

HATICE ESER ÖKTEN¹, ADNAN CORUM², HACER HANDAN DEMİR³

A COMPARATIVE ECONOMIC ANALYSIS FOR MEDICAL WASTE TREATMENT OPTIONS

Management practices for medical waste should be conducted using the best available techniques in order to minimize harmful effects of medical waste. Most common practices in Turkey were reported to be burying with lime and incineration. Although incineration stood out as a better option in terms of environmental and public health, it produced air pollutants such as dioxin, furan and co-planar PCBs as a result of incomplete burning of plastics. Consequently three options, namely converter, autoclave, and ozonator technologies were investigated for economic feasibility in the medical waste treatment field. ozonator technology was concluded to be the economically best option.

1. INTRODUCTION

Medical waste management has been a growing concern in developing countries within the framework of waste management, specifically for densely populated cities. World Health Organization (WHO) had a broad definition of health care waste including not only all wastes produced at hospitals, clinics, research facilities, laboratories, but also wastes produced from care-at-home practices (serum, insulin injections, dialysis, bedding, etc.) [1]. WHO reported that 75–90% of these wastes could be deemed as domestic waste and the remaining 25–10% of waste was actually hazardous. WHO categorized hazardous waste as infectious waste (containing pathogens), pathological waste (human tissues and fluids), sharps (needles, scalpels, broken glass, etc.), pharmaceutical waste (containing pharmaceuticals), genotoxic waste (genotoxic chemicals, cytostatic drugs, etc.), chemical waste (containing chemical substances), waste with high content of heavy metals (batteries, broken thermometers, etc.), pressurized containers (gas cylinders, gas cartridges, etc.), and radioactive waste [1].

¹Department of Environmental Engineering, Bahcesehir University, Istanbul, Turkey, corresponding author H.E. Ökten, e-mail: eser.okten@bahcesehir.edu.tr

²Department of Industrial Engineering, Bahcesehir University, Istanbul, Turkey.

³Vocational School, Bahcesehir University, Istanbul, Turkey.

As a preliminary approach WHO stated that it might be a good approximation to take 15% of the total health care waste as infectious and pathological waste. Daily production of health care waste for North America, Western Europe and Eastern Mediterranean was in the range of 7–10 kg/bed, 3–6 kg/bed and 1.4–2 kg/bed, respectively [1]. A study by Alagöz and Kocasoy [2] reported daily medical waste production of 1.85 kg/bed and 2.17 kg/bed for European side and Asian side of Istanbul, respectively. Another medical waste management study conducted in Turkey for the city of Bursa, which had a population of 2.6 million, found daily production of health care waste to be 1.1 kg/bed [3].

WHO emphasized the importance of safe treatment and disposal of medical wastes by publishing a fact sheet in October 2011 [4]. According to that fact sheet use of contaminated syringes caused 21 million hepatitis B virus infections in the year 2000 alone. A study by Franka et al. [5] compared a group of 300 medical waste handlers to a control group in order to test for the significance of Hepatitis B virus (HBV), Hepatitis C virus (HCV) and human immunodeficiency virus (HIV) infections. Although HIV infection was not observed in both groups, the study demonstrated that HBV and HCV infections were significantly higher for medical waste handlers. Braka et al. [6] investigated HBV infections among health care workers in Uganda and found that a relatively high percentage (60.1%) was infected either at the time of the study or previously. Since treatment of HBV infection cases in Uganda was often impossible due to economic and accessibility reasons, emphasis on preventive measures should be asserted. Therefore medical waste posed serious public and occupational health hazards if it was not managed with a systematic approach.

Sterilization of medical waste has recently become a requirement in Turkey, mandated by the changes in environmental legislation in the context of European Union alignment process. The Ministry of Environment and Urbanization announced that in the year 2010 medical waste disposal in Turkey was practiced by burying half of the medical waste using lime without further processing [7]. The remaining part of the medical waste was either sent to landfills following sterilization by autoclaving or was disposed of by incineration. Incineration of medical waste also posed great risks in terms of generating dioxin, furan and co-planar polychlorinated biphenyls (PCBs) when incomplete incineration was the case. Burying medical waste with lime caused serious environmental and human health risks, and conventional sterilization techniques were defined as high maintenance and costly. A study by Chen et al. [8] demonstrated that medical waste incineration produced significant amounts of polyaromatic hydrocarbons (PAHs), especially the more carcinogenic ones with five or more rings in the molecule, due to polyethylene, polyester teraphthalate, polyvinylchloride and polypropylene content of the waste. PAH levels were affected by both plastic content in waste incinerator feed and combustion efficiency. In another study, researchers reported that total suspended particulate matter and dioxin emissions from incinerators located at Antioquia, Colombia significantly exceeded limit values [9]. A study by Liu et al. [10] compared

incineration, landfilling, microwaving and steam sterilization as medical waste treatment options in terms of economic (net cost/ton), technical (reliability and treatment efficiency), environmental (waste residuals and probable health effects) and social (public acceptance) criteria using a fuzzy multi-criteria decision making model. Steam sterilization was concluded to be the best choice followed by microwaving, incineration and landfilling.

