Journal of Advanced Environmental Research and Technology

Vol. 1, No.4
page 71-83 ,fall 2023
***
Received 05 augest 2023
Accepted 21 augest 2023

Experimental study of consuming horse bedding for re-bedding and energy production in Tehran

Gholamreza Asadollahfardi[1],Atefeh Seilanian[2], Elham Mahmod Por[3]

1. Civil Engineering Department, Kharazmi University.
2. Civil-Environmental Engineering, Civil Engineering Department, Kharazmi University.
3. Department of Civil and Environmental Engineering, Tarbiat Modares University, Tehran, Iran.

Abstract

The quality of stable environments is crucial for maintaining the health of horses, minimizing air pollution, and potentially utilizing waste for fuel production. This study investigates the physical, chemical, and biological characteristics of dry horse bedding across twenty-four horse-riding clubs in Tehran. The objectives are to gather information on current stable practices and assess the suitability of used bedding for reuse or energy generation. The findings showed that the moisture content of the bedding ranged from 39.63% to 76.92%, resulting in high drying expenses. Ash content ranged from 7.73% to 17.20%, while nitrogen content was between 0.78% and 1.77%. Hydrogen levels were measured between 7.06% and 9.04%, and carbon content ranged from 14.74% to 24.46%. The particle size distribution indicated that 70% to 94% of particles were smaller than 3.15 mm, with 0.5% to 1.5% measuring below 0.075 mm, raising concerns about potential health risks due to the fine particles. The average gross calorific value was 19.0372 MJ/kg. While the pellet samples did not meet specifications for non-industrial use, used horse bedding pellets exhibited greater suitability for industrial applications.

key words

horse bedding

pellet

combustion

fuel quality

re-bedding

*To whom correspondence should be addressed:

[DOI: 10.22034/JAERT.1.4.71]

1. Introduction

Horse stables located in urban areas present significant environmental concerns for authorities, such as pollution of water, soil, and air, along with frequent complaints from residents living nearby due to the unpleasant odors. In developing countries, manure disposal becomes even more problematic due to limited access to biofuel technologies and inadequate systems for treating liquid waste like urine. Contaminated horse bedding is often recycled for use in stables or managed through traditional composting, adding to the complexity of waste management efforts.

Considering environmental concerns, Lio et al. (2021) examined the exploitation of horse manure for energy recovery by combustion.[11] Airaksinen (2006) applied a life cycling assessment (LCA) to understand horse manure and bedding management and their effects on the air quality and environment of stables.[2] Horse waste is typically disposed of by spreading it on agricultural land or dumping it in landfills. Horse digestion produces methane, ammonia, and other byproducts that contribute to climate change. Stable waste is usually made up of 60% solid matter and 40% urine (Mong et al., 2020; 39]. Monki et al. (2021) explored how different bedding materials affect respiratory health, tracheal mucus accumulation, and lower airway cell composition in healthy horses.[23] Fleming et al. (2008) studied a range of bedding types—including wheat straw, wood shavings, hemp shives, linen shelves, straw pellets, and paper cuttings—and found they contributed to the release of ammonia, carbon dioxide, nitrous oxide, and water vapor into the environment.[18]

In a short definition, biomass is a neutral carbon and can be defined as the amount of carbon released during combustion is the same as carbon received during growing. Solid biomass can be used as a fuel after compression, deformation, and changing to more diminutive cylindrical elements, named pellets. Regarding converting polluted horse bedding to energy production, Wartell (2009) evaluated the methane production potential of the anaerobic digestion of horse manure.[37] He concluded that the presence of sawdust would intensify methane emissions. Furthermore, he reported that adding biomass containing a high carbon-to-nitrogen ratio (C/N) would cause a reduction in ammonia emissions. Wartell et al. (2012) studied methane generation in horse stables.[38] They reported straw bedding had a remarkable methane potential than manure. In addition, soft wood-based bedding caused a decrease in the potential energy production of stall wastes.

Havukainen et al. (2020) studied the life cycle assessment (LCA) of horse manure management chains utilizing either sawdust or peat as bedding material.[19] The results indicated that combustion is the most favorable selection for sawdust manure for all studied impact categories, anaerobic digestion is the most convenient option for the potential contraction of global warming, and combustion is the best option for eutrophication potential and the reduction in latent acidification for peat manure. Mönch-Tegeder et al. (2014) studied the feasibility of using straw-based horse manure in full-scale biogas. Their results indicated pretreatment of the substrates raises specific methane production by about 26.5%. [24]

The European Union considered horse manure with bedding as a biowaste, which should be used as fertilizer or bioenergy [2, 3]. Airaksinen (2006) suggested that compost made from horse manure and peat bedding could be an effective fertilizer for organic greenhouse cultivation of crops like tomatoes, sweet peppers, and cucumbers.[2] Scott (2012) noted that reducing moisture content to below 10% significantly enhances combustion efficiency.[32] Lundgren and Pettersson (2004, 2009) assessed the application of horse manure, mixed with wood chips to produce heat energy. They are characterized by chemical compounds and ash content. [21, 22] Their results indicated that the fuel was applicable for heat production and creating low emissions, and the amount of heavy metal in the ash content was low in amount. Thek and Obernberger (2012) reported the optimized moisture of sawdust bedding for pellet production would be 12% to 13%. Additionally, sawdust wood pellets demonstrated the highest combustion efficiency, producing no smoke and remaining intact during crushing.[35] Monch-Tegeder et al. (2014) explored the energy potential of straw-based horse manure, concluding that horse manure yielded promising results for bio-energy production.[24]

Several horse stables and riding schools are in Tehran province, Iran. Routinely, their bedding is wood and dry-manure-based. The present study is unique as a case study to investigate the number of horse clubs, horses, type and amount of consumed food, and physical, chemical, and biological characteristics of horse stables bedding and riding school in Tehran.

The first objective of the present study was to experiment with the physical, chemical, and bio-

[DOI: 10.22034/JAERT.1.4.71]

logical characteristics of the polluted horse-used bedding in the stables in Tehran. The second aim was to study the feasibility of consuming used horse bedding for re-bedding and energy production (pelletization).

