Producing marketable products by low-temperature thermolysis of municipal solid waste

V S Sevostyanov¹, N T Shein², M V Sevostyanov¹, R Yu Shamgulov¹ and V V Obolonsky²

¹ Belgorod State Technological University named after V.G. Shukhov, Belgorod, Russia
² LLC "Transport company ECOTRANS", Belgorod, Russia

E-mail: shamguloff@mail.ru

Abstract. This article provides a method for recycling municipal solid waste (MSW) and industrial waste by low-temperature thermolysis. The proposed technology and technical devices make it possible to solve a range of scientific, technical, research, design, technological and environmental problems. The solutions take into account the conditions of existing production facilities and are aimed at eliminating the existing technical and technological constraints in resource-saving and energy-saving areas.

1. Introduction
The growing amounts of industrial production, outpacing the development of industrial waste recycling, as well as the steady increase of energy consumption (by 3.25 times by 2050, according to forecasts of the World Energy Council), continuously aggravate the human-induced impact on the environment.

Development of civilization is inevitably accompanied by generation of mineral and organic waste, as a result of manufacturing activity of mankind. Since 70-ies of the 20th century the United Nations Organization (UN) has begun the development and implementation of international programs for reducing hazards to environmental safety. Many countries are moving to a circular economy at the legislative level [1-4].

The purpose of this work is to develop a resource-saving and energy-saving technology and technical devices for integrated recycling of municipal solid waste (MSW) and industrial waste, with obtaining organo-mineral marketable products and reducing environmental impact.

At present the proposed technology and technical devices are undergoing pilot testing and implementation at manufacturing site of ООО "TK "Ecotrans". This enterprise is engaged in collection and recycling of MSW, as well as of certain types of industrial waste.

2. Materials and methods
After being transported to a MSW landfill, wood and basaltic fibrous materials are picked from the bulk of waste. Wood wastes, after ragging, grinding and compacting (by pelletizing, extrusion, rolling etc.), are used as an alternative fuel (RDF-fuel) for heat power generators, and fibrous wastes, after grinding, are used as fibrous aggregates for making composite mixtures and manufacturing various types of marketable products of them [5].
The initial main bulk of waste undergoes preliminary sorting in a classifying drum with separating large ≥ 70.0 mm agglomerates. Then the subsequent selective hand (or automatic) sorting is performed. Plastics are also picked; their content in the total bulk can be up to 15-20%.

The organic wastes, left after sorting and ragging, the so-called "tailings", are recycled with the use of low-temperature thermolysis technology and equipment.

The technological process is performed in a continuous mode at near-atmospheric pressure and moderate temperature – up to 5000 °C. At such process parameters the low-temperature thermolysis in sealed equipment without oxygen excludes the generation and emission of noxious substances, such as, for example, dioxins. According to the presented data [6], one of the conditions of dioxins formation is the temperature range 500-12000 °C.

The reactor system of low-temperature thermolysis was designed and researched in ООО "NPP Termoliz", Moscow, for recycling crumb rubber, obtained at grinding old tires and other industrial-rubber waste [7]. At present at the MSW landfill of ООО "TK "Ecotrans", Belgorod, together with the Technological complexes, machines and mechanisms department of BSTU named after V.G. Shukhov, the pilot testing of a process module, designed and constructed for recycling MSW and industrial wastes, is performed (figure 1).

3. Results and Discussion

The main heat processing unit of this system is a tubular thermal reactor with a helical combined-type transporting element, which provides the efficient heat-mass-exchange and prevents formation of stagnant zones, as in case with an ordinary auger conveyor [8].

The advantages of this system are:

- Continuity of raw materials input and products output.
- Low pressure 0.1-0.2 MPa in the system.
- Effective heat-mass-exchange due to constant turning of reagents.
- Small reactor residence time ≤ 20 min.
- Possibility of adjusting the flows of raw materials and reagents.
- Creating conditions for input/output of additional reagents in the form of steam, gases or liquids.
- Low-temperature conditions of the process, t≤ 5000 °C.

