Abstract:

A method for thermal decomposition of organic material and equipment for implementation of this method is described. The method involves placing organic material in a hermetically sealed flow-type apparatus and then heating it to a temperature at which decomposition occurs. The resulting gaseous, liquid, and solid products are transported through the system to be further processed.

Title: METHOD FOR THERMAL DECOMPOSITION OF ORGANIC MATERIAL AND EQUIPMENT FOR IMPLEMENTATION OF THIS METHOD

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Fig. 1

[Continued on next page]
tubular flow-type cracking reactor by means of the spiral conveyor (2) through the water cooler (7) via the opening (19) for the output of solid products to the output water seal (9) constituting the hydraulic seal, from where the solid products are taken out by means of the in-feed conveyor (20) and the spiral-type out-feed conveyor (22). Equipment for thermal decomposition (1) of organic material for implementation out the method of thermal decomposition consists of the tubular flow-type cracking reactor (la), which is positioned on the frame (32) of the tubular flow-type cracking reactor at an angle of 8 to 38 degrees relative to the horizontal plane, whereas the tubular flow-type cracking reactor (la) houses a shifting spiral conveyor (2) the bottom part of which is submerged in the input oil seal (8), with the second part (lc) of the tubular flow-type cracking reactor being enclosed by the output water seal (9).
METHOD FOR THERMAL DECOMPOSITION OF ORGANIC MATERIAL AND
EQUIPMENT FOR IMPLEMENTATION OF THIS METHOD

Field of the Invention

The present invention concerns a method of thermal decomposition of organic material and a design of equipment for thermal decomposition of organic material. The said equipment enables continuous processing of organic material and production of alternative second generation energy carriers (chemicals, solid, gaseous and liquid fuels, heating oils) and solid carbon materials by thermal decomposition of specified and/or mixed wastes from used tyres, plastics, biomass, organic portions of municipal waste, using the system of tubular flow-type cracking reactor for the processing of carbon-based waste materials.

Background Art

So far it has been mostly the conventional method of mechanical recycling that has been used for processing of organic waste. Other methods used to that end are constituted by thermal processes including thermal cracking and pyrolysis that enable to convert polymeric materials to monomers and other products. Thermal cracking of used tyres, waste plastics, biomass and municipal waste allows for their thermal degradation without the participation of oxygen/air. During thermal cracking the wastes are heated to high temperatures under which their macromolecular structures are cracked to smaller molecules. Products of thermal cracking can be divided to non-condensed gaseous fraction, liquid fraction and solid residues (coke). Thermal cracking of waste further provides a rather wide composition range of hydrocarbons and non-hydrocarbons, including low-molecular gasses (hydrogen, carbon monoxide, carbon dioxide, alkanes and alkenes C$_1$ - C$_n$) through liquid portions up to coke. Liquid products of thermal cracking are used for the production of valuable types of gasoline, kerosene, diesel fuels, heating oils, alternative oils, as well as valuable chemicals, such as dl-limonene obtained from thermal cracking of used tyres. There have been initiatives to determine optimal conditions for thermal cracking and/or suitable catalysts in order to obtain marketable products. The most valuable portions of municipal wastes include polymeric materials from industrial or municipal sources. Polymeric materials, mainly polyethylene and polypropylene, undergo thermal cracking at 165 to 750 °C and at the atmospheric pressure, generating oil-waxes with the boiling temperature of 30 to 450 °C, containing saturated and non-saturated hydrocarbons numbered C$_5$ to C$_{30}$.
Then the fraction of gasoline's is separated from oil-waxes by the process of distillation at the atmospheric pressure and at the temperature of 30 to 180 °C, and it contains saturated and non-saturated, non-branched and branched hydrocarbons C\textsubscript{s} to C\textsubscript{n}. Residue from the atmospheric distillation will then undergo vacuum distillation at the pressure of 10 Pa to 110 kPa, with diesel fuel fraction getting separated from the residue with carbons numbered above C\textsubscript{22} at the temperature of 150 to 360 °C, with the fraction containing saturated and non-saturated hydrocarbons numbered C\textsubscript{9} to C\textsubscript{22}. Gasoline's obtained by atmospheric distillation of oil-waxes and certain diesels obtained by vacuum distillation of oil-waxes can be further refined by hydrogenation using a heterogeneous catalyst [Patent SR, No. 287556, (2011); EP 2135923 A1].

