

In conventional tubular reactors heat is thus delivered to the reaction zone through the reactor walls.

Other than tubular furnaces solutions for pyrolysis equipment are known. Those include rotary reactors with complicated rotor blade arrangement. Costs for building and maintaining such equipment are higher than the profits that could be ever obtained by means thereof.

Traditional process for producing low-molecular weight hydrocarbons by thermal degradation thus encounters the following problems: 1. poor performance factor for tubular furnace reactors; 2. loss of valuable feedstock material; 3. long reaction times; 4. high secondary reactions rates; 4. high energy consumption; 5. non-optimum (less than possible) product yield and selectivity.

## SUMMARY OF THE INVENTION

Embodiments of the invention alleviate above mentioned problems by implementing a novel method of thermal, thermo-chemical or catalytic thermo-chemical processing of feedstock, such as thermal cracking of hydrocarbon-containing compounds.

Embodiments of the present invention, herein provide a rotary machine type reactor suitable for the pyrolysis of hydrocarbon-containing feedstock.

According to a first aspect of the present invention, there is provided a shock wave reactor for thermal cracking of hydrocarbon-containing feedstock, comprising: a casing wherein a duct is formed with inlet and outlet; a rotor the periphery of which contains an axial-flow blade cascade; wherein the casing substantially encloses the periphery of the rotor and a number of stationary vane cascades inside the duct, and further wherein the cascades are configured to direct feedstock containing process stream to repeatedly pass said cascades in accordance with helical trajectory while propagating within the duct between the inlet and outlet and to generate stationary shock-waves to heat the feedstock.

According to a second aspect of the present invention, there is provided the use of the above reactors in executing at least one procedure selected from the group consisting of: processing hydrocarbon feedstock preferably containing medium and light weight hydrocarbon fractions; processing gaseous, oxygen-containing, fatty acid-based feedstock material; processing gaseous, fatty-acid based feedstock material, which material is preprocessed pine oil; processing gaseous cellulose-derived, and in particular, lignocellulose-derived feedstock material; and fast pyrolysis process comprising converting biomass-derived feedstock material into oil.

According to a third aspect of the present invention, there is provided a reactor assembly, comprising at least one of the above reactors and at least one further element selected from the group consisting of: a drive engine, a heat recovery unit, a quenching unit, a pyrolysis furnace, a pyrolysis furnace with external heating, a pre-heating apparatus or an air filter.

According to a fourth aspect of the present invention, there is provided an arrangement, such as a pyrolysis plant, comprising at least two of the above reactors, functionally connected in series or in parallel.

According to a fifth aspect of the present invention, there is provided a method for thermal, thermo-chemical or catalytic thermo-chemical processing of feedstock matter, optionally specifically thermal cracking of hydrocarbon-containing feedstock, comprising: obtaining a shock wave reactor having a casing, wherein a duct optionally having a substantially ring shape meridian section is formed with inlet and outlet, further having a rotor, the periphery of which contains an axial-flow blade cascade, wherein the casing substantially encloses the periphery of the rotor and a number of stationary vane cascades inside the duct; elevating the rotation speed of the rotor to reach a predetermined process speed or speed range; feeding the feedstock containing process stream into the inlet port, whereupon both stationary cascades and the rotor cascade begin directing the feedstock containing process stream to repeatedly pass through said cascades in accordance with helical trajectory while propagating within the duct between the inlet and outlet ports, and sequentially generating stationary shock-waves to heat the feedstock stream within the reactor, causing thermal degradation or pyrolysis thereof, and directing the pyrolyzed product stream through the outlet port optionally to a predetermined post-processing unit, such as a quenching apparatus.

According to a sixth aspect of the present invention, there is provided a method for importing energy for fast endothermic- or fast exothermic reaction produced from mechanical energy of rotating blade cascades, said method comprising: obtaining a shock wave reactor and passing a preheated, feedstock containing gaseous phase into the reactor to carry out endothermic gaseous phase reactions, wherein the heat is provided by impulses, generated by shock waves resulting from mechanical energy derived from rotation of internal rotor blades.