In figure 2 a diagram of low-temperature thermolysis plant is presented.
The fragmented MSW "tailings" are fed to the loading chamber of feeder 1. Then the mass is moved along the reactor 2 by means of a combined transporting element 3, interlocked with motor reducer 4. Under the action of heat, the organic mass is decomposed to solid carbon residue and vapor-gas mixture. Through solid product outfeed 5 the solid carbon residue is released from the reactor. Passing through filter separator 6, steam-gas mixture goes to rectifying column 7. In the latter it is separated into industrial water and liquid hydrocarbons. The residual non-condensed hydrocarbon gas, taken from off-gas 8, is burnt in gas-liquid burners 9, 10. Part of liquid hydrocarbon fuel, taken from basin 11, is also burnt to heat the reactor.

The low-temperature thermolysis equipment allows recycling not only municipal waste, but also industrial waste. Thus, during the processing of lignin sludge, a solid carbon residue was obtained, the elemental composition of which was studied on an X-ray fluorescence spectrometer ARL 9900 WorkStation. The results are presented in table 1.

**Table 1. Elemental composition of the solid fraction in the processing of lignin sludge.**

| Element | Weight, % | Element | Weight, % | Element | Weight, % | Element | Weight, % |
|---------|-----------|---------|-----------|---------|-----------|---------|-----------|
| Al      | 12.32     | Mg      | 0.427     | Cr      | 0.0808    | Pb      | 0.0174    |
| Ca      | 8.39      | Ru      | 0.420     | Ce      | 0.0649    | Zr      | 0.0082    |
| Cl      | 7.97      | Ti      | 0.406     | Ni      | 0.0288    | Pt      | 0.0079    |
| Fe      | 6.46      | Na      | 0.159     | Cu      | 0.0274    | Ar      | 0.0060    |
| Si      | 3.25      | Pd      | 0.153     | Sr      | 0.0259    | Ga      | 0.0034    |
| Px      | 1.82      | Rh      | 0.127     | Nd      | 0.0235    |         |           |
| Sx      | 1.19      | Zn      | 0.108     | Mo      | 0.0234    |         |           |
| K       | 0.879     | Mn      | 0.0876    | V       | 0.0225    |         |           |

**Table 2. Elemental composition of the solid fraction in plastic processing.**

| Element | Weight, % | Element | Weight, % | Element | Weight, % | Element | Weight, % |
|---------|-----------|---------|-----------|---------|-----------|---------|-----------|
| Al      | 11.28     | K       | 0.782     | Mn      | 0.0772    | V       | 0.0222    |
| Ca      | 10.30     | Ti      | 0.530     | Cr      | 0.0694    | Sr      | 0.0218    |
| Cl      | 8.46      | Ru      | 0.424     | Ce      | 0.0655    | Pb      | 0.0144    |
| Fe      | 5.76      | Mg      | 0.420     | Ni      | 0.0296    | Zr      | 0.0099    |
| Si      | 3.21      | Na      | 0.161     | Nd      | 0.0254    |         |           |
| Px      | 1.68      | Pd      | 0.151     | Cu      | 0.0233    |         |           |
| Sx      | 1.13      | Zn      | 0.145     | Mo      | 0.0233    |         |           |
Table 2 shows the elemental composition of the solid carbon residue obtained during the processing of plastic, also studied on an X-ray fluorescence spectrometer ARL 9900 WorkStation.

For comparison, table 3 shows the elemental composition of the solid carbon residue obtained during the processing of MSW and studied using an EDAX energy-dispersive spectrometer.