Critical technological parameters with the strongest influence on the composition of reaction products obtained under thermal cracking include chemical composition of feedstock, temperature, heat transfer rate, pressure, reaction time, reactor type, presence of reactive gasses (e.g. oxygen), catalyst, additives contained in the feedstock, gaseous and liquid phase of the process. Reactor type is critical with respect to the heat transfer quality, mixing, retention time in gaseous and liquid phases, and the release of primary decomposition products. Reactor is to be selected mainly on the basis of technical aspects, such as heat transfer and working properties of the feedstock and products. In many processes the polymeric material is first dissolved in a polymer melt or wax, or dispersed in a salt bath in order to reduce the melt viscosity. Other processes use the property of excellent heat and material transfer in the fluid bed of thermal or catalytic reactors. The increased temperature affects thermodynamics, namely in terms of the relative stability of each product and the kinetics, as well as in terms of the physical conditions of the reaction mass. High temperature and heat transfer, low pressure levels and retention times support the generation of primary products.

In order to ensure high efficiency of cracking reactors involving chemical cracking of polyalkenes, the reactors must be built using the flow design. For the same reasons, they should have the capacity to continuously remove coke during the decomposition of plastic waste that involves high generation of coke and mineral residues.

The best solutions are offered by the processes involving a fluid bed. These are known from refineries as the fluid catalytic cracking (FCC) applied in the processing of crude oil fractions using a cracking catalyst, or as the fluid thermal cracking using coke or other mineral particles constituting the fluidizing medium.
In compliance with the U.S. Patent No. 5856599 the cracking or liquefaction of plastic waste is performed in a three-stage or four-stage screw extruder with an increasing temperature. Similarly, the catalyst (if applied) becomes removed with coke and mineral residues. At the end of the process the distillable hydrocarbon fractions are separated from the solid residue and coke.

According to another American patent, namely the U.S. Patent No. 5744688, the mixture of polyalkenes and used tyres gets charged into a batch reactor equipped with a special agitator. The reactor is charged using a screw extruder or other equipment. Material is batched to this semi-continuous reactor for a certain period of time, with gaseous and liquid fractions, as well as a mixture of carbon black, mineral impurities and coke being generated as the main products. When the production cycle is finished, the process stops and the reverse run of the agitator starts. In this cycle the agitator blades scrape the coke off the inner walls of the reactor. The main disadvantage of this solution resides in the semi-continuously working reactor with a relatively low production capacity and a problem using the cracking catalyst.

In terms of another reactor design, the U.S. Patent No. 5811606, the agitator blades have exactly the same shape and size as the inside of the reactor. During the process of thermal decomposition the solid material deposited inside the reactor is being scraped off the hot reactor walls. The scraped off coke falls down and is evacuated from the reactor bottom together with a portion of reaction products through an exhaust pipe. The main products of thermal cracking are the gaseous fractions (suitable for heating), gasoline and light heating oil, and paraffin fractions.

A batch reactor equipped with a screw feeder and an agitator is described in another American patent, the U.S. Patent No. 5738025. Special grating is installed inside the reactor above the melted mixture of waste plastics being cracked. Waste plastics charged into the cracking reactor are melted on the special grating and then fall down to the reaction mixture. Similarly to the description in the previous patent, i.e. the U.S. Patent No. 5811606, also in this case there is an agitator having a specially designed shape, scraping the coke off the reactor walls down to a specially shaped reactor bottom, from where it is removed by means of a screw conveyor. The temperature in this process reaches 450 °C.

In patent EP 0591703 the German researchers presented gasification of waste plastics in a plasma reactor including recovery of waste heat from the turbine to use the heat for steam production. Details of the process efficiency are not available. The main
advantage of the solution resides in the possibility to make use of the different composition of feedstock.
The procedure presented by Polish colleagues in WO 03104354 is based on the design of a special semi-continuous reactor equipped with replaceable heat tubes (elements). The heat tubes, heated inside by waste gasses, ensure the heating of the feedstock, resulting in a melt down and enabling the cracking of plastics. Secondary cracking reactions lead to the generation of coke. Coke becomes deposited on the outer surface of the heat tubes. A special design of the cracking reactor enables to remove carbon deposits by means of heat tube vibrations. When the equipment is turned off, the heat tubes can be disassembled and replaced.