Another fuzzy multi-criteria decision making study conducted in Turkey which adopted two different approaches (one considering fuzzy measure and fuzzy integral and the other considering hierarchical distance) concluded that steam sterilization was the preferred treatment option for the medical wastes of Istanbul [11]. Incineration was the least preferred treatment option in the study which evaluated capital and operating costs along with environmental and public health effects. A study by Soares et al. [12] compared microwave, autoclave and lime treatments in terms of their environmental performance by comparing costs and eco-efficiencies. Although all treatment options met the criteria of 100% treatment efficiency under specific conditions, microwave treatment had the least adverse effect on environment. Furthermore monthly treatment cost for microwave was found to be the lowest (\$3.29), followed by autoclave (\$29.44) and lime treatment (\$40.90). Besides the mostly used treatment processes such as steam sterilization (autoclaving) and incineration, new processes were being developed for medical waste disposal. In this study, two novel technologies, namely converter and ozonator ones, were evaluated and compared to a conventional technology (autoclave).

2. MATERIALS AND METHOD

Three medical waste treatment technologies, namely converter (OMPeco), ozonator (Ozonator Industries Ltd.) and autoclave (Tuttnauer) were evaluated considering capital and operating costs. Information regarding the process details and capital costs were retrieved from the manufacturers. Cost evaluation was conducted utilizing the present worth method. Process schemes for the technologies are summarized in Fig. 1.

Converter technology. Several different processes such as pasteurization, sterilization, grinding and pulverization, trash compaction and dehydration were conducted in the same unit. Time span for one treatment cycle was 30 min. Following the loading of medical waste to the converter chamber, shredding was conducted under ca. 5.72 MPa chamber pressure and waste temperature of 50 °C. Next step was evaporation at 80 °C under 5.61 MPa. Overheating followed the process, at 105 °C and 5.34 MPa. Then waste temperature was increased to 155 °C while the chamber pressure decreased to 3.48 MPa for the sterilization stage. Finally cooling was conducted under the chamber pressure of 6.93 MPa in order to reduce waste temperature below 100 °C. Significant reductions of weight (40%) and volume (70%) were achieved.

A converter could be operated under the atmospheric pressure. Nevertheless superheating conditions and steam generation were achieved by variable pressure control, which was a result of cycling between ambient and negative pressures within the treatment chamber. Instead of using an external water input, converters used the moisture present in the treatment chamber to obtain steam sterilization. Moreover, the manufacturer claimed that water was recycled within the system significantly reducing wastewater production. Sterilization level was reported to be approximately higher than 6 log.

