the time, China employed emergence disposal system in response to the rampant increase of medical waste generation during the pandemic. The emergency systems employed include hazardous medical waste incineration (Rotary Kiln incinerator, Cement kiln co-incineration technology, and municipal solid waste incineration), movable pyrolysis equipment, movable steam sterilization and movable microwave equipment. These technologies involve the process of high heat disinfection which is able to effectively kill the covid-19 virus. Furthermore a smart transfer vehicle was developed by china in order to reduce contact of medical waste by the waste handlers.

For future recommendations and research perspectives, technical strategies and principles for emergency disposal in facilities with different disposal capacities based on the technical applicability and cost-effectiveness should be further studied and discussed. Furthermore, cities with insufficient MW disposal capacity can establish an interregional emergency response coordination mechanism with neighboring cities with excess MW disposal capacity in china. This research perspective is not limited to china but can be adopted by other countries. In addition they is need to further improve the technology of co-incineration of MW and MSW in order to reduce the negative impact of long-term disposal of MW on the operating costs and equipment life of MSW incineration facilities (Hailong Zhao, Hanqiao Liua, GuoxiaWei , Ning Zhang, 2021).

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