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ON ALL TOPICS OF INDUSTRIAL AND MUNICIPAL ECOLOGY

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Z OBLASTI PRŮMYSLOVÉ A KOMUNÁLNÍ EKOLOGIE

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Vážení čtenáři,

patronem tohoto čísla je konference Odpady za a pro stavebnictví. Bude se letos konat spolu se symposiem Výsledky výzkumu a vývoje pro průmyslovou a komunální ekologii ODPADOVÉ FORUM v rámci Týdne výzkumu a inovací pro praxi a životní prostředí TVIP 2023 (17. – 19. 10. 2023, Hustopeče).

V rámci zmíněného symposia jsme se od letošního, jeho již 17. ročníku rozhodli inovovat a pro jednu konkrétní skupinu odpadů vyhradit ne vlastní sekci v rámci symposia, nýbrž samostatnou konferenci. To proto, že v jejím rámci nechceme jen prezentovat nejnovější výsledky výzkumu v daném oboru, ale i přehledové přednášky, co vše už dříve bylo vymyšleno a jak se to využívá v praxi, případně, v čem spočívají případné bariéry. Proto zde nebudeme spoléhat jen na příspěvky, které „samy“ přijdou, nýbrž chceme program připravovat společně s programovým výborem, do kterého chceme zapojit zástupce zainteresovaných pracovišť.

Pod termínem „skupina odpadů“ zde nemíníme skupinu či podskupinu z Katalogu odpadů, ale nějakou logickou množinu odpadů, které spojují buď podobné vlastnosti, oblasti využití či původci z konkrétní významné průmyslové oblasti. Pro letošní ročník jsme se rozhodli pro Odpady ze a pro stavebnictví.

Odpady ze stavebnictví, to jsou především stavební a demoliční odpady. Těm si myslím, že je věnována dostatečná pozornost, mají už léta svou vlastní konferenci Recycling, kterou pořádá Asociace pro rozvoj recyklace stavebních materiálů. Tyto odpady nemůžeme úplně vynechat, ale hlavní pozornost chceme zaměřit na Odpady pro stavebnictví. Těmi myslíme nejrůznější druhy odpadů a vedlejších produktů různého původu, které slouží (nebo mohly sloužit) k výrobě stavebních hmot a materiálů.

Z příspěvků, které zazní na této konferenci a které doporučí programový výbor, bude sestaveno tematické číslo WASTE FORUM 2024, 1.

S některými pracovišti, která se tímto výzkumem zabývají, jsme již spolupráci navázali, s jinými na tom intenzivně pracujeme. Pokusil jsem se v této věci oslovit všechny, které by toto téma mohlo zajímat. Ale jistě jsem mohl na někoho zapomenout, přehlédnout.

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Ondřej Procházka

Pro autory

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The deadline of the next issue is on April 8, 2023, more on July 8, 2023.

Pyrolysis of sewage sludge to obtain valuable products

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Abstract

This paper focuses to pyrolysis of different sourced sewage sludge in a scaled-up semi-batch reactor at temperatures of 300 and 500°C. It was found that both the temperature and raw material composition had a significant effect on the product yields and properties. The highest gas and synthesis gas yield was observed in pyrolysis of distillery sewage sludge at 500°C, while composition of chicken manure favored for the formation of bio-oil (9.8 and 17.1%). The gas product was characterized by H_2/CO ratios up to 0.6; therefore further quality improvement is needed prior to use for synthesis. The bio-oil (5.2 – 17.1%) contained significant amount of oxygenated compounds, but after hydrogenation it is suitable to substitute the conventional fuels. During the pyrolysis the elemental composition of char (22.8 – 71.4%) has also changed due to carbonization and removal of functional groups.

Keywords: *sewage sludge, pyrolysis, synthesis gas, bio-oil, bio-char production*

Introduction

The increasing in sewage sludge production necessitates the introduction of more feasible processes to reduce the socio-economic and environmental problems associated with its current treatment. In terms of dry matter, nearly 23 million tons of municipal sewage sludge is generated annually[1]. Sewage sludge contains proteins, carbohydrates, lipids or fats, organic and inorganic compounds and various harmful materials such as bacteria, viruses, dioxins and heavy metals[2]. Nonetheless, in Bosnia and Herzegovina, Croatia, Romania, Serbia and Turkey landfilling is the most widely used sewage sludge handling method. In Bulgaria, Czech Republic, Ireland or Norway, the agricultural utilization is the mostly used method for sewage sludge treating, meanwhile that of the composting in the Baltic countries, Slovakia, Luxembourg or Hungary[3]. The main disadvantage of the current methods is that they can significantly increase the emission of nitrogen, phosphorous, heavy metals and various pathogens into the environment[4].

To reduce the harmful effects of sewage sludge, pyrolysis has been proposed due to the better economic performance, greater volume reduction and higher efficiency of converting carbon rich products into energy and/or fuel[5,6]. Pyrolysis is a degradation process carried out in an oxygen-free environment in a temperature range of 300 – 600°C. During the process, the organic constituents are transformed into bio-oil, gas product and carbonaceous residue, so-called char. Pyrolysis, like other thermochemical processes is affected by many factors, including raw material, temperature, reaction time, residence time, heating rate and catalyst[7]. Raw material has a great influence on both the quantity of products and their composition. In general, raw materials with high cellulose content result significant amount of water and other oxygen-containing components. Nitrogen, sulphur and other non-metallic elements can appear both in the gas, liquid and solid fractions, meanwhile the metals accumulate in the liquid and solid products[8,9]. Other substances mixed with sewage sludge (e.g. biomass, plastic) also affect the reactions taking place and the product properties. During co-pyrolysis of sewage sludge and biomass, dilution and synergistic effects can also be prevailed, resulting in lower decomposition temperature and higher gas yields[10,11]. Temperature is also a key factor for the product yields and compositions. Higher temperature promotes the formation of gas product and results in higher hydrogen content. In addition, higher temperatures can also contribute to the more significant coke formation[12,13]. The reaction time has also a significant effect on the products in terms of secondary reactions. High heating rates increase the amount of volatiles[14]. However, it is important to note that high heating rates are usually combined with short reaction times, thus the liquid yield is also higher[13]. Catalyst (e.g. alumina, silica or zeolites) can also be used to influence the yield structure and composition of the pyrolysis. However, their use should be complicated, because of the significant cost requirement or difficult recovery and regeneration[15].

Pyrolysis of sewage sludge can be carried out in fixed, fluidized or circulating fluidized bed reactors. Nonetheless, the degradation processes were most often investigated in thermogravimetric devices (e.g. TG-FTIR)[16-18], which should be problematic for reproducibility and representativeness. To investigate realistic cases, there are some articles about pyrolysis carried out in larger scales (10 – 50 g). Alvarez et al. carried out pyrolysis experiments using 50 g of sewage sludge, at 450 – 600°C[19]. They focused exclusively on the production of bio-oil and did not provide information on the yield, composition and properties of gas and solid products. Sun et al.[20] pyrolyzed 35 g of raw materials as Xie et al.[21] also conducted scaled-up pyrolysis experiments. Although information was provided on the yield and composition of gas and solid products, a catalyst (coated alumina or ZSM-5) was also used to increase the amount of volatile products and modify the product structure in a favourable direction. Based on the referenced articles, it can be concluded that bio-oil has potential to substitute conventional engine fuels, and the purified and/or conditioned gas product can also be used as feedstock of Fischer-Tropsch or methanol synthesis. The solid pyrolysis product may be suitable for use as a catalyst or sorbent. Nonetheless, there is practically no information about experiment where at least 100 g of raw material would be pyrolysed – especially thermally – and the usage for all products would be examined.

Experimental part

Based on the aforementioned, this study investigates the pyrolysis of sewage sludge in a scaled-up semi-batch reactor system (Figure 1) in terms of the yield, composition and usability of pyrolysis products. During the experiments, 100 g of sewage sludge (municipal sewage sludge (MSS), distillery sewage sludge (DSS) and chicken manure (CHM) was placed into the reactor and pyrolysed at 300 and 500°C. The heating rate was constant (25°C/min) and the reactor was kept at the target temperature for 45 minutes. In order to maintain an inert atmosphere, constant nitrogen flow (1.5 dm^3/h) was established in each experiment. To control the temperatures PID controllers were used. The pyrolysis vapours were condensed in a heat exchanger at room temperature, the non-condensable gases were collected in a Tedlar bag. The amount of the liquid product and the residue was determined by weight measurement and the weight of the gas product was calculated by the difference. After the weight measurement, the liquid product was separated into an aqueous and oily phase (so-called bio-oil) by a funnel (sedimentation time: 2 hours). The amount of each phase was also determined by mass measurement.

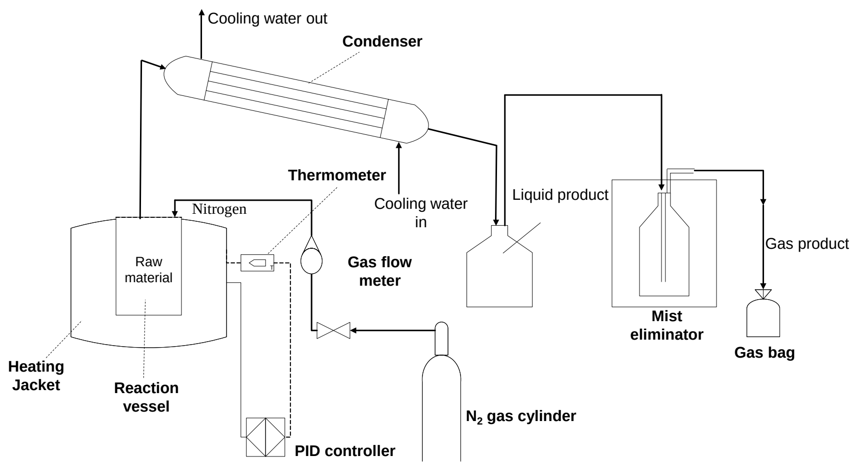

Figure 1: The scheme of the experimental apparatus

The most relevant properties of sludge samples were determined as the average of three parallel measurements and summarized in Table 1. The repeatability of the measurements has standard deviation value up to 8%. To define the water content, weight measurement was carried out for the wet and dried samples and mass differences were related to the weight of the wet samples. In order to determine the fixed carbon, ash and volatile contents proximate analysis was conducted. The detailed analysis conditions can be found elsewhere[22]. The carbon, hydrogen, nitrogen and sulphur contents were measured by a Carlo Erba type elemental analyser. In case of elemental analysis weight percentages of C, H, N and S were defined, and the oxygen and other element content was calculated from the difference.

Table 1: Main properties of dried sewage sludge samples

Sample	MSS	DSS	CHM
Water content, % (1)	55.36	47.42	35.28
Fixed carbon, %	7.75	23.23	15.07
Ash content, %	47.61	24.19	20.21
Volatiles, %	44.64	52.28	64.72
C	23.4	42.3	34.7
H	3.4	5.2	4.5
N	3.8	0.8	4.6
S	2.0	0.0	1.6
O+Other	67.4	51.7	54.6

(1) Water content before the analysis (this water content was evaporated at 110°C prior to the analysis).

The produced gases were analysed by a Dani type gas chromatograph comprising flame ionization and thermal conductivity detectors. The equipment contained two columns (Rtx-1 PONA (100 m x 0.25 mm x 0.5 μm) and Carboxen TM 1006 PLOT (30 m x 0.53 mm)). In case of PONA column isotherm conditions and 230°C of injector and detector temperature was applied. For Carboxen TM 1006 PLOT column the applied heating program was the follows: 35°C for 18 min, heating to 120°C with a heating rate of 15°C/min and held at 120°C for 2 min. The retention times of the components were determined using gas mixtures and individual components.

Heating value of obtained gases was calculated from the gas chromatographic results according to the following equation:

$$Heating\ value, \frac{MJ}{m^3} = H_2 \times 10.283 + CO \times 12.663 + CH_4 \times 35.949 + CO_2 \times 0.589 + C_{2-5} \times 70$$

Similar to analysis of gas products, composition of the bio-oil was also determined by a Dani type gas chromatograph. For the analysis Rtx-1 column (30 m x 0.53 mm x 0.25 μm) was used. Both the injector and detector temperature were 340°C, and the applied heating program was the follows: 40°C for 5 min and heating to 340°C (heating rate: 15°C/min) and held at 340°C for 30 min. Before the gas chromatographic analysis, bio-oil samples were diluted with carbon disulphide.

Results and discussion

During the pyrolysis gas, liquid and solid products were also formed (Figure 2). As expected, gas and liquid product yields increased with the temperature and the amount of char varied along the opposite trend. The increasing gas and decreasing char yields were attributed to the lower thermal stability of components at higher temperatures. In addition to temperature, pyrolysis reactions and thus the product yields were also affected by the raw materials. The highest gas yields were observed in pyrolysis of DSS sample, while it seems that the composition of CHM favoured the formation of liquid products.

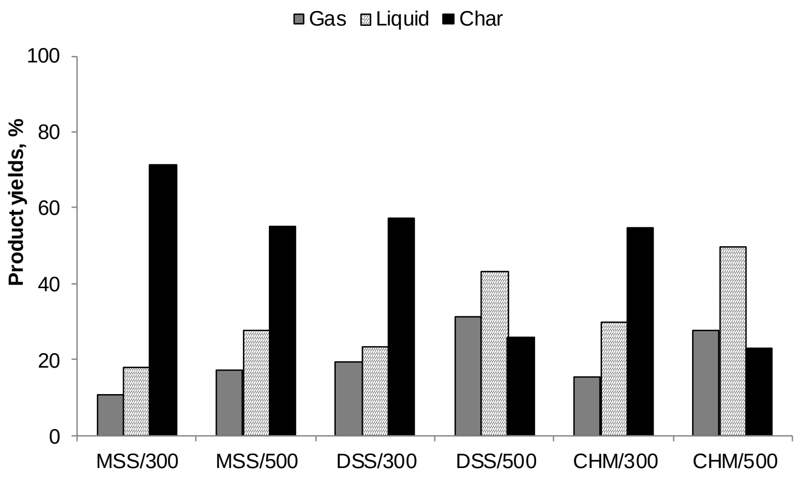

Figure 2: Product yields of pyrolysis in function of the raw material and temperature

Gas product

The composition of gases was determined by GC-FID and GC-TCD methods (Figure 3). Based on the results, there are clear differences in the composition of the gas products using different raw materials and reaction temperatures. At 300°C, no hydrogen was produced and the share of carbon monoxide was also below 10%. At the same time, the most dominating compound of the gas product was the carbon dioxide. In contrast, at 500°C a higher degree of synthesis gas production (mixture of CO and H_2) also took place. This also proves that thermal degradation is a series of complex reactions. In general, only the moisture content of sewage sludge is removed up to 200°C. The slow degradation of hemicellulose and cellulose begins only in the torrefaction stage (T=200 – 350°C), where the main product is the solid carbonaceous material, the so-called bio-char. Above 350°C, the pyrolysis reactions become dominant and result in synthesis gas production, as confirmed by our experimental results.

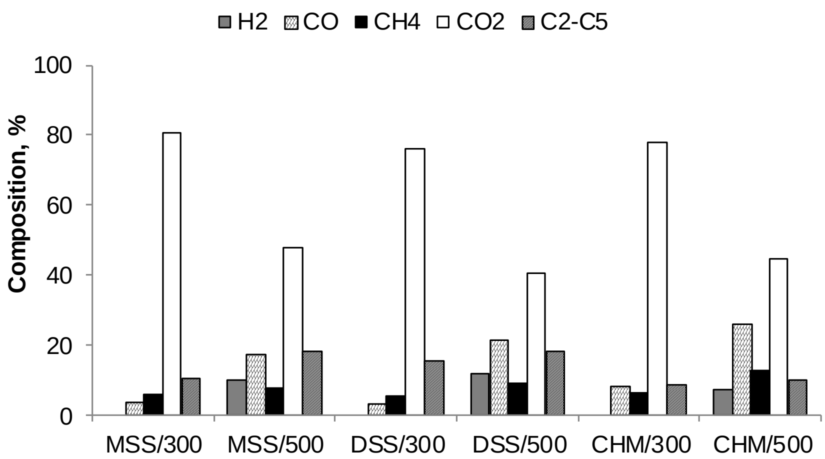

Figure 3: Composition of gas products in function of the raw material and temperature

In order to evaluate the usability of the gas product, synthesis gas yields, H_2/CO ratios (Figure 4) and heating values (Figure 5) have also been calculated. As Figure 4 depicts, the highest synthesis gas yield was observed in pyrolysis of DSS and followed by CHM and MSS raw materials.

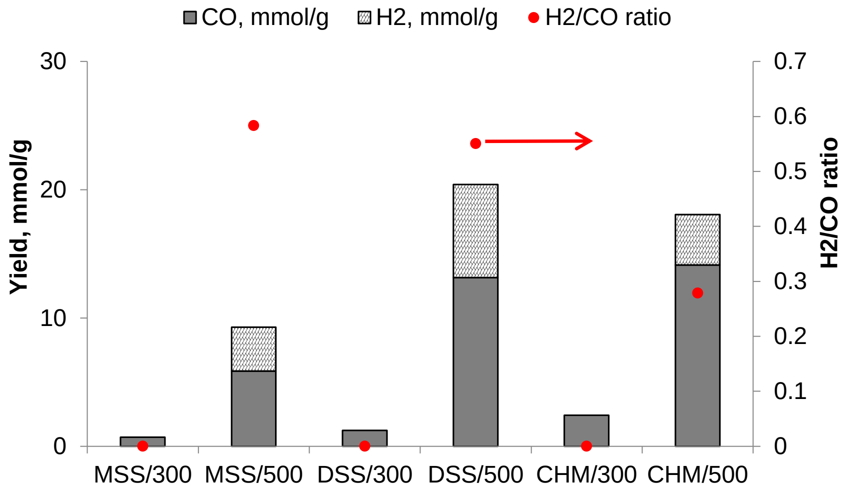

Figure 4: Synthesis gas yields and H_2/CO ratios

The H_2/CO ratios changed between 0.3 and 0.6; thus the produced gases require further quality improvement prior to the use for chemical synthesis. The reason for this is that theoretical H_2/CO ratio of synthesis gas for cobalt catalysed Low Temperature Fischer-Tropsch synthesis is around 2:1, 1.5:1 for aldehydes, higher alcohols and dimethyl ether, 1:1 for acetic acids and 1:2 for polycarbonate production[23,24]. Heating value can also be a valuable characteristic for energetic purposes. The heating values were in the range of 9.5-19.9 MJ/m^3. Not surprisingly, the highest heating value was observed where smaller hydrocarbons were present in the highest percentage (DSS/500). These smaller hydrocarbons as individual components provide a higher heating value than the other compounds present in the mixture.

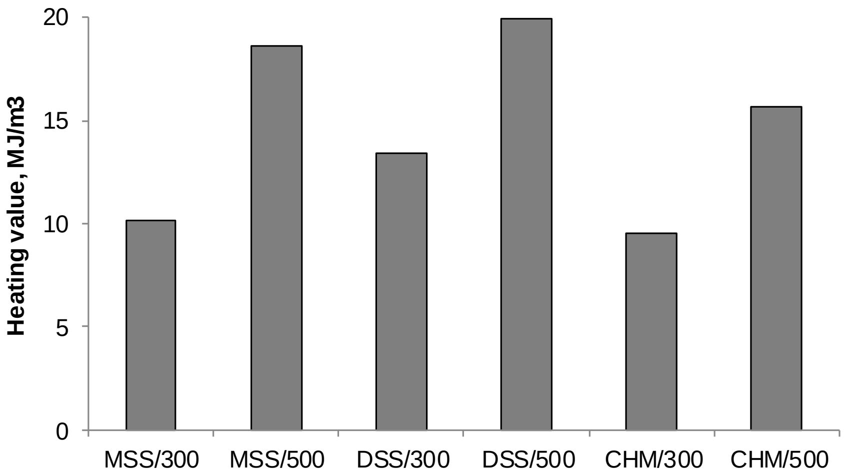

Figure 5: Heating values of the produced gases

Liquid product

The liquid products consisted of aqueous and organic phase (Figure 6). Their main component was the water (yield: 12.7 – 32.6%), which resulted from the dehydration reactions and the secondary cracking of oxygen containing, high molecular weight compounds, especially at higher temperature[25].The organic phase, i.e. the bio-oil contained aldehydes, ketones, carboxylic acids, phenols and their derivatives, alcohols and aromatic or aliphatic hydrocarbons (Figure 7).

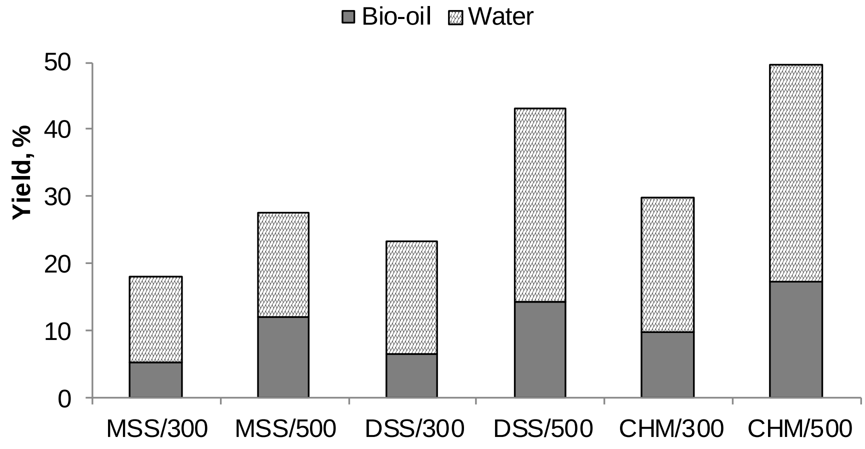

Figure 6: Bio-oil yield

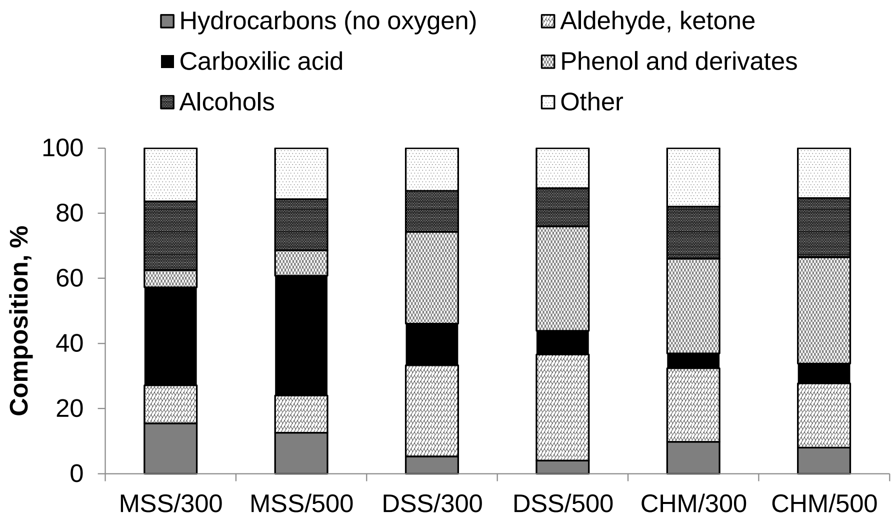

Figure 7: Composition of the bio-oil

The oxygen-containing compounds were mainly formed from the cellulose and lignin; and their major representatives were phenols and their derivatives, as was also found by other researchers[26,27]. The concentration of aldehydes and ketones decreased with the temperature; while the share of the phenolic compounds varied along the opposite trend. The decrease in yield of aldehydes and ketones was attributed to the secondary cracking reactions. Due to the high share of oxygenated compounds, heating value of the produced bio-oils is lower than that of the conventional fuels. In addition, oxygen may also promote the polymerization reactions and increase the viscosity, therefore prior to use as engine fuel or engine fuel blending component it is needed to improve the quality of bio-oil by catalytic hydrodeoxygenation.