2. Material and Methods

2.1. The study area

Tehran has an area of 730 km2, a population of around 8.5 million, is the largest city in Western Asia, and is located at 35^° 41^’ 4^” N and51^° 25^’ 23^” E. From the north, it reaches the Alborz mountains (about 1980 meters above sea level), and from the south, reaches the central desert (about 1200 m above sea level) (Figure 1). Tehran contains four accurate seasons with an annual mean rainfall of about 220 mm. The maximum and minimum temperature and relative humidity of the city are 43°C,-15°C, and 40%, respectively [34].

2.2. Chemical characteristics of the bedding

Initially, the numbers of horse-riding stables, locations, bedding materials, and horse feed in Tehran province were surveyed (Fig. 1). The data collection process involved two main steps. First, we conducted a survey to determine the number of stables in Tehran. Following this, we visited the stables and interviewed the managers of various horse clubs. Horse bedding samples were gathered at three different stages early in the morning before the daily cleaning routine. These samples included a mix of contaminated horse manure with urine, sawdust bedding, and soiled wood chaff bedding. Additionally, we collected mixtures of dried, contaminated manure with bedding materials, as well as combinations of dried horse manure, fresh manure, and urine. Each set of samples was collected three times, and the average of the experimental results was recorded. The second sampling stage included the dry manure mixed with the fresh urine plus manure (one specimen); moreover, the polluted sawdust with fresh manure (samples 1 and 2).

We experimented with the moisture, ash, nitrogen, carbon, hydrogen contents, and calorific values in the first and second sampling stages. For moisture content, experiments were performed according to EN14774-1(2009).[13] In addition, we employed a moisture analyzer, model number MX-50 (A & D Company Ltd, Tokyo). Each type of sample was collected three times and recorded its average.

The nitrogen, carbon, and hydrogen amounts were based on the Pregl-Dumas method [29]. Therefore, we used the Perkin Elmer CHAN Analyzer (Model: PE 2400 Series II) for measuring the carbon, nitrogen, and hydrogen samples’ contents. In this regard, we exposed a sample of a known mass of the bedding in the presence of helium and oxygen in a chamber with a temperature of 980 Celsius. Then, the temperature decreased to 675 degrees. The sample released carbon dioxide, water vapor, and nitrogen. The gases were passed through a particular column, a potassium hydroxide aqueous

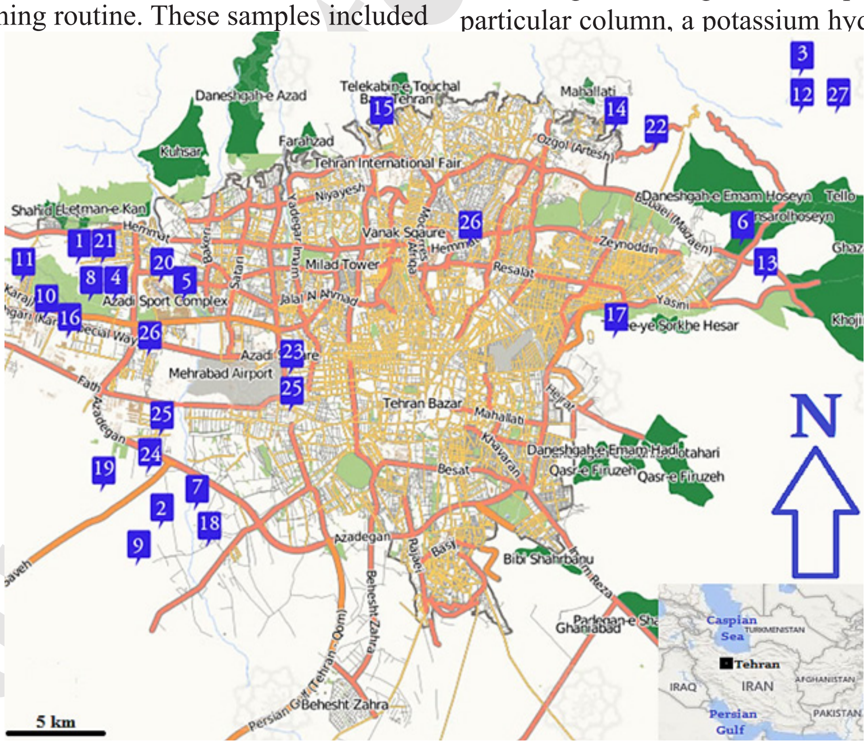

Fig. 1. The location of sampling stations in the study area

solution, to absorb carbon dioxide and water. The carbon dioxide rising from the carbon combustion was trapped in a small tube containing soda lime, and water was trapped in a similar tube as hydrogen-containing phosphorus pentoxide. The computation of the masses and percentages of carbon and hydrogen became possible. Then, the nitrogen gas was collected and measured. The absolute and detailed description of the Dumas method could be found in other sources [20, 29, 30].

We analyzed the calorific values using a bomb calorimeter according to ASTM E711(2004).[5] The calorific determination approach can be found in the Association of Official Analytical Chemists (Cunniff 1995) with more details and descriptions.[10] EN ISO 17225-2 (2014) defines classes A1 to B with ash contents of < 0.7, < 1.2, and < 2.0.[16] For the use of quality classes, A1 to B in our study, standard EN ISO 17225-6(2014) for non-woody pellets with different values for classes A and B was used. Classes A1 to B refer to non-industrial use.[17] Part 1 in the standard is relevant for industrial purposes, i.e., EN 14961-1(2010) or ISO 17225-1(2014). [14, 15] There is ash content classes A10.0+ (for > 10.0 w.-% dry basis) and nitrogen classes up to N3.0+ (for > 3.0 w.-% dry basis).

Several other essential chemical elements play a crucial role in combustion, including potassium, chloride, and sulfur. Additionally, magnesium and calcium are significant, although they are also considered heavy metals. These elements are important for assessing ash melting temperatures and understanding slagging behavior during combustion (K, Mg, Ca). Moreover, some of them form aerosols (K, Na, Cl, Pb, Zn), lead to corrosion (Cl) or are critical for ash deposition (all heavy metals). However, due to the budget limitation, such experiments were not performed.

