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INCINERATION OF TANNERY WASTE IN A TUNNEL FURNACE SYSTEM

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The leather industry generates significant amounts of waste for which there is not comprehensive treatment method. Such waste is mainly landfilled, which is an environmental threat. However, solid tannery waste could be incinerated since it contains organic matter. This paper describes research on the incineration of solid tannery waste which was conducted on an experimental installation with a tunnel furnace as the main component. The paper includes brief characteristics of tannery waste and the experimental installation overview. Further on, the experimental conditions as well as measurements and residue analysis results are presented.

Keywords: tannery waste, tunnel furnace, waste incineration, waste treatment

1. INTRODUCTION

Production of leather is one of the oldest industrial processes in mankind's history. It is based in the conversion of raw hide or skin, a highly putrescible material, into leather, a stable material, which can be used in the manufacture of a wide range of products. The whole process involves a sequence of complex chemical reactions and mechanical processes. Among these, tanning is the fundamental stage, which gives leather its stability and essential character [1].

Processing hides into leather requires a substantial input of energy and water. It generates significant amounts of waste, wastewater and odors. Thus, the leather industry is considered to have a negative impact on the environment and is a burden on the tanneries' immediate neighborhood [2].

Depending on the technology, from ca. 450 to ca. 730 kg solid waste is produced per 1 Mg of input material processed [3]. Its treatment is a huge problem for tanneries since there is no comprehensive method applicable for all types of solid waste. In most situations the only economically efficient method

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is landfilling which, according to the European Waste Hierarchy, is the least favored waste treatment method [4].

Worth noting is the fact that most types of tannery solid waste consist of organic matter and therefore their heating values are high enough for combustion processes. The research on a comprehensive thermal method of solid tannery waste treatment is currently being developed at the Cracow University of Technology. The aim of the research is to develop the technology for solid tannery waste combustion which, on the one hand, utilizes waste in an economically efficient manner and, on the other hand, meets all the standards for waste incineration. For this purpose an experimental installation has been designed and manufactured. In this paper the first measurements conducted on a new type of installation as well as brief thermal characteristics of tannery waste are presented.

2. CHARACTERISTICS OF TANNERY WASTE

Leather processing involves a series of operations. It can be broadly classified into pretanning (known as beamhouse operations), tanning, post-tanning, and finishing. The crucial operation is tanning during which tanning agent compounds crosslink collagen fibers of the hides. As a result the leather gains its biological stability. The most commonly used tanning agents are chromium(III) compounds. The content of chromium in finished leather amounts to approximately 4-5 %w/w [1].

The waste generated prior to and after tanning differs significantly. Untanned waste includes hide trimmings (or unusable pieces of raw hides) and fleshing (or mechanically scrapped out tissues adjacent to the hide). Tanned wastes containing trivalent chromium are leather trimmings, splits (obtained during splitting operation), shavings and buffing dust. These wastes are biologically stable. Solid waste also comes from wastewater sludge [2], [5]. The input/output overview for a conventional tanning process including the quantities of solid waste generated is shown in Fig. 1.

All major types of solid tannery waste were characterized for their suitability for disposal in a combustion process. Total organic content, water content, combustion residue, as well as lower heating value were analyzed [6]–[8]. The characteristics are presented in Table I.

Heating values of all types of waste (with the exception of sludge) are relatively high, which indicates that combustion of the waste is feasible. The problem is the high water content in some types of waste – up to 60 %w/w. This implies the necessity of preliminary drying prior to actual incineration. The combustion residue consists of ash in relatively small amounts – 4-8 %w/w (apart from sludge, which contains significantly more inorganic incombustible matter). Ash created during combustion of tanned waste contains mainly chromium(III) oxide and therefore it can be used as a substitute for chromium ore in chromate(VI) production [8].