Solid product

The elemental composition of char samples are summarized in Table 2. The repeatability of the measurements has standard deviation value up to 8%. During the pyrolysis, the hydrogen content of MSS (3.4%), DSS (5.2%) and CHM (4.2%) raw materials decreased to 1.4 – 2.9, 1.6 – 2.8 and 1.5 – 2.7%, respectively. The nitrogen contents (MSS: 3.8%, DSS: 0.8%, CHM: 4.6%) also became less, as well as there was a significant decrease in sulphur content of MSS and CHM raw materials (2.0 and 1.6%). As the elemental composition shows, chemical composition has changed due to carbonization and removal of functional groups.

Table 2: Main properties of char samples

	MSS/300	MSS/500	DSS/300	DSS/500	CHM/300	CHM/500
HHV, MJ/kg	7.1	5.3	8.4	6.2	7.3	5.7
C, %	18.4	23.7	19.3	22.9	16.1	22.1
H, %	1.4	2.9	1.6	2.8	1.5	2.7
N, %	1.9	1.6	1.1	0.8	1.7	1.8
S, %	0.8	0.9	0.0	0.0	0.0	0.0

Conclusions

In this study, municipal sewage sludge (MSS), distillery sewage sludge (DSS) and chicken manure (CHM) was pyrolysed in a scaled-up semi-batch reactor at temperature of 300 and 500°C. During the experiments, the effects of raw material and reaction temperature were investigated on the yields and composition of pyrolysis products. During the experiments, 10.7 – 31.1% gas, 17.9 – 43.0% liquid and 22.8 – 71.4% solid product was formed. The gas and liquid product yields increased with the reaction temperature and the amount of the char varied along the opposite trend. The highest gas and synthesis gas yield was observed in pyrolysis of DSS raw material at 500°C, while composition of CHM favored the formation of liquid products, especially the bio-oil (yield: 9.8 and 17.1%). In terms of gas product it was found that higher temperature than 300°C is needed to produce synthesis gas and due to the lower H_2/CO ratios (<0.6) further quality improvement is needed before use for synthesis. The liquid product contained aldehydes, ketones, carboxylic acids, phenols and their derivatives, alcohols and hydrocarbons. However, after hydrogenation it can be suitable to use as fuel. The char may be suitable for use as a catalyst or sorbent, after its elemental composition was changed due to carbonization and removal of functional groups.

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Pyrolýza čistírenských kalů k získání cenných produktů

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Abstrakt

Tento článek se zaměřuje na pyrolýzu odpadních kalů z různých zdrojů ve zvětšeném semi-vsádkovém reaktoru při teplotách 300 a 500 °C. Bylo zjištěno, že jak teplota, tak surovinové složení měly významný vliv na výtěžnost a vlastnosti produktu. Nejvyšší výtěžnost plynu a syntézního plynu byla pozorována při pyrolýze kalu z lihovarů při 500 °C, zatímco složení kuřecího hnoje upřednostňovalo tvorbu biooleje (9,8 a 17,1 %). Plynný produkt byl charakterizován poměry H_2/CO do 0,6; proto je před použitím pro syntézu zapotřebí další zlepšení kvality. Bioolej (5,2 – 17,1 %) obsahoval značné množství kyslíkových sloučenin, ale po hydrogenaci je vhodný jako náhrada konvenčního paliva. Během pyrolýzy se také změnilo elementární složení polokoksu (22,8 – 71,4 %) v důsledku karbonizace a odstranění funkčních skupin.

Klíčová slova: *čistírenský kal, pyrolýza, syntézní plyn, bioolej, výroba biouhlu*

Urea hydrolysis as an efficient method for flue gas denitrification in waste-to-energy plant–experimental study

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Abstract

This paper presents the results of experimental research on the modernization of technology for the removal of nitrogen oxides (NO_x) from flue gas in hazardous waste incineration plant (waste-to-energy unit). The investigated technological solution is a combination of traditional SNCR (selective non-catalytic reduction) method, and a modern technology based on urea hydrolysis. A semi-operating hydrolysis reactor is applied to produce gaseous ammonia, which is subsequently used to remove NO_x from the flue gas in a hazardous waste incineration plant. Both the NO_x reduction efficiency and the operating parameters of the semi-operating device are observed. The results show that the proposed technological solution is very efficient in terms of NO_x reduction, where concentrations around 60 mg/scm can be easily achieved. Due to the simplicity of the proposed solution, the semi-operating device is also very reliable. However, in case of insufficient heating of the transport paths of the generated ammonia, there is a risk of deposits and clogging, as presented in the paper.

Keywords: *urea hydrolysis, flue gas denitrification, selective non-catalytic reduction, waste-to-energy*

Introduction

Incineration of waste and its energy recovery is an effective way for economical and environmentally friendly waste removal[1]. Combustion processes, however, produce nitrogen oxides (NO_x), in particular nitric oxide (NO), nitrogen dioxide (NO_2), and others. Nitrogen oxides, are environmentally harmful and form toxic gases associated with acid rain and smog formation, respiratory irritation, or reduced oxygenation of the body[2]. In order to minimize the environmental impact of waste incineration, flue gas denitrification technology is often applied. The most common denitrification technology is the selective non-catalytic reduction (SNCR), which is based on the injection of the reducing reagent to the hot flue gas stream at temperatures of 850-1100 °C (i.e., to the primary or secondary combustion chamber). In this process, the dominant reaction is the reduction of NO by the NH_2^- radical, see equation (1) below[3].

$$NH_2^- + NO \rightarrow N_2 + H_2O \tag{1}$$

Alternatively, selective catalytic reduction (SCR) technology is applied, where the reagent is injected into the flue gas stream at temperatures of 180 - 290 °C and the NO_x is subsequently removed on the catalytic bed[4]. This method is very efficient, but the investment costs are considerably higher compared to SNCR.

The most frequently used reagents are aqueous urea solution, ammonia solution or pure liquified ammonia. Urea solution is safe to store and handle, but the NO_x removal efficiency is lower, reaction with NO_x slower and it has higher propensity to corrosion of heating surfaces due to the isocyanic acid formation during the urea decomposition in the flue gas[5]. Generally, the ammonia reagents (ammonia solution or pure ammonia) are better in terms of NO_x removal efficiency and can be used at lower flue gas temperatures[6]. However, as the ammonia is flammable and toxic substance, there are substantial operational risks and excessive costs for handling and storage. The reduction of NO by urea is shown in equation (2) and by ammonia in equation (3).

$$4NO + 2CO(NH_2)_2 + O_2 \rightarrow 4N_2 + 2CO_2 + 4H_2O \tag{2}$$

$$4NH_3 + 4NO + O_2 \rightarrow 4N_2 + 6H_2O \tag{3}$$

The modern approach is to produce gaseous ammonia from urea solution by hydrolysis reaction, while the ammonia gas is directly injected into the flue gas. In this way, high NO_x removal efficiency could be achieved with minimal safety requirements during reagent handling. The urea hydrolysis is an endothermic reaction taking place at elevated temperatures (above 120 °C) according to the equation (4).

$$NH_2CONH_2(l) + H_2O(l) \rightarrow 2NH_3(g) + CO_2(g) \qquad \Delta H_f^\theta = +161,5\ kJ/mol \qquad (4)$$

First, the process of urea hydrolysis was investigated in a batch[7] and semi batch[8] reactor. For industrial applications, however, the continuous production of ammonia is necessary, so the results of the experimental study were published on the use of a continuous hydrolysis reactor for flue gas denitrification in combination with SCR technology[9]. It was further confirmed that there is minimal risk of by-product formation in the process of urea hydrolysis if the liquid in the reactor and the produced gas are kept at sufficiently high temperatures[9].

As mentioned above, due to the lower investment costs the SNCR technology is preferred in many (especially smaller) incineration plants compared to SCR. Currently, no experimental studies have been published on the reduction of NO_x emissions using SNCR technology in combination with hydrolysis of urea as a source of reagent for the denitrification process ($DeNO_x$). To fill this research gap, an experiment based on a combination of hydrolysis technology and SNCR was conducted to observe the NO_x reduction in flue gas produced in an industrial hazardous (medical) waste incinerator. In this paper, the results of the experiment are presented.

Experimental part

An experimental device (urea hydrolyser) for ammonia production by urea hydrolysis decomposition was set up. The heart of this device is a pressure vessel with 40 L liquid volume (hydrolysis reactor) into which a urea solution was fed by a membrane feed pump. The liquid in the reactor was maintained at elevated pressure and temperature by electrical heating from the surface of the reactor. Under continuous heat supply to the reactor, hydrolytic decomposition of urea into gaseous ammonia and CO_2 (according to equation (4)) and further evaporation of excess water occurred. The produced gas was then injected into the flue gas using a sonic nozzle of own manufacture. The direct measuring of the flow rate of the generated gas would require an expensive Coriolis flow meter, so to reduce costs the flow rate was measured indirectly by measuring the gas pressure before entering the nozzle. With knowledge of the nozzle geometry (especially outlet diameter), the ammonia gas flow rate was then calculated using subsonic flow theory.

A constant amount of liquid is maintained in the reactor during operation by a float level gauge. A schematic of the urea hydrolyser is shown in Figure 1 and the actual device is illustrated in Figure 2. The main parameters of semi-operational urea hydrolyser are summarized in the Table 1. The composition of feed urea solution and the produced ammonia gas is given according to the mass balance in Table 2.

Table 1: Basic characteristics of experimental semi-operational urea hydrolyser.

Temperature [°C]	Pressure [bar_{abs}]	Liquid volume [L]	Heating	Power input (max/min) [kW]	Urea feed concentration [$\%_{wt}$]	Ammonia production [kg/h] (max/min)*
130 – 155	6	40	electric	7.15/0.5	30	1.6/0.1

* *The ammonia production range is valid for $30\%_{wt}$ urea solution feed. Greater ammonia production can be achieved with a more concentrated inlet urea solution.*

Table 2: Composition of feed urea solution and produced ammonia gas according to mass balance

Feed liquid [$\%_{wt}$]		Product gas [$\%_{wt}$]		
urea	H_2O	NH_3	CO_2	H_2O
30	70	17	22	61

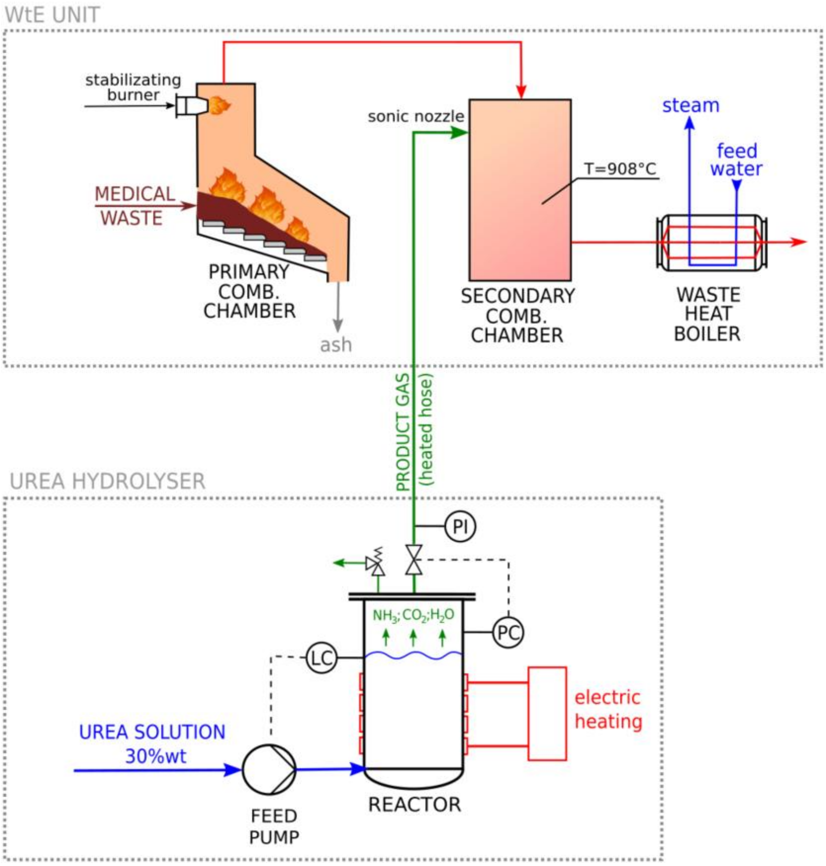

Figure 1: Technological layout of the urea hydrolyser and the WtE unit

Figure 2: The semi-operational urea hydrolyser

The experiment was then carried out on waste-to-energy unit processing a hazardous waste consisting mainly of hospital waste. The product gas was injected into the cylindrical secondary combustion chamber of the WtE unit, where the highly turbulent tangential flue gas flow occurs, which promoted an effective mixing of the ammonia with the flue gas. The main parameters of the flue gas in the place of ammonia injection are summarized in Table 3. Currently, no NO_x reduction technology is applied here, as the emission limits are complied with. However, with the emission limits tightening, the application of SNCR technology is here also expected in the future. The final experimental setup is illustrated in Figure 3.

Table 3: Treated flue gas properties and composition.

Flow rate [scm/h] (dry basis)	**Temperature [°C]**	**Pressure [kPa_{abs}]**	**Composition [$\%_{vol}$]**				
			CO_2	**O_2**	**H_2O**	**N_2**	**NO_x**
2 750	908 °C	97	4,3	13,7	9,7	72,3	148.3 mg/scm*

* *NO_x concentration is valid for dry flue gas and O_2 reference concentration $11\%_{vol}$.*

Figure 3: The experimental setup

The aim of the experiment was to measure NO_x reduction in two steady-state operating stages (high-rate and low-rate product gas injection) and to observe the transitional behavior between these two stages. The experiment can be divided into five sub-steps:

- **Normal operation –** The urea hydrolyser was not running. The flue gas reference parameters were monitored. The results are shown in Table 3.
- **Transition region 1 –** The product gas flow rate was determined by stoichiometric calculation based on the data in Table 2 and 3 in such a way that the stoichiometric excess of Ammonia was equal to 3 (standard value for SNCR applications). In the start-up process, the concentration of ammonia in the produced gas is, however, lower than in steady state[9].
- **DeNO$_x$ stage 1** - The amount of injected product gas was kept constant and the NO_x concentration in the flue gas was stable. It is assumed that chemical equilibrium in the reactor and steady state operation are achieved.
- **Transition region 2** - The amount of injected product gas was reduced to correspond to a stoichiometric excess of ammonia 1.1, assuming a gas composition according to Table 2. The ammonia content of the product gas was assumed to be initially higher than the values in Table 3 and gradually decreased until the chemical equilibrium was achieved.

- **DeNO$_x$ stage 2** – Chemical equilibrium and steady state operation is reached with ammonia excess equal to 1.1.

During the experiment, the temperature and pressure of the product gas upstream of the sonic nozzle were measured to calculate the gas flow rate using the theory of subsonic flow through the nozzle. ammonia slip in the flue gas was also measured by spectrophotometry method.

Results and discussion

The duration of the experiment was 12 hours. During this time, among other things, the NO$_x$ concentration in the flue gas was continuously measured. The result of this measurement with the marked sub-steps (see Experimental part) is shown in Figure 4.

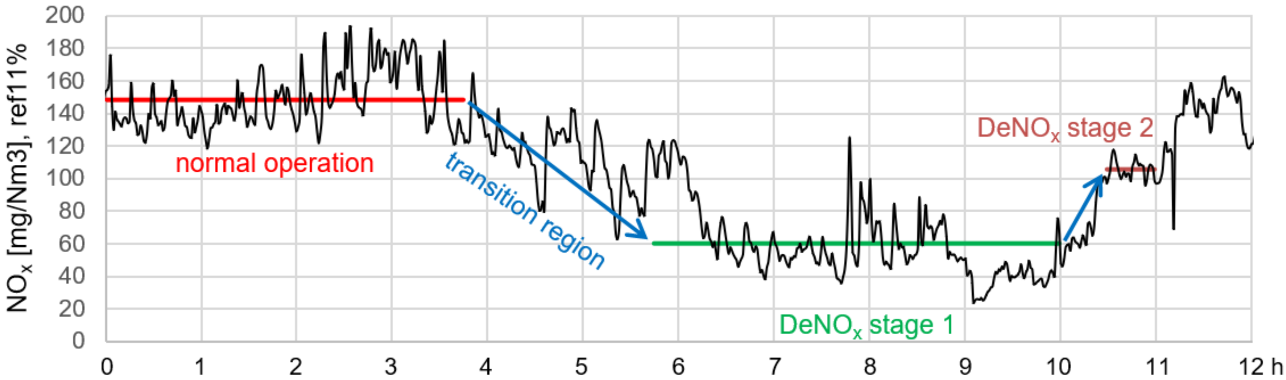

Figure 4: NO$_x$ concentration in the flue gas

As can be seen from Figure 4, the NO$_x$ concentration in the flue gas was significantly reduced during the experiment. Therefore, the hydrolysis technology can be used for flue gas denitrification in combination with SNCR technology. The experimental results are also summarized in Table 4.

In addition to NO$_x$ reduction, ammonia slip in the flue gas was also monitored. In total, 4 half-hourly measurements were carried out and the results of which are summarized in Table 5. As expected, the highest ammonia slip occurred when more product gas was injected (during time 7:30-8:00). Surprisingly, the ammonia slip during the reduced ammonia gas injection (time 10:30-11:00) was higher than at the beginning of the experiment. This may be, for example, due to a lower concentration of ammonia in the produced gas in the initial phase of the experiment, as explained in Experimental Part. However, the values are within legal emission limits, and it can be assumed that most of the injected ammonia reacted with NO$_x$ or was thermally decomposed into N_2 and H_2O.

There was a significant fluctuation in NO$_x$ concentration throughout the experiment. The periodic fluctuation (with a period of approximately 15 minutes) is due to the movements of the grate on which the waste is combusted, as these temporarily accelerate the combustion. Longer term fluctuations can also be observed, especially between the times 7:45-8:45. This significant deviation from steady state was not due to a change in the amount of product gas injected as this was constant. However, similar prolonged fluctuations are relatively common in this operation and are caused by the inhomogeneous nature of waste composition.

As mentioned in the Introduction, SNCR technology commonly uses a liquid reagent injection into the flue gas. It is performed by two-phase nozzles where the reagent is atomized using pressurized air or steam. The advantage of this design is the intensive penetration of the reagent in the flue gas stream, which promotes a uniform distribution of the reagent in the flue gas even in large combustion units. However, the disadvantages of this design are the higher purchase cost of the nozzles and associated equipment and operational difficulties such as clogging, unstable atomization of the liquid reagent and the danger of local subcooling of the combustion chamber walls.

With the urea hydrolyzer, the gaseous reagent is injected into the flue gas using a single-phase nozzle. This has the disadvantage of lower penetration through the flue gas stream than two-phase nozzles but it is sufficient for smaller combustion plants. The great advantage then lies in the simplicity of design and operational reliability coupled with less tendency to fouling. In addition, the consumption of pressure air is minimal, as it only serves to cool the nozzle when product gas is not being injected.

Even though very good results have been achieved and the urea hydrolyzes proved to be suitable technology for SNCR process, there are several aspects that must be carefully considered:

- Sufficient penetration of product gas to the flue gas stream. As the combustion chamber is relatively large and the flue gas flows at high velocity, there is a risk of low product gas penetration to the flue gas stream resulting to insufficient degree of mixing, which leads to low $DeNO_x$ efficiency and high ammonia slip. To minimize this danger, ammonia gas was injected into the flue gas at a nearly sonic velocity (M=0.95) during the experiment. However, at a later stage of the experiment, when a lower amount of gas was injected, even a rate corresponding to M=0.38 proved to be sufficient.
- Retention time. NO_x reduction efficiency is dependent on the retention time of reagent in combustion chamber. In this experiment, the retention time was 1.36 seconds before the flue gas was cooled in the boiler, which also proved to be a sufficiently long period to reach good results.
- Danger of reverse chemical reactions. In the transport pipeline between the hydrolyser and the nozzle the formation of ammonium carbamate (a corrosive crystalline substance that can clog the transport routes) is a risk when the temperature of the product gas drops below approx. 100°C. To avoid this danger, the transport pipeline was equipped by electrical heating to maintain the temperature of gas at around 130°C. However, there was a blind section in the flow path at the point of pressure measurement in the pipe without electrical heating, where ammonium carbamate was formed, which led to a gradual blockage as shown in Figure 5.

Table 4: The experimental results

	$T_{reactor}$ [°C]	$p_{reactor/nozzle}$ [bar_{abs}]	Mach no.*	$\dot{V}_{prod.gas}$ [scm/h]*	Stoich. excess	NO_x [mg/scm]	η_{DeNOx} [%]***	η_{NH3} [%]***
Transition region 1	138.9	6.0/1.8	0.95	1.94	0 – 3**	113.9	23.2	-
$DeNO_x$ stage 1	138.5	6.0/1.8	0.95	1.94	3	60.2	59.4	19.8
Transition region 2	138.0	6.0/1.1	0.38	0.78	3 – 1.1**	70.4	52.5	-
$DeNO_x$ stage 2	135.6	6.0/1.1	0.38	0.78	1.1	105.7	28.8	26.2

* *The subsonic nozzle with the diameter 1.5 mm was used. The Mach number is then calculated applying the subsonic flow theory. From the Mach number, the product gas flowrate was determined.*

** *Stoichiometric excess in transition regions can´t be determined accurately as the hydrolysis reactor didn´t reach chemical equilibrium and thus the product gas composition isn´t known.*

*** η_{DeNOx} *– NO_x removal efficiency is determined as the ratio of the measured NO_x concentration to the reference concentration measured in normal operation stage (Table 3).*

η_{NH3} *– reagent efficiency determines the ratio of ammonia reducing NO_x to the total amount of the ammonia injected to the flue gas. It is also the ratio of η_{DeNOx} to the ammonia stoichiometric excess.*

Table 5: Ammonia slip (101 325 Pa, 0°C, dry basis).

	4:30 – 5:00 h	5:30 – 6:00 h	7:30 – 8:00 h	10:30 – 11:00 h
ammonia slip [mg/m^3]	1.8	3.6	10.0	8.4

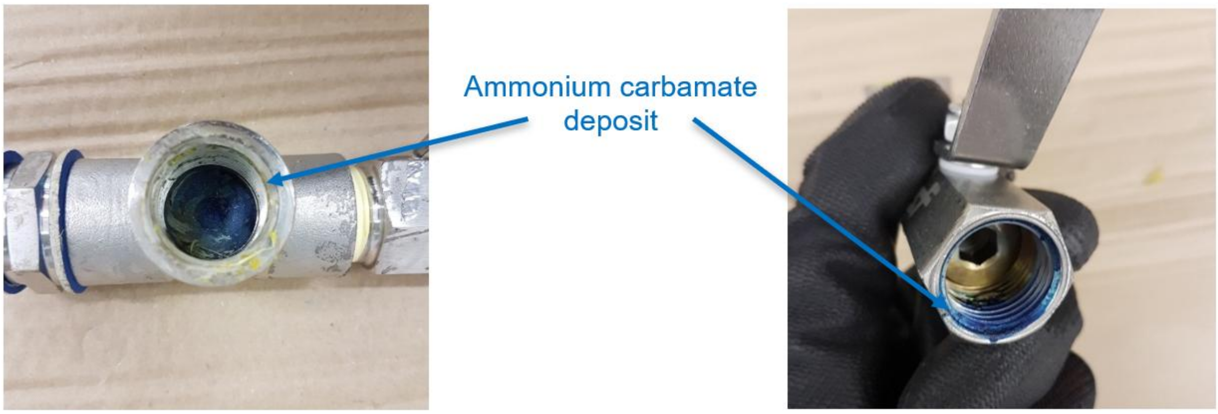

Figure 5: Ammonium carbamate deposit in unheated section of the pipeline.

Conclusions

The paper presents the results of an experimental research focused on the use of the urea hydrolytic decomposition technology as a source of reagent (gaseous mixture of ammonia, CO_2 and H_2O) for the removal of nitrogen oxides from the flue gas produced in waste-to-energy unit processing a hazardous waste. The NO_x reduction was performed by the SNCR method, where the reagent was injected into the secondary combustion chamber using a sonic nozzle.