**Table 3. At MSW processing.**

| Element | Weight,% | Element | Weight,% | Element | Weight,% | Element | Weight,% |
|---------|----------|---------|----------|---------|----------|---------|----------|
| C       | 66.84    | Na      | 1.27     | P       | 0.33     | Mn      | 0.05     |
| O       | 14.35    | Fe      | 1.19     | S       | 0.31     | Cr      | 0.03     |
| Ca      | 6.30     | K       | 1.04     | Mg      | 0.30     |         |          |
| Si      | 3.42     | Al      | 0.97     | Zn      | 0.23     |         |          |
| Cl      | 2.71     | Ti      | 0.44     | Cu      | 0.23     |         |          |

Experimental research confirms the opportunity of obtaining the following types of marketable products (in varying percent by weight, depending on composition of raw feedstock – "tailings"):

- Technical carbon (solid carbon residue) – 25-35%.
- Industrial water, with water-soluble acids – 20-30%.
- Liquid hydrocarbon fuel – 15-20%.
- Hydrocarbon gas – 10-15%.
- Other impurities (fine fractions of stone, metal, glass) – ≤10%.

The proposed resource-saving and energy-saving technology and technical equipment allow obtaining various marketable products, which can be used for different technological purposes: for preparing composite mixes with mechanically activated components and fibrous fillers; making compacted materials (grains, pellets, tablets etc.); for heat and electric energy generation from nonconventional fuels; for obtaining highly-efficient filtering elements with the developed inner surface, or porous aggregates for composite mixes and products, made of them etc.[9-11].

With this, the in-house materials and heat-and-power resources of a municipal solid waste recycling enterprise are used for obtaining various types of innovative products.

4. Conclusion

The developed technology and technical equipment for low-temperature thermolysis recycling of municipal solid waste and industrial waste allow obtaining from 1 ton of municipal solid waste at specific energy consumption (0.35-0.45 kW hour/kg) the following types of secondary products:

- Technical carbon – 25-35.0%.
- Liquid hydrocarbon fuel – 15.0-20% (sulfur content up to 0.15%).
- Synthetic gas – 10.0-15%.

The proposed technology is implemented at rather low temperature values (T≤5000 С), low thermal treatment time (t≤20 min.) and low pressure (up to 0.1 MPa).

Acknowledgments

The work is performed as part of the project № 10089447, program of REC "Innovative solutions in AIC", scientific and production platform "Rational nature management".

References

[1] Bobylev S and Solovyeva S 2020 Circular economy and its indicators for Russia. World of New Econ. 2 63-72
[2] Sustainable materials management in USA Retrieved from: https://www.epa.gov/smmm

[3] Nosko P 2019 Trends in the circular economy development in the European Union. Russian Journal of Resources, Conservation and Recycling 1(6)

[4] Erokhin V 2021 China’s Five-Year Plan for 2021-2025 and the Long-Range Economic Development Benchmarks. Marketing and Logistics 34(2) 5-155

[5] Glagolev S, Shein N, Sevostianov V, Obolonsky V and Shamgulov R 2020 Technologies for integrated processing of solid municipal waste. Ecology and Industry of Russia 12(24) 11-15

[6] Gordon McKey 2002 Dioxin characterisation, formation and minimisation during municipal solid waste (MSW) incineration: review. Chemical Engineering Journal 86(3) 348-368

[7] Bochaver K 2018 Spiral Reactors in Heterogeneous Technological Processes (Beau Bassin: LAP LAMBERT Academic Publishing) 135-147

[8] Philip J Owen and Paul W Cleary 2010 Screw conveyor performance: comparison of discrete element modelling with laboratory experiments. Progress in Computational Fluid Dynamics, an International Journal 10(5-6) 327-333

[9] Dezhen C, Lijie Y, Huan W and Pinjing H 2014 Pyrolysis technologies for municipal solid waste: review. Waste Management 34(12) 2466-2486

[10] Ivanovskiy V 2019 Carbon black. Processes and apparatus schoolbook (Omsk: Printing house Blankom) 2 254

[11] Leong C K and Chung D D L 2006 Improving the electrical and mechanical behavior of electrically conductive paint by partial replacement of silver by carbon black. Journal of Elec. Materi. 35 118–122