In one embodiment, the helical-path reactor comprises a rotor with a shaft and a disk provided with blades forming an axial-flow rotor blade cascade, a stationary directing ring-shaped rim optionally provided with at least two stationary vane cascades adjoining the axial-flow rotor cascade, and a casing. The outer surface of the directing rim arranged within the casing substantially defines the duct with the inner surface of the casing to remain there between. Alternatively, at least some of the stationary vane cascades could be formed on the

duct wall-defining inner surface of the casing, for example. Cross-section of the duct in the meridian plane forms a ring-shaped profile.

The duct may comprise several dividing partitions arranged in such a way to create several operational chambers. Operational chambers are preferably of equal size; however, other technical implementations are possible whether appropriate.

The reactor comprises at least one inlet port for feedstock stream and at least one outlet port for product stream. The inlet port is preferably arranged after each dividing partition in the direction of rotation of the rotor and the outlet port is preferably arranged before the dividing partition. The inlet and outlet ports may be integrated within the duct.

In various embodiments, the reactor is adapted to process fluid feedstock, preferably gaseous feedstock matter.

In some embodiments the reactor is adapted to process oxygen-containing feedstock matter, such as carbohydrate- and glyceride (such as e.g. triglyceride)-based feedstock matter.

In still another embodiment the reactor is adapted to process biomass-based, preferably cellulose-derived or in particular lignocellulose-derived feedstock matter provided into the reactor in gaseous form.

In another embodiment of the invention a reactor assembly is provided, comprising the above reactor, connected to the drive engine, a heat recovery unit and a quenching unit.

In still another embodiment of the invention an arrangement in the form of a pyrolysis plant is provided, said arrangement comprises at least two reactors of the present invention connected in series or in parallel.

In a further embodiment of the invention a method for thermal cracking of hydrocarbon-containing feedstock utilizing an embodiment of a reactor disclosed herein is provided.

In still further embodiment of the invention, a method of importing energy for fast endothermic chemical reaction by means of shock waves, produced from mechanical energy of rotating blade cascades of the reactor disclosed herein, is provided.

The utility of embodiment of the present invention arises from a variety of reasons depending on each particular embodiment thereof. Firstly, the rotary machine type reactor implemented in accordance with some embodiments enables conducting a novel cracking process under conditions close to an operation mode of a perfect flow-displacement reactor. The rotary machine type reactor thus provides a new method for a pyrolysis of hydrocarbon-containing compounds, in particular suitable for obtaining low molecular weight hydrocarbon-containing compounds. Reactor design is based on a high speed rotor that transforms the mechanical energy to the high thermal energy inside the reactor, and the pyrolysis process provided herein differs from a conventional thermal cracking technique by a method of heat supply to reacting mixture. Whereas in conventional tubular pyrolysis furnace heat for pyrolysis is transferred through tubular coil wall, the reactor disclosed herein is configured to enable heat generation directly inside the reacting mixture.

The decomposition reactions in the reactor take place due to heat generated directly in feedstock containing process stream when it passes through series of stationary shock

waves of high intensity. Such method of heat supply enables significant decrease in temperature of the walls confining the reaction zone, thus providing an opportunity to overcome limitations in speed of heat supply, otherwise typical to tubular furnace. The time that feedstock gas spends in the reaction zone, which consists of space limited by stationary and rotor cascades and vaneless space, is very short (approximately 0,01 seconds or less), that is about 10 times shorter comparing to a conventional pyrolysis furnace. The process thus becomes more controllable than conventional thermal cracking, although chemical reactions remain substantially the same. The yield of desired pyrolysis products increases because it is possible to decrease pressure and reduce time of residence of feedstock gas in the reaction zone, as well as due to a more uniform temperature profile in a cross-section of the process stream. Since the aforesaid process is characterized with extremely high yield of main products, such as olefins, for example, the technology thus provided represents in the first place a next step in a development of cracking processes to produce additional value from a smaller amount of feedstock, such as oil and gas. Utilization of said reactors in industry enables more cost-effective processing of raw materials therefore positively effecting efficiency and profitability of oil refinement plants.

Secondly, the provision of rotary machine type reactor makes it possible to solve a coke formation problem. The reason for reduced coke formation rate in comparison to the conventional technology is lower residence time of gaseous feedstock in the reaction zone combined with lower temperatures of reactor static parts (walls). Furthermore lower residence times favour reaction selectivity towards desired products.