As the plastics also contain inorganic components, the use of chemical and non-catalytic processes provides certain advantages against the catalytic process. Chinese researchers designed a two-stage process in terms of CN 1397627/2003. The first stage involves thermal cracking by which the plastics become partially cracked. At the same time the inorganic compounds become separated. In the next stage the partially cracked products undergo further cracking on a fixed catalyst.

Japanese and Chinese inventors designed and patented several original solutions for cracking reactors. The same cracking reactor design is used in the two patents - WO 9620254 (1996), U.S. Patent No. 2156332 - presented herein. Waste plastics are introduced by means of a screw extruder through a tube reactor with a parallel-shape design containing an inner conveyor. Mixing inside the vessel is followed by melting, cracking and vaporization in the respective zones. Japanese researchers developed a tube reactor with a screw agitator and a conveyor system in terms of the patent JP 100446158 (1998)]. Although the design solution of the reactors is not clearly indicated, it is obvious that the main advantage of these reactors resides in the removal of coke, carbon residues and catalyst (if applied) from the inside of the reactor. The design provides no indication of the product output from the reactor system.

At the Wroclaw University of Technology they developed a tube reactor with a special screw-type inner agitator Polish patent application No. P 355826; J. Walendzievski, Continuous flow cracking of waste plastics, Fuel Proc. Technol. 86, 1265 (2005)]. Melted plastics from a screw extruder are carried to a multi-tube reactor to go through the process of cracking at the temperature of 420 to 500 °C. The specially shaped inner agitator has been designed to mix the melted plastics, scrape the coke off the inner surface of the tube reactor and remove the coke from the reactor. Granules of the coke being removed fall down to a container at the end of the reactor terminal section,
while the hydrocarbon vapours proceed through air coolers and water coolers to
separators in order to separate gasses from liquids. Laboratory experiments (0.3 -
2 kg) and semi-operation equipment with the capacity of 20 - 30 kg/h have shown that
this type of reactors can be suitable for commercial application if used with a flow
design. The main advantage of this solution is the continuous removal of coke from the
reaction tubes. The reactor cracking unit will comprise six or more tubes equipped with
inner agitators, enabling either the thermal or catalytic cracking of waste polyalkenes.
It appears that cracking reactors with a fluid bed (thermal or catalytic) are the best
solution in terms of their industrial application. However, the regeneration and
circulation of the so called equilibrium catalyst is only possible for relatively clean
injections, such as the residues from vacuum distillation of gas oils from petroleum.
Municipal plastic waste contains various mineral impurities, trace amounts of products
and additives that can deactivate the valuable catalyst in short time. In most cases the
catalyst recovery is not possible and therefore the cracking of plastics should be
performed using a cheap and accessible catalyst. Expensive and sophisticated zeolites
or other molecular sieves, as well as rare metal-based catalysts will probably find only
limited application in recycling processes.
Another solution is offered by thermal processes using inert fluidizing medium that
include a coke removal section. Applicable solution for smaller operations is offered by
multi-tube reactors with inner agitators.
The available data about the ways of waste recycling and reactors for thermal cracking
are thus used - while eliminating the related deficiencies - in terms of the method for
producing chemicals, gaseous and liquid fuels, heating oils, solid carbon materials by
thermal cracking, i.e. through specified and/or mixed wastes from used tyres, plastics,
biomass, organic portions of municipal waste using a universal tubular flow-type
cracking reactor according to this invention, the aim of which is the processing of waste
carbon materials to obtain alternative second generation energy carriers (chemicals,
environmentally friendly quality fuels) and new carbon materials.
Despite enormous efforts in the field of research, there are very little data available in
the scientific and patent-related literature concerning the coke formation during radical
processes. Coke formation is undesirable because carbon products become gradually
deposited on the inner surface of the reactor, having a deteriorating impact mainly on
the heat transfer property of the reactor wall. Efficient control of the decomposition
process becomes problematic. As a result of coking, the obtained products neither
achieve the required composition, nor can they be produced in an effective way. This
leads to the decrease in the reactor performance and thus also in the economy of the process. The products are contaminated by carbon blacks, which makes them unsuitable for use as marketable fuels.