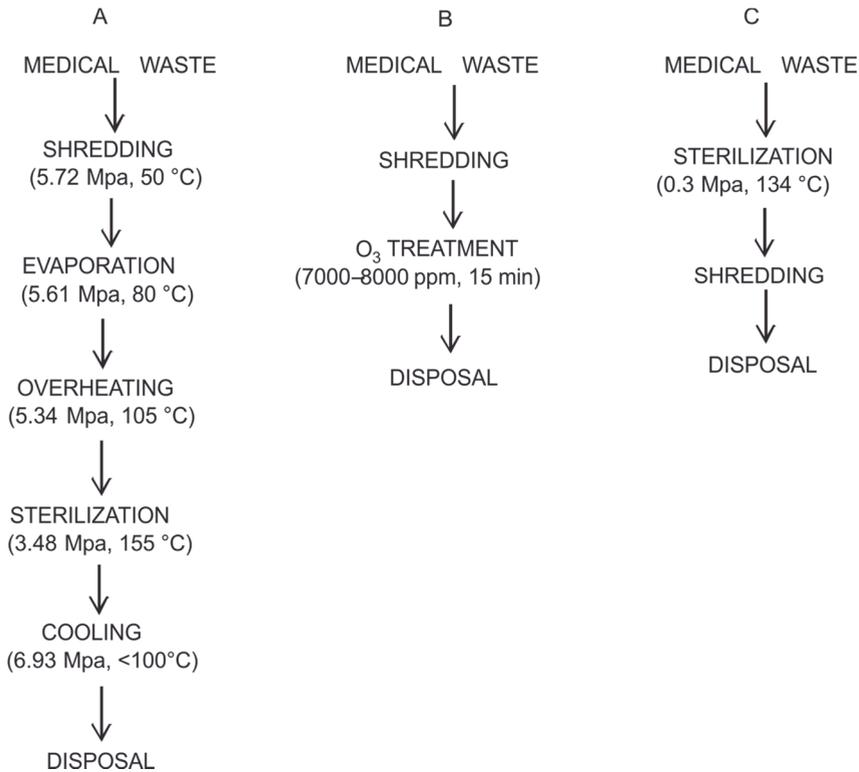


Fig. 1. Process flow charts for converter (A), ozonator (B), and autoclave (C) processes

Autoclave sterilization. Infectious and sharp wastes were sterilized with compressed water vapor. Process continued for 30–90 min at 130–190 °C and under 100–500 kPa. Medical wastes might be shredded before or after sterilization in a pressured vessel. Sterilization level was reported to be above 6 log, while volume reduction was 75%.

Ozonator technology. An integrated system of a loader, shredder, ozone reactor, treatment chamber, and disposal tank employing ozone were used to treat medical waste. Ozone was known for its high oxidative characteristics, which was in concordance with the aim of medical waste treatment. Also any redundancy in the amount of

ozone production did not pose an environmental problem since ozone was converted back to oxygen in 30 min under atmospheric conditions. Manufacturers reported on the volume reduction up to 90% with the ozonator process due to effective shredding.

Operation cycle for ozonator has begun by dumping the load of waste into the receiving hopper. Once the proper level of ozone was achieved in the treatment chamber, waste shredding was started. ozonator model NG-1000 treated waste using ozone concentrations of 7000 and 8000 ppm. This process continued for 900 seconds and then waste was transferred to the disposal container. Ozone concentrations and contact time used in the system were sufficient when the time and dosage values for the destruction of various organisms given in Table 1 were considered. Average destruction of spores was reported to be 6 log.

Table 1

Dosage and reaction times for destruction
of microorganisms through ozone treatment

Microorganism	Ozone dosage [ppm]	Reaction time [s]
<i>Escherichia coli</i>	0.2	30
<i>Streptococcus</i>	0.2	30
Enterovirus	0.1–0.8	30
Enteric cytopathic human orphan virus (ECHO)	1	60

3. A CASE STUDY

The investment and operating costs of three different waste treatment technologies were evaluated for 10 000 kg of waste per day. In all three systems, initial system investment was a fixed cost defined as the first cost paid to purchase the system. Operating costs were variable costs of electrical energy, as well as of water and natural gas consumption.

Table 2

Costs for converter, ozonator and autoclave technologies

Subject	Converter 5000H	Ozonator NG1000	Autoclave 3648144
Initial cost/system, \$	1 200 000	1 350 000	650 000
Energy consumption/hour, kWh	300	37	35
Water consumption per hour, dm ³	300	8	2040
Natural gas per hour, N·m ³	–	–	35
Treatment capacity per hour, kg	500	800	385

Water consumption of the autoclave, due to steam sterilization, was significantly larger than in the other technologies. At the end of the sterilization, exhaust air was drawn from the chamber and it was sterilized using high temperature steam. If steam sterilization of exhaust air was not preferred, a biological filter option was also possible, which could remove any airborne pathogens. In the converter technology, water was fed to the chamber during sterilization and cooling stages, which lasted 4 min in total. In the converter technology, water was evaporated in those stages, and then water vapor was entrapped in the sterilized output. Remaining water was recirculated in the close loop system in order to reduce water consumption and to eliminate wastewater flow from the system. Water consumption for the ozonator technology was minimal, and wastewater was not produced at the end of treatment.

Hourly treatment capacity of the ozonator technology was higher than in the converter and autoclave technologies (Table 2). It would take 20 h with the converter 5000H, 12.5 h with the ozonator NG1000 and approximately 26 h with the autoclave 3648144 to treat 10 000 kg of medical waste. In order to converge treatment times for all technologies, two parallel processing units were needed for the converter and autoclave technologies. Therefore it would take 10 h with a converter, and approximately 13 h with an autoclave to treat 10 000 kg of waste. The cost for 1 kWh, 1000 dm³ of water and 1 Nm³ of natural gas were accepted as \$0.10, \$0.30, and \$0.40, respectively. The total operating cost to treat 10 000 kg of waste by three different technologies assuming 20 working days per month are given in Table 3.