The available facilities for sieving analysis (vibration, horizontal screening) experiment was at Kharazmi University, Soil Mechanics Laboratory, Karaj, Iran (Fig. 2). Sieve analysis was carried out in two stages. In the First stage of sieving analysis, four different types of polluted bedding were carried out in early December, and in the second stage in March, 18 samples were performed. For any polluted type of horse bedding, three samples were collected, and the mean of the experimental results was recorded. All samples were dried at temperatures of 105°C.(EN 14774,2009). For sieve analysis purposes, we selected the Association of State and Highway Transportation Officials [1] to select the size of the sieve. The samples were not crushed to remove cohesion between particles before sieve analysis and vibration tests. Because the size of about 70% of a mixture of sawdust and horse bedding was smaller than 3.15mm, we selected sieve sizes of 45, 16, 3.15, 2, 1.4, 1, 0.5,0.25, and 0.075 mm. For measuring the humidity, the samples were weighed with a weighing device with an error of

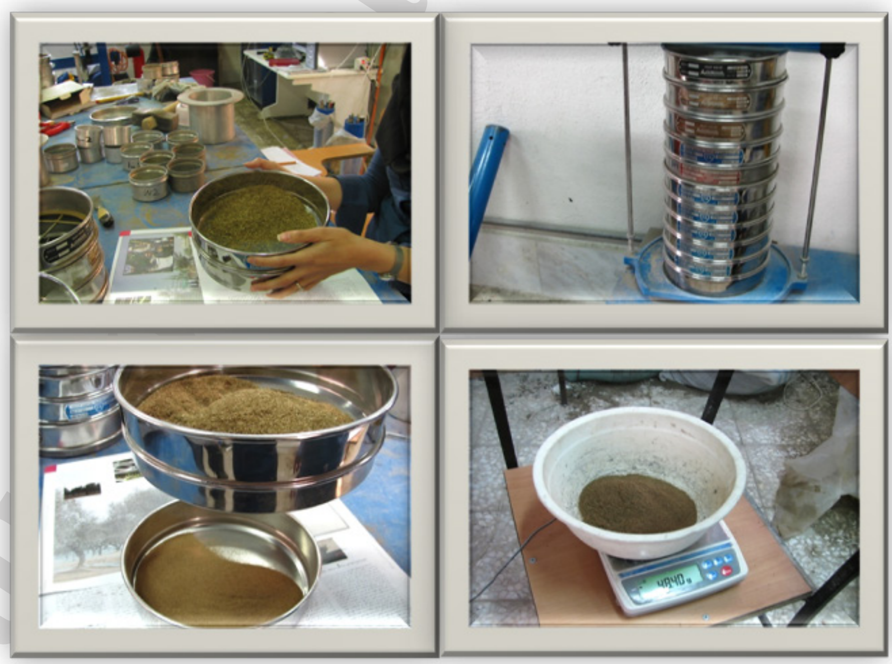

Fig. 2. Sieve analysis equipment used for different polluted horse bedding

0.01 g.

Refer to Quinn's 2001 report, which lists disturbing pathogens of animal origin in priority one and two, according to available laboratory facilities and culture medium, a bed sample containing a mixture of dry manure and sawdust with fecal and urine contamination of horses was selected for the biological test.[28] The microbial culture of polluted horse bedding samples was performed at two different times. The experiment was carried out in the faculty of veterinary at Tehran University.

We experimented with the microbiology of bedding, including Salmonella, Escherichia coli, and Listeria. The samples were a mixture of dry manure bedding and sawdust bedding contaminated with horse waste and urine. The samples were prepared under the following circumstances:

- Mixing of fresh polluted samples from horse bedding
- Mixing of bedding samples after 20 h in a 60°C in an oven.
- Mixing of bedding samples after 20 h in an 80°C in an oven
- Mixing of bedding samples after 20 h in a 100°C in an oven

The available grow condition for the microbiology test was MacConkey and blood agar in the laboratory [39].

3. Results and discussion

3.1. Results of the survey and interview

Table 1 indicates the names of horse clubs, number of horses, types of foods, and amounts of food consumed by the horses.

We identified twenty-nine horse riding and training complexes in Tehran, encompassing 2106 stables, but only the information of twenty-four horse clubs was collected since the five other clubs' information was not accessible. Horses are fed about six tons of alfalfa, barley, and stubble. For the racehorses, in addition to the main feed (Table 1), concentrate, beet pulp, pomace, corn, and vitamins are also consumed. In these complexes, the horses' bedding, manure, and food waste were the significant elements of the solid waste. Moreover, twenty-four horse complexes used 7 to 8 tons of

Table 1 - Statistical information of horse clubs located in Tehran province

Row	Club Name	Horticultural and agricultural use	Outdoor drying for rebidding	Weigh of the material used in horse bedding (kg)	Materials used in horse bedding	Number of horses	Daily alfalfa for a horse (kg)	Daily barley for a horse(kg)	Daily stubble for a horse (kg)	Daily straw for a horse(kg)	A total daily feed of one horse (kg)	The total annual feed of a center (ton)
1	Abrash	+		3 kg Woodchip + 4 kg Sawdust	Woodchip +Sawdust	78	7.5	7.5			15	427
2	Iran Novin	+		5 kg	Woodchip	35	4	3	4		11	141
3	Imam Khomeini		+	5 kg Dried manure + 4 kg Stubble	50% Dried manure + 50% Stubble and dried manure	53	9.5	3	2.5		15	290
4	Ariasb	+		5-10 kg	Woodchip	110						
5	Azmoon	+		6 Kg	Woodchip	280	3.5	4	4		11.5	1175
6	Alghadir	+	+	6 kg Dried manure + 5 kg woodchip	30% Dried manure + 70% woodchip + Dried manure	60	5	3	3		11	241
7	Jam	+		5-10 kg	Woodchip	51	6	3			9	168
8	Chitgar			5-1 kg	Woodchip	88	10	4			14	450
9	Habibi		+	3-4 kg	Dried manure	40	7	1	1		9	131
10	Rakhsh Saba		+	5-10 kg	Woodchip	60	9	4	3		16	350