To eliminate coking and thus to make it possible to obtain products with the required composition, we need to have scientific knowledge about the mechanism of polymeric carbon material decomposition and about the development of secondary reactions resulting in coke formation. In that regard, the currently available conventional technologies are ineffective, as they neither have the capacity to effectively prevent coking, nor to effectively lead thermal decomposition in the desired direction. Based on our detailed research activity and knowledge of the mechanism of carbon polymeric material decomposition and the development of secondary reactions leading to coking we may conclude that the decomposition of polymeric carbon materials to gaseous, liquid and solid products develops through the following processes: the solid feedstock material softens, melts and transforms to the liquid state. Material in the liquid state is then heated and decomposes from higher polymeric structures to low-molecular structures depending on the decomposition temperature. Gaseous components are cooled down to products of standard composition. Composition of the obtained products and their molecular weight largely depends on the decomposition temperature. The aspect that is important for the resulting composition of the obtained products is the development of cracking reactions in the liquid state.

The highest occurrence of coke (carbon) generated at thermal decomposition of carbon polymeric materials is mainly seen when the emerging gaseous low-molecular non-saturated hydrocarbons remain in the reaction zone and are subject to heating over a long period of time. All conventional processes are currently realized under conditions in which the gaseous components are slowly released from the reaction zone of a reactor vessel that is heated with high intensity. They are captured either by absorption on the solid feedstock material and on the emerging coke, or they become absorbed in liquid products. These are the main reasons for the formation of the enormous amounts of coke. Therefore, the most important task is to ensure thermal cracking of carbon materials to be realized in such a way that the gaseous, rather reactive components (mainly the non-saturated ones) - released by the decomposition of liquid portions - are taken away from the reaction zone as quickly as possible in order to prevent them from being subject to intensive and long heating. It should be mentioned here that in case of conventional technologies using the equipment that works based on the principle of extruding the melt out, the liquid components are transported in a high-
density form after liquefaction. Retaining such liquids in the reaction zone results in the formation of high amounts of coke. Moreover, the generated thin layer made of polymers has low thermal conductivity, which can lead to wrong temperature control in the centre of the reactor and thus to deteriorated control over the composition of the obtained products.

Summary of the Invention

The subject-material of the invention which eliminates the above stated deficiencies is the method of producing alternative second generation energy carriers (chemicals, solid, gaseous and liquid fuels, heating oils) and solid carbon materials by thermal decomposition of specified and/or mixed wastes from used tyres, plastics, biomass and organic portions of municipal waste. The present solution consists in providing a new design of a tubular flow-type cracking reactor enabling continuous processing of waste carbon materials.

According to this method the thermal cracking takes place in a hermetically enclosed flow apparatus. The feedstock material transformed to crushed material, shreds or chippings with the size of up to 350 mm is transported to a batching hopper. The modified feedstock material is transported by a spiral-type batching conveyor through a decomposition oil filling, which constitutes an input oil seal, to a tubular flow-type cracking reactor equipped with a shifting spiral conveyor. The feedstock carbon material undergoes thermal cracking in a tubular flow-type cracking reactor at the temperature of 165 to 750 °C, at the atmospheric pressure ranging from 100834.6675 Pa to 101815.3325 Pa (i.e. at the atmospheric pressure ranging from -50 mm up to +50 mm of water column) to obtain gaseous, liquid and solid products. Generated decomposition products are transported out from the tubular flow-type cracking reactor through two outlets leading to the condensation system. Solid products (coke) are transported through the upper section of the reactor by means of a screw conveyor via a water cooler through an opening for the output of solid products entering the output water seal acting as a hydraulic seal. From there they are collected by means of a spiral conveyor.

