Office de la Propriété Intellectuelle du Canada
Un organisme d'Industrie Canada

Canadian Intellectual Property Office
An agency of Industry Canada

CA 2186744 C 2003/06/24

(11)(21) 2 186 744

(12) BREVET CANADIEN
CANADIAN PATENT

(13) C

(86) Date de dépôt PCT/PCT Filing Date: 1995/03/31
(87) Date publication PCT/PCT Publication Date: 1995/10/12
(45) Date de délivrance/Issue Date: 2003/06/24
(85) Entrée phase nationale/National Entry: 1996/09/27
(86) N° demande PCT/PCT Application No.: FI 1995/000177
(87) N° publication PCT/PCT Publication No.: 1995/027019
(30) Priorité/Priority: 1994/03/31 (941528) FI

(51) Cl.Int.^{6}/Int.Cl.^{6} C07C 4/06, C10G 11/18

(72) Inventeurs/Inventors:
HILTUNEN, JYRKI, FI;
FAGERSTOLT, KRISTER, FI;
KRAUSE, OUTI, FI;
KAARIAINEN, KARI, FI;
RUOTTU, SEPPO, FI;
HALME, ARI, FI

(73) Propriétaire/Owner:
FORTUM OIL AND GAS OY, FI

(74) Agent: OGILVY RENAULT

(54) Titre : PROCEDE ET APPAREIL PERMETTANT DE PRODUIRE DES OLEFINES LEGERES
(54) Title: PROCESS AND APPARATUS FOR PRODUCING LIGHT OLEFINS

(57) Abrégé/Abstract:
A process and apparatus for catalytically converting hydrocarbons to light olefins with a short contact circulating fluidized bed reactor system. The process comprises the steps of feeding a hydrocarbon feedstock into a reaction zone (1) containing a solid catalyst, contacting the hydrocarbon feedstock in the reaction zone (1) with the catalyst under conditions which favour catalytic conversion of hydrocarbons into light olefins, separating the reaction products obtained from the reaction zone (1) after catalytic conversion, recovering the catalyst, and regenerating the deactivated catalyst in a regenerator (3). According to the invention, the hydrocarbon feedstock is contacted with the catalyst in a circulating fluidized bed reactor (1) at a residence time in the range of 0.1 to 3 seconds. The process is used for preparing propylene, butylenes and pentenes and high octane, low benzene gasoline fraction by catalytic conversion of LGO, HGO, VGO or naphta, using conventional or improved FCC catalysts. The process can also be used for preparing propylene, isobutylene or isoamylene rich products by catalytic dehydrogenation from propane, isobutane or naphta, respectively, using conventional or improved dehydrogenation catalysts for fluidized bed service.

PCT WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ^{6} **:** C10G 11/18 — **A1**

(11) International Publication Number: **WO 95/27019**

(43) International Publication Date: 12 October 1995 (12.10.95)

(21) International Application Number: PCT/FI95/00177

(22) International Filing Date: 31 March 1995 (31.03.95)

(30) Priority Data:
941528 31 March 1994 (31.03.94) FI

(71) Applicant *(for all designated States except US)*: NESTE OY [FI/FI]; Keilaniemi, FIN-02150 Espoo (FI).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: HILTUNEN, Jyrki [FI/FI]; Högbackantie/KK, FIN-04130 Sipoo (FI). FAGERSTOLT, Krister [FI/FI]; Kristiinankuja 1 C, FIN-06650 Porvoo (FI). KRAUSE, Outi [FI/FI]; Smedsinportti 1 B, FIN-02700 Kauniainen (FI). KÄÄRIÄINEN, Kari [FI/FI]; Liljatie 9 A 4, FIN-01300 Vantaa (FI). RUOTTU, Seppo [FI/FI]; Ukonkellonkatu 23, FIN-48800 Karhula (FI). HALME, Ari [FI/FI]; Päivättärenkatu 1, FIN-48700 Kyminlinna (FI).

(74) Agents: LAINE, Seppo et al.; Seppo Laine Oy, Lönnrotinkatu 19 A, FIN-00120 Helsinki (FI).