During the main part of the experiment (DeNO$_x$ stage 1), the NO_x concentration was reduced from 148.3 mg/scm to 60.2 mg/scm (i.e., by 59.4%) at a stoichiometric excess of ammonia equal to 3. A significant NO_x reduction of 28.8% was also achieved when a smaller amount of reagent with a stoichiometric excess of 1.1 was injected during the DeNO$_x$ stage 2. Thus, the results clearly indicate that very effective NO_x reduction in flue gas can be achieved using urea hydrolysis technology in combination with SNCR method.

Compared to the traditional technological approaches of the SNCR method, where the reagent is injected in liquid form using two-phase nozzles, the presented solution has proven to be both very reliable due to the simple nozzle design and economical, as a minimum amount of pressurized air is required for operation. The disadvantage of the presented solution is the danger of ammonium carbamate formation in the transport routes if they are not heated sufficiently.

The objective of future research is to further optimize the urea hydrolysis technology and to perform further laboratory experiments and operational tests in waste-to-energy units and other combustion plants.

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Hydrolýza močoviny jako účinná technologie pro denitrifikaci spalin ve spalovně odpadu – experimentální studie

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Souhrn

Článek předkládá výsledky experimentálního výzkumu zabývajícího se modernizací technologie pro odstraňování oxidů dusíku (NO_x) ze spalin ve spalovacích provozech, jako například v jednotkách waste-to-energy. Zkoumaným technologickým řešením je kombinace tradiční technologie SNCR (selektivní nekatalytická redukce) a moderní technologie založená na hydrolýzním rozkladu technické močoviny. Poloprovozní hydrolýzní reaktor je zde aplikován k výrobě plynného amoniaku, který je následně využit k odstranění NO_x ze spalin ve spalovně nebezpečného odpadu. Sledována je zde jak účinnost redukce oxidů dusíku, tak provozní parametry poloprovozního zařízení. Z výsledků vyplývá, že navržené technologické řešení je z hlediska redukce NO_x velice účinné, kdy lze snadno dosáhnout koncentrací okolo 60 mg/Nm^3. Díky jednoduchosti tohoto technologického řešení je poloprovozní zařízení také velice spolehlivé. V případě nedostatečného ohřevu dopravních tras generovaného plynu zde ale hrozí vznik úsad, jak je v článku prezentováno.

Klíčová slova: *Hydrolýza močoviny, denitrifikace spalin, selektivní nekatalytická redukce, waste-to-energy*

Biogas generation potential of starch- and polylactide-based biodegradable plastics

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Summary

Plastic materials decompose with an extremely slow rate and many decades are required for their complete degradation. Lately, commercial plastics have been partially replaced by biodegradable additives. Polylactic acid (PLA) and starch-based biopolymers are indicative alternatives employed to replace a 50-100 % of the mass of conventional plastic materials. In this work, a conventional and two different biodegradable commercial bags were subjected to single-stage mesophilic anaerobic digestion for 100 days to investigate their degradation performance and examine their biogas and methane production potential. LDPE-based plastic (LDPE-50) decomposed only negligibly producing 0.0785 m^3 kg_{VS}^{-1} of methane after 100 days of digestion whereas PLA-based bioplastic (PLAS-31) showed a better degradation performance (0.1782 m^3 kg_{VS}^{-1}). A methane production of 0.1941 m^3 kg_{VS}^{-1} was attained from a second type of PLA-based biodegradable bag (PLAS-13) indicating that bioplastics under specific anaerobic digestion conditions could provide a significant amount of biogas. The degradable organic material in bioplastics was the principal factor defining their conversion to biogas and methane. Anaerobic digestion had a minimal impact on the surface of LDPE-50, while the most significant modification of surface was seen for PLAS-13 where clean polymeric structures emerged after digestion due to a removal of a significant fraction of organics. PLAS-31 showed a great potential to further degrade even after the end of the 100 days of anaerobic digestion.

Key words: anaerobic digestion, BMP tests, bioplastics, LDPE, polylactic acid, biodegradation

Introduction

Nowadays, the generated global amount of wastes continuously rises, and therefore it is more than imperative to implement measures that will mitigate the waste volume[1]. Bioplastics is a wide family of bio-decomposable materials that could assist towards this direction. Bioplastics can be divided into three classes depending on the origin and the biodegradability characteristics: (i) biodegradable with bio-origin, (ii) biodegradable with fossil-origin and (iii) non-biodegradable with bio-origin[2]. Polylactic acid (PLA), starch, cellulose pulp, polyhydroxyalkanoates (PHAs) are examples of biopolymers that have been used for the production of bioplastics, such as bags, dishes, straws, etc[3]. Several countries e.g. Italy established legislation according to which aerobic and anaerobic biological plants are obliged to accept and treat degradable bioplastics[4]. Although currently biodegradable plastics hold a relatively limited share in plastics market they have attracted a considerable attention for substituting conventional plastic materials[5]. A lot of different bioplastics have been formulated, some of which degrade fast presenting a short life-cycle which makes them acceptable for the environment[1].

Because of the great interest for biodegradable plastics a number of standard methods have been established to evaluate their composition and set the conditions for their use. For instance, European standard EN 13432[6] defines the criteria that must be fulfilled and a bioplastic be used as a packaging material. Standard method 14995 specifies the properties of a biodegradable bag, i.e. (i) decompose by 90 %wt. under carbon dioxide atmosphere within a period of 6 months, (ii) a 90 %wt. of bag must decay to a particle size less than 2 mm after a period of 3 months when the material is mixed with other organics, (iii) the material should not impede a composting process, and (iv) heavy metals contained in the final compost must fall within specific standard limits[7]. According to another standard method (EN 14046) the biodegradability of a material is determined in composting trial conducted under controlled temperature and humidity conditions for a period of 45 days. The final products of the process must be composed of CO_2, H_2O, mineral salts and a newly formed biomass with minimal environmental risk[3].

Biodegradability depends on a number of factors with crystallinity being a primary one[5]. Theoretically, the amorphous parts are more easily degradable than the crystalline areas. The ordered structure of crystalline regions impedes intrusion of microorganisms. In contrast, a loose packed structure in amorphous parts makes the specific regions more flexible and easily accessible to microorganisms[8]. Chemical structure is another factor influencing the biodegradation of bioplastics. In principle, biodegradation is performed with a concurrent contribution of biotic and abiotic factors. Generally, abiotic factors such as temperature, water and sunlight lead to an initial scission of chemical bonds in the polymer producing shorter oligomers that can pass through the cell walls of microorganisms. Degradation of short units is then completed by biotic agents such as aerobic or anaerobic microorganisms[2].

Currently, there is a substantial interest in the anaerobic digestion of bioplastics, although there are contrasting opinions about the degradation potential of those materials. According to an opinion, PLA-based bioplastics are characterized by a high degradation ability at anaerobic conditions whereas starch-based plastics by a moderate one[8]. Contrary to that, Battista et al.[9] who studied the methane generation capability of the same two bioplastic types reported that both materials remained almost unaffected by the anaerobic treatment even after 250 days, whereas methane yields were significantly low ranging between 0.1-0.2 $m^3\ kg_{VS}^{-1}$. In another study, PLA-based bioplastics showed a very small decomposition while starch-based bioplastics an extremely high one approaching an 86 % of conversion even only after 23 days of anaerobic processing when they were co-digested with food waste in a thermophilic reactor[10]. Therefore, although degradation of bioplastics was examined in a number of studies there are great uncertainties about the degradability of the materials under anaerobic conditions especially for long digestion periods.

In the current work, a conventional plastic and two different biodegradable bags were subjected to mesophilic anaerobic digestion in long-term BMP tests. The aim was to examine the degradation of the materials designed to replace the conventional fossil-produced plastics and investigate their potential to produce biogas and methane. Another target was to compare the degradation of plastic bags composed of different biodegradable substances and identify any differences in their conversion over long treatment periods. The investigations were extended to the evaluation of the effect that anaerobic digestion had on the surface structure of the bioplastics.

Experimental part

Substrates and inoculum

Inoculum was a digestate obtained from the first stage of a mesophilic (40 °C) biogas plant (BPS Klokočov, Moravian-Silesian Region). Unit’s feedstock composed of a mixture of beef slurry, straw, manure, grass, distillery waste, and small amounts of processed waste from paper industry. Digestate was homogenized under constant temperature (30 °C), shredded in a screw mill (2 mm openings) and used without any further treatment or filtration. Physicochemical parameters of inoculum and substrates are listed in Table 1.

Three types of bags were used as substrates for anaerobic tests. A first (referred to as LDPE-50) was a mixture containing low-density polyethylene (LDPE) and characterized by a thickness of 50 μm. A second (referred to as PLAS-31) and third (referred to as PLAS-13) were delivered with the indication that were prepared from polylactic acid with starch filling at different ratios. The thickness of PLAS-31 and PLAS-13 were measured at 31 and 13 μm, respectively. An IKA Tube Mill Control knife mill equipped with a disposable plastic head was used to reduce the size of samples in order to avoid any potential effect of the materials thickness on their anaerobic degradation. The milling process was carried out cryogenically (liquid nitrogen to avoid potential melting of materials. Before the tests all samples were sieved and a powder with particles diameter lower than 1 mm was obtained. The three bags in powder form are shown in Figure 1.

Figure 1 Milled and sieved biodegradable (a) LDPE-50, (b) PLAS-31, (c) PLAS-13

Biochemical methane potential (BMP) tests

The biogas and methane production potential of substrates were determined in mesophilic BMP tests. The tests were conducted in glass-bottle bioreactors (volume 1 L) equipped with glass-burettes acting as the gas collectors allowing the measurement of the generated biogas volume. The experiments were performed by following the ČSN EN ISO 11734[11] and VDI 4630[12] standard methods. An amount of 800 g of inoculum and 10 g of substrate were inserted in a glass bottle tightly closed with a burette to secure the anaerobic conditions. The degradation of inoculum was also examined by adding 800 g of inoculum alone in a distinct reactor. To increase the measurements accuracy each test was duplicated resulting in a total of eight reactors running in parallel. The reacting mixture was continuously stirred by using magnetic stirrers rotating with a frequency of 150 rpm. Reactors were placed in a water bath steadily operated at 40 ± 0.5 °C whereas the gas burettes maintained at atmospheric temperature. The temperature of water bath was continuously inspected, whereas biogas volume, temperature and barometric pressure were continuously measured on a daily basis. Biogas composition was recorded once per day using a “Biogas5000” analyzer (Geotechnical Instruments Ltd.) equipped with dual infrared sensors for CH_4 (0-70% ± 0.5%) and CO_2 (0-60% ± 0.5%) and electrochemical sensors for O_2 (0-25% ± 1.0%), H_2 (0-2000 ppm ± 2.0%) and H_2S (0-5000 ppm ± 2.0%). The presented biogas volume and composition results were calculated by subtracting the corresponding biogas volume and composition measured for the inoculum. More details about the BMP tests and the process followed can be found in an earlier study[13].

The presented results are average values of two repetitions. The deviations between each two tests were statistically verified using the two-sample t-test analysis of Microsoft Excel. According to the analysis, statistical differences between two measurements were significant when the p-value was less than 0.05. The differences between the repeated tests were found insignificant in all cases.

Analyses

The pH of samples was determined potentiometrically using a WTW 340i pH-meter with SenTix 410 sensor[14]. Total solids (TS) content was measured by drying approximately 10 g of material at 105°C under oxygen atmosphere to constant weight (weight change <2.0 %wt) in a KERN DLB 160 3A moisture analyser with halogen lamp[15]. A thermogravimetric analyser (LECO TGA 701) was used for the determination of volatile solids (VS). The process included heating of sample at 550 ºC in O_2 atmosphere to constant weight according to EN 15935:2012[16]. The accuracy in the determination of TS and VS was ensured by repeating each measurement for five times. Samples density was assessed in a Thermo Fisher Scientific Pycnomatic ATC semi-automatic gas pycnometer operated with helium at 50 kPa following the standard methods of EN 12154:2014 and ASTM D5373-16[17,18]. Elemental composition (CHNSO) was determined in a LECO Truspec CHN 628+ S628 elemental analyser according to the EN18753:2017 standard method[19].

A scanning electron microscope (SEM) (Tescan Vega) with Tungsten cathode and energy-dispersive X-ray spectroscope (EDS) was used for the examination of microstructure of bags. Micrographs were obtained using a secondary electron (SE) and backscattered electron (BSE) mode with an acceleration voltage of 30 KeV. Samples before imaging were gold sputtered in order to ensure adequate electron conductivity. For a more accurate characterization of the materials the thickness of bags was also determined using the obtained micrograms.

Results and discussion

Plastic bags characterisation

Physicochemical characteristics of plastic samples such as pH, TS, VS, density and elemental content are presented in Table 1. Total solids (TS) content of LDPE-50 (99.35 %wt) and PLAS-31 (99.52 %wt) were noticeably close, whereas the proportion in PLAS-13 (96.97 %wt) deviated from those values only by a 2 %wt. On the other hand, the volatile solids (VS) content of PLAS-31 (95.08 $\%wt_{TS}$) and PLAS-13 (99.41 $\%wt_{TS}$) were similar, whilst the VS concentration in LDPE-50 was significantly lower (78 $\%wt_{TS}$). VS content of the two bioplastics agree well with the values appearing in the literature for similar biodegradable polymers, which in all cases are higher than 95 $\%wt_{TS}$[20]. PLAS-31 and PLAS-13 showed also similar elemental composition containing mainly carbon (55.23-56.07 $\%wt_{TS}$) and a fairly high amount of hydrogen of 6-7 $\%wt_{TS}$. In contrast, the carbon content of LDPE-50 was merely at 44.37 $\%wt_{TS}$ and the hydrogen at 4.74 $\%wt_{TS}$. According to these results PLAS-31 and PLAS-13 would likely be more efficient substrates than LDPE-50 in an anaerobic digestion reactor. The opposite however can be predicted from the pH values measured for the three bags. In particular, LDPE-50 presented a pH of 7.47, which is far inside the alkaline range, whereas the pH of PLAS-31 and PLAS-13 was much lower and inside the acidic range (4.89 and 4.73, respectively). Anaerobic digestion process is favoured by alkaline environment while inhibited by acidic conditions[21]. With respect to the pH, therefore, LDPE-50 would likely constitute a more competent substrate in an anaerobic digestion system. Biodegradable plastic bags contain a great amount of carbon and small or negligible proportions of nitrogen[22], therefore the C:N ratio was remarkably high. The C:N ratio of a substrate influences the anaerobic digestion performance of the material[23]. A C:N ratio between 20 and 30 favours the stability of digestion and ensures an adequate supply of nutrients for microbial cell growth. The significantly high C:N ratio found here indicates that co-digestion of bioplastics and a proteinaceous substrate would be a favourable option for the valorisation of bioplastics in biogas production[24].

From Table 1, LDPE-50 showed the highest density (1480 kg m_{TS}^{-3}) among the bioplastics, followed by PLAS-13 (1321 kg m_{TS}^{-3}), whereas PLAS-31 presented the lowest density value (1250 kg m_{TS}^{-3}). Similar density characteristics could not be seen in the SEM images (Figure 2). In this case, PLAS-31 appeared to have a dense structure consisting of parallel layers of slab-type formations leaving only small fractures among them. On the opposite, the most “open” structure appeared for PLAS-13, whereas the surface of LDPE-50 was seen to consist of small pores and voids forming a surface that was far from dense. Nevertheless, SEM images were taken by focusing on specific and substantially small areas on material’s surface, and thereby cannot be exclusively considered for the evaluation of the density of a material.

Table 1: Physicochemical characteristics of inoculum and plastics

Material	pH	TS	VS	ρ	C	H	N	S	O
	-	wt%	$\%wt_{TS}$	kg m_{TS}^{-3}	$\%wt_{TS}$				
Inoculum	8.20	7.36	63.0	1054	34.54	4.57	3.06	0.19	21.01
LDPE-50	7.47	99.35	77.64	1480	44.37	4.74	0.009	0.04	29.55
PLAS-31	4.89	99.52	95.08	1250	56.07	6.31	0.16	0.04	32.69
PLAS-13	4.73	96.97	99.41	1321	55.23	6.98	0.18	0.07	36.92

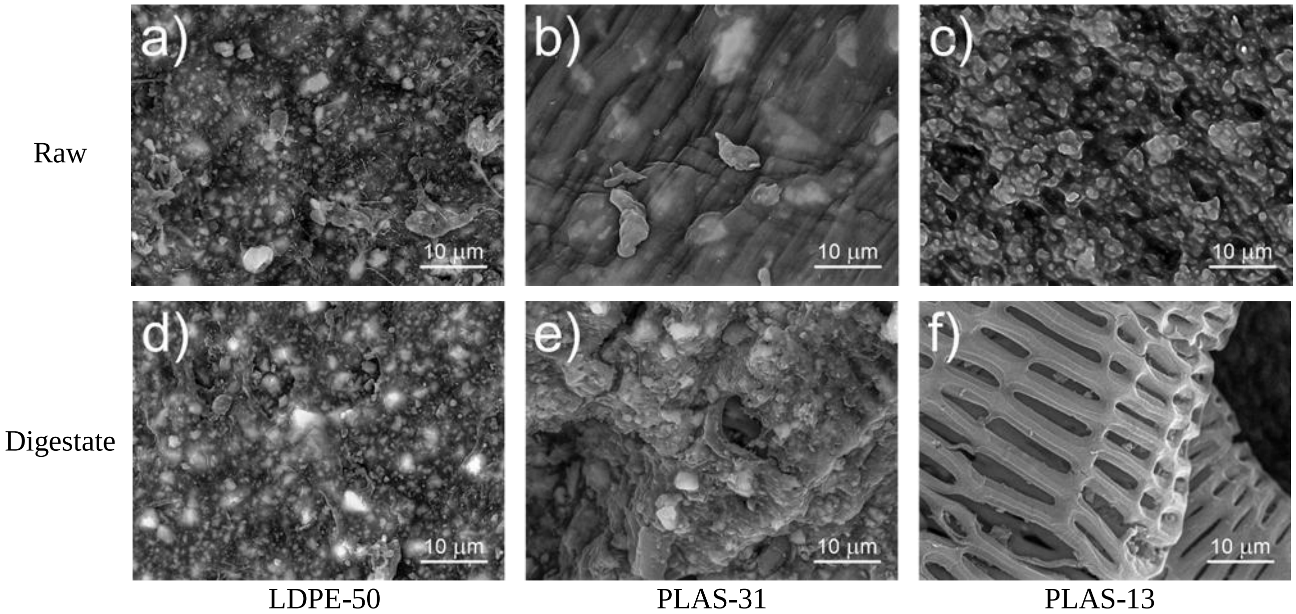


Figure 2: SEM images of the plastic bags before (a, b, c) and after anaerobic digestion (d, e, f)

Anaerobic digestion results

Table 2 presents total amounts of biogas and methane (volumetric basis) produced from the mesophilic anaerobic digestion of bioplastics. A relative generation factor describing biogas and methane yields from a bioplastic as proportion of yields from inoculum (baseline) was also shown. PLAS-13 showed the most significant biogas release after 100 days of digestion and LDPE-50 the lowest. Biogas and methane production from PLAS-13 was by 59 % and 46 % higher than that attained by LDPE-50. Similarly, biogas and methane generated from PLAS-31 were by 43 and 39 % greater than those of LDPE-50. However, LDPE-50 showed an appreciable methane release of 0.00324 m^3 which was by 23 % higher than that of inoculum. This suggests that even the LDPE-based material exhibited a relatively small potential to be converted during the anaerobic digestion process.

Table 2: Biogas and methane production after 100 days of digestion (in m^3)

Reactor	**Material**	**Biogas**		**Relative generation**	**Methane**		**Relative generation**
		m^3		**%**	**m^3**		**%**
1	Inoculum	0.00365	0.00374	100	0.00256	0.00263	100
2		0.00382			0.00270		
3	LDPE-50	0.00447	0.00460	123	0.00314	0.00324	123
4		0.00472			0.00334		
5	PLAS-31	0.00619	0.00620	166	0.00425	0.00425	162
6		0.00620			0.00426		
7	PLAS-13	0.00692	0.00679	182	0.00452	0.00443	169
8		0.00667			0.00435		

Table 3 provides biogas and methane production results for the anaerobic digestion of the three bags on a VS-basis. PLAS-13 released the greatest biogas amount (0.3182 m^3 kg_{VS}^{-1}) during digestion followed by PLAS-31 with 0.2599 m^3 kg_{VS}^{-1} and LDPE-50 with 0.1113 m^3 kg_{VS}^{-1}. The same trend was also observed for the production of methane. In particular, methane yields after 100 days of digestion from PLAS-13 were 0.1941 m^3 kg_{VS}^{-1}, the maximum amount achieved from the anaerobic digestion tests. On the other hand, cumulative methane yields from the decomposition of LDPE-50 were the lowest

(0.0785 m^3 kg_{VS}^{-1}). Methane release from PLAS-31 (0.1782 m^3 kg_{VS}^{-1}) was lower than the yields from PLAS-13 and much higher than those from LDPE-50. Considering the biogas and methane generation potential, therefore, the materials can be lined up in the order of PLAS-13>PLAS-31>LDPE-50, which is similar to the classification that can be received according to their TS and VS contents (Table 1). This observation suggests that the degradable organic fraction in polymers was likely principal factor defining the generation of gas. The proportional correlation between VS and methane generation was also plausible indicator of an absence of inhibition during the anaerobic digestion process. Table 3 presents methane partial pressures in biogas streams generated from anaerobic digestion of the three plastics. Although biogas and methane yields from PLAS-13 were the greatest, the partial pressure of methane in biogas was fairly low. In general, the proportion of methane in biogas released from the plastics followed an inverse rank than that of the total biogas yields, i.e. biogas yields from LDPE-50 contained the greatest proportion of methane (70.5 %vol.), trailed by the yields from PLAS-31 (68.5 %vol.), while biogas from PLAS-13 contained only a 61.0 %vol. of methane. Nevertheless, the total quantity of methane produced from each bioplastic was mostly defined by the amount of released biogas.

The extent of decomposition of each plastic was evaluated by computing a theoretical maximum gas production based on the elemental composition of the material. Theoretical calculations were based on a formula developed by Richards[25] and the results (VS-basis) are included in Table 3. “Anaerobic biodegradability (B_d)” was used to characterize the biodegradation of materials[26]. This factor describes the actual conversion achieved by a substrate in a BMP assay as percentage of the maximum conversion that can be achieved according to the chemical composition of the substrate and can be expressed as:

$$Anaerobic\ biodegradability\ (B_d) = \frac{Experimental\ conversion}{Theoretical\ conversion} \times 100\% \quad (1)$$

In essence, B_d represents the percentage of degradable constituents of a substrate decomposing within the time span of a BMP test. From Table 2, PLAS-13 contained the highest proportion of organics converted to biogas at the end of 100 days (30.4 %), while LDPE-50 the lowest (10.3 %). Likewise, PLAS-13 contained the highest percentage of organics converted to methane (32.9 %), LDPE-50 the lowest (13.6 %), whereas PLAS-31 an average amount (28.7 %). It should be emphasized that the theoretical calculation based on the elemental content of bioplastics and thereby computed biogas and methane encompassed hypothetical yields from conventional plastic fractions of bioplastic used as supporting materials in the production of bags that were evidently not degradable during anaerobic digestion. For a given plastic, therefore, theoretical gas yields would be overestimated and not precisely indicative for the real gas generation potential of the material. Hence, it is expected that the real degradability of each material would be higher than that shown in Table 3 based on the elemental composition of substrates. Nevertheless, B_d factor constituted an excellent indicator for making comparisons on the conversion of the three plastic materials.