The tubular flow-type cracking reactor is heated by a heating furnace consisting of two sections, the first stage and the second stage, namely by means of heat transfer from combustion products generated by the combustion in furnace burners of cleaned cooled gas brought in from the process of thermal cracking with preheated air from the recuperator. The feedstock material is preheated already in the initial stage of batching,
namely by heat from the oil filling generated by a condensate of high-boiling portions of decomposition oil running down from the area of the tubular flow-type cracking reactor by the force of gravity. The tubular flow-type cracking reactor is positioned on a metal frame at a certain angle relative to the horizontal plane. The tubular flow-type cracking reactor houses a shifting spiral conveyor with its bottom part being submerged in an oil seal. The top part is enclosed by a water seal, with the oil and water seals hermetically enclosing it. The oil and water seals constitute essential and indispensable parts of the tubular flow-type cracking reactor. Thermal decomposition of carbon materials taking place inside the tubular flow-type cracking reactor is thus realized at the atmospheric pressure ranging from 100834.6675 Pa to 101815.3325 Pa (i.e. at the atmospheric pressure ranging from -50 mm up to +50 mm of water column). With the said configuration, at which there is no overpressure generated in the tubular flow-type cracking reactor, the oil and water levels are stable. Sudden (abrupt) release of vapours of the emerging products leads to the overpressure in the reaction zone. When this happens, the liquid seals enable the gas overpressure to be relieved into the air, thus preventing the pressure of the emerging gases from exceeding the permitted limit, allowing it to be relieved into the atmosphere. This prevents possible breakage of or other damage to the tubular flow-type cracking reactor. In case of a sudden increase of pressure in the reactor the safety system connected to the liquid seals can immediately stop the charging of feedstock to the system and start a safe shut down of the thermal cracking operation.

The spectrum and quality of products depend to a great extent on the reactions that take place. The first ones, which are prevailing, include primary cracking of carbon materials to low-molecular products. The second ones include secondary condensation reactions, thermal alkylations, oligomerizations, polymerizations and cyclizations of primary products that can even result in carboids (coke). It derives from the equilibrium composition that thermal decomposition supports the overall pressure reduction in the reaction system thermodynamically. Unlike the decomposition reactions, the secondary reactions are of a higher than the first order. They are supported by a higher concentration of reactive components, such as alkenes, acetylene, dienes, aromates and by pressure. Higher pressure is therefore not desirable during cracking also due to kinetics. Likewise, condensations resulting in a concentrated liquid phase are not desirable either. Condensations, which eventually lead to coke formation, are therefore even more sensitive to temperature fluctuations in the reactor and exchangers. More distinct are the molecular condensation reactions, such as Diels-Alder syntheses.
Polyenes, polyaromates, tar and coke become gradually formed in case of these reactions.
In case of thermal cracking, coke becomes deposited on the inner surface of the reactor on regular basis. Opinions concerning the coke formation mechanism differ. There probably exist two mechanisms. In case of the first one, the coke-forming substances become adsorbed directly from the gaseous phase on the active points of the surface, where they become transformed to coke by gradual reactions with radicals from the gaseous phase and through the subsequent polymerizations and condensations. In case of the second one, the given interactions, polymerizations and condensations take place in the gaseous phase up to the formation of aerosol. The resulting droplets settle on the surface and through further reactions they turn to coke. The coke formed in the second case is fibrous. In the second case the form of the coke depends on weather the droplets drench the surface or not. If they do, it results in the formation of an amorphous coke surface. Otherwise it is the globular (spheroidal) coke that becomes formed. Important precursors include vinyl and phenyl radicals, as well as polyenes, polyacetylenes and polyaromates generated from these radicals. Effect of the surface composition is rather important. The advantage of reduced pressure (not overpressure) in the reactor is that it limits the development of secondary reactions of gaseous carbons.