[DOI: 10.22034/JAERT.1.4.71]

11	Siahpoosh			6 Kg Dried manure + 4 Kg Woodchip	60% Dried manure + 40% woodchip and dried manure	120						
12	Samand	+	+	6 kg Dried manure + 5 kg Woodchip	A mixture of dried manure + woodchip	20	6	6	3		15	110
13	Sohanak		+	6 kg	Dried manure	25	9	3			12	110
14	Shaki	+		5- 10 kg	50% Woodchip + 50% sawdust	28	5	5	3		13	133
15	Shahrak Ghazali	+		3-4 kg Woodchip + 4-5 kg Sawdust	Woodchip + sawdust	7	5	2		2	9	23
16	Shohada			6 kg	Dried manure	225						
17	Shabnam		+	4-5 kg Dried manure + 5-6 kg woodchip	50% Dried manure + 50% woodchip	36	8	3	2.5		13.5	177
18	Shakouri	+		12-13 kg	Woodchip	34	3	3	3		9	112
19	Milad		+	6 kg Dried manure + 0.33 kg woodchip + 0.33 kg sawdust	90% Dried manure + 10% woodchip and sawdust	30	7	6			13	142
20	Army Ground Forces		+	2 kg Sawdust + 8 kg Dried manure	80% Dried manure + 10% sawdust +10% sawdust and dried manure	220	5	3	3		11	883
21	Nowruz Abad		+	9 kg Dried manure + 0.15 kg stubble + 0.35 kg sawdust + 0.5 kg woodchip	90% Dried manure + 3% stubble + 7% sawdust and dried manure or woodchip	80	6	3	2		11	321
22	Namak Abroud			3-4 kg Dried manure + 6-7 kg woodchip	35% Dried manure + 65% woodchip	30	9	9			18	197
23	Abbas Abad	+		8 Kg	Woodchip	30	6	1	2		9	99
24	Saghafi	+	+	4-5 kg woodchip + 4-5 kg dried manure	50% Woodchip + 50% dried manure	69	6	3	3		12	302
Σ	1809	136.5	79.5	37	2	257	5982					

wood chips and sawdust daily for bedding (about 2800 tons annually).

According to Table 1, from 24 horse club centers with 1809 horses, the horse manure production can be estimated at nearly 33 tons per day or 12,000 tons per year. Only 1,900 tons of dry manure, which is eighty percent of the 2,400 tons of biomass waste, has been dried, and with a maximum moisture content of 30%, 2,700 tons of fresh manure is returned to re-bedding. Therefore, at least 9000 tons of the remaining manure produced by the horse should be managed flawlessly. The bed is contaminated with horse manure, which is left in the open air for a long time to lose its moisture.

After drying, the manure is stored to be saved for the rainy season when this drying method is not possible. Horse manure generally requires one to two weeks to dry in the open air, depending on the ambient temperature. To prevent pest infestations, efforts are made to store the manure as far away from the horse stables as possible. If there is insufficient space for manure storage and it is not need-

[DOI: 10.22034/JAERT.1.4.71]

ed for landscaping around the stables, the manure is typically delivered to municipal waste management. According to the club owner, manure with high nitrogen content and salts, but low phosphorus levels, is beneficial for lawns. This horse manure is often mixed with cow manure at a ratio of three parts horse manure to one part cow manure. Table 1 presents the amount of food and bedding used for horses in different stables.

We considered the mixture of bedding material, manure (dung), urine, and some food waste as the polluted beddings, including the contaminated sawdust bedding, the polluted chaff wood bedding, the polluted chaff wood, and dry horse manure, and the polluted dry horse manure.

The analysis on the first sieve was performed on samples kept in the oven for 20 hours with a humidity of 10% at 105 degrees centigrade. The second analysis was carried out on samples pretreated in the oven for 36 hours and humidity of 0%. Figure 3 indicates graduation for dried polluted horse bedding for three specimens for 36 hours and humidity of 0%.

Our horse bedding samples consisted of horse manure and sawdust. About seventy percent of the material passed through the sieve with 3.15 mm, which means the size of the materials is acceptable. The distribution of tiny materials in the air can influence public health adversely [31]. The minimum size of the sieve was 0.075 mm, which was a limitation of laboratory equipment. The size is seven times PM10 and thirty times PM2.5. In our samples, 1.5% of particle size was under 0.075 millimeters. However, the aerosol particle size should be removed before using it as re-bedding for horses or pellets (Figure 3). For industrial use purposes, 97% of the particle should be less than 3.15 mm [36].

Table 2 indicates moisture content, Ash content, Nitrogen content, Carbon content, and net calorific energy of different polluted horse bedding. The experimental study of the polluted bedding depicted that the moisture content of the samples ranged from 21.20% to 76.92% (Table 2). The wood pellet has some specifications, which are illustrated in Table 3. According to Scott (2012) and Thek and Obernberger (2012), the optimized range of moisture could be considered between 10% to 12%. Therefore, to produce energy, the selection's moisture needs to be reduced. However, about 23% of energy is used for drying the material [32, 35].