Table 3: Theoretical and experimental cumulative biogas and methane yields (on VS-basis)

Substrate	**Biogas yields**			**CH_4**		**CH_4 yields**		
	Theory	**Test**	**B_d**	**Theory**	**Test**	**Theory**	**Test**	**B_d**
	m^3 kg_{VS}^{-1}		**%**	**%vol.**		**m^3 kg_{VS}^{-1}**		**%**
Inoculum	1.0340	**0.1007**	9.7	55.5	**70.2**	0.5736	**0.0707**	12.3
LDPE-50	1.0778	**0.1113**	10.3	53.5	**70.5**	0.5762	**0.0785**	13.6
PLAS-31	1.1123	**0.2599**	23.4	55.9	**68.5**	0.6212	**0.1782**	28.7
PLAS-13	1.0478	**0.3182**	30.4	56.3	**61.0**	0.5898	**0.1941**	32.9

The superior methane generation performance of PLAS-13 is also obvious in Figure 3 where cumulative methane production from bioplastics (VS-basis) was plotted versus digestion time. For PLAS-13, methane release was intense in the very initial period of incubation and declined at significantly low values after a short period and until the end of assay. As a result, methane yields followed an inverse-L pattern consisting of a rapid gas production for the first 6-7 days and a long and almost asymptotic segment, wherein the gas generation rate was significantly low. It is interesting to note that a 78 % of the total methane yields was produced in the first twenty days and a small amount of gas (approximately 0.0427 m^3 kg_{VS}^{-1}) was released during the rest of the digestion process. Methane generation was not nil at the end of the assay and hence a small amount of gas would be produced after 100 days of the BMP test. For PLAS-31, cumulative methane yields followed a linear shape denoting continuously increasing yields throughout the digestion process. The specific bioplastic showed a high potential for conversion even on the last incubation day and therefore its degradation would likely proceed for a longer period of time than 100 days. Gas release from PLAS-13 was comparable to that from LDPE-50 from the twelfth day onwards (Figure 3). This observation presumably suggests that the increasing methane production from PLAS-13 likely resulted from a slow decomposition of plastic structures in the polymeric material. It is also interesting to mention that inoculum adopted a methane production pattern that resembled to that of LDPE-50 during 100 days of incubation. Inoculum exhibited a slightly higher methane release than LDPE-50 for the first 70 days, however, degradation of the conventional plastic started being greater than that of inoculum in the following period and until the end of digestion . Hypothetically, at an incubation time over the 100 days the cumulative methane curve of digestion of LDPE-50 would presumably follow the same increasing trend and its deviation from the corresponding curve of inoculum would be progressively augmented.

In an attempt to gain more information on the decomposition of the three polymers, plastic particles at the end of each assay were rinsed with distilled water and their surface area was examined using SEM analysis (Figure 2 (d-f)). Digestate derived from LDPE-50 possessed a very similar surface area to the pristine material which is likely related to its limited decomposition during anaerobic digestion. Polymeric structures seem to decompose slowly, as such the material would likely further degrade with a low rate in case of a prolonged process over 100 days. Surface area of PLAS-31 was more clearly influenced by digestion with the initial dense structure (Figure 2(b)) being replaced by a more open one containing voids and to some extent visible polymeric formations (Figure 2(e)) probably originating from the plastic substances used as substrate for the production of bioplastic. Plastic structures became visible probably due to a partial decomposition and removal of organic matter from the material. The remaining distinguishable organics constitute additional indication of a potential of the material to further degrade. PLAS-13 showed the most significant change of surface area. In this case, clean polymeric structures could be distinguished in Figure 2(f) that were likely related to the polymers used for the production of the bioplastic. As mentioned above, removal of soluble organic compounds from PLAS-13 was significant even by the first 6-7 days of incubation and thus any degradable components would probably be lost within 100 days of digestion. According to this assumption, methane release in most of the anaerobic digestion process based on a very slow degradation of the plastic fraction of PLAS-13 and could potentially proceed for a longer period than 100 days.

A main difference of the three polymers concerned the time of their decomposition. As discussed above, PLAS-13 decomposed mainly in the initial period of incubation (6-7 days) and then the plastic fraction degraded slowly until the end of the BMP assay. PLAS-31 converted with a stable rate throughout the digestion process and presents potential to continue decomposing with the same rate over a longer period of time than the 100 days, until the degradable part would be totally consumed by bacteria. LDPE-50 decomposed according to the same linear pattern with PLAS-31 but with a much lower rate, as such the time required for its degradation would be longer than both bioplastics. Consequently, even the conventional plastic bag showed a small decomposition under anaerobic conditions, however, the time required for its total conversion would be much longer compared to the bioplastic materials.

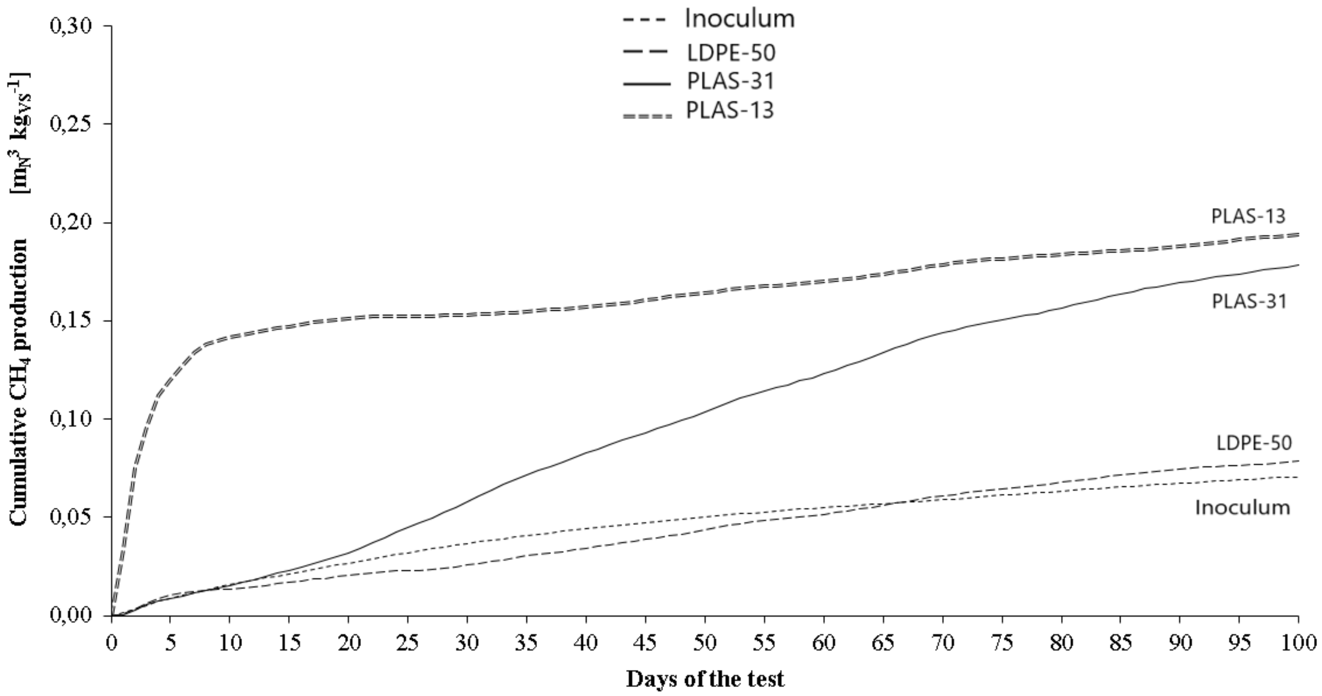
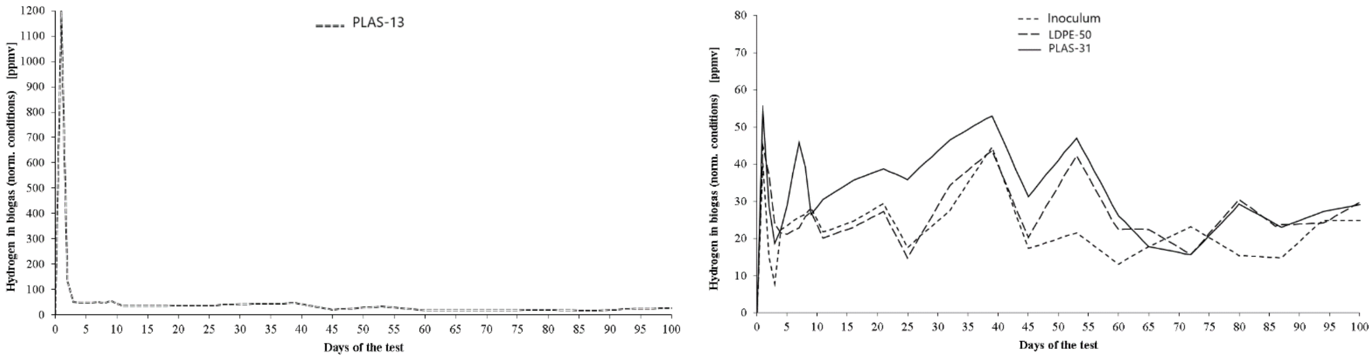


Figure 3: Cumulative CH_4 production during anaerobic digestion of polymeric materials

Figure 4 displays the daily hydrogen release from the anaerobic digestion of plastics. Hydrogen yields were significantly high over the initial three days of incubation of PLAS-13 (Figure 4(a)), which was probably related to a significant amount of methane liberated from the specific substrate at the beginning (6-7 days) of digestion (Figure 3). The large hydrogen generation rate even by the first day confirms an enhanced content of easily soluble organic compounds in PLAS-13. In essence, the soluble components are hydrolysed immediately after the process initiation leading to an accumulation of higher volatile acids, lactate ethanol, propionate, and butyrate (referred to as electron sinks) which cannot be directly consumed by methanogens. At this point, an intervention of hydrogen producing acetogenic bacteria is required for sinks degradation. These bacteria convert the electron sinks to acetate, carbon dioxide and hydrogen before acetate and hydrogen consuming methanogenic bacteria start producing biogas[27]. The high amount of hydrogen during the first three days of digestion presumably enabled an immobilization of hydrogen consuming methanogenic microorganisms and led to a rapid methane release within the first eleven days of digestion (Figure 3). Thereafter, hydrogen yields declined and became comparable to those produced by the other two polymeric materials (Figure 4(b)). This change was also reflected on the cumulative methane generation curves where the rate of methane release from digestion of PLAS-13 reduced and became comparable to that of LDPE-50 and lower than that of PLAS-31. It is interesting to mention that the hydrogen production in the case of PLAS-31 was greater than that of the other two plastics from the twelfth day and until the end of digestion. This likely led to the great methane generation rate of the specific material (Figure 3), as described above.



(a) (b)

Figure 4: Daily H_2 production during anaerobic digestion of (a) PLAS-13 and (b) LDPE-50 and PLAS-31

Conclusions

The anaerobic digestion of three types of commercial bags was examined under mesophilic conditions in long-term BMP tests. LDPE-50 decomposed only negligibly and methane produced from its digestion only slightly exceeded that of inoculum. PLA-based bioplastic (PLAS-31) showed a better degradation performance and the biogas produced from its anaerobic digestion approached a value of 0.2599 $m^3\,kg_{VS}^{-1}$ at the end of the 100 days of BMP test. The corresponding amount produced by PLAS-13 (0.3182 $m^3\,kg_{VS}^{-1}$) was the highest among the examined biodegradable bags. The biodegradable organic content of bioplastics was the main factor defining the generation of biogas and methane. Surface of LDPE-50 only slightly changed with anaerobic digestion. The most significant modification of the surface was observed for PLAS-13 where clean polymeric structures appeared after digestion. PLAS-31 presented a higher capability to produce biogas for a period longer than 100 days.

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Potenciál výroby bioplynu u biologicky rozložitelných plastů na bázi škrobu a polylaktidu

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Souhrn

Plastové materiály se při ukládání v přírodě rozkládají extrémně pomalu a jejich úplná degradace trvá mnoho dekád. V poslední době jsou složky komerčních plastových materiálů alespoň částečně nahrazovány biologicky odbouratelnými přísadami. Kyselina polymléčná (PLA) a polymery na bázi škrobu jsou alternativy používané pro tento účel, aby nahradily 50-100% hmoty plastového materiálu. Příspěvek diskutuje výsledky produkce bioplynu a methanu vsádkovou jednostupňovou mezofilní anaerobní digescí z konvenčního a dvou rozdílných komerčních biodegradabilních pytlů po dobu 100 dní, aby se zjistila jejich degradační schopnost a prozkoumal se jejich potenciál produkce bioplynu a methanu po dlouhé období procesu vyhnívání. Plast na bázi LDPE (LDPE-50) se po 100 dnech digesce rozložil zanedbatelně za vzniku 0.0785 m^3 kg_{VS}^{-1} methanu, zatímco bioplast na pázi PLA (PLAS-31) vykázal lepší degradační schopnost (0.1782m^3 kg_{VS}^{-1}). Pro další biologicky odbouratelný pytel (PLAS-13) byla získána produkce methanu 0.1941 m^3 kg_{VS}^{-1}, což naznačuje že za specifických podmínek by bioplasty mohly poskytnout poměrně zajímavé množství bioplynu. Rozložitelný organický material v bioplastech byl hlavním faktorem určujícím jejich přeměnu na bioplyn a methan. Anaerobní digesce měla minimální dopad na povrch LDPE-50, zatímco k nejvýraznější změně povrchu došlo u PLAS-13, kde po digesci vznikly čisté polymerní struktury v důsledku odstranění významné části organických látek. PLAS-31 vykazoval po 100 dnech potenciál pro další degradaci anaerobní digescí.

***Klíčová slova**: anaerobní digesce, BMP testy, bioplasty, LDPE, kyselina polymléčná, biodegradace*

Crushed ceramic wastes and its effect on strength and abrasion characteristics of roller compacted concrete pavement

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Abstract

The high rate of using ceramic and tile in building industry has led to the release of a high volumes of ceramic and tile wastes after the end of life of a building and the demolition process which has negative effects on environment. If these wastes could be used as an alternative for a portion of concrete's natural aggregates, its destructive effects will be reduced. In this study, wastes of the ceramic and tile factories located in central Iran are crushed and granularized within the range of regulations. Then, 15% and 30% of the aggregates weight in the pavement concrete mix is replaced with the wastes. The pavement concrete mix containing crushed ceramics undergoes the investigations of fracture mechanical behavior (compressive and flexural strength tests) in curing periods of 3, 7, and 14 days. The results show that 15% replacement will improve abrasive resistance; while, 30% replacement of these wastes has reduced the compressive and flexural strength of rolling concrete in different ages. The relationship between compressive strength and abrasion resistance of crushed ceramics were obtained using second-order nonlinear regression. The intersection of these two curves results replacing 18.95% of aggregates weight with crushed ceramics; that suggests the compressive strength and abrasion rate of 29.36 MPa and 2.10%, respectively.

Keywords: *ceramic and tile wastes, flexural strength, pavement,* roller-compacted concrete pavement*, fracture energy, abrasive resistance.*

Introduction

The increase in industrial wastes around the world, that arises many environmental problems and the need for producing new materials, has led to the utilization of factories wastes in recycled form. The roller-compacted concrete pavement (RCCP) is one of jointed plain concrete pavement (JPCP) types. Because of easy implementation and the lack of need for using steel, the RCCPs are used widely in most countries, including Iran. In the present research, concrete's mechanical behaviors, including compressive and flexural strength, have been investigated. Besides, evaluation of the void space in concretes produced with ceramic wastes is addressed. The ceramic wastes are used as different portions of natural aggregates to evaluate the mechanical strength of recycled concretes samples. These pavements have a more sensitive surface and higher possibility for damages and destructions than conventional and reinforced concrete pavements because of the curing type and low slump. According to ACI Committee 201, pavement concrete's abrasion resistance is the ability to resist abrasion and friction caused by contact of vehicle's wheels and slipping and abrasion of the pavement caused by other materials. In recent years, utilizing waste in concrete as an alternative for aggregate cement has obtained researchers attention and building industries. The use of ceramic wastes and fibers in producing concrete [1-3], and using powdered and crushed tiles as pozzolan in producing ready-mix concretes (RMCs) has been studied [4,5]. Also, using ceramic powder and waste bricks and nano-silica for producing high-strength concrete has been investigated [6-8]. Utilizing ceramic powder as a part of cement [9,10], studying the mechanical properties and durability of concretes containing methacholine [11], and investigating the effect of methacholine on the properties of high-strength concretes [12] have been addressed. A study has been performed on using ceramic and paper wastes to produce porous concrete. Different aggregates have been used in this study, and the void content, strength, and permeability were measured. The results indicate that this concrete's strength is lower, while its permeability is acceptable [13]. The 16 mix designs with 0, 10, 20, and 30% of fine-grained materials replaced with crushed ceramics, and 0, 5, 10 and 15% of cement replaced with ceramic powder were used to determine the effect of replacing aggregates with waste crushed ceramic and replacing cement with ceramic powder on the properties of the fresh and hardened concrete. In this study, the water to powder ratio of 0.4, 0.45, 0.5 and 0.55 were prepared. According to the analyses performed by the Taguchi method and from the tests results, it was found that adding crushed ceramics instead of aggregates is useful up to 20% of weight ratio; on the other hand, adding ceramic powder up to 10% ratio of weight is useful. Using both weight ratios mentioned earlier is recommended in terms of strength and economics [2].

An investigation has been done on the effect of using green Tuff of Shahindezh on the mechanical behavior of the roller-compact concretes. The compressive strength results at the ages of 7 and 28 days show that at 28 days, all of the studied mixtures have compressive strength is higher than 35 MPa. Besides, the ratio of fracture module to the square of compressive strength was calculated 0.7. The permeability results underwater pressure indicate that by reducing the water to cement ratio of 0.38 to 0.33, in equal Vee-Bee time, water permeability reduces from 14 to 10 mm. The very low permeability (5mm) of mixtures containing silica fume and pozzolanic cement indicates more dense microscale of the mixtures mentioned above [3]. Different works have been done worldwide on utilizing industrial and ceramic wastes in the RCCP and conventional concrete pavements [4-6]. The effect of granulation and content of rubber crumbs or recycled asphalt crumbs and cement on the stress intensity factor in modes I and II has been investigated in a paper about RCC beams containing rubber crumbs and recycled asphalt crumb. Sample's stress intensity factor results show that the RCC mix has a significant effect on its failure behavior. Besides, although the recycled material mix has increased the flexibility and toughness of samples, it will have a negative effect on the failure stress intensity factor of the samples and their bearing capacity [7].

The purpose of this research is to experimentally investigate the utilization of crushed ceramics in the RCC mix. To achieve this purpose, the crushed ceramics are used between the aggregates, and different contents of them are replaced in concrete instead of the required sand. The RCCP is a mixture of water and cement, which is relatively stiff and dry with a slump near zero. Compared with conventional concrete, the RCCP has higher density and durability, more execution speed, lower costs, and no rebar is needed. Of course, due to the numerous advantages of roller-compact concrete, it is used mostly for low-traffic areas, parking, roadsides, and highways.

Materials and methods

The tests that are performed, including the cubic sample's compressive strength at the ages of 3, 7, and 14 days, also the flexural strength of the concrete samples in these curing periods. Some other tests include water absorption (dry and fresh concrete) and elasticity module using the ultrasonic method. The proposed contents for replacing crushed ceramic are 15 and 30%, and they are available in three different granulations gradation. The granulation used in the concrete pavement is according to the ASTM mix design code [14]. Table 1 lists the stone materials ratio code according to the national regulations and previous specifications. The water to cement ratio and the cement to aggregates ratio used for producing the samples are 35% and 25%, respectively. Coding of the laboratory samples, after the letter "C", is the percentage of the waste ceramic content. To increase accuracy, three samples were made from each mixing design, If the Coefficient of Variation of the results data was more than 15%, the number of samples would increase.

Table 1: A mix ratio of components of a sample containing crushed ceramic (kg/m^3)

Sample code	*Water*	*Cement*	*Fine Aggregate*	*Coarse Aggregate*	*Crushed Ceramics*
C00	95	322	470	1010	-
C05	95	308	470	800	210
C10	95	295	470	700	310
C20	95	290	470	600	410
C30	95	281	470	500	510

To select appropriate materials (cement and aggregate), the stone materials were prepared from Barez concrete supplier. These materials are mainly mountainous and containing limestone. The specifications of these materials and their standards are presented in Table 2.

Table 2: Aggregates quality tests Results

Test Description	**Results**	**Test Standards**		**Max Allowable**
		ASTM	**AASHTO**	
Los Angeles Abrasion (%)	19	C131	T96	25
Max Water Absorption ،Coarse Aggregate (%)	2.2	C127	T85	2.5
Max Water Absorption ، Fine Aggregate(%)	2.4	C128	T84	2.5
Max Flakiness Index (%)	6	BS812		-
One Fractured Face Test (%)	92	D 5821	-	-
Two Fractured Face Test (%)	97	D 5821	-	-
Bulk Density (kg/m^3)	2020	C29	-	-
Porosity (%)	21.7	C830	-	-

The 15 cm cubic samples and the 10×10×35 cm flexural beam samples were used for compressive strength and flexural tests, respectively. The cylindrical samples with 5 cm diameter and 15cm length were used for the abrasion test according to the revolving abrasion test with the E-2045 standard [15]. The samples were cured for 14 days for the strength test. The reason for selecting this short period was the possibility of reopening a path. In the present study, for investigating abrasion resistance in concrete containing recycled crushed ceramics, 18 concrete samples were produced and tested. These samples were used to measure compressive, flexural, abrasion, and friction resistance. As shown in Table 1, due to the variability of the crushed ceramic content, the samples were coded. Some conventional samples (without crushed ceramics) were produced for comparison. The Portland cement type II prepared from Abadeh factory was the cement used in this study. The cement's specific surface is 2900 gr^2/cm (ASTM C204-16) [14], and its chemical components are shown in Table 3.

Table 3: Chemical and physical specifications of Portland cement type II

<table>
<tr><th colspan="2" rowspan="2">Physical Specification</th><th rowspan="2">Blaine (cm^2/gr)</th><th colspan="3">Vicat setting time (min)</th><th colspan="6">Strength Test (kg/cm^2)</th></tr>
<tr><th>Primary</th><th colspan="2">Secondary</th><th colspan="2">2 Days</th><th>3 Days</th><th>7 Days</th><th colspan="2">28 Days</th></tr>
<tr><td colspan="2">Value</td><td>2900</td><td>150</td><td colspan="2">200</td><td colspan="2">160</td><td>200</td><td>310</td><td colspan="2">400</td></tr>
<tr><td>Chemical characteristics</td><td>LOI</td><td>Total Alkali</td><td>F.Co</td><td>Inr</td><td>Cl</td><td>SO_3</td><td>Al_2O_3</td><td>SiO_2</td><td>MgO</td><td>Fe_2O_3</td><td>CaO</td></tr>
<tr><td>Percent</td><td>1.2</td><td>0.7</td><td>1.1</td><td>0.65</td><td>0.03</td><td>1.8</td><td>4.5</td><td>21</td><td>2.5</td><td>3.6</td><td>63.4</td></tr>
</table>

Since aggregates compose approximately 75 to 85% of concrete volume, selecting aggregates in roller-compact concrete is essential. The regulations for aggregates assumed in the RCC are the same as those of conventional concrete. The maximum size of aggregate in the RCC has a considerable effect on the degree of density of thin layers, although, in thicker layers, this effect is negligible. In the pavement RCC, aggregates with size more than 25.4 mm are not recommended, because creating a relatively smooth surface for road pavement using coarse aggregates is difficult.

The crushed materials were prepared from the crushed ceramics of the Meybodtile factory. The large pieces of ceramics were completely crushed in the lab using a compaction hammer. First, the 2-inch sieve was used to separate and gradation the crushed ceramic to keep their specifications of one type and size. Then, a brand was used so that the ceramic wastes specifications remain constant during the research. The samples gradation is presented in Table 4, and specifications of aggregates obtained from ceramic wastes are listed in Table 5.