The method of producing alternative second generation energy carriers (chemicals, solid, gaseous and liquid fuels, heating oils) and solid carbon materials in a tubular flow-type cracking reactor according to the present solution provides an original technology using waste carbon polymeric materials from municipal wastes with universal application to produce environmentally friendly quality fuels. The universal character of a tubular flow-type cracking reactor consists primarily in the fact that it enables to recycle varied feedstock materials, such as used tyres, waste plastics, biomass and municipal wastes. The process in terms of the present invention is efficient also due to the recovery of waste heat in order to pre-heat the air. Before entering the burners, the air is heated in recuperators. The heating medium is constituted by combustion gases. The waste heat from the process is also used for preheating the incoming feedstock that accepts the heat from the oil seal.
A benefit provided by the method of thermal decomposition in terms of the present invention is also its technical simplicity in the connection of the reactor cracking tube with the batching hopper through the input oil seal, while the tubular cracking reactor is equipped with a conveyor for solid products and an out-feed conveyor in its upper part.
The cracking tubular reactor is designed in such a way that the gaseous and solid products can leave the reaction zone as quickly as possible. This prevents their overheating and the development of secondary reactions leading to coke formation. The method of thermal decomposition in terms of the present invention is a process that is energy and material unintensive. Recycling of carbon polymeric wastes protects the environment while enabling to produce quality and environmentally friendly alternative fuels of second generation. This substitutes a part of fossil fuels, mainly petroleum, which has to be imported by many countries (including Slovakia). Further data concerning the method of producing alternative second generation energy carriers (chemicals, solid, gaseous and liquid fuels, heating oils) and solid carbon materials by thermal cracking of specified and/or mixed wastes from used tyres, plastics, biomass, organic portions of municipal waste in a universal tubular flow-type cracking reactor, as well as the other advantages are obvious from the examples of the embodiment, which examples, however, do not limit the scope of the invention.

Description of the Drawings

The invention is further clarified by the figures in the drawings. Fig. 1 shows the equipment for thermal decomposition of organic material. Fig. 2 shows a detail of the oil seal, and Fig. 3 shows a detail of the water seal.

Examples for realization of the Invention

The technological process of thermal decomposition of carbon materials is realized in a tubular flow-type cracking reactor. The universal character of a tubular cracking reactor consists primarily in the fact that it enables to recycle varied feedstock materials, such as used tyres, waste plastics, biomass and municipal wastes. The technological equipment consists of three sections: a batching section, a reactor section (hot section) and an output section (cold unloading section). The tubular flow-type cracking reactor is schematically represented in Figure 1.

Feedstock material batching is located in the bottom part of the tubular flow-type cracking reactor 1a. It ensures the input of feedstock material through the batching hopper 15 in conjunction with the batching spiral-type conveyor 16 that contains a decomposition oil filling constituting the input hydraulic seal 8. Connection between the spiral conveyor 16 and the tubular flow-type cracking reactor 1a forms an angle of 90 to
125 degrees. Feedstock material batching is provided by a spiral-type batching conveyor \(16\) with an electric drive \(18\) of the batching spiral-type conveyor. The basis of the hot section is constituted by the tubular flow-type cracking reactor \(1a\) positioned on the frame \(32\) at an angle of 8 to 38 degrees relative to the horizontal plane. The tubular flow-type cracking reactor \(1a\) is made of stainless steel with the inner diameter of up to 550 mm and the length of up to 16.0 m, containing a spiral conveyor \(2\) to transport feedstock material and products along the tubular flow-type cracking reactor \(1a\). Drive \(3\) of the spiral conveyor is placed at the bottom part of the reactor. The other parts of the hot section include a heating furnace \(4\) of the first stage of the tubular flow-type cracking reactor and a heating furnace \(5\) of the second stage of the tubular flow-type cracking reactor, a gas burner \(12\), an air pre-heater \(6\), an input oil seal \(8\) at the feedstock inlet, and a water cooler for solid residues \(7\). The tubular flow-type cracking reactor has two consecutive stages with different operating temperatures. Temperature in the first part of the heating furnace \(4\) is maintained at 165 to 500 °C, temperature in the second part of the heating furnace \(5\) is at 520 to 750 °C, with the temperature being controlled in relation to the feedstock material. Tubular flow-type cracking reactor is positioned in the heating furnace of the first \(4\) stage and heating furnace of the second \(5\) stage of the tubular flow-type cracking reactor with heat insulation. The tubular flow-type cracking reactor \(1a\) is heated with the heat from hot combustion products flowing from the gas burner \(12\), which is located in the second stage heating furnace \(5\), in the opposite direction against the feedstock material movement. Following the process start-up, the decomposition gas generated by thermal cracking of the injected feedstock material is burned in the gas burner \(12\) together with air. Combustion products from the heating furnace \(4\) of the first stage are drawn away through point \(11\). They are led through the air pre-heater \(6\) to the stack \(29\). Gaseous fission products generated by thermal cracking of carbon materials leave the tubular flow-type reactor through the opening \(13\) in the first part. Decomposition gas generated in the process of radical cracking leaves the tubular flow-type reactor also through the opening \(14\) in the second part of the reactor. There is an opening \(17\) in the bottom part of the tubular flow-type reactor body designated for the feedstock material intake. The upper part of the reactor contains an opening \(19\) designated for the discharge of solid products (coke, steel cords from tyres). The emerging decomposition gas is taken away from the tubular flow-type cracking reactor through the first outlet \(13\) and the second outlet \(14\) to undergo condensation. It passes through a two-stage condensation system. In the first condensation step it
enters a quench column. The decomposition gas vapours are quenched by the emerging decomposition oil to the temperature of 65 to 80 °C. In the second condensation step the gas product vapours are cooled down to the temperature of 30 to 35 °C when mainly the hydrocarbons C₄ and C₅ are condensed. Water becomes separated from light heating oil in the separator. The condensed water is collected in an intermediate store and is returned back to the technological process. The decomposition gases are compressed into storage tanks. After filtration and pressurization they are used for burning in the gas burners of the cracking furnace.