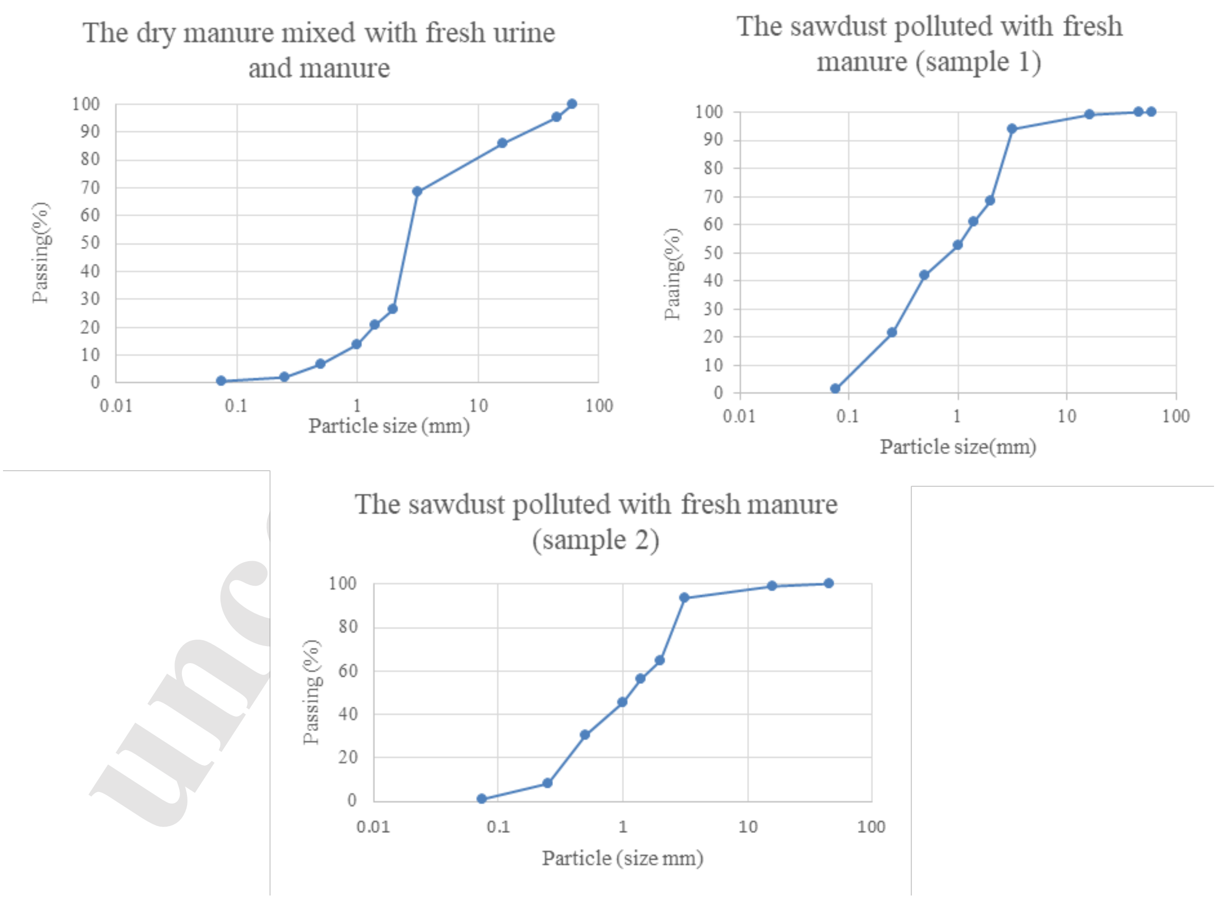

Fig. 3. Sieve analysis for collected samples, testing results

[DOI: 10.22034/JAERT.1.4.71]

Table 2- moisture, Ash content, Nitrogen content, Carbon content, and net calorific energy of different polluted horse bedding.

Samples	Moisture content (%)	Ash content w.-%	Nitrogen content (%)	Carbon content (%)	Net calorific value (MJ/kg)
The polluted sawdust bedding (PSDB)	76.92	7.73	1.47	-	19.43
The polluted chaff wood bedding (PCWB)	72.45	9.50	1.36	-	21.23
The polluted chaff wood and dry horse manure (PCWDHM)	39.63	17.20	1.77	-	16.79
The polluted dry horse manure (PDHM)	74.55	10.15	1.54	-	18.73
The dry manure mixed with fresh urine and manure (DM-FUM)	21.20	-	1.64	24.18	-
The sawdust polluted with fresh manure (sample 1) (SPFM)	24.40	-	1.42	28.61	-
The sawdust polluted with fresh manure (sample 2) (SPFM)	36.46	-	0.78	19.08	-

Ash is a mineral material, which remains after the complete combustion and burning of all organic material. All samples had higher ash contents than the mentioned standard (Table 3). Ash production alone does not determine the feasibility of reusing materials for horse bedding; however, minimizing ash is crucial for effective energy generation. It is vital to have a proper outlet in the combustion chamber for ash removal, ensuring that solid ash can be cleared at appropriate intervals [35]. Despite this, some fuels may face issues such as ash lumping and slag formation [7]. Thus, while ash content is significant for combustion efficiency, the quality of the ash and its propensity for slagging are equally important factors to consider. For instance, high amounts of potassium raise ash melting behavior and slagging tendencies. These are more significant problems than the overall higher ash content for industrial.

The nitrogen content does not affect the pellet production directly or reusing for horse bedding. However, it causes an increase in nitrogen oxides (NOX), which is a greenhouse gas[26]. Carvalho et al. (2008) indicated that the emission rate of the NOx from wood biomass would be 300 mg/MJ.[7] Nevertheless, the NOx emission amount from horse manure was between 450 and 600 mg/MJ. According to DIN 51731(1996) and ONORM M 7135(2003), the optimum value of nitrogen content was less than 0.5.[12] The experimental results showed that the nitrogen content of our horse bedding was higher than the standard. Car-

Table 3. The comparison between the non-industrial Specifications of wood pellets and our results

Property class	Unit	A1	A2	B	The minimum results of our study
Origin & source a		- Stemwood - Chemically untreated wood residue	- Whole trees without roots - Stemwood - Logging residues - Bark - Chemically untreated wood residues	- Forest, plantation, and other virgin wood - By-products and residues from wood processing industry - Used wood	- Used Horse bedding
Moisture (M)	W%	≤10	≤10	≤10	21.2
Ash (A)	W% - dry	≤0.5a ≤0.7a	≤1.0	≤3.0	7.73
Net calorific value (Q)	MJ/kg	≥16.5	≥16.5	≥16.5	16.79
N	W% - dry	≤0.3	≤0.3	≤0.3	0.78

[DOI: 10.22034/JAERT.1.4.71]

valho et al. (2008) reported the suitable nitrogen content of combustion at 0.6% of dry weight.[7] Lundgern and Pettersson (2009) achieved 1.8% nitrogen for horse manure mixed with a straw and 0.9% nitrogen content for wood bedding. Cotton (2009) found 0.64% of dry-weight nitrogen from wood bedding.[9] Alakangas (2010) proposed the 1 % nitrogen content of the bedding for class B pellets.[4] The reduction of nitrogen oxide (NOX) would decrease the ratio of oxygen per fuel, which means the suitability of manure as fuel is practical [4, 7, 8, 9].