The reactor of embodiment of the invention also enables processing of oxygen-containing feedstock materials derived e.g. from bio-based feedstock. Other possible application areas for said reactor include therefore refining of biomass or biomass-derived matter to produce renewable fuels in processes such as direct catalytic hydrogenation of plant oil (e.g. pine oil) or animal fats into corresponding alkanes, for example. Still further, valorization of bio-based pyrolysis gas or synthesis gas may be implemented by means of the present reactor, wherein the term "valorization" is referred in present document as to indicate enhancement or refinement of gaseous matter.

Alternatively or additionally the reactor of embodiment of the invention may be provided with catalytic surface(s) to enable catalytic reactions.

With special concern to various embodiments of an axial compressor- or turbine-type reactor of the present invention, a so called plug flow model may be attained. At the same time non-desirable side reactions, taking place in the rotor chamber as a result of product and feedstock mixing and leading to coking may be avoided with the arrangement

## Claims

1. A shock wave reactor for thermal cracking of hydrocarbon-containing feedstock, comprising:

a casing wherein a duct is formed with inlet and outlet;

a rotor the periphery of which contains an axial-flow blade cascade;

wherein the casing substantially encloses the periphery of the rotor and a number of stationary vane cascades inside the duct, and further

wherein the cascades are configured to direct feedstock containing process stream to repeatedly pass said cascades in accordance with helical trajectory while propagating within the duct between the inlet and outlet and to generate stationary shock-waves to heat the feedstock.

2. The reactor of claim 1, wherein the duct has a substantially ring-shaped meridian section.

3. The reactor of any preceding claim, wherein the stationary vane cascades comprise at least two cascades, the first stationary vane cascade being configured upstream and the second stationary vane cascade being configured downstream the axial-flow blade cascade.

4. The reactor of claim 3, wherein the stationary vane cascades are arranged such that a vaneless space is created between the first cascade entrance point and second cascade exit point.

5. The reactor of any preceding claim, comprising a stationary directing rim inside the casing, the outer surface of which rim substantially defines the duct to remain therebetween with the inner surface of the casing.

6. The reactor of claim 5, wherein the outer surface of the rim is provided with at least some of the stationary vane cascades.

7. The reactor of any preceding claim, wherein the cascades are substantially adjacent inside the duct.

8. The reactor of any preceding claim, provided with two inlet ports and two outlet ports.

9. The reactor of claim 1, wherein the duct is configured to define a substantially conical, truncated cone- or cylindrical-shaped chamber.
10. The reactor of claim 9, wherein blades of the axial-flow rotor cascade(s) are configured to alternate with vanes of corresponding stationary vane cascades in longitudinal direction of the rotor forming sequential cascading units, each unit comprising rotor blade spatially located between stationary vanes.
11. The reactor of claim 9 or 10, wherein the first stationary vane cascade comprises a plurality of nozzle vanes and the second stationary vane cascade comprises a plurality of diffusing vanes, said nozzle and diffusing vanes being configured to mutually alternate in longitudinal direction of the rotor.
12. The reactor of any preceding claim, wherein the axial-flow blade cascade is configured to provide kinetic energy and to add velocity to feedstock containing process stream, and at least one stationary vane cascade is configured to reduce the velocity of the stream and convert kinetic energy into heat.
13. The reactor of any preceding claim, wherein the flow velocity of the feedstock containing process stream is supersonic at the cascades and subsonic in the vaneless space within the duct.
14. The reactor of any preceding claim, wherein at least some of the stationary vane cascades are arranged on the duct wall-defining inner surface of the casing.
15. The reactor of any preceding claim, wherein inlet and outlet ports are integrated within the duct.
16. The reactor of any preceding claim, wherein at least two dividing partitions are arranged within the duct symmetrically relative to a rotor axis so as to form at least two substantially identical operational chambers, each being associated with inlet and exit for the process stream.
17. The reactor of any preceding claim, wherein the first stationary vane cascade comprises a plurality of nozzle vanes having a curved profile and being preferably disposed by their convex sides in the direction of rotor rotation, and wherein the second stationary vane cascade comprises a plurality of diffusing vanes having a curved supersonic compressor profile and being preferably disposed by convex sides in the direction of rotor rotation.

