Rendering of Waste by Application of Microwave Energy

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1. Introduction

Waste utilization is one of the most important problems of civilization. Continuously growing stream of waste from industrial processes and communal waste, and at the same time emission of polluted gases into atmosphere, needs new efficient solutions. Prometeus Ltd. has developed several new innovative methods for waste treatment with the use of high power microwaves. The technologies developed have been applied in industrial scale, and they seem to be very promising alternatives for conventional methods.

Development of the high-power microwave systems create a new technical possibility to apply microwaves in industrial scale with reduced utilization costs. The main advantages of the developed microwave reactors are:

- Possibility of bringing up any dielectric material to the temperature range of 1000-1200ºC (rousting).
- Possible precise control of the temperature within the reactor (temperature stabilization).
- Shorter starting times of the installation (a 1000ºC temperature is reachable after 20 minutes).
- Rousting process could be operated in a controlled atmosphere, for example in a reactor filled with air (in waste burning) or with inert gases (in heat treatment without oxidation).
- Rotational operating mode (provides a continuous mixing of the reactor contents, which increases the possible contact with oxides from the air, and uniformly distributes the heat).
- Possibility of nesting active centers in the catalyst carrier in the form of granulated ceramics (depending on wastes qualities, using the appropriate catalyst could accelerate a temperature reduction or even enable reducing the problem of toxic compounds created in undesirable reactions of thermal condensation).
- Ability to meet customer needs in terms of capacity along the technical line. It is possible to build a mobile unit mounted in a standard 20-foot container with a capacity of about 200kg/h, or to build a plant with a capacity of several tons per hour.
- Research of the hazardous wastes utilization shows 99% loss of harmful organic compounds.

The system can be used in many fields thanks to the flexibility and ease of control of the three basic parameters of the process, namely: temperature, quantity and quality of the provided atmosphere, as well as the time spent in the reaction zone.

2. HR-series microwave reactors

The most important element of the installation is the microwave reactor made in the form of a cylindrical drum situated within a metal chamber equipped with microwave radiators. The microwave energy emitted from the microwave radiators is transmitted inside the ceramic drum, which contains the treated waste (sometimes mixed with a special additive enhancing the absorption of microwaves). Depending on the process, the content is heated up with microwave energy to a temperature in the range 900-1300°C in its entire volume. The system guarantees a uniform heating with microwaves thanks to the mixing of the waste in the rotating drum and the application of a special system of microwave radiators deployed along the process chamber. The reactor applies several horn antennas, which excite the TE_{01} and TE_{02} modes. The antennas (radiators) are positioned in such a way that neighboring antennas emit waves of mutually-perpendicular polarization. This minimizes the transmission of microwave energy between neighboring microwave lines. The construction of the HR reactor is shown in Fig. 1.

The reactor with a capacity of 200 kg/h is powered by 14 microwave generators operating at

2,450-MHz and 3-kW CW power each. Ferrite circulators with water loads are installed in the microwave system. The reflection coefficient, measured during the utilization of asbestos waste, varied in the range $|\Gamma| \approx 0.08 - 0.1$ (in conditions in which the asbestos waste introduced into the reactor was preheated to ~800°C).

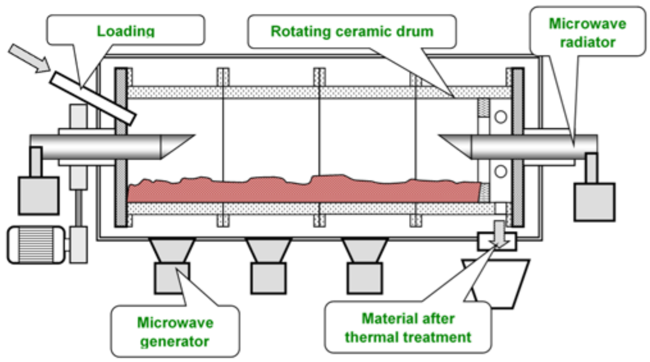

Figure 1. A schematic of the HR reactor.

