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TECHNOLOGIES OF VEGETABLE BIOMASS, TECHNICAL RUBBER, AND PLASTIC WASTE PROCESSING

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The present paper considers novel thermal technologies of vegetable biomass, technical rubber, and plastic waste processing into fuel and raw material resources on the basis of the processes of vapor thermolysis of organic materials.

Introduction. By the beginning of the 21st century, the amount of globally consumed natural resources became comparable to the earth's reserves of minerals. About 20 tons of source raw materials are output and produced yearly per person on the earth, which are then processed into about 2 tons of useful products. Thus, about 10% of the raw materials go to useful products and the major amount of output resources turns into solid, liquid, gaseous, and heat wastes. In this connection, there is every reason to speak of the practical inexhaustibility of wastes and, therefore, the development of novel technologies for highly effective use of industrial and consumption waste is one of the most important directions of scientific-technological progress.

The urgency of the problem of waste processing stems from the depletion of our effective oil and natural gas fields, the rise in prices for material and power resources, and the high rates of environmental pollution.

Under the conditions where raw material and power problems are very acute in many countries of the world, these problems can be resolved by using highly effective technologies of waste processing into useful products, power, and raw materials.

The present work is devoted to justification of the prospects of using the processes of organic material thermolysis in a medium of superheated water vapor for developing new thermal technologies for processing a wide range of wastes.

For the main kinds of wastes, it is shown that the specific features of the decomposition of organic substances in a vapor medium at temperatures up to 1000^{o}C and low pressures (up to 3 atm) provide the possibility of realizing waste conversion into products that can be used as fuel, raw materials, adsorbents, and other materials.

Processing of Vegetable Biomass Wastes. One of the kinds of wastes that are accumulated in large amounts (potential resources for power use alone amount to 70–80 billion tons per year in terms of the oil equivalent) is the biomass waste.

Analysis of the sources of biomass waste formation and composition permit the following classification: urban waste representing by-products of the vital activity of cities and suburbs, agricultural waste consisting of vegetable remains that are not used in the production of agricultural and other products, animal husbandry waste, industrial waste formed in the food industry and hydrolysis productions, and wood waste that is accumulated during logging and wood-working.

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TABLE 1. The Elemental Composition (%) and Specific Combustion Heat (kJ/kg) of Heat-Treated Biomass

Components	Source biomass	Biomass treated with vapor to ^oC				
		200	220	240	260	280
Carbon	50.58	54.80	56.90	57.80	69.53	74.10
Hydrogen	6.24	6.0	5.13	4.98	4.38	3.88
Oxygen	43.18	39.20	37.97	37.22	26.09	22.02
Specific combustion heat	18.92	20.30	20.50	20.72	25.31	26.80

The present-day technologies of obtaining fuel and power resources from a biomass are based on the processes of burning, gasification, pyrolysis, biogasification, liquefaction (obtaining of liquid fuel), and granulation.

The most widely used technologies are the technologies of direct biomass burning in both conventional furnaces and special furnaces with dense, boiling, and circulating layers [1–3].

The necessity of increasing the ecological safety and efficiency of obtaining power from a biomass calls for a change from direct burning to new technologies. In this connection, in the last few years technologies of gasification and pyrolytic biomass processing have been actively developed. These technologies permit obtaining from a biomass not only fuel, but also raw material resources (technical carbon, charcoal, resins).

A promising direction of biomass processing is the biotechnological conversion in the process of which not only fuel, but also organic fertilizers are obtained. This direction received a powerful stimulus for development, especially during the period following the energy crisis of 1973.

At present, a number of European countries have a few hundred industrial biogas plants, and in China small biogas plants have received particular attention.

The obtaining of solid fuels from vegetable biomass wastes (agricultural waste, wood waste) is based on briquetting and granulation technologies. The obtaining of bricks and granules from vegetable biomass is also important due to the fact that these products can be used as a source raw material in the processes of pyrolysis, gasification, and burning.

By now, a number of technologies and equipment for obtaining bricks and granules from a biomass have been developed. However, the major problems of all these technologies, leading to a sophistication of equipment and a rise in prices for finished products, are effective drying of source raw materials and ecologically clean binders for imparting the necessary water-repelling and strength characteristics to the bricks and granules.