Table 4: Results of gradation test

Sieve number	Remaining on the sieve (gr)	Remaining on the sieve (%)	Passed through the sieve (%)	Cumulative Remaining (%)
12.5	0	0.00	100.00	0.00
9.5	94.7	4.74	95.26	4.74
6.35	875	43.82	51.43	48.57
#4	782	39.16	12.27	87.73
#8	183	9.17	3.11	96.89
#16	46	2.30	0.80	99.20
Sub-sieve	16	0.80	0.00	100.00
Sum	1996.7	99.835		

Table 5: Specifications of chemical compounds and physical specifications decompositions of tile

<table>
<tr><th colspan="2">Detected element</th><th colspan="2">Quantity (%)</th></tr>
<tr><td colspan="2">SiO_2</td><td colspan="2">69</td></tr>
<tr><td colspan="2">Al_2O_3</td><td colspan="2">18.5</td></tr>
<tr><td colspan="2">MgO</td><td colspan="2">0.72</td></tr>
<tr><td colspan="2">P_2O_3</td><td colspan="2">0.03</td></tr>
<tr><td colspan="2">TiO_2</td><td colspan="2">0.73</td></tr>
<tr><td colspan="2">SO_3</td><td colspan="2">0.06</td></tr>
<tr><td colspan="2">MnO</td><td colspan="2">0.08</td></tr>
<tr><td colspan="2">CaO</td><td colspan="2">1.5</td></tr>
<tr><td colspan="2">Na_2O</td><td colspan="2">2.01</td></tr>
<tr><td colspan="2">K_2O</td><td colspan="2">1.63</td></tr>
<tr><td colspan="2">Fe_2O_3</td><td colspan="2">4.81</td></tr>
<tr><td colspan="2">LOI</td><td colspan="2">0.5</td></tr>
<tr><th rowspan="2">Properties</th><th rowspan="2">Standard. No.</th><th colspan="2">Dimension of broken waste tile</th></tr>
<tr><td>Fine grained</td><td>Coarse-grained</td></tr>
<tr><td>Absorption of water</td><td>ASTM C642</td><td>7</td><td>5</td></tr>
<tr><td>Particle Shape</td><td>ASTM D 4791</td><td>-</td><td>cubic</td></tr>
<tr><td>Bulky density</td><td>ASTM C29</td><td>2.35 (gr/cm^3)</td><td>2.33 (gr/cm^3)</td></tr>
<tr><td>Coefficient of thermal conductivity</td><td>ASTM C177</td><td colspan="2">1.04 (W/m.K)</td></tr>
</table>

Since the roller-compact concrete is almost dry, a different method is used for producing RCC samples compared to conventional ones. In the sample compaction method, the RCC sample is placed in a mold and is compacted on a vibrating table under the effect of overhead and layer weights according to the ASTMC1176-13 standard [14]. In this method, the samples are compacted and prepared by compaction hammer blows in five layers according to the ASTMDISS7-12 standard [14]. Compacting using a compaction hammer gets closer to the real density; therefore, this method is selected in this research. The 15×15×15 cm samples and the 10×10×35 cm flexural beam samples were used to evaluate compressive and flexural strength. The compression tests were carried out in a 3000 kN hydraulic testing machine according to ASTM- C78 [14] .First, samples were placed in a mold for 24h and covered with plastic. Then, samples were extracted from mold and were maintained in water for 3, 7 and 14 days. Fabricated samples for this study are shown in Figure 1.

According to the British standard, the cubic samples have dimensions of 150mm, which are filled in three layers; each layer is compacted with a stick 25 times. Besides, as an alternative method, these concrete cubes can also be compacted by a vibrator. However, since the concrete samples were of RCC type, and their water content is less compared to other samples, the concrete mold was compacted 25 times per layer, so the creation of air cavities in concrete and honeycombing are prevented.

Figure 1: Variation of the samples tested in this study

In fact, the concrete cube samples test provides an overall idea of all concrete specifications. With this test, it can be recognized whether the concrete is good enough for our study. The concrete's compressive strength affecting different factors including water to cement ration, cement strength, concrete quality, quality control during the production and so on. This test is performed on the cubic-shaped pieces of concrete. Therefore, this is called a cube sample test, but it is also common to perform this test on the cylindrical pieces. Depending on the aggregates size used in concrete, the 15×15×15 cm or 10×10×10 cm samples are made. Given that in this test, the maximum nominal size of aggregate is 19mm, the cube samples with dimensions of 15 cm are used. Since strength depends on the loading rate, for hydraulic jacks, the sample must undergo the loading at a controlled rate between 0.15 to 0.35 MPa/sec; on the other hand, for mechanical jacks, the deformation rate must be limited to 1 mm/min. The loading continues until the failure point, which is the maximum loading the sample can bear. Then, the maximum loading and failure are reported.

The lack of crack is essential in maintaining and durability of concrete structures to maintain rebars and prevent steel rebar corrosion [16]. Since applying axial tensile to the concrete sample is difficult, the concrete tensile strength is determined indirectly using the flexural test and Brazilian test. Such methods predict the strengths higher than the real strength under axial tensile loading. In the flexural strength test, the maximum theoretical tensile was created in the lower axis of the studied beam, called modulus of rupture, used to design highways and airports pavement. This test is recommended by ASTM C 78 standard [14].

British pendulum number (BPN) is an index for pavement surface skid resistance to express friction resistance. The ASTME404 standard is used to calculate this type of resistance [14]. The 6.35×6.35×25.4 cm samples were used in this test, and the moving path length of the slider is 12.5cm, and the surface of the samples were cleaned and wetted. Figure 2 shows the British pendulum test.

Figure 2: Sample of concrete surface under British pendulum test

The aggregate abrasion value test, Dorry test, which gives a measure of the resistance of an aggregate to surface wear by abrasion [17], is performed according to Figure 3. This machine has a disc with a diameter of 60cm. The abrasive materials are inserted in three samples with a 7 – 900 gr/min rate and the test is performed according to EN1097-8 standards [15]. The aggregate abrasion value is the difference between the material surface's weight and its weight after the test in terms of its initial weight within the materials wear limit.

Figure 3: A view of concrete sample surface in Dorry test

Results and discussion

The variations of compressive strength in samples can be attributed to aggregates shape and strength in the concrete. Since ceramic wastes aggregates have fracture percentages, therefore they have low water absorption and high stiffness. It is observed that the compressive strength increases as the crushed ceramic content decrease. This increase continues until the waste materials content of 15%; then, by increasing the waste aggregates content and the lack of enough water to perform hydration reactions caused by tiles water absorption, the sample approvals are reduced. Figure 4 shows an example of strength variations. Lower energy is required for starting and growing cracks within the paste in the uniaxial tensile mode. The main factors for fracture in the concrete are rapid growth and the relation between the cracks system, including cracks in the transmission area and new cracks within the paste. The sample fracture has low fragility in compression mode than the flexural because more energy will be needed for creating and propagating cracks within the paste. Basically, for concretes with low to medium strength, it is agreed that in the uniaxial pressure test, new cracks do not occur in stresses less than 50% of fracture stress.

A stable system of cracks, called shear continuity cracks, exists near the coarse aggregates in this stage. New cracks are created in the paste for higher stresses, which rapidly increases as the stress has increased. The cracks exist in the paste, and the transition area (shear continuity crack) is finally connected and creates a fracture with an angle of 20 to 30 degrees respect to load direction. Given the existence of glaze in some crushed ceramics, and very low permeability of this side of crushed ceramic, the transition area is too weak, and most of the cracks are started in this area. As a result, the higher percentage of crushed ceramics are used, the number of shear continuity cracks increase and will have a higher effect on the sample's fracture.

According to the results obtained from tests, variations of compressive strength in the samples can be attributed to aggregates shape and strength in the concrete. Since the ceramic waste aggregates have some fractures, they have little water absorption and high stiffness. It is observed that with an increase in the crushed ceramic percentage, the compressive strength increases by up to 15%. With further increase in the waste aggregates content and due to the lack of enough water to perform hydration reactions caused by water absorption by tile, the samples approvals are reduced.

The main factors for fracture in the concrete are rapid growth and relation between the cracks system, which includes cracks available in the transmission area and new cracks within the paste. In compression mode, the sample fracture has low fragility than the flexural because more energy will be needed for creating and propagating cracks within the paste. Figure 5 shows how samples fracture as the loading is applied. Basically, for concretes with low to medium strength, it is agreed that in the uniaxial pressure test, new cracks do not occur in stresses less than 50% of fracture stress. A stable system of cracks, called shear continuity cracks, exists near the coarse aggregates in this stage. New cracks are created in the paste for higher stresses, which rapidly increases as the stress increases. The cracks exist in the paste and in the transition area (shear continuity crack) are finally connected and create a fracture with an angle of 20 to 30 degrees respect to load direction shown in Figure 6. Given the existence of glaze in some crushed ceramics, and very low permeability of this side of crushed ceramic, the transition area is too weak, and most of the cracks are started in this area. As a result, the higher percentage of crushed ceramics are used, the number of shear continuity cracks increase and will have a higher effect on the samples fracture.

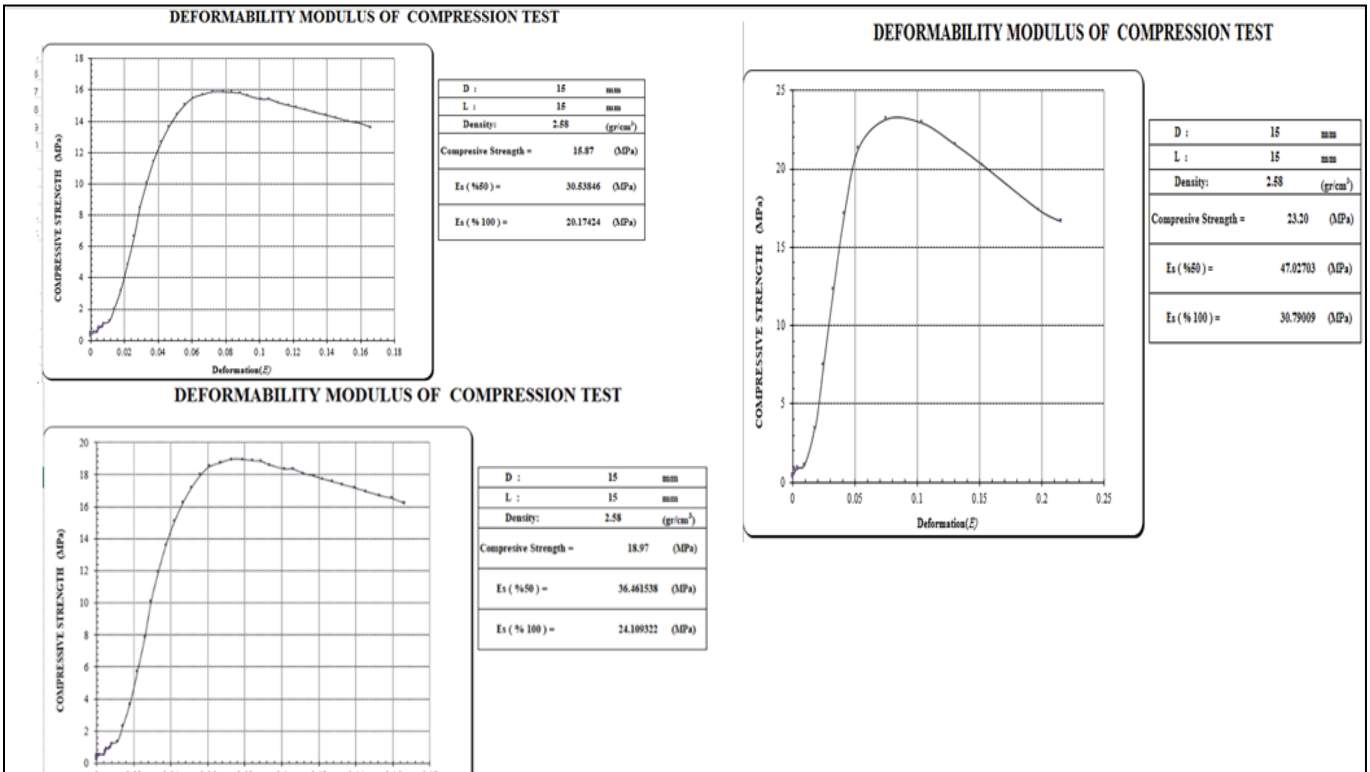

Figure 4: Deformation-stress variations plots

Figure 5: Images showing the cracks propagation in compressive samples

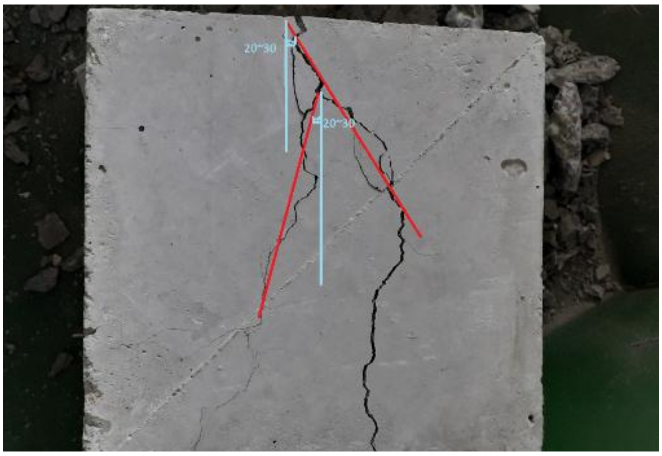

Figure 6: Cracks propagation angles in compressive samples

The flexural strength of samples is one of the parameters used in pavement design. Concrete pavements with higher flexural strength will have higher fatigue life and will crack later. This index is used in designing concrete pavements. Figure 7 shows the flexural strength of different mixtures in three different periods. As can be seen from the figure, the mixes containing crushed ceramic wastes have higher flexural strength. Besides, how the samples are fractured and the rupture at the time of applying load is shown in this figure.

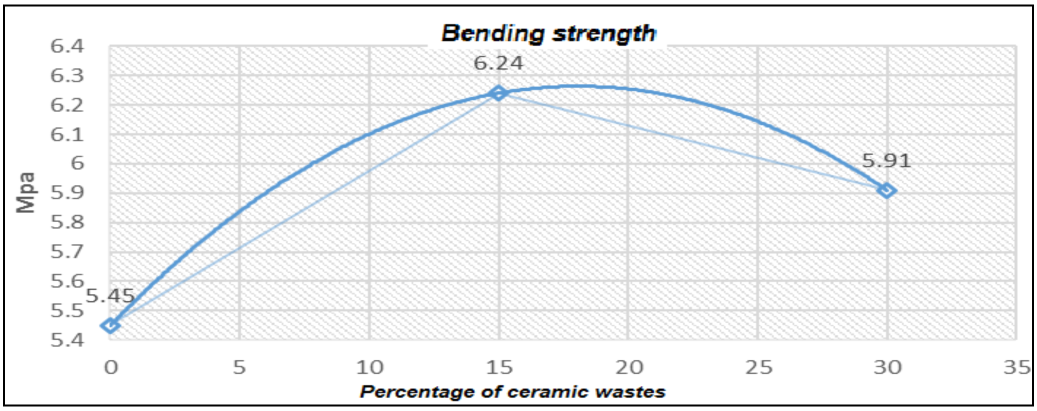

Figure 7: Flexural strength variation curve of samples containing different percentage of ceramic wastes

British pendulum number (BPN) is an index for pavement surface slip resistance to express friction resistance. To measure this resistance the same test condition for the samples was employed, as the previous ones. Figure 8 presents the abrasion results according to the usage of different percentages of ceramic wastes.

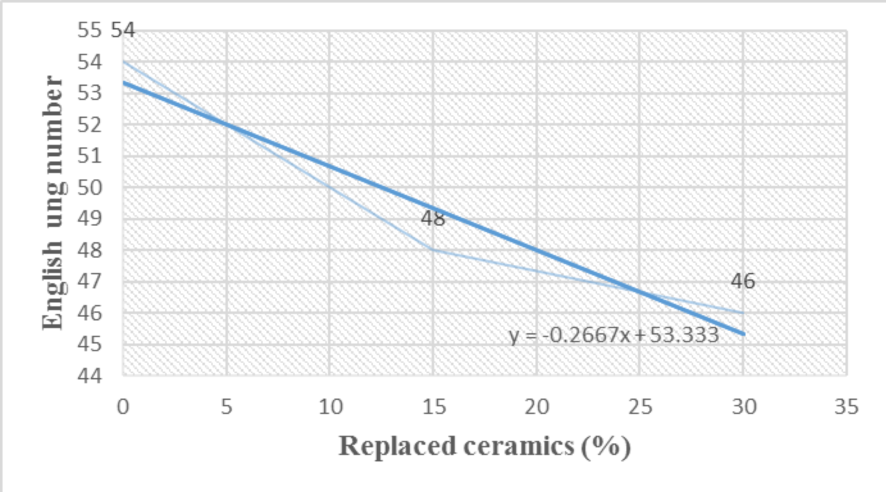

Figure 8: Friction test British pendulum number (BPN) results

In this study, the Dorry test was used to evaluate the abrasion resistance. The images of concrete samples surface before and after abrasion are shown in Figure 9. It is evident from this figure that when the crushed ceramics are used, the friction abrasion is reduced. By replacing 15% of ceramic in the samples, the surface friction rate has decreased which is due to the addition of aggregates with a smooth surface (in crushed ceramics). The sample with 30% of crushed ceramics has better abrasion resistance than the sample with 15% of crushed ceramics. This may be due to a strong bond of cement-crushed ceramic matrix and the higher stiffness of crushed ceramic against the abrasion; in tile and ceramic production industry, the product must have high abrasion resistance. Dorry test results are presented in Table 6 and Figure 10.

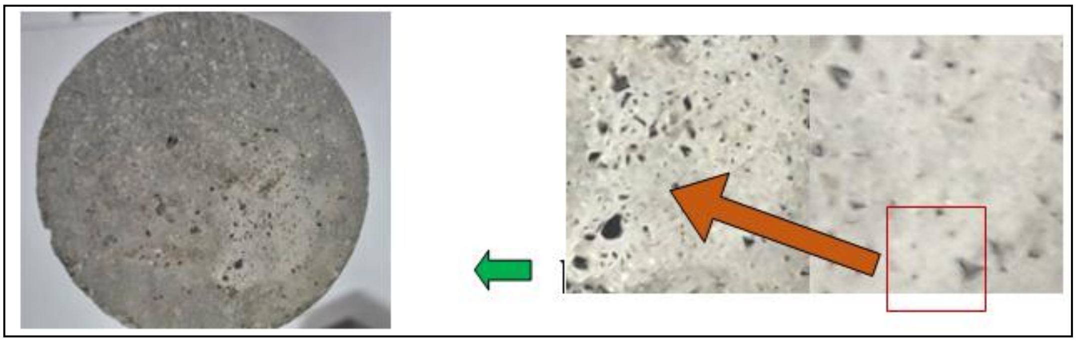

Figure 9: One concrete sample surface after abrasion test

Table 6: Dorry test results

Sample code	Weight before the test (gr)	Weight after the test (gr)	Weight Loss (%)
0%	241.3	234.4	2.86%
15%	291.2	284.8	2.20%
30%	195.5	191.6	1.99%

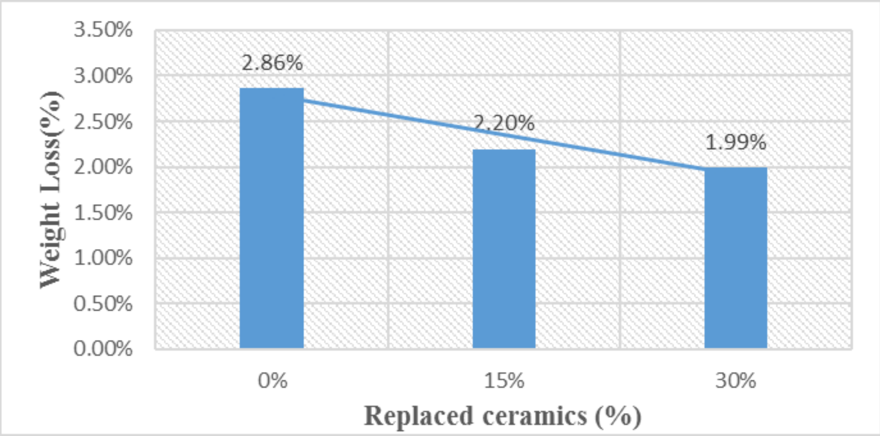

Figure 10: Weight loss variation of samples containing different percentages of ceramic wastes

Two indices, including compressive strength and abrasion resistance, were used to determine the optimal percentage of crushed ceramic. These indices are the main specifications of RCC samples. Figure 11 shows the optimal percentage of crushed ceramics. Since the two indices mentioned earlier have different measurement units, the standardized values in coordinate axes were used. Equation was used for standardization:

$$X_n = \frac{X_i - X_{\min}}{X_{\max} - X_{\min}}$$

where X_i, X_{min}, and X_{max} show the observed, minimum and maximum values of each variable, respectively.

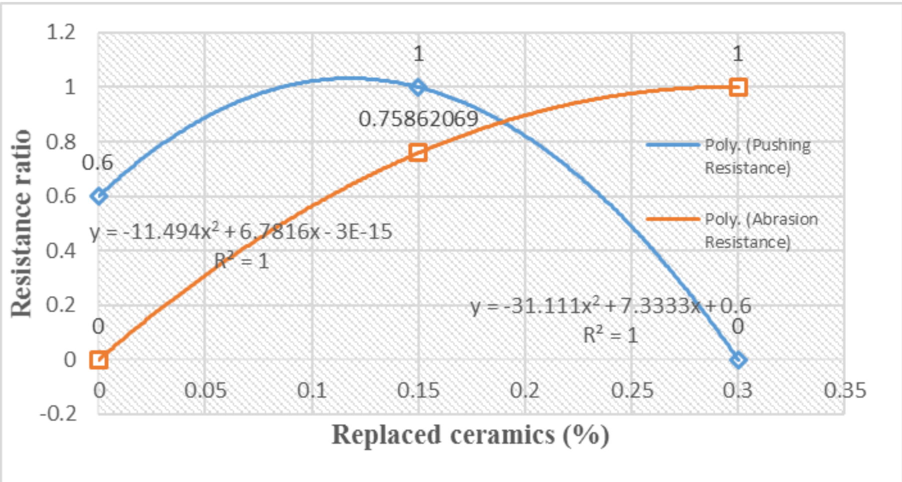

Figure 11: Plots for determining the optimal percentage of ceramic wastes

Other researchers confirm these findings and even point out, Concrete including waste ceramics(WC) decreases the renewed hardened density and density, and it reduces linearly with the increase in the ceramic content. The hardened properties of concrete usually decrease as the ceramic content incorporated is improved. Though, the compressive, flexural, indirect tensile strength (ITS), and elasticity modulus of WC concrete, which is slightly above reference concrete . WC concrete has more water absorption than RC. WC materials exhibit high abrasion resistance, freeze–thaw resistance, electrical resistance, and resistance to sulfate and nsulphuric attacks and environmental factors [18].

Conclusions

The need for managing industrial wastes is a way to preserve the environment in today's world. According to the tests performed on the ceramic wastes to determine the strength and abrasion of RCC, the following results are highlighted:

- With an increase in the contents of crushed ceramic wastes, the strength first increases. However, with the further addition of crushed ceramic (more than 15%), the compressive strength of RCC samples is decreased.
- Given the reduced costs, preserving the environment, waste management, and enhanced mechanical and abrasion resistance of RCC samples, using the crushed ceramic wastes in different conditions can be an action for sustainable development.
- The optimal percentage of crushed ceramic and the relationship between compressive strength and abrasion resistance were obtained using a second-order nonlinear regression. These two plot's intersection indicates that the optimal crushed ceramic percentage to be added to aggregates is 18.95%. At this point, the compressive strength and abrasion rates are 29.36 MPa and 2.10%, respectively.