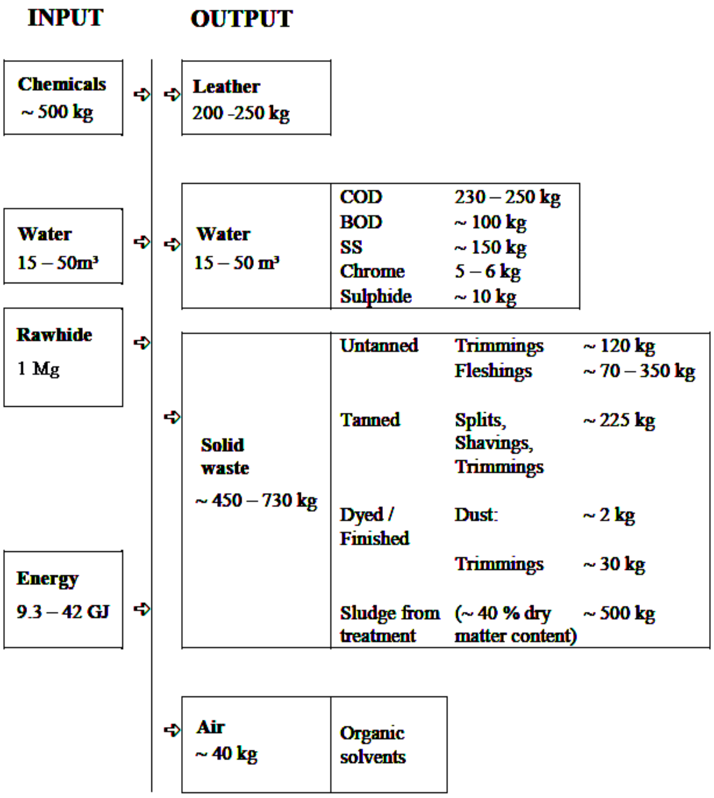

Fig. 1. Input/output overview for a conventional chrome-tanning process for bovine salted hides per 1 Mg of raw hide processed [3]

Table 1. Characteristics of Tannery Waste [6]–[8]

Type of waste	Total organic substances content in dry matter (% w/w)	Water content (%w/w)	Combustion residue – ash (%w/w)	Lower heating value (kJ/kg)
Shavings	87.5	53.6	7.8	6 663
Sludge	65.5	54.7	24.3	716
Buffing dust	87.4	14.3	6.2	16 953
Leather trimmings	87.7	10.2	4.7	19 772
Hide trimmings	86.9	59.9	4.7	7 753
Fleshings	91.4	59.5	4.6	8 952

3. THE EXPERIMENTAL INSTALLATION

In order to carry out research on tannery waste incineration an experimental installation was designed and built [4], [8], [9]. The contractor for the construction was Firma CZYLOK, Poland. The installation is located at the site of Krakowskie Zakłady Garbarskie S.A. (Cracow Tannery Works S.A., Cracow, Poland), who participate in the research and enable direct access to the waste. The main component of the installation is a tunnel furnace. As mentioned, tannery waste contains a significant amount of moisture, which needs to be evaporated prior to combustion. In a tunnel furnace it is possible to maintain thermal conditions which continuously change along the length of the tunnel. Thus, the tunnel can be virtually divided in a few sections corresponding to the following processes: waste drying, volatilization of organic matter, and combustion.

The scheme of the installation is presented in Fig. 2. The tunnel is approx. 7 m long. The waste is put into containers which can be transmitted along the tunnel by a roller system. The bottoms of the containers are perforated to enable air penetration. The nominal efficiency of the installation is 50 kg of waste per hour, but it can be changed in a wide range by 1) regulating the amount of waste in each container, 2) by regulating the velocity of the rollers. In order to preheat the furnace and to maintain the set temperatures three sections of electric heaters were installed. Technical reasons excluded the application of gas burners which had been preferable. The nominal power of the total system is 78 kW. Pressure, temperature and oxygen sensors give information about: temperature at several points of the system, pressure at the entrance and in the combustion section, as well as oxygen concentration in the flue gas. The flue gas which leaves the tunnel passes through a heat exchanger system with water and air as cooling media. The heated water is used by the tannery, the air is the intake air for the process. The air can be subsequently heated electrically and its flow can be regulated. The heat exchange enables the reuse of energy input to the system as well as waste energy recovery. The cooled flue gas passes next through the filter chamber where flue-ash is partially deposited, and leaves the system through a chimney. In the chimney there are measurement points which enable the mounting of gas sensors.

4. EXPERIMENTS

In one experimental series 81 kg of waste was incinerated. The tanned wastes incinerated were: leather trimmings, shavings, and buffing dust, in a weight ratio of 2:2:1. The average lower heating value of the mixture is ca. 13 900 kJ/kg, the average water content – ca. 28 %w/w. Each container consisted 3 kg (+/- 0.1 kg) of the mixture.