Table 3

Operating costs for the converter, ozonator and autoclave technologies [\$]

Subject	Converter 5000H	Ozonator NG1000	Autoclave 3648144
Total daily energy consumption	600	46.25	91
Total daily water consumption	1.8	0.03	15.91
Total daily natural gas consumption	–	–	364
Daily total	601.8	46.28	470.91
Monthly total	12 036	925.6	9418.24

In order to compare three systems, the present worth (*PW*) method was used. It was quite popular because all future cost and revenue estimates were transformed to equivalent dollars to the present day. All future cash flows were converted to present amounts at a specific rate of return so that the opportunity cost of any investment was considered. Therefore it was possible to compare systems and determine the economic advantage of one alternative over another [13].

In our case, the *PW* comparison of mutually exclusive technologies with equal service lives was conducted. The technology that had the smallest *PW* value of its cost was

selected. Annual effective interest rate (i) was accepted as 0.75% per month. Technologies were compared for 20 years of service time (n). It was assumed that technologies would not have any salvage value after 20 years.

$$PW = \text{Investment cost} + (\text{Monthly operational costs}(P/A, 0.75\%, 240)) \quad (1)$$

$$(P/A, 0.75\%, 240) = \frac{(1+i)^n - 1}{i(1+i)^n}, \quad i = 0.0075, \quad n = 240 \quad (2)$$

Thus particular PW s, \$, are

$$(P/A, 0.75\%, 240) = 111.145$$

$$PW_{\text{converter}} = 2 \times 1\,200\,000 + 12\,036 \times 111.145 = 3\,737\,741$$

$$PW_{\text{ozonator}} = 1\,350\,000 \times 1 + 925.6 \times 1 = 1\,452\,876$$

$$PW_{\text{autoclave}} = 650\,000 \times 2 + 9418.24 \times 111.145 = 2\,346\,790$$

Ozonator technology was selected since the PW of its costs was the lowest. It was economically the most advantageous option among others. Even though ozonator technology was investigated for municipality-scale operations in this study, it was also possible for medical waste producers to implement the system on-site. Therefore costs such as temporary storage room construction and operation could be avoided along with waste treatment fees that were charged by municipalities. Output product of the system could be considered as domestic waste and could be transferred safely to the landfill area.

A study was conducted on waste characterization at several general hospitals in Southern Italy and it revealed that wet waste's high heating value (HHV) and low heating value (LHV) were 3900 kcal/kg and 3500 kcal/kg, respectively [14]. A study conducted to test the performance of a pilot scale incinerator in Thailand reported the LHV of approximately 6000 kcal/kg for medical waste [15]. Furthermore, Diaz et al. [16] reported that medical wastes from maternity ward and emergency room in Sao Paulo, Brazil, had LHV values of 1589 kcal/kg (HHV = 4990 kcal/kg) and 3463 kcal/kg (HHV = 4303 kcal/kg), respectively. Despite production of air pollutants, incineration of medical waste was much preferred practice since it provided significant volume reduction and reliable sterilization. However heating values in the range of probable energy yielding might not always correspond to actual energy generation. In order to keep the medical waste's heat content high, waste segregation, which would have inherent risks of exposure to pathogens, might be required. On the other hand the product of converter

technology was found to have high heat content. Converter technology, which was implemented in mid-Anatolian region of Turkey, produced an output that had the heating value of 6000 kcal/kg. It was comparable to heating value (7000 kcal/kg) of imported coal in Turkey.

4. CONCLUSIONS

Three technology options were investigated in terms of economic feasibility in order to be proposed as a solution to medical waste treatment problem. Technical data and data referring to costs were obtained from the manufacturers and present worth (*PW*) method was utilized. The *PW* method was widely used due to its characteristic of transforming future costs and revenue estimates into present day equivalent dollars. Annual effective interest rate (*i*) was accepted as 0.75% per month. Technology options were compared for 20 years of service life period. It was assumed that systems would not have any salvage value after 20 years.

The *PW* analysis considering cost of each investment demonstrated that the ozonator technology was economically the most advantageous, while the converter technology was found to be the most costly option. Furthermore it should be noted that the product of converter technology had the calorific value that was significantly high. If there had been a waste code for the final product of converter technology, it could have an economic value as a fuel, changing the results of evaluation in converter technology's favor. Therefore the medical waste legislation in Turkey should be updated and re-evaluated regularly. Consequently, research and development on the solid waste treatment was an ongoing process. Thus development and practice of the best available technique for medical waste sterilization should regularly be conducted.

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