List of symbols

BPN *British Pendulum Number Test*
JPCP *Jointed Plain Concrete Pavement*
RCCP *Roller-Compacted Concrete Pavement*
RMC *Ready-Mix Concretes*

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Drcený keramický odpad a jeho vliv na pevnostní a obrusné vlastnosti válečkově válcovaných betonových vozovek

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Abstrakt

Vysoká míra používání keramiky a dlaždic ve stavebnictví vedla k uvolňování velkého množství keramických a dlaždicových odpadů po skončení životnosti budovy a demoličních procesech, což má negativní vliv na životní prostředí. Pokud by tyto odpady mohly být použity jako náhrada části přírodního kameniva do betonu, jeho destruktivní účinky se sníží. V této studii jsou odpady z továren na výrobu keramiky a dlaždic umístěných ve středním Íránu drceny a granulovány v rámci rozsahu předpisů. Poté je 15 % a 30 % hmotnosti kameniva ve směsi vozovkového betonu nahrazeno odpady.

Dlažební betonová směs obsahující drcenou keramiku je podrobena zkoumání lomově mechanického chování (zkoušky pevnosti v tlaku a ohybu) v dobách zrání 3, 7 a 14 dnů. Výsledky ukazují, že 15% náhrada zlepší pevnost při válcování; zatímco 30% náhrada těchto odpadů snížila pevnost v tlaku a ohybu válcovaného betonu v různém stáří. Vztah mezi pevností v tlaku a otěruvzdorností drcené keramiky byl získán pomocí nelineární regrese druhého řádu. Průnik těchto dvou křivek vede k nahrazení 18,95 % hmotnosti kameniva drcenou keramikou; což naznačuje pevnost v tlaku a rychlost otěru 29,36 MPa a 2,10 %, v tomto pořadí.

Klíčová slova: *keramické a dlaždicové odpady, pevnost v ohybu, vozovka, válečková zhutněná betonová dlažba, lomová energie, otěruvzdornost.*

The Current Status and Steps Towards Hospital Waste Management in the Public and Private Sector Hospitals of District Swabi, KP, Pakistan.

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Abstract

Hospitals in Pakistan generate a huge mass of waste which has been reported to be managed and handle poorly by the hospital administration. This mismanagement causes several environmental and health problems inside the hospital and outside of the population. The present study aimed to describe the qualitative results of observations of 4 major public and private sector hospitals in the city of Swabi, KP, Pakistan. The required data was obtained through direct and indirect observations of the medical and administrative staff to know the way they handle the waste. One of the important aspects of our methodology was the development of appropriate questionnaires to understand the nature of the system. Findings of the study showed that almost public sector hospitals generate a big mass of solid waste (120-130 kg per day) and don't keep its management on their priority. The practices of waste handling, segregation, storage, transportation and disposal were below the Pakistan biosafety rules-2005. The private sector hospitals participate about 30-50 kg waste generation per day and were observed in better condition for waste handling and management. The recovery efficiency of collected salable waste was calculated as follows: plastic 14-10%, paper 10-15%, glass 12-17% and scrap/metal with 7-12% respectively. Rules and regulations regarding biomedical waste are not adequately followed. The study highlights improper management of waste in public sector hospitals. For better waste management, the hospital needs financial resources, skilled staff and the implementation of the 2005 hospital policy.

Keywords: *infectious waste, non-infectious waste, waste management, collection efficiency, waste disposal.*

Introduction

Hospitals are a place where patient problems are diagnosed, analyzed and treated. The generation of waste is essential during these activities. This waste is called "hospital waste" and refers to all waste, biological or non-biological, which has been discarded and will never be reused [1]. In hospitals, waste is produced during the treatment of infections and injuries. Most of the time, medical waste is considered contagious waste, if medical waste and other waste are not collected separately. When all waste is combined, then hospital waste is considered contagious waste [2].

The term hazardous waste is applied differently in different countries, including harmful chemicals, industrial easte, hospital waste, electronic waste, radioactive waste. These waste put harmful health impacts on human when not handled properly. Hazardous waste is considered risky to health which includes infectious, pathological, pharmaceutical, chemical, genotoxic and radioactive wastes. Traditionally, hospital waste is disposed of with municipal waste. However, since the late 1980s, the proliferation of blood related diseases such as the HIV hepatitis and various other diseases raised public awareness of the dangers of hospital waste recycling [3]. Concerns have been raised. Therefore, medical waste requires special treatment and should not be mixed with municipal waste. Good medical waste management requires special handling such as disposal or landfill facilities. Previous studies show that the best available technology for medical waste disposal is ignition [4]. Non-hazardous waste is produced by food scraps and their packaging [5]. Poor management of hospital waste has serious health effects from a public health point of view. A literature revealed the average production of infectious waste by a local/rural hospital in Pakistan is about 1.35 kg per day [6]. According to a latest study by Sadia et al, [7], an average of 1.33 kg minimum and upto 5 kg maximum of infectious waste is produced by a rural hospital per day in Pakistan. This happened because many medical accessories and clinical materials have been used in emergency cases, especially in maternity cases.

In Pakistan, the situation of hospital waste management is not much better because solid waste consists of toxic and noxious items that are difficult to handle. Exposure to this solid waste, when not properly managed, has a significant impact on the local environment and public health. For example, biohazardous waste generated by hospitals and other medical establishments contains a variety of components that have potentially infectious properties and pose a particular threat to public health as well as to the natural environment. It becomes more dangerous during pandemics and during curing methods [7]. The literature has revealed that most hospitals and independent doctors in Pakistan do not follow medical waste management practices, resulting in serious injuries and infections for themselves, other staff and patients [8,9,10]. Hospital waste in Pakistan is a source of various diseases and is also a target for soil researchers who rely on collection, recycling of syringes and other hazardous waste [11]. In particular, undercover teams in Pakistan are involved in selling used syringes in the markets [12]. In Pakistan, junior health workers suffer serious injuries that are of concern to hospitals and account for around 54% of health workers. This is poorly trained staff, poor calibration system, ignorance of waste management and concern for teaching staff [13]. Providing health care is a challengeable task for many underdeveloped countries. Pakistan also ranked among poor countries with 22.3% poverty line covering 5% of population with social health insurance [14,15]. Therefore, people become dependent on private health care providers. Therefore, the situation of private hospitals is to some extent better than that of public hospitals. It has been pointed out that the legitimacy of all aspects of cervical cancer in Pakistan is due to lack of trust in doctors, tenacity, compassion for female patients in certain issues and this standard should be measured on a large scale [16]. The researcher discovered in 2007 that hospitals do not have an infection control committee or any other unit. Healthcare did not show clean hands when treating patients [17]. The study found significant differences between public and private hospitals in terms of patient satisfaction and confidence. The standards of hospital services are improved and surgical instruments are safe in private hospitals. In private hospitals, doctors, as well as other service providers, differed in their intellectual skills and professionalism. Patients rely on the services of physicians based on their comprehensive training. Respect for the environment, maintenance staff, cleanliness and invincible products are important to mention in private hospitals [18].

COVID-19 has significantly affected the health sector, particularly in low-income countries having already a friable system [19]. In addition to the loss of life, the COVID-19 pandemic has also affected waste disposal and recycling practices. The excessive use of masks has increased the problems of pollution of the environment (aquatic and terrestrial ecosystems). Total containment has stopped the waste reception centers. An increase in COVID, patients may not delay diagnosis and treatment of the surgical disease, but also played a significant role in poor waste management practices [20]. Hospital waste comprises a big share of non-hazardous waste and a lower part of infectious waste. Risks to hospital waste can lead to illness. The hazardous nature of hospital waste may be due to one or more of the following characteristics, such as containing infectious agents and being genotoxic. The persons who are in contact or exposed to hospital waste are potentially at higher risk, comprising hospital staff such as medical personnel (doctors and nurses) and sweepers who handle this waste or are exposed to it as a result of mismanagement [21].

This study highlights the challenges and initiatives adopted to ensure safe waste management services in Swabi district hospitals. Swabi District is located in the south and southwest of Khyber Pakhtunkhwa Province, Pakistan. The city is located near the bank of the Indus River, covers about 1,543 km² area with a population load of 1,624,616 [22]. The district health system is good, but not too good. Several public and private hospitals are available in the district. In Swabi city, the main public hospitals are the Swabi District Health Quarters hospital (DHQ) and the Bacha Khan Medical Complex

(BMC). Among the private sector hospitals, the well-equipped health center is Jamal Medical Center (JMC)and Sardar Swabi Medical Center (SMC). All of these hospitals are located by road and easily accessible to visitors. The availability of medical staff at the public hospitals is not sufficient to treat patients. Therefore, locals used to go to private sector hospitals for medical treatment.

Material and methods

In this study, two type hospitals in the Swabi district of Khyber Pakhtunkhwa were selected and assessed to know the process of hospital waste management. For this, major public and private sector hospitals were selected. i) District Head Quarter Swabi, Bacha Khan Medical Complex (public) and ii) Sardar Medical Center Swabi, Jamal Medical Centre Swabi (private). The hospital investigation consists of critically examining the quantity of waste generated, waste collection, transportation, segregation, treatment and disposal. This assessment studied the protection at work of the responsible person, the degree of intensity with which the various directives are followed in the institutions and the rules and procedures obligatory by the organizational staff to maintain a hygienic environment around. This investigation also focused on potential difficulties to staff and workers associated with disposal of waste. To assess this, a questionnaire analysis was developed and a survey was conducted in selected hospitals. The data was collected on the basis of interactive interview sessions with the person in-charge, the survey of hospital units, field visits and crucial site observations.

Hospital Survey and Analysis

First, a reconnaissance survey was conducted to locate and identify hospitals. In the results, four hospitals were selected as representative for the study. The selection of hospitals was made on the basis of the locality (the most accessible sites), the number of patients and the area covered by the hospitals. The selected hospitals are the well-known health care units in the city having high bed capacity with high volume of patient visitors per day. About 7-8 field visits were paid and the selected hospitals were kept under observation for waste generation process until waste disposal.

Questionnaire Survey

To find out about the waste management strategy, a questionnaire session was supervised. Two questionnaires were designed, comprising both structured and unstructured questions. These questionnaires were completed by the team responsible for the hospital and waste management. These questionnaires were designed to identify various factors that limit the appropriate management of waste generated in various hospital units and its safe disposal. The questions of the mentioned questionnaires were planned to cover subjects of following given categories;

1. Quantity of waste generation
2. Waste collection and transportation
3. Waste storage
4. Waste segregation
5. Waste treatment and
6. Waste disposal.

Composition of Hospital Solid Waste

To know about waste composition, samples were divide into two groups for recyclable and non-recyclable items. For this, different waste items were identified in separate labelled plastic bags. These items were in dry form including paper, plastic glass, sharps etc. (Table-1). Each item was weighted/quantified with the help of digital scale and their quantity was expressed in percentage. Furthermore, scrap collection points locally called as *kabari shops* were also visited to know about the quantity and composition of waste coming from hospitals on daily basis.

Table 1: Composition of Solid Waste at Hospitals

Type	Waste
Recyclable/Saleable Waste	Plastic
	Paper
	Food
	Metal/Iron scrap
	Glass
Non-Recyclable Waste	Syringes and Sharps , Construction and demolition waste including sand, stones etc.

Visit to Tehsil Municipal Administration (TMA)

The 3rd part of the questionnaire was designed to gather information from Tehsil Municipal Administration Swabi (TMA). TMA is an administrative department, responsible for solid waste collection and its disposal. The office of the TMA was visited and data was collected regarding the following categories as:

1. Quantity of waste collection
2. Number of vehicles used for waste collection
3. Number of waste management team
4. Pattern of waste collection for hospitals
5. Pattern of waste Disposal
6. Site of disposal

Data Analysis

The data was analyzed using Microsoft Excel sheet-2007.

Waste Collection efficiency: The collection efficiency of waste generated by hospitals was calculated using equation (Equ.1).

$$E = CW/TW \times 100 \quad \text{……………………………….. } (1)$$

In this equation, E shows the collection efficiency of solid waste, CW shows the overall waste collected where TW shows the total waste generated by particular hospital. TW was calculated by investigating hospitals for waste generation while CW was measured at dumping site, ensuring waste carried by vehicles per day.

Results and discussions

Management and Implementation in Public/Private Sector Hospitals

Personal observation of the present study observed that both public sector hospitals were two-story buildings with 33 and 22 departments in the DHQ and BMC respectively. In privet sector hospitals, the building were also double-stories with 22 (SMC) and 6 (JMC) departments respectively. These departments include the department of Surgery, Medicine, Ayurveda, Radio-diagnosis and Imaging, Pediatrics and Adolescent Medicine, Gynecology and Maternity, Orthopedic Surgery, Dentistry and Physiotherapy. Inside the hospital premises, the hospital wards are well equipped with adjoining toilets and intercom facilities in the general wards and ventilators, piped oxygen, central vacuum and compressed air in intensive care units (ICU). The hospital waste is looked after by the waste management team in the public sector hospital included 30-36 staff members and it is around 8-10 members in the private sector hospitals. The medical staff record in the public sector hospital was in the range of 350-403 and 10-12 in the private hospitals (Table 2).

Table 2: Data collected from Public and Private Sector Hospitals

S.No	Question	Response			
		Public Hospital		Private Hospital	
		DHQ	BMC	SMC	JMC
1	Bad capacity/patient	90-100	360	30	35
2	Outdoor patients per day	1500-2000	2700-3500	250-300	500-800
3	No. operation theaters	3	6	1	3
4	No of medical wards	5	10	2	3
5	Major operations conducted per day	12-15	18 -20	5-8	10-15
6	No. Medical staff	403	350	10	12
7	No. HWM staff	30	36	10	8
8	knowledge about HWM-2005 rules	No	No	No	Somehow
9	Existence HWM plan	No	No	No	Yes
10	Record of HWM in written	Monthly	No	Monthly	Annually
11	Budget for HWM	NA	NA	80000/ month	100000/ month
12	Tasks for HWM team	Not specified	No	Neat and clean	Neat and clean
13	Training about health care waste management	No	No	Yes	Yes
14	Quantity of waste generation (kg per day)	120	130	35	50
15	Waste collection	Yes	120	Yes	Yes
16	Temporary waste storage site	Yes	Yes	Yes	Yes
17	Color coding for waste segregation	Yes	Yes	Yes	Yes
18	Waste handling and transport	Yes	Yes	Yes	Yes
19	Use of proactive equipment's (gloves, masks, proactive shoes, aprons etc.)	All	All	All	All
20	Waste transportation (Onsite, Offsite, Both)	Both	Both	Both	Both
21	Internal transport containers	Plastic bags/bins	Plastic bags/bins	Plastic bag	Plastic bags
22	Transport vehicles	Trolley	Trolley	Trolley	Trolley
23	Waste treatment (Incineration, chemical disinfection, autoclaving, Encapsulation, Microwave irradiation)	Incineration	Incineration	Incineration	Incineration
24	Waste disposal (open dumping, landfill, discharge into sewer, burying inside premises)	Open Dumping	Open Dumping	Open Dumping	Open Dumping
25	Incinerators (Functional, non-functional)	Functional	Non-Functional	Functional	Functional
26	Is hospital waste segregated	Yes	Yes	Yes	Yes
27	Who segregate the waste	Municipality Workers	Municipality Workers	Municipality workers	Municipality workers
28	Place of segregation available	Yes	Yes	Yes	Yes
29	Are containers identified and disinfected	No	Yes	Yes	Yes
30	For how long the medical waste used to be storage	24hrs	24hrs	24hrs	24hrs
32	Any expectations from the government in terms of waste management.	To facilities hospitals with trained staff, budget, and health facilities.			

The bed/patient capacity in the public sector hospital was recorded as 100 to 360. In private sector hospitals, the bed limit 30-35. The number of outdoor patients per day was 2000-3500 per day in the public sector hospitals and 300-800 per day at the private sector hospitals. The number of wards was observed respectively 5-10 and 2-3 in public and private hospitals. While the number of operations theaters in the public sector was 3-6 where major operations of 15-20 are conducted per day. In the private sector hospitals, the number of wards observed as 1-3 where 5-10 major operations were performed daily. In public sector hospitals, supervisors of the hospital waste management team were unaware of the HWM-2005 rules. While the private sector hospitals had appropriate HWM plan. To follow up on this plan, a training session on health care and waste management is organized once a month, replied the respondent of the private sector hospitals. The HWM file is recorded monthly in written form. All these hospitals are operational for 24 hours (Table 2).

Waste Generation

Comparative observations of the hospitals surveyed revealed that the both type of hospitals generate both infectious and non-infectious waste. The average amount of solid waste generated by the public sector hospitals studied was found to be 120 kg and 130 kg per day. The private sector hospitals generate waste as 35-50 kg per day by (Figure 1). The investigations of the present study reveals that greater part of infectious waste is generated in O.T, ICU and Cario-thoracic vascular surgery 30-35 kg per day. While the causality monitoring & O.P.D. departments generate 25 kg per day waste. In addition, construction and demolition waste was observed about 30 kg per day due to construction work in hospitals. In both hospitals, the greatest contribution among infectious and non-infectious infections was observed for sharps and syringes and food waste.

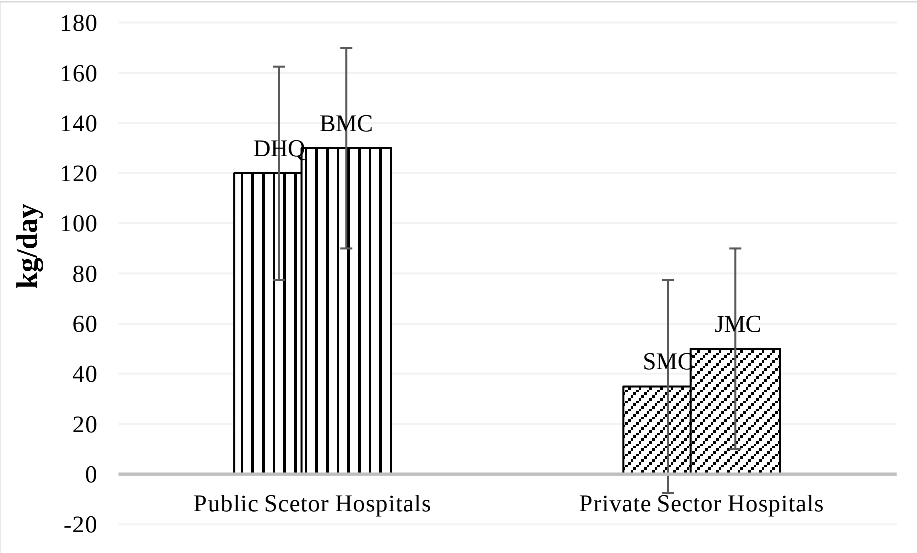

Figure 1: Average waste generated per day in selected hospitals of Swabi district.

Waste Collection and Transportation

Hospital waste is collected by the hospital waste management team (HWM-team). Waste is collected and stored in plastic bins. The daily collection of solid waste by the Tehsil Municipal Administration (TMA) is approximately 50-80 kg from the public hospitals and approximately 20-35 kg from the private sector (Figure 2). These hospitals have their temporary waste storage sites inside the hospital. Proactive equipment was used like gloves, masks, proactive shoes, aprons, etc. The transport of waste takes place both indoors and outdoors. The internal transport containers were plastic bags and mobile bins. The collected waste is transported to the hospital storage site where it is stored for 24 hours. Collection efficiency was calculated as 53-60% and 60-70% for public and private sector hospitals. This waste is transported to the disposal site by vehicles. Each hospital discharges its wastewater into the sewer system directly. The quantitative account of wastewater discharge on daily basis was not in their record.

Waste Segregation

All the investigated hospitals were observed with labeled colored bins with color coding of Yellow, Red and Green to collected different types of wastes. The red bin is for infections waste (sharps), the green bin collects non-infections (food, paper) while the yellow bin collects the recyclable items (plastic). In public sector hospitals, the infectious waste such as sharps is segregated at the spot and then subjected to incineration plant. While the rest is sent to the disposal site. The same method is followed by the private sector hospitals. Each hospital has claimed that waste is transported with proper labeling through labeled containers to the central storage point. Dumping site is located outside of the hospital at a distance of about 5-km from hospitals.

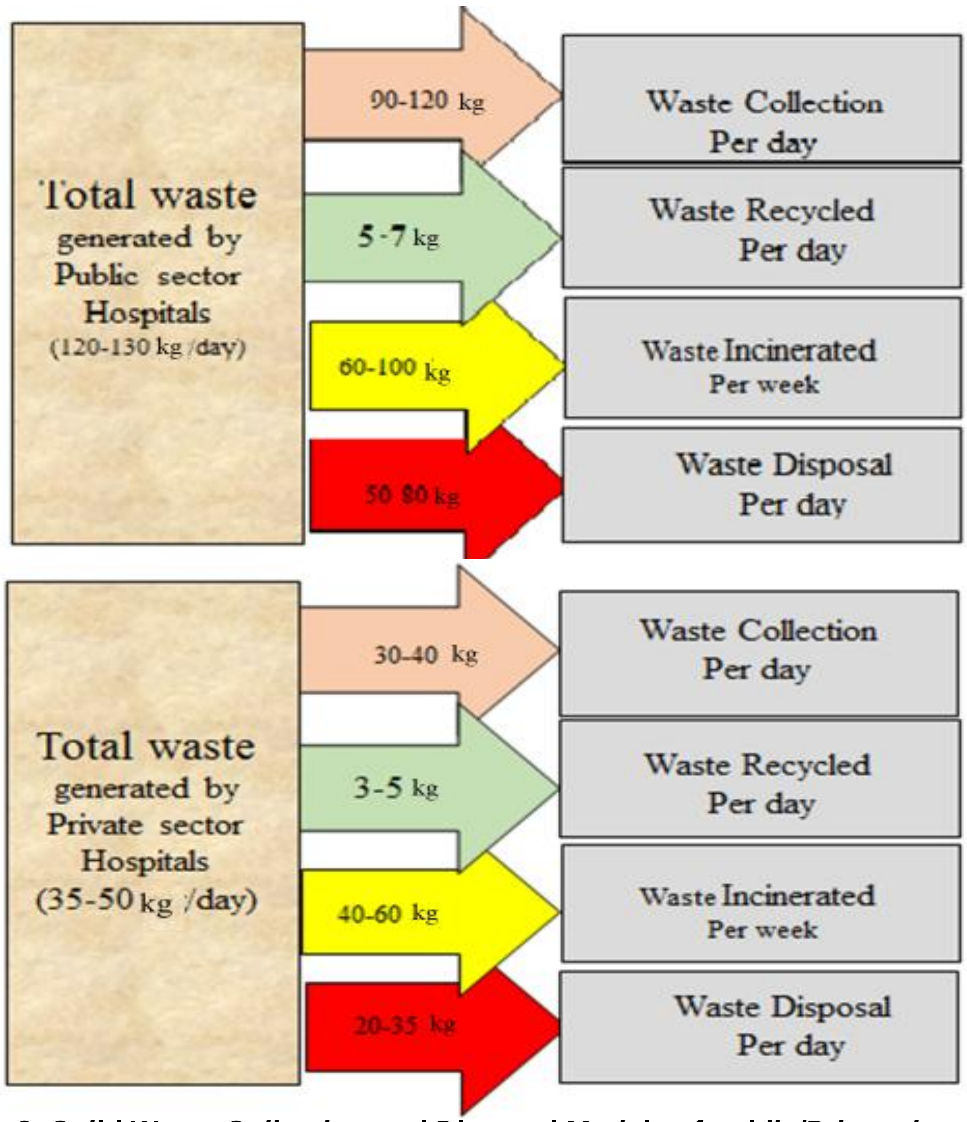

Figure 2: Solid Waste Collection and Disposal Models of public/Private hospitals

Waste Treatment and Disposal

The hospitals were observed with no proper treatment plants inside or outside of the hospitals. All the collected waste is segregated at the plant site. The plastic waste is transported for the recycling whereas, the sharpen waste are subjected to incineration. For the incineration, there was a separate department. Incineration plants are installed in hospitals to incinerate the hazardous waste materials. Incineration was carried out at 8000^{o}C to 1100^{o}C. The resultant ash latter is dumped into the dumping site. The technician was observed fully covered with protective dress, gloves, mask, shoes and eye protector. About 60-100 kg waste is burnt in the incineration plant once in a week by the public sector hospital. But, the incineration plant of one of the public sector hospitals (BMC) found non-functional for longer time. The person-incharge claimed that due to lacking of technical experts and financial funds, this plant is usually remained non-functional which reflects a bad picture of waste management. It was observed that the people which are directly involved in disposal and treatment procedure were not undergone any proper training program. In the private hospital, about 5-6 kg infectious waste is burnt per day. In case of any troubleshoot problem, the hospital has an expert of mechanical engineering for maintenance and fault checking. Usually the infectious waste is disposed to the dumping site, segregated by sweepers and the containers were not disinfected. For liquid wastes, no hospital has autoclaving or other methods of waste sterilization and the selected hospitals were not found serious about it.