The temperature of the preheated combustion air was 350 ^{o}C. The air is introduced right after the entrance door of the tunnel. The temperature in the combustion section was set at 875^{o}C in order to exceed 850 ^{o}C – the minimum temperature of waste incineration allowed by EU regulations. The introduction of containers started when the temperature in the combustion section approached 650 ^{o}C. The time interval between the introduction of containers was 12 min. This gives 5 containers (or 15 kg of waste) per hour. The total time of container transmission through the tunnel was 1 h 45 min. The temperatures, pressures, and oxygen content in the flue gas were recorded.

A AWE-PW analyzer was used for analysis of the volatile organic compounds (VOC) present in the flue gas (producer: ZAM Kęty sp z o.o., Poland).

The residue ash was weighted and analyzed using powder X-ray diffraction (XRD). XRD measurements were performed on an X'pert Phillips diffractometer using a CuKα radiation (λ = 1.54178 Å) in 2 Theta range from 10^{o} to 60^{o}. A Perkin Elmer 2400 CHN Elemental Analyzer was used for carbon, hydrogen, and nitrogen (CHN) elemental analysis.

5. RESULTS

As a result of the process the waste was incinerated, leaving residues of ash and flue gas. The variation of temperature during the process at several measurement points of the installation is presented in Fig. 3. The time 0:00 refers to the introduction of the first container. Noticeable is the periodicity corresponding to the introduction of following containers. The highest temperature amplitude is observed in the first section. Immediately after the introduction of waste, drying and subsequently volatilization takes place. It lasts app. 3-4 min. and then ignition occurs which manifests itself through the rapid increase of the temperature. After the burning waste moves further into the tunnel and leaves the first sensor range, the temperature in the first section decreases. In subsequent sections the temperature is higher due to preheating and the fact that hot flue gas from the first section passes through them and raises the temperature. The temperature in the final combustion section rises to 850 ^{o}C after about 4.5 h and is stable during the rest of the experiment. The amount of electrical energy required to maintain the temperature decreases significantly at this stage of the experiment, but some electrical input is still required.