Inclination of the tubular flow-type cracking reactor 1a serves the following functions: it naturally provides for the required input oil seal 8 in the bottom part of the tubular cracking reactor 1a; it enables easy and trouble-free movement of feedstock material even in the form of crushed material, shreds, as well as of the reaction intermediate and final products (coke, steel cords) along the tubular flow-type cracking reactor 1a; it ensures fluent and easy transfer of heat and material for decomposition gases, liquids and coke during the decomposition process; it enables natural flow of residual decomposition oils into the oil seal.

In the upper output part of the tubular flow-type cracking reactor 1a there is an in-feed spiral conveyor 20 for solid products (coke, steel cords from used tyres) including a drive 21 of the in-feed spiral conveyor, and an out-feed spiral conveyor 22 with a drive 23. Between the in-feed spiral conveyor 20 for solid products and the out-feed spiral conveyor 22 there is an output water seal 9. The level 24 of the output water seal provides a barrier that prevents the outside from entering the inert environment inside the reactor. The water intake to the water seal is at point 25. Connection between the conveyor 26 for solid products and the out-feed screw conveyor 22 forms an angle of 90 to 125 degrees.

The input oil seal 8 located at the input-batching section of the tubular flow-type cracking reactor 1a and the output water seal 9 located at the output section of the tubular flow-type cracking reactor constitute essential and indispensable parts of the reaction system. The oil and water fillings provide hermetic enclosure of the reaction zone. Thermal decomposition taking place inside the tubular flow-type cracking reactor 1a is thus realized at the atmospheric pressure. With the given configuration the oil 10 and water 24 levels are stable. A sudden release of vapours of the emerging products (decomposition process bubble theory) sometimes results in an overpressure inside the reactor area. The liquid seals enable the gas overpressure to become relieved into the air and thus to prevent the increasing pressure of the emerging gases from
exceeding the safe limit. This prevents possible breakage of or other damage to the tubular flow-type cracking reactor la. In case of a sudden increase of pressure in the reactor the safety system connected to the liquid seals 8 and 9 can immediately stop the charging of feedstock to the reactor and start a safe shut down of the thermal cracking operation.

Industrial utilizability

The method of thermal decomposition within the production of alternative second generation liquid carriers of energy (chemicals, gaseous and liquid fuels, heating oils) and solid carbon materials by thermal cracking while using specified and/or mixed wastes from used tyres, plastics, paper, textiles, biomass and organic portions of municipal waste in the equipment for thermal decomposition of organic material by means of a tubular flow-type cracking reactor in terms of the present invention is mainly applicable for recycling of waste carbon materials in small-scale as well as large-scale power engineering. It enables to use in a flexible way either the minor facilities with an annual processing capacity of 20,000 tons built on green-field sites, or the large-capacity facilities at oil refineries enabling to valorize the obtained products to an even greater extent.
PATENT CLAIMS