Figure 2. The HR-200 reactor installed inside a standard 20-feet container.

3. Microwave oxidation system (MOS)

One important element of the installation is the device which purifies exhaust gases leaving the HR reactor. It is also used for afterburning of exhaust gases from furnaces, incinerators, thermal processing equipment for certain substances, from paint shops, arduous odour-emitting plants, and other sources that emit polluted exhaust gases.

In case of utilizing asbestos waste, a stream of exhaust gases may contain asbestos fibers and other harmful substances released athigh temperature (e.g. hydrocarbon emitted due to degradation and burning of varnished coatings and other contaminants). For effective purification of hot gases, a unique structure of the microwave generator has been designed, in the form of an insulated chamber filled with special crystals made of ceramics which absorbs microwaves. These elements are heated up to ~900-1100°C by microwaves emitted from radiators deployed on the metal casing of the chamber. In turn, gaseous contaminants become oxidized; however, this process is catalyzed through contact with the special ceramics heated to a very high temperature. This process is illustrated in Fig. 3 by a simplified scheme of the MOS reactor structure.

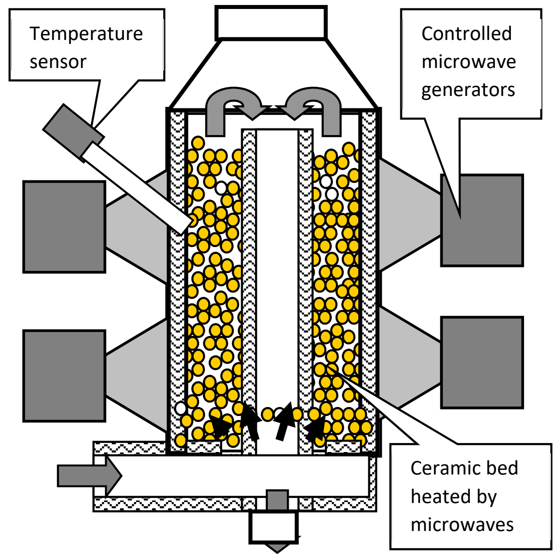

Figure 3. MOS construction scheme.

The temperature of the ceramic insert inside the MOS-reactor chamber is measured with a system of thermocouples deployed in each section. The MOS reactor with a capacity of 700 – 1000 Nm^3 is equipped with 12 microwave generators (2,450 MHz, 3-kW CW each). The microwave generators are connected with the radiators through water-loaded ferrite circulators. Microwave energy is emitted into the MOS reactor through horn antennas deployed on the metal casing. Further in this case, the antennas emit polarized waves hence their proper deployment reduces the coupling between individual generators and ensures the uniform heating of the ceramic inserts within the chamber. Measurements of the temperature distribution inside the chamber have shown that the heating up of ceramic inserts is sufficiently uniform (the temperature differences do not exceed 60-90 °C at ~1000 °C average temperature of the ceramics). The effectiveness of gases purification in the MOS reactor has been confirmed numerous times in studies conducted by certified laboratories. This effectiveness is illustrated, among others, by the data shown in Fig. 4. Two MOS reactors of capacities of 600 m^3/h and 4500 m^3/h are shown in Fig. 5.

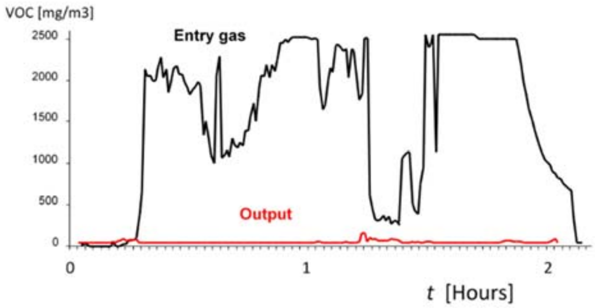

Figure 4. Measurements of volatile organic compounds (VOC) before and after MOS reactor.