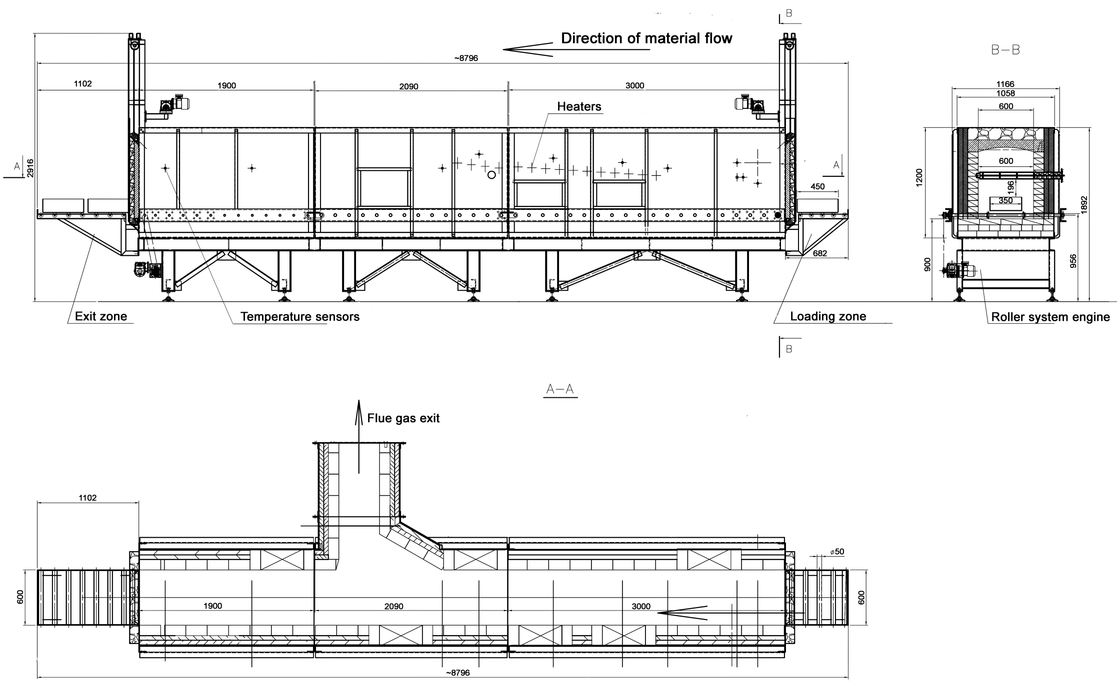

Fig. 2. Scheme of the tannery waste incinerating installation

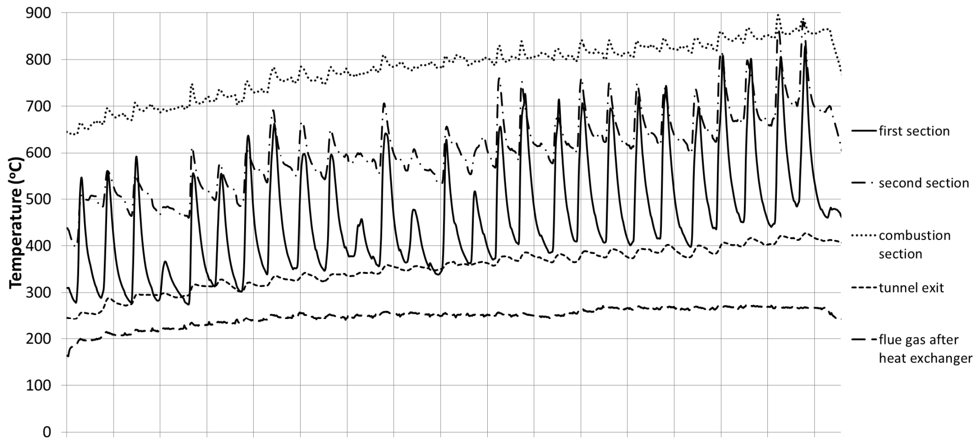

Fig. 3. Furnace temperature vs. time diagram

From 4:40 after the start to the end of the experiment the concentration of VOC was measured and recorded. The results were converted for the standard oxygen concentration of 11 %. The diagram of VOC concentration, oxygen concentration and the temperature variation in the first section of the tunnel are shown in Fig 4. The average oxygen concentration is relatively high, and it decreases significantly (to 11-14 %) only when the ignition and rapid combustion of the new portion of waste takes place. After ca. 3 min the oxygen concentration rises again to ca. 18 %. Keeping the oxygen concentration at a high level is not particularly efficient (more preheated combustion air is needed) but it is necessary to not allow oxygen concentration to drop too much during the ignition of each portion of waste. Unfortunately, the air flow cannot be regulated dynamically.

Noticeable in Fig. 4 is the fact that immediately after the introduction of a new portion of waste (which took place at 4:48, 5:00, and 5:12) and before the ignition (demonstrated by the sudden drop of the oxygen concentration) the VOC concentration rises. Then, during ignition, it decreases for a short time and rises again. The explanation of such a trend lies in the process of volatilization of organic matter. Shortly after the input of waste into the furnace the volatilization starts. The concentration of VOC rises (first of two peaks in the diagram) but soon it reaches the level when in the given thermal conditions ignition occurs (VOC concentration and oxygen concentration both drop). The combustion is at first rapid and some incomplete combustion may occur, which results in another rise in the VOC concentration. After ca. 2 min. the combustion calms and the VOC concentration decreases again.

The fluctuations of curves at 4:46, 4:58, and 5:11result from the disturbances caused by opening the exit door and allowing the container to exit the tunnel. The average VOC concentration during the measurement was 18.84 mg/m^3 and it did not exceed the emission standard (20 mg/m^3).

The total amount of ash after the experiment was 6.3 kg, which gives 10 % of the weight of waste incinerated. The ash was analyzed using XRD. The resulting diagram is presented in Fig. 5. The only visible peaks correspond to the structure of chromium(III) oxide. The CHN analysis shows that concentration of elemental carbon in the ash amounts to 0.21 %w/w, hydrogen and nitrogen were not found (meaning their concentrations are below 0.1 %w/w). These results indicate that the obtained ash contains mostly chromium(III) oxide and could be perfectly used as a chromium ore substitute in chemical industry.