1. A method of thermal decomposition of organic material from specified and/or mixed wastes from used tyres, plastics, paper, textiles, biomass and organic portions of municipal waste in an inert atmosphere without the participation of oxygen/air, characterized in that the thermal decomposition takes place continuously in a hermetically enclosed flow-type apparatus for thermal decomposition (1) in such a way that the modified feedstock in the form of crushed material, shreds or chippings with the size of up to 350 mm is transported to the batching hopper (15), then it is transported by means of the batching spiral-type conveyor (16) through the decomposition oil filling (17), which constitutes the input oil seal (8), to the tubular flow-type cracking reactor (1a) by means of the shifting spiral-type conveyor (2), where thermal cracking of material is taking place in the tubular flow-type cracking reactor (1a) at the temperature of 165 to 750 °C at the atmospheric pressure from 100834.6675 Pa up to 101815.3325 Pa (i.e. at the atmospheric pressure from -50 mm up to +50 mm of water column) resulting in gaseous, liquid and solid products, wherein the gaseous decomposition products are further transported from the first part (1b) of the tubular flow-type cracking reactor through the outlet (13) and through the outlet (14) in the second part (1c) of the tubular flow-type cracking reactor into the condensation system, then the solid products are transported to the second part (1c) of the tubular flow-type cracking reactor by means of the spiral conveyor (2) through the water cooler (7) via the opening (19) for the output of solid products to the output water seal (9) constituting the hydraulic seal, from where the solid products are taken out by means of the in-feed conveyor (20) and the spiral-type out-feed conveyor (22).

2. A method of thermal decomposition according to claim 1, characterized in that the heating of the tubular flow-type cracking reactor (1a) takes place in the heating furnace (4) of the first stage (1b) of the tubular flow-type cracking reactor and in the heating furnace (5) of the second stage (1c) of the tubular flow-type cracking reactor by heat transfer from combustion products generated by the combustion in the furnace burner (12) of cleaned cooled gas brought in from the process of thermal cracking (30) with preheated air (27) from the recuperator (6).

3. A method of thermal decomposition according to claim 1, characterized in that the feedstock material is preheated already in the initial stage of batching, namely by heat
from the oil filling (17) generated by condensed high-boiling portions of decomposition oil running down from the area of the tubular flow-type cracking reactor first stage by the force of gravity.

4. Equipment for thermal decomposition of organic material for implementation out the method of thermal decomposition according to claims 1 and/or 2 and/or 3, characterized in that it consists of the tubular flow-type cracking reactor (1a), which is positioned on the frame (32) of the tubular flow-type cracking reactor at an angle of 8 to 38 degrees relative to the horizontal plane, whereas the tubular flow-type cracking reactor (1a) houses a shifting spiral conveyor (2) the bottom part of which is submerged in the input oil seal (8), with the second part (1c) of the tubular flow-type cracking reactor being enclosed by the output water seal (9).

5. Equipment for thermal decomposition of organic material according to claim 4, characterized in that the first part (1b) of the tubular flow-type cracking reactor is positioned in the heating furnace (4) of the first part of the tubular flow-type cracking reactor and the second part (1c) of the tubular flow-type cracking reactor is positioned in the heating furnace (5) of the second part of the tubular flow-type cracking reactor, wherein there is an air pre-heater (6) positioned on the heating furnace (4) of the first part of the tubular flow-type cracking reactor, needed for the combustion in the burner (12) of the gas from thermal cracking (30).

6. Equipment for thermal decomposition of organic material according to claim 4, characterized in that the connection of the tubular flow-type cracking reactor (1a) with the batching conveyor (16) through the input oil seal (8) forms an angle of 90 to 125 degrees, whereas in its second part the tubular flow-type cracking reactor (1a) includes an opening (19) provided for the output of solid particles and a connection provided between the in-feed spiral conveyor (21) and the out-feed conveyor (22) forming an angle of 90 to 125 degrees.

7. Equipment for thermal decomposition of organic material according to claim 4, characterized in that the gaseous products from thermal cracking leave the tubular flow-type cracking reactor (1a) through the outlet opening (13) of the tubular flow-type cracking reactor first stage and through the outlet opening (14) of the tubular flow-type cracking reactor second stage, and the solid products through the outlet opening (19).
Fig. 2