(a)

(b)

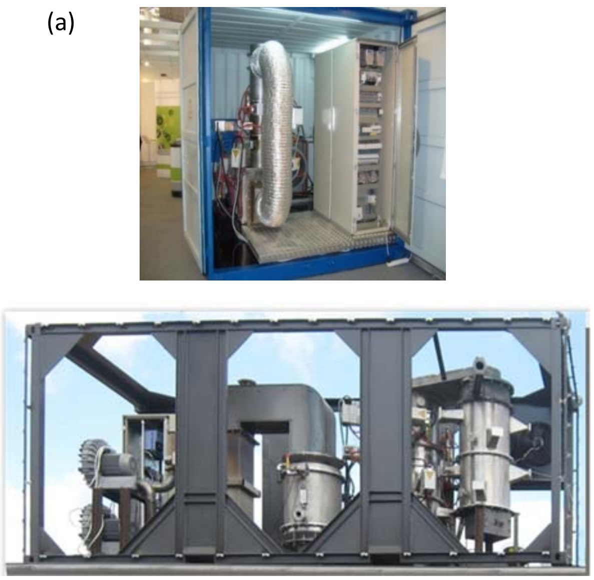

Figure 5. MOS reactors installed in 20-feet containers, with capacities of 600 m^3/h (a) and 4500 m^3/h (b).

4. Municipal waste utilization and energy recovery

One of the most significant applications of the HR reactor is in the processing of municipal waste. Its storage is currently being reduced through legal regulations in many countries, which makes it necessary to use utilization technologies, i.e. by way of burning or gasification. The described microwave technology provides some unique opportunities in this respect because the process of thermal treatment in HR reactors can be conducted in a controlled atmosphere, e.g. in high shortage of oxygen. Therefore, the process of gasification of waste in the HR microwave reactor provides an advantage over conventional methods thanks to heating the whole volume of waste and without the transmission of heat energy through the walls of the chamber. No slag or other coke substances settle on the walls of the HR reactor and the material is heated volumetrically, and is gassed effectively when mixed in the ceramic drum. At the same time, through a controlled selection of the amount of air fed into the reactor, waste can be partially burned, thus creating only carbon monoxide (CO), which, together with other generated gases such as methane, hydrogen, butane, propane and other light hydrocarbons, are then used for powering the engine coupled with the power generator. Figure 6 presents a diagram of an installation for utilization of municipal and other waste with recovery of electricity.

The most important element of the installation is the HR 5000 microwave reactor, which allows the gasification of 3-4 tonnes of waste per hour and is equipped with two microwave generators with capacity of 75 kW or 100 kW (CW) each and operating at 915 MHz. Gases from this reactor are directed to the unit of the separator of oily and tar fractions, where they are pre-cooled and purified. The separated substances are returned to the HR 5000 reactor, in which, due to heating up with microwaves to a high temperature, they are decomposed into light hydrocarbons and then fed again to the separator. The stream of gases from the separator is then directed to the scrubber, where chlorine, fluorine, and sulphur (elements harmful to the operation of the motor) are separated. The purified gases power the engine coupled with the power generator. Such a system allows to generate e.g. ~2 MW of electric power when utilizing around 3-4 tonnes of selected waste with calorific value of around 12-14 MJ/kg.

The system with HR5000 reactor is shown in Fig 7. The estimated energy balance for the system with HR5000 reactor used for gasification of waste is shown in Fig. 8. The method described here of municipal waste utilization by microwave energy is protected by a patent.

5. Treatment of Asbestos Containing Materials

With its outstanding physical and chemical characteristics, asbestos has been used on a mass scale for many years. For its thermal resistance and chemical stability, it has been applied as a component in insulation materials, roof covering (Eternit panels), construction elements, insulation filling in ships, laboratory elements, and many others. This material has turned out though to be highly harmful to people, and to cause the so-called asbestosis (fatal lung disease) among others. In Poland, approximately 14m tonnes of asbestos waste have been removed, mostly in Eternit panels, which were once commonly used for roof covering. Also in other countries it has been necessary to neutralize millions of tonnes of this hazardous material.