For management of biomedical waste, incineration is considered as the most common method that reduces 10% of waste by volume. But some wastes (urine bags, body parts) cannot be disposed by incineration and thus need other treatment methods. According to legislative sections and hospital policy of Pakistan, the installation of incineration plant is mandatory in all big hospital. While failure of law is punishable by imprisonment of maximum 5-years and 1000000 rupees cash or both due to negligence of law.

Composition of Hospital Waste

The hospital waste of public sector was consisted of recyclable/saleable items such as paper (12-16%), plastics (10-12%), glass (8-15%) and iron scrap/metals (5-8%). The non-recyclable waste was observed as sharps (12%), and 25% (sand and stones etc.) as shown in Fig-3. Food waste was observed as 19-25%. Some paper and plastic shoppers, degraded or damaged cannot be recycled. In private sector hospital, the non-infectious waste was food waste (22-29%), glass (14-18%), paper (14-16%) and plastic (9-11%). The infectious waste was about 18-20% sharps produced by the outpatient department (OPD) shown in Fig-3.

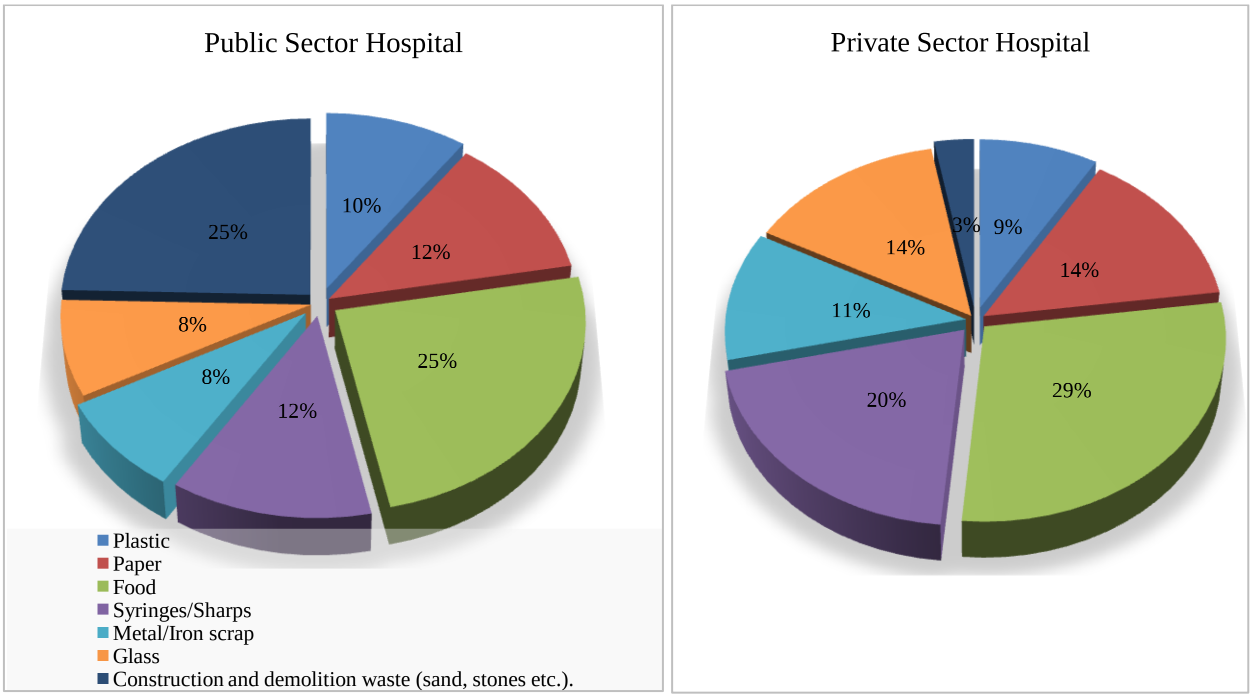

Figure 3: Solid Waste composition at Hospitals

Tehsil Municipal Administration

The daily waste collection by the TMA is recorded as 50-60 kg and 20-30 kg from public and private hospitals respectively. This waste is evacuated to a common landfill in Swabi located at a distance of 5 km. It has been observed that no hospital has its own treatment methods for paper and food waste mechanism. In response to a question, TMA officials replied that they were collecting garbage from 14 Union Councils in Swabi District. The number of workers in the TMA is 26. The type of waste collected is municipal, commercial and hospital. There are 6 vehicles for waste collection including trolley and pickup. The number of containers placed at different points is 15. The number of containers placed near hospitals is 4. No special type of vehicle for the collection of hospital waste is used. Hospital waste is mixed with municipal waste. Daily trips for waste collection are made from the hospitals by the TMA. The overall daily collection of hospital waste form Swabi area by the TMA is about 2000 kg (Table-3). It was observed that on-site workers associated with the collection and transport of waste wear a mask, gloves and an apron. The TMA does not organize any formal training on the management of medical waste. The waste is disposed of in the form of an open dump. A register of waste collection and transport is drawn up each year. No landfill is present in the district of Swabi. The collected waste is transported to an open dumping site, located in Swabi (shago dapaan). The TMA expects the government to facilitate them by providing quality health care facilities as well as setting an additional budget for health workers and they should be given life insurance to deal with dangerous situations (Table 3).

Table 3: Responses of the Questionnaire by the TMA

S.No	Question	Response
1	Area for waste collection	14 union council
2	Number of workers	26
3	Number of vehicles	6
4	Number of containers placed at various points	15
5	Number of containers or dustbins placed near hospitals	4
6	Type of vehicles for waste collection and transportation (Trolleys/ carts/ others)	Trolleys, tractor, Carry
7	Do you collect waste from hospitals	Yes
8	the pattern of waste collection from hospitals	Daily
9	Quantity of Waste collection kg per day	2000
10	Any special type of vehicle for hospital waste collection	No
11	Use of proactive equipment: gloves, masks, proactive shoes, aprons etc	Yes
12	annual budget for TMA	
13	Any formal Training about health care waste management: (monthly, annually)	No
14	Disposal of hospital waste	Open dumping
15	Are containers identified and disinfected	Yes
16	Record of waste collection and transportation in written	Yes
17	Expectations from government	The government should facilitate us by providing quality health care facilities as well as to fix some extra budget for the sanitary workers and they should be provided life insurance for dealing with such risky situations

Composition of Solid Waste at Scrap Collection Shops

The quantity of waste collected from dumping site was consisted of items such as paper, plastic, glass bottles, and iron scrap. These items are collected by scavengers and then sold to scrap collection shops (*Kabari shops)*. The scrap collection shops are located outside the hospitals and dumping site. The shops buy saleable items with different rates according to item type (Table 4).

Table 4: Composition and Collection Efficiency of Hospital Waste

S.No	Composition of Solid Waste	Average Quantity of Recyclable Waste generated (kg per day)		Total weight sold to kabari Shops (kg per day)	Price per kg (PKR)	Recovery Efficiency (%)
		Public Sector Hospitals	Private Sector Hospitals			
2	Paper	14	06	08	15/-	10-15
3	Plastic	17	04	10	20/-	14-10
4	Glass	15	07	07	05/-	12-17
5	Iron scrap/metals	8	05	08	07/-	07-12

Solid Waste Collection Efficiency

The collection efficiency for hospital solid waste was calculated as 48 and 62% for public and private sector hospitals. Based on composition of hospital waste, the recovery efficiency of plastics, paper, glass, iron scrap/metal was calculated as 14-10%, 10-15%, 12-17%, and 7-12% respectively (Table-5). About half or less than half of disposed waste is collected while remaining part is dumped openly or thrown near road side which is one of the major environmental problems. When compared with solid waste collection in other parts of the province, the situation was almost similar. In Pakistan general and KP particular, the hospital waste is usually discarded into open dumps and not treated**.** This mismanagement causes severity of hazard to environment [23]. In Pakistan, solid waste management practices in hospitals are not effective due to lack of government law enforcement. While in China and other developed countries, the gradual development of waste disposal and utilization is high. This study found that the management of hospital waste in Pakistan needs adequate funding trained personnel and effective policies [24].

Conclusions

According to the observations and report from public and private sector hospitals in Swabi District, it is concluded that all no hospital has its own treatment mechanism. They keep the waste in bins and after that, the municipal authority collects all the waste in a common place. The discharge point is located approximately 5 km from the hospitals. It has also been observed that there is waste leakage during collection and transport from the source level to the target location. Staff at the private sector hospitals are trained to handle waste but in the public sector hospital the staff were not aware. There is no attempt to minimize the amount of waste generated nor any mechanism to decrease the toxicity of the waste. Likewise, there is no provision from the management to have innovations, equipment in the future to deal with the generation of waste at the basic level.

At the central disposal and management plant, there is an ease of accumulation and separation of solid waste especially through colored and labeled containers. Central plant staff are not properly trained. Thus, it is clear that in the hospitals of Swabi district, there is little effective management of hospital waste. The rules and regulations regarding biomedical waste are also to some extent adequately followed. Private sector hospitals are the least interested in good management and disposal of their waste in accordance with environmental rules.

Recommendations:

- **Awareness:** The hospital staff needs proper trainings to know the healthcare effects due to infectious waste of hospital.
- **Financial funding:** The efficiency of the hospital waste management should be enhanced by funding.
- **Skilled Staff:** Formal trainings are important to be conducted by the health department about public health awareness and waste handling in hospitals.
- **Monitoring:** A regular inspection of collection, transportation and storage facilities need to be monitored on regular basis.
- Monitoring team should keep proper and regular check and balance to evaluate the number, location, condition, appropriate colour coding, and waste collection. Also, mapping and inspection of storage areas and transport routes needs to be managed.
- **Implementation of Effective Policies:** Efficient and effective policies are required to be implemented in hospitals. The hospital rule-2005 policy needs direly to implement. For Furthermore, review of health care waste policy, procedures and list of hazardous health care is important or regular basis.
- **Research:** Researchers can take a cue from the present study to conduct similar surveys in other hospitals of the country.
- Once enough information is available, the findings can be used for public policy making.
- This is a serious issue and needs to be tackled in a timely manner to avoid future crises.
- It is important to effectively mobilize resources for the management of COVID- 19 patients and also maintain the surgical services necessary for the population.

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Authors contribution

This work has been done as research work of the BS degree in Environmental Sciences.

Conflict of Interests

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

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Současný stav a kroky k nakládání s nemocničním odpadem v nemocnicích veřejného a soukromého sektoru v okrese Swabi, KP, Pákistán

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Abstrakt

Nemocnice v Pákistánu produkují obrovské množství odpadu, o kterém bylo hlášeno, že s ním správa nemocnic špatně nakládá. Toto špatné nakládání způsobuje několik environmentálních a zdravotních problémů uvnitř nemocnice i mimo ni. Cílem této studie bylo popsat výsledky sledování 4 velkých nemocnic veřejného a soukromého sektoru ve městě Swabi, KP, Pákistán.

Požadovaná data byla získána přímým i nepřímým pozorováním zdravotnického a administrativního personálu, abychom věděli, jak s odpadem nakládají. Jedním z důležitých aspektů naší metodologie byl vývoj vhodných dotazníků pro pochopení podstaty systému. Studie ukázala, že nemocnice veřejného sektoru produkují velké množství pevného odpadu (120–130 kg/den) a jeho nakládání s ním není prioritou. Postupy nakládání s odpady, třídění, skladování, přeprava a odstranění nesplňovaly pákistánská hygienická pravidla hygienické z roku 2005. Nemocnice soukromého sektoru se podílejí na produkci asi 30-50 kg odpadu za den a byla pozorována lepší úroveň nakládání s ním. Úroveň využití sebraného prodejného odpadu byla vypočtena následovně: plast 14 – 10 %, papír 10 – 15 %, sklo 12 – 17 % a kovy 7 – 12 %. Pravidla a předpisy týkající se biomedicínského odpadu nejsou dodržovány.

Studie poukazuje na nesprávné nakládání s odpady v nemocnicích veřejného sektoru. Pro lepší nakládání s odpady potřebuje nemocnice finanční zdroje, kvalifikovaný personál a realizaci nemocniční politiky z roku 2005.

Klíčová slova: *infekční odpad, neinfekční odpad, odpadové hospodářství, účinnost sběru, likvidace odpadu.*

Bio-Medical Waste Management and Analysis for Selected Hospitals in Southern and middle parts of Iraq

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Abstract

In terms of understanding the many types of waste and disposal options, this paper discusses how to handle medical waste. Over the past two decades, medical waste issues have become a problem with detrimental effects on environmental health. As a result, experts in public health and environmental issues started researching this phenomenon in all its manifestations. They tried to comprise it by putting in place different health controls and coming up with a cure. In addition to estimating the volume of solid medical waste produced in a few hospitals in the cities of Najaf and Basra, the research aims to provide a clear picture of the reality of biomedical waste management in Iraqi hospitals. Six sizable neighborhood hospitals with various specializations were selected to meet the study goals. For four months, waste (solid medical) was collected. The findings revealed that hospitals produced solid medical waste at an average rate of 0.42 to 3.90 kilograms per patient per day and that this rate was overall (1019 kg). Al-Sader Hospital had the highest proportion of waste output out of all the hospitals, reaching 34.15% when it was operating. In contrast, Al-Hakeem Hospital had the lowest percentage, just (6.67%) while operating. The most crucial management phase is storing, storing, and transporting hospital waste. It is necessary to understand why each sort of waste is handled in the way that it is. Consequently, it might be the outcomes in safe and effective medical waste management and the accomplishment of the requirements to safeguard society and the environment.

Keywords: *Bio-Medical Waste, Hospitals, Solid waste, Disposal.*

Introduction

Solid wastes also rise in proportion to population growth. In the end, waste pollution turns into a really significant problem for both the environment and general health. Medical waste is any waste created by a medical facility (private or public), a medical research facility, or a laboratory that is associated with providing health services [1]. However, not all garbage generated by healthcare institutions may be categorized as medical waste. The majority (75 – 90%) of the garbage generated by medical establishments is either municipal waste or general waste. Municipal garbage management services often handle this trash. Medical waste, which makes up the remaining 10 – 25% of healthcare waste, may be very toxic and harmful to human health [2–5]. Medical wastes are divided into four categories: pharmaceutical wastes, radioactive wastes, hazardous wastes, and infectious wastes [6]. Infectious wastes includes bodily fluids, blood, swabs, cultures, gloves, and bandages. Hazardous wastes include sharps, equipment, and chemicals.

Health treatment is important to our safety and wellbeing, but medical waste is a serious issue for living nature and the human environment [7]. In certain nations, patient waste is becoming a major health threat, and to reduce these hazards, a clinical management scheme must be introduced. Biomedical waste disposal has increasingly become a significant point of concern for hospitals and nursing facilities, as well as environmental and law enforcement authorities, the media, and the general public. Today, proper biomedical waste treatment has become a global humanitarian problem. While the dangers of weak medical waste management have ignited global concern, particularly in light of their far-reaching impact on human health and the climate, It is now generally accepted that the "Hospital waste" created during medical care has several negative and unhealthy impacts on the ecosystem, involving human beings. Clinical pollution represents a health concern to health-care staff, the general population, and the surrounding flora and fauna. Waste management problems in hospitals and healthcare facilities have been a rising point of concern. [8].

Biomedical waste (BMW)

It is a wider concept that applies to waste created or generated throughout human or animal study practices such as evaluation, care, or immunization, as well as waste produced or generated the processinsg or testing of biological or in health camps [8,9].

Bio-Medical Waste produced by: Forensic Laboratories, Health Camps, Institute/Research Labs, Research/Educational, Clinical Establishment, Blood Banks/Blood Donation Camps, Pathological Laboratories, Dispensaries and Hospitals [10].

Specific to hospitals Bio-medical waste

It is characterized as waste that is polluted with patient body fluids and is produced during the diagnosis, care, or immunization of humans (including microbiological, disposables plastics, dressings, placenta, body parts and organs, ampoules, needles and syringes wastes) [11].

The World Health Organization (WHO) reports that between 75% and 95% of biological waste is non-hazardous. Just 10% – 25% is dangerous, with about 10% being contagious as shown in Figure 1, with the other 5% being non-infectious still containing hazardous chemicals such as methyl chloride and formaldehyde as shown in Figure 2. The dangerous component of the waste poses a human, environmental, and/or microbiological danger to the general public and health-care personnel who are engaged in waste handling, storage, and disposal [11,12].

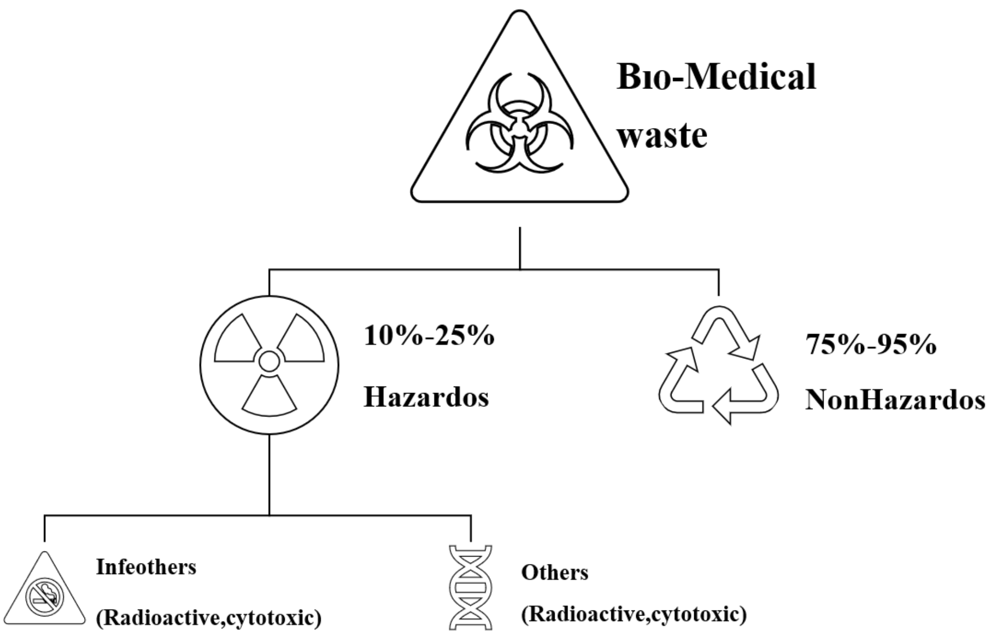

Figure 1: Bio-Medical waste [11].

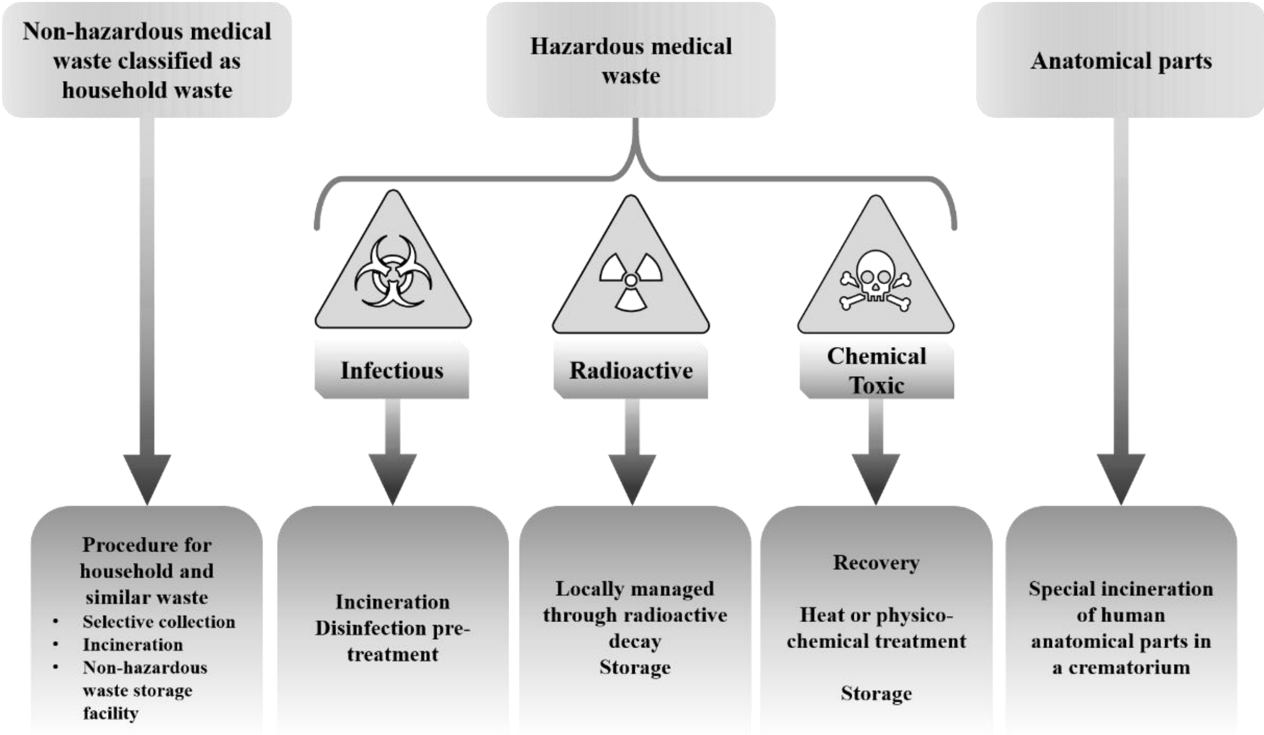

Figure 2: Non-hazardous and hazardous medical waste [11,12].

Biomedical Waste Management Process

Hospital waste may be treated, transported, stored, separated, collected, and disposed of in a safe manner to avoid hospital infection [13].

Biomedical Waste Management Rule

It is a legal obligation to dispose of biomedical waste in a safe manner, table 2 shown the Types of biomedical waste, According to these laws, it is the obligation of the "occupier," that is, the individual who has authority over the organization or its premises, to take all appropriate measures to ensure that the waste produced is treated in a way that does not endanger human health or the environment, therefore it must be disposed of by a set of stages as in the Figure 3. [13].

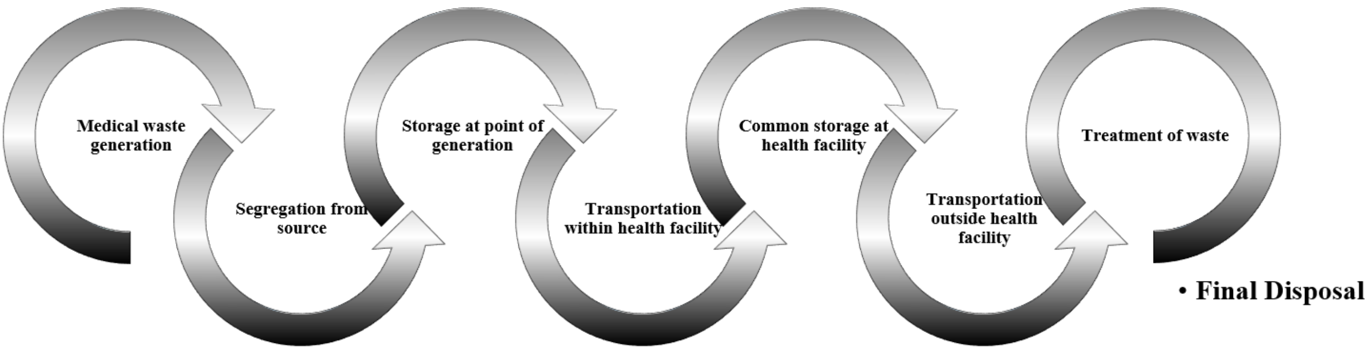

Figure 3: Process Flow Chart [14].