(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, JP, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MN, MX, NL, NO, NZ, PL, PT, RO, RU, SE, SI, SK, TJ, TT, UA, US, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

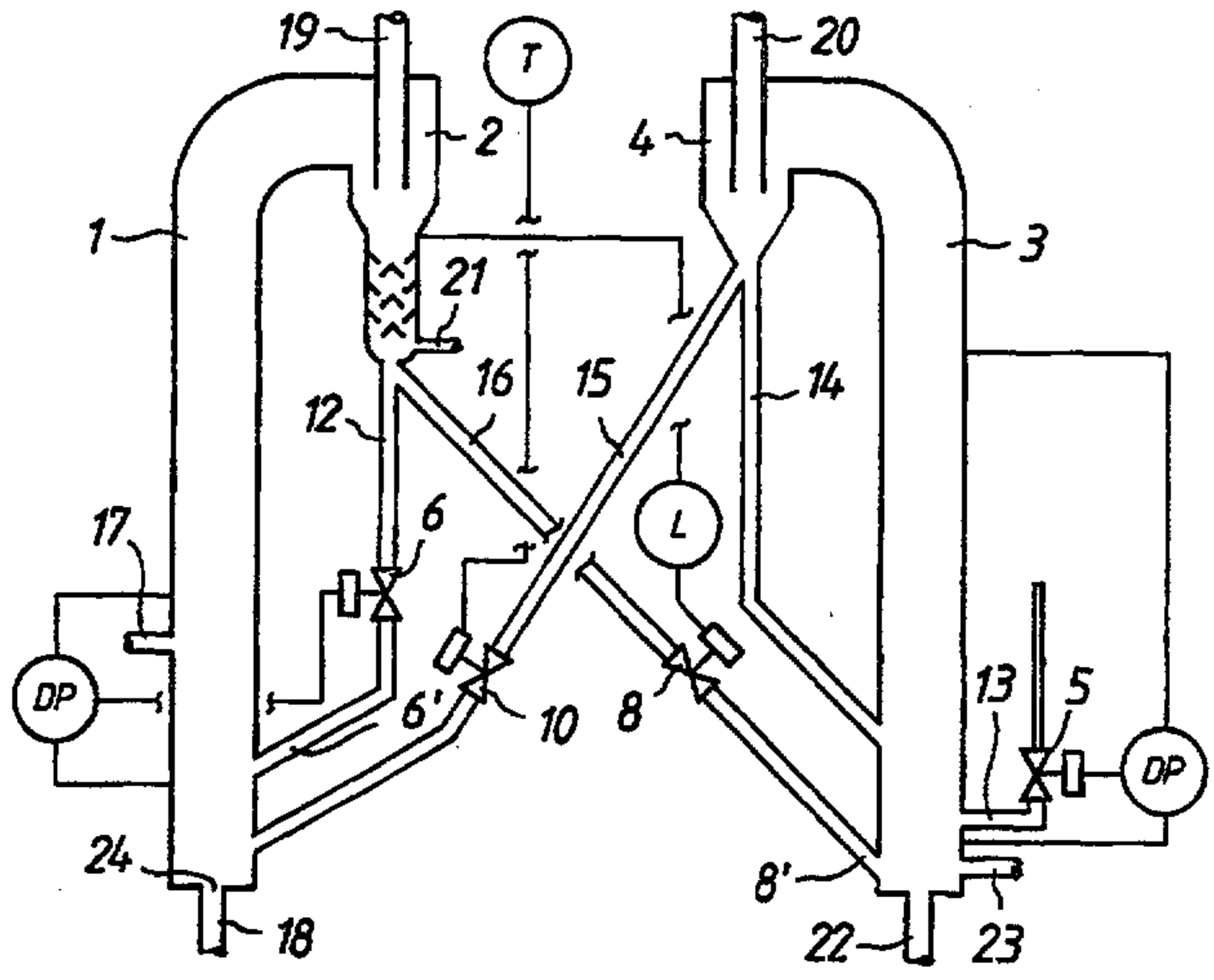
Published
With international search report.