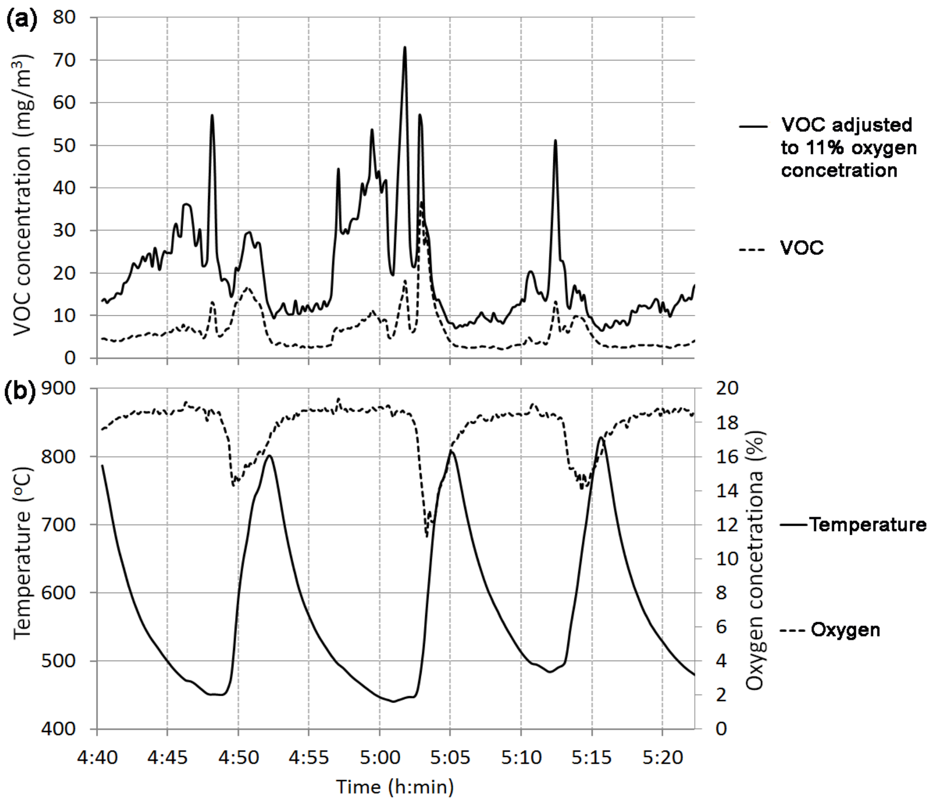

Fig. 4. (a) VOC concentration in flue gas and VOC concentration adjusted to 11 % oxygen concentration vs. time; (b) Temperature in the first section of the tunnel and oxygen concentration in flue gas vs. Time

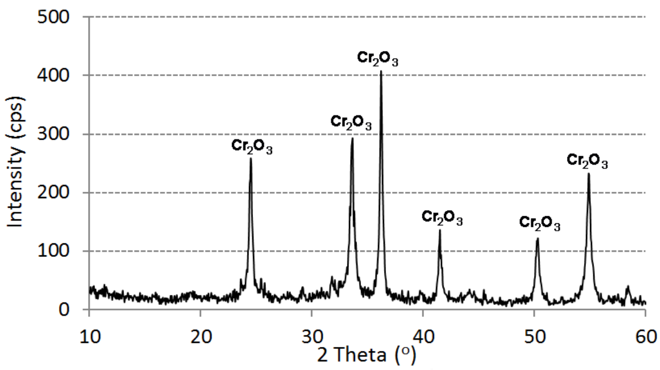

Fig. 5. XRD pattern of residue ash

6. CONCLUSION

The experiment proves that incineration of tanned wastes from the leather industry is feasible. An installation based on a tunnel furnace concept is suitable for such a process. It is possible to set process conditions such that combustion is complete and the obtained ash contains mostly chromium(III) oxide. Measurements of oxygen and VOC concentrations in the flue gas enabled an overview of volatilization process preceding ignition.

Further planned experiments include changing amounts and types of waste incinerated (including untanned waste), velocity of rollers, different temperature and air flow set, and additional analysis of the flue gas composition. Further on, the energy balance will be calculated so that the efficiency of the process could be estimated. It is expected that the experiments will allow us to choose the best parameters for the tannery waste incineration technology which could find wide application.

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SPALANIE ODPADÓW GARBARSKICH W PIECU TUNELOWYM

S t r e s z c z e n i e

Przemysł garbarski generuje znaczne ilości odpadów, dla których nie istnieje kompleksowa metoda unieszkodliwiania. Odpady te są głównie składowane, co wiąże się z zagrożeniami dla środowiska. Możliwe jest jednakże spalenie stałych odpadów garbarskich ze względu na znaczną zawartość materii organicznej. W artykule opisano badania dotyczące spalania odpadów garbarskich w doświadczalnej instalacji, której głównym komponentem jest piec tunelowy. Przedstawiono zwięzłą charakterystykę odpadów, opis instalacji doświadczalnej, jak również warunki prowadzenia eksperymentów oraz wyniki pomiarów i analiz pozostałości poprocesowych.