An original technology of obtaining bricks from a vegetable biomass has been developed at the Academic Scientific Complex "A. V. Luikov Heat and Mass Transfer Institute" of the National Academy of Sciences of Belarus jointly with the Scientific-Technological and Scientific-Introduction Association (STSI) "TOKEMA" and the industrial association "Belaz" [4]. The technology is based on the use of superheated (up to 300^oC) water vapor for processing a ground biomass prior to the process of compaction into bricks (granules).

A distinguishing feature of biomass thermolysis in a medium of superheated water vapor is the fact that the latter acts not only as a heat-transfer medium (which is observed during the biomass decomposition in an inert medium), but also as a reaction substance.

Another feature is the fact that at the first stage of biomass treatment with vapor there occurs vapor condensation and biomass humidification. Then the condensate formed vaporizes and the biomass is warmed up to the thermolysis temperature, thus prolonging the heating process. This leads to a decrease in the resinification, enrichment of the treated mass with carbon, and a decrease in the oxygen and hydrogen content. As a result of this process, the specific combustion heat of the vapor-treated biomass increases.

Table 1 presents experimental data characterizing the change in the elemental composition of the biomass (wood waste) caused by the vapor treatment depending on the temperature.

TABLE 2. Comparative Characteristics of Fuel Bricks and Coal

Characteristics	Fuel bricks from wood waste		Coal	
Combustion heat, MJ/kg	19–26		18.5	
Humidity, mass%	0.5		13–18	
Ash content, mass%	0.5–4		24.4–35	
Density, kg/m^3	1050–1200		1440	
Composition of the working mass, %	Carbon 52–68	Hydrogen 6–5.1	Carbon 47	Hydrogen 3.4
	Oxygen 42.5–24.1	Ash 0.5–4	Oxygen 8.1	Ash 24.4
	Moisture 0.5		Sulfur 3.1	Nitrogen 1.0
			Moisture 13	

TABLE 3. Output of Worn-Tire Processing Products

Product	Output limits, %	Product	Output limits, %
Liquid hydrocarbons	35–50	Metal	5–8
Activated coal	39–44	Gas	10–28

The effects of the dependence of resinification and enrichment of the treated mass with carbon on the regimes of vapor treatment have been used in developing a technology of obtaining bricks from a vegetable biomass. The characteristics of the fuel bricks produced by this [4] technology are presented in Table 2. From this table it follows that the fuel bricks have a high combustion heat, a low ash content, and a low humidity.

The production process of fuel bricks is energetically self-sufficient. The water vapor (heat-transfer agent) condensation heat is used for drying the source mass, and part of the bricks (20–28%) is expended in producing the heat-transfer medium.

The Process of Obtaining Liquid Fuel and Adsorbents from Worn Tires. Throughout the world, about 6–6.5 million tons of tires are removed from service every year, and the amount of those subjected to processing makes up only 20% of their yearly accumulation [5].

Up to now, not a single country of the world has managed to solve the problem of processing worn tires. Analyzing the known methods of this processing, one may conclude that the most promising of them for the coming few years are the thermal methods.

The scientific-production company "Ékologiya–Énergetika" (Moscow), jointly with the Academic Scientific Complex "A. V. Luikov Heat and Mass Transfer Institute," National Academy of Sciences of Belarus, has developed a novel thermal method for processing worn tires in the medium of a vapor-gaseous heat-transfer agent [6].

The products of worn-tire processing are: a liquid hydrocarbon product, activated carbon, metal, and gas. Table 3 gives the output of products obtained by processing worn tires by this method.

The composition of liquid decomposition products of worn tires includes four groups of basic compounds.

The first, the most volatile group incorporates compounds of the type of $(CH_3)COCH_3$ (up to 5% of the mass of liquid products); the second group includes aromatic compounds (up to 50% of the mass); the third group — C_8H_{16} (up to 10–15% of the mass), and the fourth group — unsaturated hydrocarbons with the number of carbon atoms from 15 to 25 with small impurities of the corresponding alkenes (up to 30% of the mass).

One of the components of liquid products is aromatic hydrocarbon of the composition C_8H_{16}, which is widely distributed in ethereal oils. It is used in compounding perfumes, soap perfume additives and food essences, liqueurs, aromatization of pastries and chewing gums.

A valuable product is alcohol, which finds various applications in industry, in particular, for compounding various fragrant substances, synthesizing fruit essences, producing nitrocellulose lacquers, and obtaining antiasthmatic preparations.