The nitrogen content in the present work is inconsistent with Lundgern and Pettersson's (2009) study. However, for all samples except sample 2, nitrogen was too high for combustion. Only the sawdust polluted with fresh manure (sample 2, Table 2) met the maximum permissible amount of nitrogen content for domestic use. The high nitrogen content in pellets enforces pellet producers to pretreat their raw material [26]. Using additives or more wood is a method to decrease nitrogen content. The flue gas recirculation method can reduce NOx during combustion by 20% [41].

Hydrogen, carbon, and oxygen contents are the crucial parameters for biomass fuels [7]. Hydrogen can increase the gross calorific value while it reacts with oxygen. In other words, the net calorific value will decrease due to H2O production. In addition, hydrogen can cause the release of HCl or chlorinated hydrocarbons [7, 26]. Some chlorinated hydrocarbons are of great toxicity to plants or animals, including humans [8]. This is a problem if we have high Cl content in fuel. For assessing HCl production, Cl should be measured. However, because of budget limitations, the experiment was not carried out.

The higher carbon content in the polluted horse bedding increases the calorific value and combustion quality. Our results indicated that carbon contents varied between 19.08% and 28.61% on a dry-based weight, lower than in other parts of the world. Lundgren and Pettersson and Carvalho et al. (2008) studied horse manure mixed with straw. [7] They reported that the allowable carbon content was 43.6%. Cotton (2009) examined the wood bedding in Florida, United States, and achieved 42% carbon content.[9] The composition of bedding material, including wood and non-wood materials, and the region could influence the carbon content [26]. In this study, the majority of the collected samples consisted of a maximum amount of manure and a minimal amount of wood material. This is largely due to economic constraints in Iran, which limit stable owners' ability to incorporate additional wood materials into bedding. Wood biomass typically has a higher carbon content compared to non-woody biomass, resulting in a greater gross calorific value [27]. In woody biomass, there are high amounts of lignin which has a higher C compared to cellulose. Therefore, we have more C in wood than reused horse bedding. Re-bedding carbon content is not considerable.

The ratio of carbon to nitrogen (C/N) can affect the gross calorific value. The C/N ratio in our work was between 14.74 and 24.46, which was less than the other studies. Cotton (2009) achieved the C/N of horse bedding in Florida, polluted with manure and urine, at 72.1.[9] Furthermore, Smith and Swanson (2009) found that the C/N of horse bedding in Virginia, contaminated with dung and urine, was 72.1. The addition of chip wood or waste wood to the horse bedding samples can improve the ratio of C/N [7, 33].

We compared the minimum values of our experimental results to the standard values of some

Table 4. The comparison between the industrial specifications of wood pellets and our results (Verhoest and Ryckmans, 2012)

Property class	**Unit**	**I1**	**I2**	**I3**	**The minimum results of our study**
		- Forest, plantation, and other virgin wood - Chemically untreated wood residue	- Forest, plantation, and other virgin wood	- Forest, plantation, and other virgin wood	- Used Horse bedding
Moisture (M)	W%	≤10	≤10	≤10	21.2
Ash (A)	W% - dry	≤1.0	≤1.5	≤3.0	7.73
Net calorific value (Q)	MJ/kg	≥16.5	≥16.5	≥16.5	16.79
N	W% - dry	≤0.3	≤0.5	≤1.5	0.78

[DOI: 10.22034/JAERT.1.4.71]

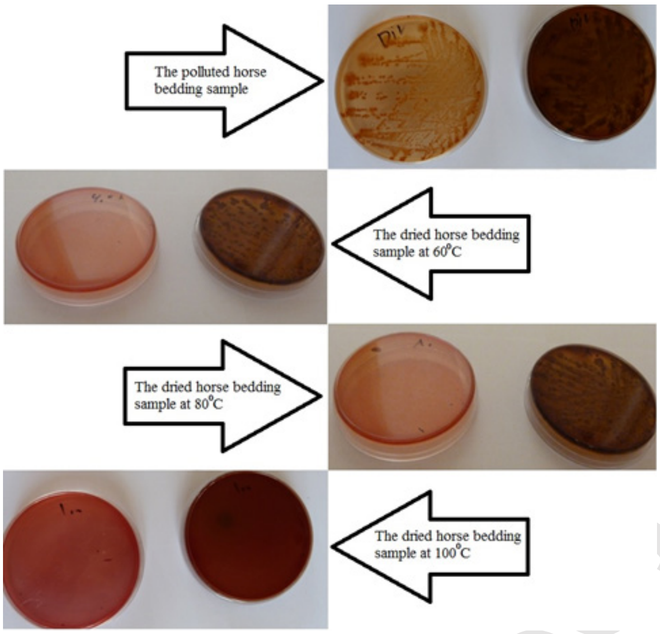

Fig. 4. The growing and removal of bacteria in different temperatures

specifications of the wood pellet for non-industrial use (Table 3). According to Table 3, the moisture, ash, and nitrogen contents of the horse bedding samples did not match the standard values of mentioned classes of wood pellets. One of the limitations of utilizing manure combustion is the amount of moisture content which is about 60%. Lio et al. (2021) reported that for removal of 62% w.b. moisture decreases by 23% potential energy content of the manure.[11] Also, nitrogen content may create public health problems and global warming. Ash content removal needs a budget and a suitable landfill. However, the net calorific value had an acceptable value.

According to the result in Table 4, the industrial use of the horse bedding pellets was more satisfactory. The minimum nitrogen content, which was 0.78 and less than 1.5, and the net calorific value of the samples (16.5 M/kg) met the standard for industrial use. However, the ash was 7.73%, which is more than 3%, and the moisture content was 21.2%, which was more than 10%. However, the moisture content can be reduced by drying.