18. The reactor of any preceding claim, wherein the axial-flow blade cascade contains a plurality of blades having a profile of active turbine blade, the blades being preferably installed by concave side thereof in the direction of rotor rotation.
19. The reactor of any preceding claim, configured to process gasified carbohydrate-containing feedstock matter.
20. The reactor of any preceding claim, configured to process gasified glyceride-containing feedstock matter.
21. The reactor of any preceding claim, configured to process gasified preprocessed cellulosic biomass material.
22. The reactor of any preceding claim, configured with a number of catalytic surfaces.
23. The reactor of claim 22, wherein the catalytic surface(s) are formed by catalytic coating of at least several of the individual blades or vanes within the reaction zone and/or by catalytic coating of the duct wall-defining inner surface of the casing.
24. The reactor of claim 22 or 23, comprising a number of catalytic modules defined by ceramic or metallic substrate(s) or support carrier(s) with an active coating optionally realized as monolithic honeycomb structures.
25. The reactor of any preceding claim, wherein the reactor contains intermediate cooling or heating element.
26. The reactor of any preceding claim, where the reactor is configured for intermediate injection of diluent or reactive material.
27. The reactor of any preceding claim, configured such that the time gaseous feedstock spends in the reaction zone is substantially equal or less than about 10 milliseconds.
28. Use of the reactor of any preceding claim in executing at least one procedure selected from the group consisting of: processing hydrocarbon feedstock preferably containing medium and light weight hydrocarbon fractions; processing gaseous, oxygen-containing, fatty acid-based feedstock material; processing gaseous, fatty-acid based feedstock material, which material is preprocessed pine oil; processing gaseous cellulose-derived, and in particular, lignocellulose-derived feedstock material; and fast pyrolysis process comprising converting biomass-derived feedstock material into oil.

29. A reactor assembly, comprising at least one reactor according to any of claims 1-27 and at least one further element selected from the group consisting of: a drive engine, a heat recovery unit, a quenching unit, a pyrolysis furnace, a pyrolysis furnace with external heating, a pre-heating apparatus or an air filter.

30. An arrangement, such as a pyrolysis plant, comprising at least two reactors according to any of claims 1-27, functionally connected in series or in parallel.

31. Method for thermal, thermo-chemical or catalytic thermo-chemical processing of feedstock matter, optionally specifically thermal cracking of hydrocarbon-containing feedstock, comprising:

- a. obtaining a shock wave reactor having a casing, wherein a duct optionally having a substantially ring shape meridian section is formed with inlet and outlet, further having a rotor, the periphery of which contains an axial-flow blade cascade, wherein the casing substantially encloses the periphery of the rotor and a number of stationary vane cascades inside the duct;
- b. elevating the rotation speed of the rotor to reach a predetermined process speed or speed range;
- c. feeding the feedstock containing process stream into the inlet port, whereupon both stationary cascades and the rotor cascade begin directing the feedstock containing process stream to repeatedly pass through said cascades in accordance with helical trajectory while propagating within the duct between the inlet and outlet ports, and sequentially generating stationary shock-waves to heat the feedstock stream within the reactor, causing thermal degradation or pyrolysis thereof, and
- d. directing the pyrolyzed product stream through the outlet port optionally to a predetermined post-processing unit, such as a quenching apparatus.

32. Method of claim 31, wherein the feedstock comprises medium or light weight hydrocarbon fractions.

33. Method of claim 31 or 32, wherein the feedstock is cellulose-derived or, in particular, lignocellulose-derived preprocessed biomass, supplied into the reactor in substantially gaseous form.

34. Method for importing energy for fast endothermic- or fast exothermic reaction produced from mechanical energy of rotating blade cascades, said method comprising:

- a. obtaining a shock wave reactor and
- b. passing a preheated, feedstock containing gaseous phase into the reactor to carry out endothermic gaseous phase reactions,

wherein the heat is provided by impulses, generated by shock waves resulting from mechanical energy derived from rotation of internal rotor blades.

35. Method of claim 34, wherein the feedstock comprises medium or light weight hydrocarbon fractions.

36. Method of claim 34 or 35, wherein the feedstock is cellulose-derived or, in particular, lignocellulose-derived preprocessed biomass, supplied into the reactor in substantially gaseous form.