Table 1: Types of biomedical waste rule [15].

Waste Category	Kind of Waste	Disposal and remediation	Waste Category
Category No. 1	Human Anatomical Waste	Incineration /deep burial	Human Anatomical Waste (human tissues, organs, body parts)
Category No. 2	Animal Waste	Incineration /deep burial	Animal wastes includes animal tissue, organ, corpses, bleeding bits, fluid, semen, and laboratory animals used in testing, as well as waste caused by district clinics and colleges, discharged from hospital, and animal house.
Category No. 3	Biotechnology and Microbiology Waste	Local autoclaving/ microwaving/ incineration	Waste from Biotechnology and Microbiology, which include (lab cultures, stocks or samples of attenuated vaccines or microorganisms lives, animal and human cell culture utilized in researches and agents of infectious from researches and industrial labs, wastes from production of devices, dishes, toxins and biological utilized for transfer of cultures)
Category No. 4	Waste Sharps	Disinfections (chemical remediation/autoclaving/ micro waving and mutilation shredding	Sharps Wastes (glass, scalpels blades, syringes, needles, etc., which might be led to cuts and puncture. This involves both sharps' utilized and unutilized)
Category No. 5	Discarded Medicine and Cytotoxic drugs	Incineration / destruction and drugs disposal in secured landfills	Medicines that have been thrown out and cytotoxic products (wastes including discarded medicines, polluted and outdated)
Category No. 6	Soiled Waste	Incineration, autoclaving/microwaving	Disposal of Waste Material (Substances polluted with blood and fluids body involving line beddings, soiled dressing companies, dressings, cotton, other material polluted with blood)
Category No. 7	Solid Waste	Disinfections by chemical remediation autoclaving/microwaving and mutilation shredding	Solid Wastes (produced from disposable substances comparison with the sharps' waste including intravenous, catheters sets tubing, etc.)
Category No. 8	Liquid Waste	Disinfections by chemical remediation and discharge into drain	Liquid Wastes (produced from lab and disinfecting, housekeeping, cleaning and washing actions)
Category No. 9	Incineration Ash	Disposal in municipal landfill	Ash from incinerators (ash from wastes of biomedical incineration)
Category No. 10	Chemical Waste	Chemical remediation and discharge into drain for liquid and secured landfill for solids	Waste Chemicals (chemicals utilized in productions of chemicals, biological, utilized in ion of disinfect, as pesticides, etc.)

Research objective

1. Giving a clear picture of the reality of solid waste management in the studied hospitals.
2. Estimating the weight of waste presented by hospitals for use in the future planning process [16].

The study area

The study was conducted between a group of hospitals in the city of Najaf and the city of Basra by comparing the medical waste produced in each of the two cities, where the city of Najaf is characterized by religious tourism and has seasons characterized by tourists from their homes and abroad. Al-Najaf is a city in central Iraq about 160 km south of Baghdad. Its estimated population in 2018 was 1,471,592 people. It is the capital of Najaf Governorate. Location of Najaf within Iraq Coordinates: 32°00′00″N 44°20′00″E. Basra is a city in southern Iraq located on the Shatt al-Arab in the Arabian Peninsula. It had an estimated population of 2,908,491 million in 2018. Also, Basra is Iraq's main port. Located at Coordinates: 30°30′54″N 47°48′36″E as shown in Figure 4. As for Basra, it is a commercial and industrial city with international border outlets and a large number of local and foreign citizens [16,17].

Figure 4. A map for the selected areas.

Experimental work

Najaf hospitals

The most important data were collected from selected hospitals in the city of Najaf daily for four months (August – November 2010); This data was for: number of patients and the amount of solid 62edici waste produced. These data collcted from Najaf hospitals are summarized as shown in table 3,4,5 and 6. [17]

Table 2: Information of studied hospitals in the city of Najaf [17].

Hospitals	Number of working staff	Capacity (patient)
Al- Sader Hospital	1283	505
Al- Hakeem Hospital	810	268
Al- Zahraa Hospital	721	319

Table 3: Quantity of solid medical waste in Al-Sader hospital [17].

No.	The month	Average Solid medical waste (kg/day)	Average No. of patients/day	Rate of Waste (Kg/patient/day)
1	August	360	66	5.45
2	September	325	79	4.11
3	October	345	128	2.69
4	November	363	86	4.22
Average		348	90	3.90

Table 4: Quantity of solid medical waste in Al-Hakeem hospital [17].

No.	The month	Average Solid medical waste (kg/day)	Average No. of patients/day	Rate of Waste (Kg/patient/day)
1	August	72	51	1.41
2	September	62	56	1.10
3	October	56	61	0.91
4	November	80	54	1.48
Average		68	56	1.22

Table 5: Quantity of solid medical waste in Al- Zahraa hospital [17].

No.	The month	Average Solid medical waste (kg/day)	Average No. of patients/day	Rate of Waste (Kg/patient/day)
1	August	189	143	1.32
2	September	129	122	1.05
3	October	168	194	0.86
4	November	196	175	1.12
Average		171	159	1.08

Basra hospitals

All laboratory waste is treated as medical waste, including pathological waste. The most important data were collected from selected hospitals in the city of Basra daily for four months (September- December 2009). This data was for: number of patients and the amount of solid medical waste produced [18].

Table 6: Information of studied hospitals in the city of Basra [18].

Hospitals	Number of working staff	Capacity (patient)
Basra General Hospital	1685	564
AL Fayhaa Hospital	912	424
General Ports Hospital	981	377

Table 7: Quantity of solid medical waste in Basra General Hospital [18].

No.	The month	Average Solid medical waste (kg/day)	Average No. of patients/day	Rate of Waste (kg/patient/day)
1	September	159	334	0.47
2	October	135	499	0.27
3	November	217	454	0.47
4	December	217	441	0.49
Average	/	182	432	0.42

Table 8: Quantity of solid medical waste in AL Fayhaa Hospital [18].

No.	The month	Average Solid medical waste (kg/day)	Average No. of (patients/day)	Rate of Waste (kg/patient/day)
1	September	132	118	1.11
2	October	130	150	0.86
3	November	155	150	1.03
4	December	124	122	1.01
Average	/	135	135	1.00

Table 9: Quantity of solid medical waste in General Ports Hospital [18].

No.	The month	Average Solid medical waste (kg/day)	Average No. of patients/day	Rate of Waste (kg/patient/day)
1	September	116	177	0.65
2	October	126	199	0.63
3	November	106	213	0.49
4	December	110	186	0.59
Average	/	115	194	0.59

Results and discussion

The ammount of solid medical waste in Najaf hospitals for four months as shown in the fig.5 represent that the maximum quantity of solid waste in Al-Sader Hospital which reached to 363 kg/day in November while in Basra hospitals reached to 217 kg/day in general Basra hospitals in November and December as shon in Figure 6. Table 10 and **Chyba! Nenalezen zdroj odkazů.** 7. shows the quantities of waste produced by hospitals study in provinces Najaf and Basra. As the average amount of medıcal waste produced by these hospitals per day is 1019 kg and the rate of waste generation ranged between 0.42-3.90 Kg/patient/day. Al-Sader Hospital represents the largest percentage of waste production out of the total percentage, reaching 34.15% while it was, Al- Hakeem Hospital represents the lowest percentage of waste production out of the total percentage, reaching 6.67% while it was. The production of each of Najaf Hospital Al- Zahraa is, 16.78%. Production Basra Hospitals Basra General, AL Fayhaa, General Ports is 17.86%, 13.24%, 11.28%. Figure 8. shows the percentages of solid medical waste in hospitals.

Table 10: Quantity of solid medical waste in General Ports Hospital.

No.	Hospitals	Average Solid medical waste (kg/day)	Percentage of solid waste production (%)	Rate of Waste (kg/patient/day)
1	Al- Sader Hospital	348	34.15%	3.90
2	Al- Hakeem Hospital	68	6.67%	1.22
3	Al- Zahraa Hospital	171	16.78%	1.08
4	Basra General Hospital	182	17.86%	0.42
5	AL Fayhaa Hospital	135	13.24%	1.00
6	General Ports Hospital	115	11.28%	0.59
Total	**/**	**1019**	**100%**	**/**
Average	/	169.98	/	1.36

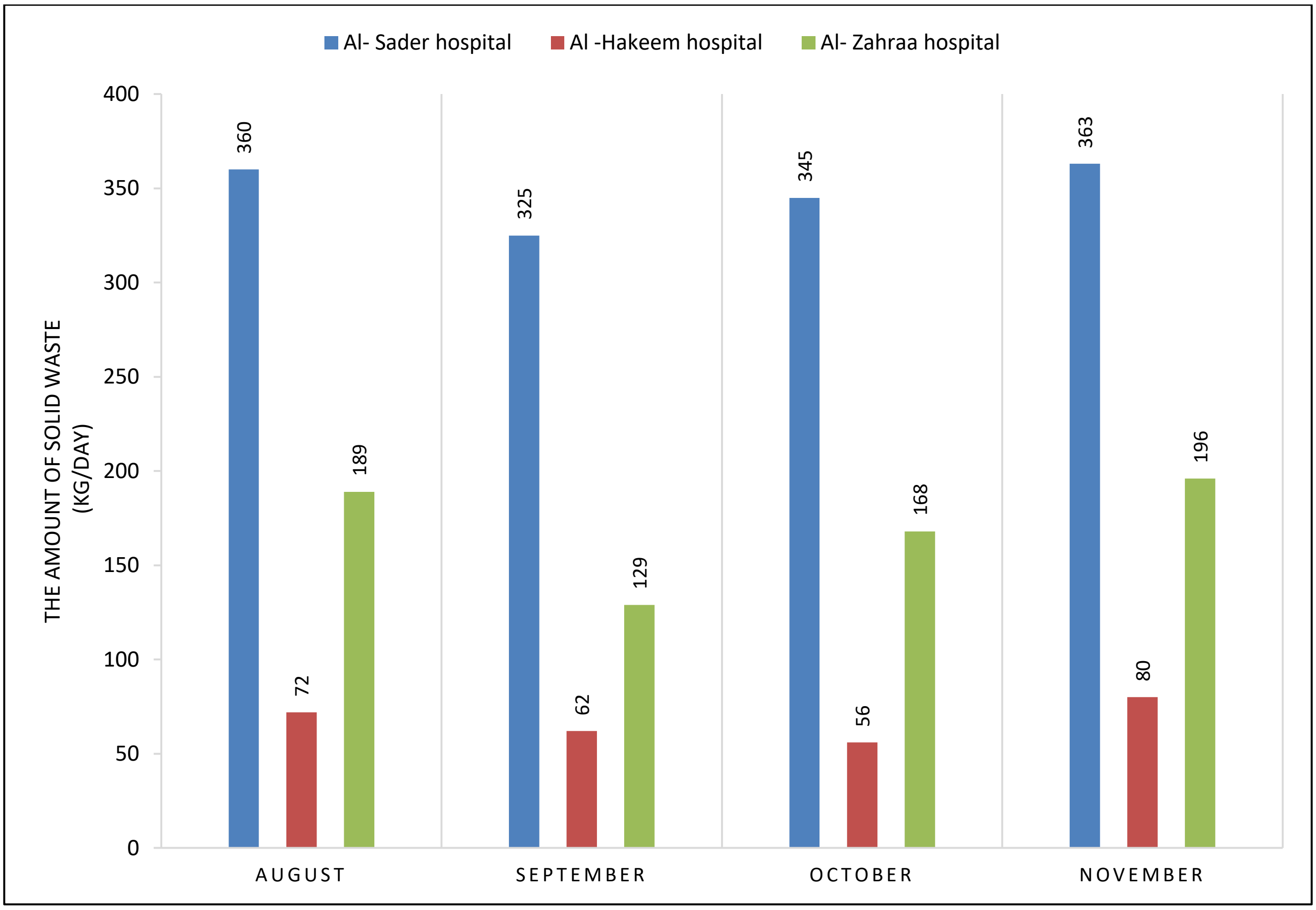

Figure 5. Solid medical waste in Najaf hospitals for four months.

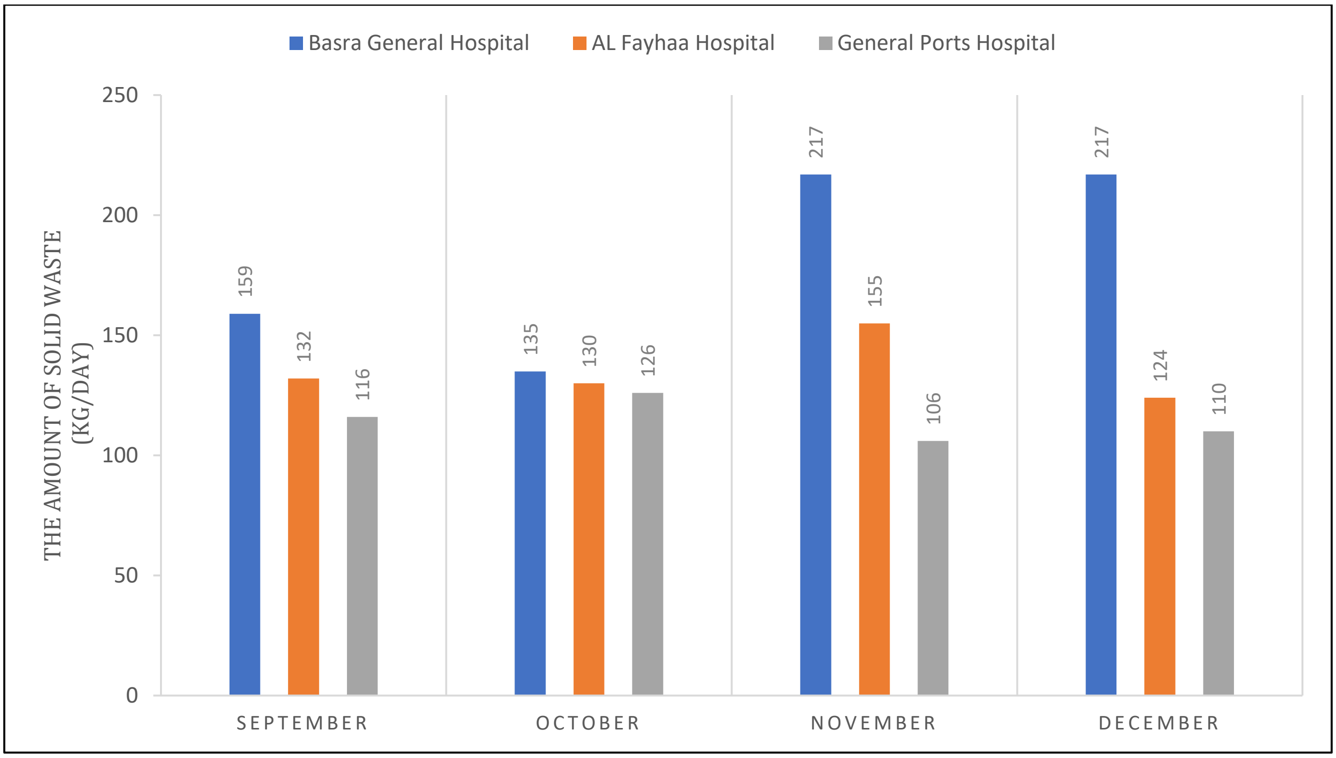

Figure 6: Solid medical waste in Basra hospitals for four months.

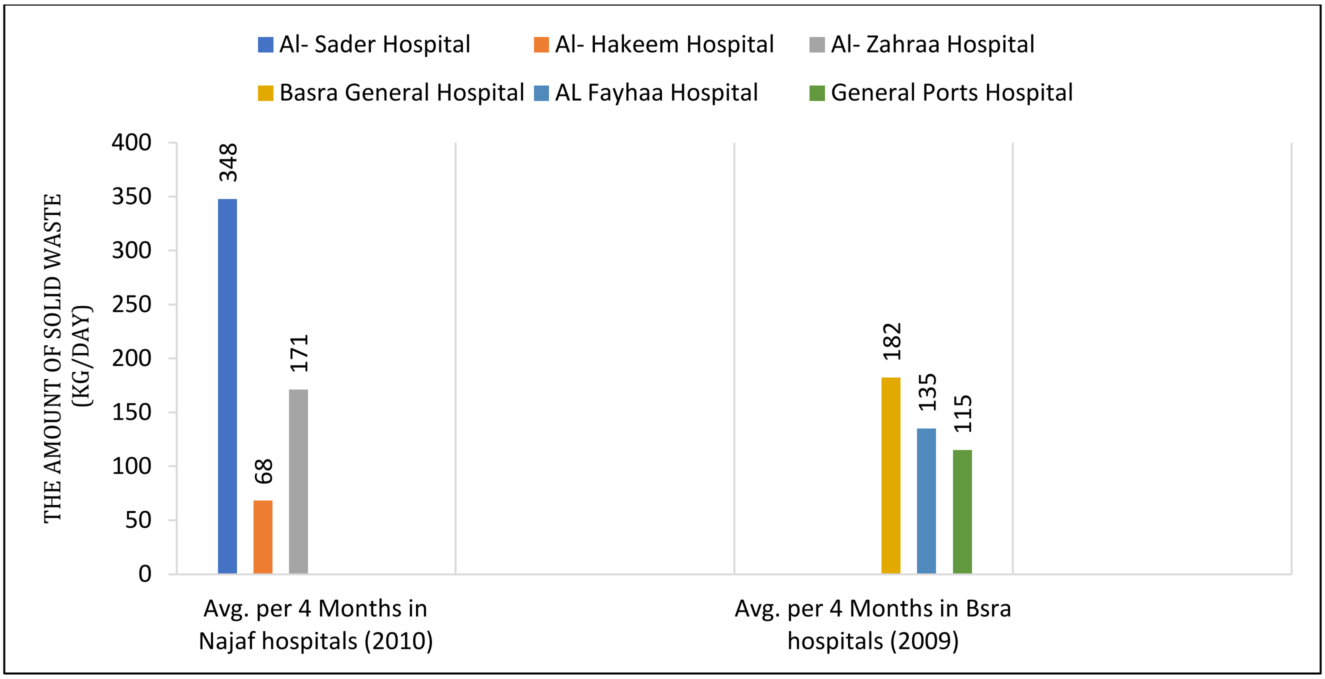

Figure 7: Solid medical waste in Najaf and Basra hospitals for four months.

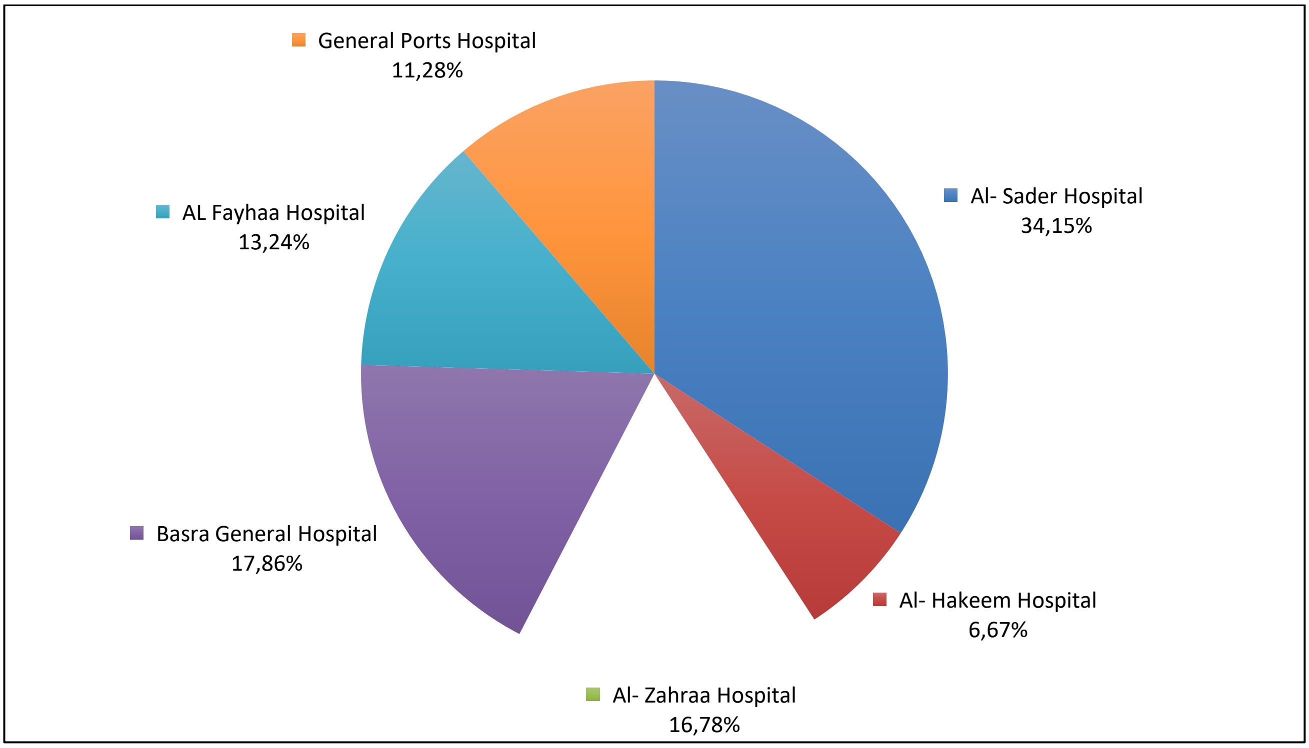

Figure 8: Percentage of solid medical waste production in hospitals (%).

Conclusion

Medical waste must be categorized depending on its source, type, and risk parameters related with its handling, storage, and final disposal. Separating waste at source is the main step, and decrease, recycling and reuse must be considered from an appropriate perspective. It is essential to think about innovative and radical measures to change the painful picture of civil disinterest on the part of hospitals and the slow implementation by the government of lowest rules, because waste production, especially biomedical waste, imposes an increase in indirect and direct costs in society. Thus, the challenge before us is the scientific management of the increasing amounts of biomedical waste that exceeds previous practices. For protecting the environment and the health of society, it should be educated ourselves on this significant problem not only for health institutions but also for the benefit of society.

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Nakládání s biomedicínským odpadem a analýza pro vybrané nemocnice v jižní a střední části Iráku

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Souhrn

Pokud jde o pochopení mnoha typů odpadu a možností jejich odstranění, tento dokument pojednává o tom, jak nakládat se zdravotnickým odpadem. Během posledních dvou desetiletí se problematika nemocničního odpadu stala problémem se škodlivými účinky na zdraví životního prostředí. V důsledku toho začali odborníci v oblasti veřejného zdraví a životního prostředí zkoumat tento fenomén ve všech jeho projevech. Snažili se to řešit tím, že zavedli různé zdravotní kontroly a přišli s projektem. Kromě odhadu objemu pevného lékařského odpadu produkovaného v několika nemocnicích ve městech Nadžaf a Basra je cílem výzkumu poskytnout jasný obraz o realitě nakládání s biomedicínským odpadem v iráckých nemocnicích.

Pro splnění cílů studie bylo vybráno šest velkých sousedních nemocnic s různými specializacemi. Po dobu čtyř měsíců se sbíral odpad (pevný zdravotnický). Zjištění odhalila, že nemocnice produkovaly pevný zdravotnický odpad v průměrné míře 0,42 až 3,90 kilogramů na pacienta a den a že tato míra byla celková (1019 kg). Nemocnice Al-Sader měla nejvyšší podíl na produkci odpadu ze všech nemocnic, když v době provozu dosáhla 34,15 %. Naproti tomu nemocnice Al-Hakeem měla za provozu nejnižší procento, právě (6,67 %). Nejdůležitější fází je třídění, skladování a přeprava nemocničního odpadu. Je nutné pochopit, proč se s každým druhem odpadu nakládá tak, jak má. Výsledkem může být bezpečné a efektivní nakládání se zdravotnickým odpadem a splnění požadavků na ochranu společnosti a životního prostředí.

Klíčová slova: *Zdravotnický odpad, nemocnice, nebezpečný odpad, odstranění.*

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