To analyze the microbial specifications of the bedding samples, we dried the used horse bedding. To identify the optimum temperatures and times required for removing the pathogenic bacteria, we compared the polluted samples with different samples, which were dried by 60, 80, and 100 for 20 hours. According to Winn et al. (2006), we grew the specimen in the framework of MacConkey and blood agar in the laboratory. In the direct sample, the growth and reproduction of all three types of bacteria, including Listeria, Salmonella, and Escherichia coli, as well as bacteria of the families Bacillus, Staphylococcus, Klebsiella, Pseudomonas, and Crinibacterium were observed [40].

In the samples, which dried at 60°C, germ-negative bacteria such as Salmonella and Escherichia were removed (Fig. 4). Biswas et al. (2019) reported E coli and Salmonella were undetected within an hour at 60°C. [6] Our result is inconsistent with the mentioned study. Other bacteria, such as Klebsiella, Pseudomonas, and germ-negative bacteria such as Bacillus, Staphylococcus, and Listeria, were observed in the growing condition.

In the samples, which dried at 80, gram-negative bacteria such as Bacillus, Staphylococcus, Listeria, and germ-negative Pseudomonas bacteria were observed. At 100, all the bacteria were eliminated (Fig. 4). The results match the optimized energy for drying the samples.

4. Conclusions

Considering the results and discussions of the experimental work associated with the used horse bedding, we summarize the following conclusions:

- The polluted horse bedding in Tehran contained a high amount of moisture content, which is crucial to dry before being used for energy production or reuse.
- The ash content was between 7.73% and 17.20%, which means the contaminated horse bedding in Tehran has higher ash content than the other wood pellets. The ash content of used horse bedding contained high ash, which is not suitable for pellet produc-

tion. Not only the ash content is important for combustion, but also ash quality and slagging are significant. For instance, high amounts of potassium increase ash melting behavior and slagging tendencies.

- The nitrogen content in used horse bedding was between 0.78% and 1.77%. The sample containing 0.78% nitrogen was in class B of the pellet production. Merely the sawdust polluted with fresh manure (sample 2) satisfied the maximum permissible amount of nitrogen content for domestic use. Consuming additives or more wood consumption are suggested for decreasing nitrogen content. In addition, a flue gas recirculation method for reducing nitrogen content is also recommended.
- The used horse bedding, in the present study, contained a permissible net calorific value for industrial use.
- The hydrogen content of the used horse bedding was between 7. 06% and 9.04%, and carbon content varied between 14.74% and 24.46%. The parameters are not essential to produce pellets. However, the amount of hydrogen was higher than other biomass, which leads to an increase in the gross calorific value. Tehran horse bedding has a lower wood material content than other parts of the world. The amount of carbon was about half of another biomass.
- The average gross calorific value of the horse bedding was 19.0372 MJ/kg. The amount of energy from combustion and the production of pellet fuel was suitable. However, the gross calorific value is not determinative for reusing horse bedding.
- More than 70% of the bedding particles were less than 3.15 mm, and 1.5% of them were less than 0.075 mm. The bedding particle sizes were suitable for the production of pellets and combustion. However, aerosol particles (PM10 and PM2.5) that are less than 0.075 mm must be removed for reusing as horse bedding.
- We observed Salmonella, Escherichia coli, Pseudomonas, and reproduction, and growth in all polluted bedding samples. Other bacteria, such as Klebsiella, Pseudomonas, and positive, gram bacteria, for instance, Bacillus, Staphylococcus, and Listeria were also detected in the condition of bacteria growth. All mentioned bacteria were removed at 100°C after 20 hours.

[DOI: 10.22034/JAERT.1.4.71]

References

1. AASHTO (American Association of State and Highway Transportation Officials) (2011). T27: Standard Method of Test for Sieve Analysis of Fine and Coarse Aggregates. Standard Specifications for Transportation Materials and Methods of Sampling and Testing. Washington D.C. US.
2. Airaksinen, S. (2006). Bedding and manure management in horse stables. Its effect on stable air quality, paddock hygiene, and the compostability and utilization of manure. Kuopio University Publications C. Natural and Environmental Sciences, 190(52), 1235-0486.
3. Airaksinen, S., Heinonen-Tanski, H., & Heiskanen, M. L. (2001). Quality of different bedding materials and their influence on the compostability of horse manure. Journal of equine veterinary science, 21(3), 125-130.
4. Alakangas, E. (2010). European Standard (EN 14961) for wood chips and hog fuel. Forest Bioenergy, 329-40.
5. ASTM E711. 2004. Standard Test Method for Gross Calorific Value of Refuse-Derived Fuel by the Bomb Calorimeter. American Society for Testing and Materials, West Conshohocken.
6. S. Nazmi, A, Pitesky, M.Gallardo, R.Pandey, P.(2019) Thermal Inactivation of Escherichia coli and Salmonella Typhimurium in Poultry Carcass and Litter at Thermophilic Temperatures Journal of Applied Poultry Research, 28(2), 307-317
7. Carvalho, L., Lundgren, J., & Wopienka, E. (2008). Challenges in small-scale combustion of agricultural biomass fuels. International Journal of Energy for a Clean Environment, 9(1-3) 127-142. DOI: 10.1615/InterJEnerCleanEnv.v9.i1-3.100
8. Connell, D. W., Lam, P., Richardson, B., & Wu, R. (2009). Introduction to ecotoxicology. John Wiley & Sons. The UK.
9. Cotton, D. L. (2009). On-site evaluation of manure management practices and nutrient composition of stall waste produced by Florida horse operations. MSc Thesis, Florida University, Florida, US.
10. Cunniff (1995) Association of Official Analytical Chemists (AOAC). Official Methods of analysis of AOAC 16th edition. AOAC, Arlington, VA, USA.
11. Da Lio.L. Da Castello, P. Gianfelice, G. Cavalli, P. Canu.P (2021). Effective energy exploitation from horse manure combustion. Waste management, 128, 243-250. doi: 10.1016/j.wasman.2021.04.035
12. DIN 51731(1996). Testing of Solid Fuels—Compressed Untreated Wood, Requirements, and Testing. Deutsches Institut fur Normung, Berlin.
13. EN14774-1(2009). Solid biofuels - Determination of moisture content - Ovendry method - Part 1: Total moisture - Reference European Committee for Standardization: Management Centre, Avenue Marnix 17, B-1000 Brussels.
14. EN 14961(2010) Solid biofuels – Fuel Specification and classes, Part 1 – General requirements. CEN (European Committee for Standardization). January 2010. 52 p.
15. EN ISO 17225-1:2014. Solid biofuels – Fuel Specification and classes, Part 1 – General re-