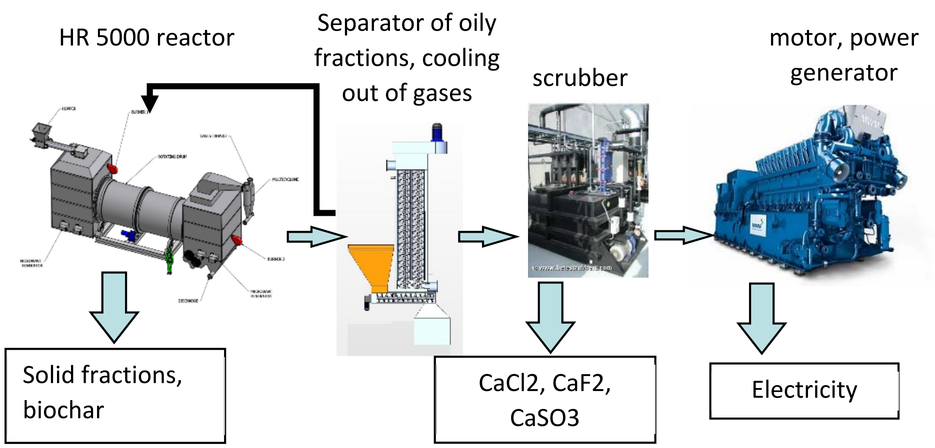

Figure 6. Installation for utilization of municipal waste with electricity production.

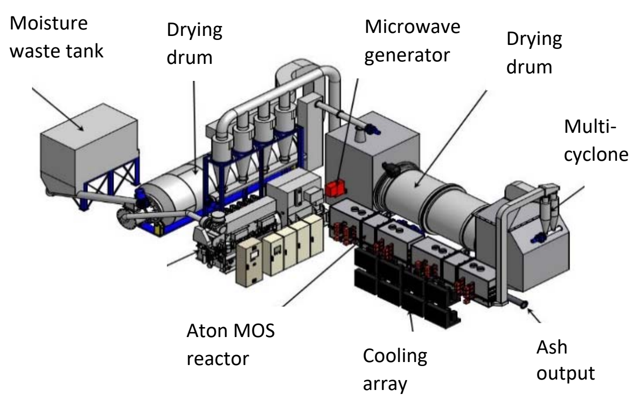

Figure 7. A system with HR 5000 reactor.

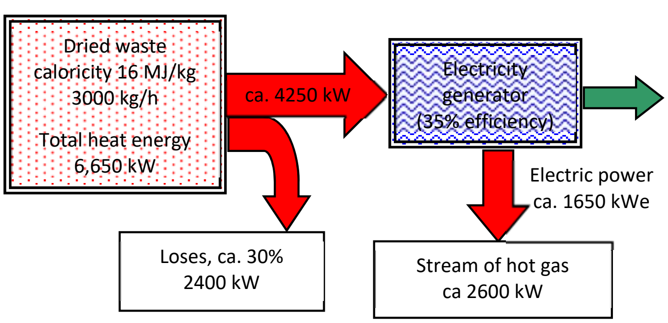

Figure 8. Energy balance for the system of microwave gasification of waste with caloricity of ~16 MJ/kg.

The scale of the problem associated with the removal and neutralization of asbestos waste is huge, and, like in other countries with large amounts of such waste, it is necessary to come up with, and to implement, new effective methods of its neutralization. There are unique opportunities in many developed countries (e.g. in Switzerland and the UK) to adopt such methods, which previously deposited asbestos waste being uncovered in order to neutralize it with physical and chemical methods. Also Poland currently has technical and economic capacities allowing to implement procedures for neutralizing asbestos with the new microwave thermal treatment (MTT) method, developed in the country and implemented at a technical scale.