TABLE 4. Composition of Plastic Waste Decomposition Products

Phase state of the sample	Basic components	Component concentration in the sample, mg/liter
Polystyrene-containing plastics		
Condensate (10 μl in 5 ml of water), amount of liquid — 10 mass%, of gas — 28 mass%	Styrene	73.22
	$CH_2 = C(CH_3)–COOH_3$	52.86
	Toluene	9.39
	Hexane	3.51
Residue (solid), amount — 6.2 mass%	Derivatives of aromatic hydrocarbons, biphenyls, etc.	
	Polynuclear aromatic hydrocarbons	
	Hydrocarbons with a chain length of more than 15 atoms	
Polypropene-containing plastics		
Gas (50 μl of gas in 5 ml of water), amount — 56 mass%, combustion heat — 44.9 MJ/kg	Propene	68.08
	C_4H_8	58.47
	Pentane	22.63
	C_6H_{12}	15.11
	Chloromethane	7.89
	1-Pentene	7.28
	Hexane	4.75
	Benzene	3.92
	2-Methyl-Furan	2.26
	Isobutane	2.18
	1,4-Pentadiene	1.94
	Ethyl Chloride	1.62
	Acetone	0.83
	Toluene	0.64
	Styrene	0.21
Condensate (10 μl in 5 ml of water), amount of liquid — 28 mass%	Acetone	11.62
	CH_3CHO	7.92
	Styrene	6.58
	2-Octanone	3.91
	Benzene	1.34
	Toluene	0.76
Residue (solid), amount — 16 mass%	Derivatives of aromatic hydrocarbons, biphenyls, etc.	
	Polynuclear aromatic hydrocarbons	
	Hydrocarbons with a chain length of more than 15 atoms	

Thus, liquid decomposition products of worn tires contain a number of valuable organic compounds and can be used as a raw material for obtaining aromatic hydrocarbons.

As a fuel for power supply of the process of processing worn tires, one uses a portion of the liquid product (up to 20%), the inherent gas (combustion heat of 19 MJ/kg), and an electric power of 100 kW·h per ton of tires.

Technology of Plastic Waste Processing. The world's yearly output of plastics amounts to more than 60 million tons. One of the accompanying effects of the growth of the plastic industry is a simultaneous increase in the amount of plastic wastes.

In recent years, in solving problems of plastic waste reclamation, thermal methods and technologies have become increasingly promising. They are especially suitable in those cases where wastes are practically not used and cannot be reclaimed by their processing into products or different compositions.

A new thermal technology of plastic waste processing has been developed by the workers of the Academic Scientific Complex "A. V. Luikov Heat and Mass Transfer Institute," National Academy of Sciences of Belarus, the Scientific-Production Company "TOKEMA," and the Unitary Enterprise "Ékores."

The point of this technology is the thermal destruction of plastics in a medium of superheated water vapor at temperatures of 500–600^{o}C. This process does not require preliminary sorting or grinding of wastes [7, 8].

Calculating on 1 ton of processed plastic waste of a composite composition, the energy consumption is as follows: vapor — 3800 kg; electric energy — 930 kW·h; water (circulating) — 34 m^3. The following products are thereby produced: combustible gas — 420 kg; synthetic waxes — 215 kg; carbon remainder — 365 kg; secondary heat (for hot water supply) — 2.25 Gcal.

Table 4 gives the components of the products of the processing of the most widely distributed kinds of plastic wastes. Analysis of these data shows that organic compounds of three types enter into the composition of solid (waxy) products. A common product of plastic waste thermolysis in the medium of superheated water vapor is liquid (condensate). The condensate composition consists of water and organic compounds (see Table 4).

One variant of reclaiming the condensate formed is its use for obtaining a heat-transfer agent (water vapor). Since the allowable content of organic substances in water used for producing superheated water vapor is 0.5–1 mg/liter, the necessity of purifying the condensate arises. This can be realized by conventional methods.

Gaseous products of thermal decomposition of plastics can be used as a fuel for obtaining working water vapor.

The range of applications of solid (waxy) products of plastic waste thermolysis is fairly wide (components of different kinds of protective compositions, oils, emulsions, impregnating materials, etc.).

Conclusions. The investigations made and the experimental tests of the novel thermal technologies of processing vegetable biomass and plastic wastes and worn tires have shown that it is promising to use superheated water vapor and vapor-gas mixtures as heat-transfer agents and transportation media for decomposition products.

These advantages provide the possibility of using the condensation methods for concentrating decomposition products, effective recovery of waste heat, preventing release of decomposition products into the atmosphere, processing wastes without preliminary sorting, obtaining valuable chemical source materials from waste, and intensifying processes.

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