requirements.
16. EN ISO 17225-2(2014) Solid Biofuels Fuel Specifications and Classes. Part 2: Graded Wood Pellets; National Standards Authority of Ireland: Ireland, UK, 2014.
17. EN ISO 17225-6(2014) Solid Biofuels Fuel Specifications and Classes. Part 6: Graded Non-Woody Pellets; National Standards Authority of Ireland: Ireland, UK, 2014.
18. Fleming, K., Hessel, E. F., & Van den Weghe, H. F. A. (2008). Evaluation of factors influencing the generation of ammonia in different bedding materials used for horse keeping. Journal of equine veterinary science, 28(4), 223-231.
19. Havukainen, J Väisänen , S. Rantala ,T.Saunila, M. Ukko, J.(2020) Environmental impacts of manure management based on life cycle assessment approach, Journal of Cleaner Production, 264, 121576. . https://doi.org/10.1016/j.jclepro.2020.121576
20. Hayman, D. F., & Adler, S. (1937). Microanalysis of nitrogen in certain pyrimidines by the Dumas method. Industrial & Engineering

[DOI: 10.22034/JAERT.1.4.71]

Chemistry Analytical Edition, 9(4), 197-197.

21. Lundgren[1], J., & Pettersson, E. (2004). A practical, environmental, and economic evaluation of different options for horse manure management. 16th International Congress of Chemical and Process Engineering; 22-26 August; Prague, Czech Republic

22. Lundgren, J., & Pettersson, E. (2009). Combustion of horse manure for heat production. Bioresource Technology, 100(12), 3121-3126.

23. Monki, J, Saastamoinen, M. Karikoski ,N. Rajamäki, M. Raekallio, M. Junnila. J. Särkijärvi S. Norring, M. Valros A. Ben Fatma, S.O. Mykkänen,A. Effects of Bedding Material on Equine Lower Airway Inflammation: A Crossover Study Comparing Peat and Wood Shavings Front. Vet. Sci https://doi.org/10.3389/fvets.2021.656814

24. Mönch-Tegeder, M. Lemmer, A. Oechsner,H. Jungbluth,T.(2013) Investigation of the methane potential of horse manure, Agricultural Engineering International : The CIGR e-journal 15(2):161-172

25. Mönch-Tegeder, M., Lemmer, A., & Oechsner, H. (2014). Enhancement of methane production with horse manure supplement and pretreatment in a full-scale biogas process. Energy, 73, 523-530. https://doi.org/10.1016/j.energy.2014.06.051

26. Obernberger, I., & Thek, G. (2004). Physical characterization and chemical composition of densified biomass fuels with regard to their combustion behavior. Biomass and bioenergy, 27(6), 653-669.

27. Obernberger, I., & Thek, G. (2010). The Pellet Handbook – The Production and Thermal Utilization of Biomass Pellets, Earthscan

28. Quinn, A. (2001) Does Horse Manure Pose a Significant Risk to Human Health? Envirohorse. http://www.californiastatehorsemen.com/enviro/

29. Patterson, R. K. (1973). Automated Pregl-Duma's technique for determining total carbon, hydrogen, and nitrogen in atmospheric aerosols. Analytical Chemistry, 45(3), 605-609.

30. Rhee, K. C. (2001). Determination of total nitrogen. Current protocols in food analytical chemistry. Wiley, New York, US.

31. Russell, A. G., & Brunekreef, B. (2009). A focus on particulate matter and health. Environmental science & technology, 43(13), 4620-4625.

32. Scott, C. (2012). The Beginners Guide to Pellet Production. Available from: https://www.pelheat.com/Beginners_Guide_To_Pellet_Production.html. Visited on 6 March 2014

33. Smith, C., & Swanson, C. A. (2009). Horse Manure Management. Available from: https://vtechworks.lib.vt.edu/bitstream/handle/10919/48534/406208_pdf.pdf?sequence=1&isAllowed=y

34. Tehran Municipality (2014). Tehran Bus Company. Available from: http://bus.tehran.ir/Default.aspx?tabid=41. Visited on 5 February 2022.

35. Thek, G., & Obernberger, I. (2012). The pellet handbook: the production and thermal utilization of biomass pellets. Routledge, UK.

36. Verhoest, C., & Ryckmans, Y. (2012). Industrial wood pellets report. ENplus. Available from: ENplus http://www. enpluspellets. EU/wp-content/uploads/2012/04/Industrial-pellets report_PellCert_2012_secured. pdf.

37. Wartell A (2009). Anaerobic digestion of equine waste (Doctoral dissertation, Rutgers, Ph.D. Thesis. The State University of New Jersey, US.

38. Wartell, B. A., Krumins, V., Alt, J., Kang, K., Schwab, B. J., & Fennell, D. E. (2012). Methane produced from horse manure and stall waste with softwood bedding. Bioresource technology, 112, 42-50.

39. Wheeler E., Smith Zajaczkowski J. 2002. Horse Stable Manure Management, College of Agricultural Sciences, G-97, Penn State Cooperative Extension, USA.

40. Winn, W. C. (2006). Koneman's color atlas and textbook of diagnostic microbiology. E. W. Koneman (Ed.). Lippincott Williams & Wilkins. Philadelphia, US.

41. Zandeckis, A. (2010) Methods of Nitrogen Oxide Reduction in Pellet Boilers Scientific Journal of Riga Technical University 4,123-129. DOI: 10.2478/v10145-010-0027-2 2010.