The system of microwave reactors described in this article has also been successfully applied, following proper adjustments, in other processes of waste utilization. The applications include purification of ground contaminated with oil derivatives; utilization of municipal waste with energy recovery; utilization of medical waste, and so on. A separate scope of application is provided by the MOS gas purification system, described further in the article.

The essence of the technical solution developed and implemented by ATON-HT SA and developed by PROMETEUS Ltd. consists in thermal destruction of hazardous asbestos fibers by heating these with microwaves. In this method, which is protected by patent applications (P-209165 in

Poland and in EP16461505.6 in Europe), Eternit or other waste containing asbestos, after preliminary shredding (in a shredder with a specially pressurized structure), is mixed with small amounts of enhancers and fed to the chamber of the microwave reactor. As a result of heating this mixture up to a temperature of ~1200ºC, the crystalline structure of asbestos fibres transforms into an amorphous one. The transformation of the physical structure of asbestos as a result of thermal processing enhanced by microwaves (MTT method) is presented in Fig. 9.

(a) (b) (c)

Figure 9. (a) Chrysotile asbestos, (b) asbestos fibers in shredded Eternit, and (c) ATONIT, a product of Eternit processing in the microwave reactor by the MTT technology.

One characteristic of the method is the "contact-free" heating up of hazardous waste with a high concentrated microwave energy to the required temperature and in a controlled gas atmosphere, optimized for the process. Other existing conventional methods do not provide such capabilities. Importantly, the method in question - thanks to applying appropriate enhancing substances - involves an improved process of absorption of microwaves by the shredded waste virtually regardless of their composition, and moreover the temperature in which the whole transformation (destruction) of hazardous asbestos fibers takes place is reduced. It is significant for obtaining complete effectiveness of the transformation of all asbestos fibers into a safe material and for the improvement of energy-efficiency of the whole process.

The portable set consists of both reactors together with auxiliary devices, such as a system for loading waste, systems for cooling microwave generators, cabinets with chargers of microwave generators and control sets, all installed in two containers, as shown in Fig. 10. A similar system of a microwave reactor for utilization of waste has also been designed which has a capacity of 3-5 tones per hour. It is a stationary structure with two microwave generators of 75/100 kW CW power, each operating at 915 MHz. The choice of this frequency allows to heat thicker layers of waste moved inside the drum due to a deeper penetration of the electromagnetic field. Thus, it is possible to transport higher amounts of material to be thermally processed and heated up.

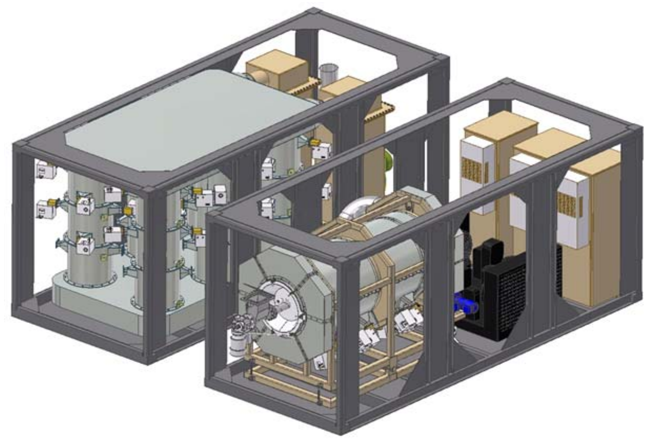

Figure 10. System for asbestos treatment installed within two standard containers.

6. Hospital waste management

A microwave system with HR reactors and MOS reactors can also be effectively applied for treatment of hospital waste. In this case, the waste material can be loaded into the shredder in standard plastic bags or left in loose form. The size of the bags should not exceed 120 *l*. The waste is crushed to a fraction of ~25 mm in an airtight chamber of the shredding machine, and then it is fed to the microwave process chamber using a worm heater. The purpose of the worm heater is to (*i*) make the water content in the waste evaporate, and (*ii*) preheat the waste. Optionally, the device does not need to be equipped with a shredder. Should this be the case, the shredded waste can be directly loaded into the worm heater. As a result of microwave heating to the temperature of ~800-850°C, the waste material is thermally cracked in the absence or deficiency of oxygen into smaller molecules, and thereby disposed of. The following processes, initiated by electromagnetic energy, occur in the reactor: decomposition, reduction and gasification. Their products include post-process gases and small amounts of solid fractions consisting of carbon and mineral substances. The released post-process gases are purified in the MOS microwave reactor. Its interior is made of a cylinder filled with special microwave-absorbing ceramic balls; this is where complex physical and chemical reactions take place at the temperature of ~1000°C influenced by electromagnetic waves generated by microwave emitters. The purification process occurs between the microwave-absorbing ceramics and the gas phase and it is initiated by electromagnetic excitation. Its key elements include separation of carbon particulates and mineral substances, breakdown (decomposition) of complex chemicals in strong magnetic fields, reduction, oxidation, and chemical reactions as a result of which chlorine combines with other elements.

In this novel process of gas purification, compound gaseous and solid substances (such as particulates) break down and contaminants in the pseudo-catalytic system are removed under the influence of strong magnetic fields. Both the microwave field and the surface of ceramic parts increase the rate of chemical reactions. The purification process might be exothermic (i.e. the heat is released with the products) but it always requires additional supply of microwave energy in order to (*i*) initiate some physical and chemical reactions, and (*ii*) maintain (stabilize) optimal process conditions. Once the gases pass through the MOS and the recuperator (heat exchanger), they are cooled down in the gas cooler before they reach the exhaust fan. Energy is recovered in the gas cooler (heat exchanger) from heating utility water to be used, for instance, back in the hospital.

7. Summary

Microwave energy has been applied in a number of significant processes for the neutralization of hazardous wastes, such as waste containing asbestos, as well as in utilization of municipal and other wastes. The most important advantages of this microwave method, which have already been verified on industrial scales, include the following capabilities:

- to heat up the waste volumetrically to very high temperatures;
- to conduct the process in a controlled atmosphere, e.g. lack of oxygen; and
- to control precisely the process parameters through a quick and precise stabilization of the temperature of the waste in the process chamber.

Conventional methods do not provide such capabilities, and the use of microwaves is currently a very beneficial and often the only way of effective neutralization of a number of wastes.

The practical experience gained in this work allows one to design and produce safe and long-lasting installations on an industrial scale, and to create new and often unique technological opportunities. So far, such installations are built and operated at a test stage. However, currently an installation is being prepared for utilization of municipal waste through gasification by microwaves with a capacity of over 3 tonnes per hour and which will generate electricity of ~2 MW.

For a few years now, odor-removal installations (MOS reactors of varying capacities) have been in operation. Their characteristics, including their high efficiency in burning out contaminants in the air and high reliability, provide a positive outlook onto a growing number of uses of installations based on the microwave technology described in this paper. The obstacle, however, is the high cost of building high-power microwave installations. Yet, the popularization of such microwave technologies will ultimately decrease the costs, and make these more competitive.

About the Author

Ryszard Parosa, researcher, president of PROMIS-TECH LTd (www.promistech.pl) and urrently scientific consultant in PROMETEUS LTd - was born in 1948 in Wroclaw, Poland. Graduated at the Technical University of Wroclaw, where received an M.Sc and a PhD in Electronic Science. In 1972–1983 he worked at the Technical University of Wroclaw as a university lecturer, and the next two years he was engaged in research at the Institute of Plasma Physic Nagoya University, in Japan. In 1985 he established a small high-tech company PLAZMATRONIKA LTd specializing in the application of microwave power for laboratories and industry. In his research he has concentrated on microwave plasma generation and the application of microwaves for drying of fruits and vegetables and for microwave pasteurization of fruits. Latterly he has concentrated in developing high power microwave equipment for processing many different forms of wastes. He is the author and co-author of several international patents and scientific publications.

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