2186744

(54) Title: PROCESS AND APPARATUS FOR PRODUCING LIGHT OLEFINS

(57) Abstract

A process and apparatus for catalytically converting hydrocarbons to light olefins with a short contact circulating fluidized bed reactor system. The process comprises the steps of feeding a hydrocarbon feedstock into a reaction zone (1) containing a solid catalyst, contacting the hydrocarbon feedstock in the reaction zone (1) with the catalyst under conditions which favour catalytic conversion of hydrocarbons into light olefins, separating the reaction products obtained from the reaction zone (1) after catalytic conversion, recovering the catalyst, and regenerating the deactivated catalyst in a regenerator (3). According to the invention, the hydrocarbon feedstock is contacted with the catalyst in a circulating fluidized bed reactor (1) at a residence time in the range of 0.1 to 3 seconds. The process is used for preparing propylene, butylenes and pentenes and high octane, low benzene gasoline fraction by catalytic conversion of LGO, HGO, VGO or naphta, using conventional or improved FCC catalysts. The process can also be used for preparing propylene, isobutylene or isoamylene rich products by catalytic dehydrogenation from propane, isobutane or naphta, respectively, using conventional or improved dehydrogenation catalysts for fluidized bed service.



PROCESS AND APPARATUS FOR PRODUCING LIGHT OLEFINS

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to the production of light olefins. In particular, the invention relates to a process in accordance with the preamble of claim 1 for producing light olefins, such as propylene, butylenes and amylenes, from hydrocarbon feedstocks comprising, e.g. light, heavy and vacuum gas oils, naphta, propane, butanes or light condensates. The invention also relates to an apparatus in accordance with the preamble of claim 17 suited for the production of light olefins from said hydrocarbon feedstocks.

Description of Related Art

Several commercially utilized methods are currently known for the production of propylene, butylenes or amylenes from various petroleum-based hydrocarbon feedstocks. These methods include steam cracking, fluidized bed catalytic cracking and dehydrogenation. The prior art methods suffer from certain disadvantages indicated as follows:

Steam cracking: The main product of the steam cracking process is ethylene. Propylene and heavier olefins are the most important by-products and their yields cannot substantially be increased by a change of operating conditions. Other by-products are comprised of fuel gas, aromatic tar and coke, which are harmful to the process and will have low or no value.

Conventional fluidized bed catalytic cracking (FCC): The yield of light olefins is low and the quality of the main product component, FCC gasoline, is poor for future requirements due to its low octane number and high content of benzene and heavy olefins. To increase the formation of light olefins, higher temperatures and short residence times are needed, which are not practical in the present reactors, as will be described below. When the temperature is raised, the reaction becomes more endothermic and the temperature difference between the reactor and the regenerator decreases because the regenerator temperature cannot be raised without damaging the catalyst. For the supply of all the energy needed, either the catalyst-to-

oil ratio must be increased or a part of energy must be transferred in some other way.

Catalytic dehydrogenation: Hydrogenation of hydrocarbons takes place at relatively high temperatures. The dehydrogenation reaction is highly endothermic requiring high, carefully controlled heat input to the reaction zone. This has resulted in complicated, expensive reactor/regenerator designs.

The reactor types which have been used in hydrocarbon conversion processes can be classified as follows:

1. Fixed bed reactors and
2. Fluidized bed reactors.

At very high fluidizing velocities, the bed surface is no longer sharply defined but replaced by a zone, where the solids content slowly decreases with the height. If particles are fine, this leads to fast fluidization where the solids entrainment occurs at such high rates that, in general, fast fluidized beds can only be maintained by recirculation of the entrained solids via cyclones. This kind of system is called circulating fluidized bed, CFB.

One of the most widely used reactor system is the FCC system, the main components of which are the riser operating in the fast fluidized flow region, the high volume reactor, operating in the dilute suspension phase, and the regenerator, operating in the fluidized bed region. This kind of reactor system has typically a high riser (30 - 40 m) compared to the regenerator, which makes it possible to connect the regenerator to the riser-reactor combination at a point located between the reactor upper part and the riser lower part. The riser must be clearly higher than the regenerator to ensure the hydrodynamic viability of the system. This sets limiting conditions for the process caused by residence time and equipment design. These limiting conditions are particularly unfavourable, when short residence times and high solids concentrations are needed in the reactor. This sets limits regarding residence time and solids concentrations — very short residence times or high solids concentrations cannot be achieved with a FCC system.

US Patent Specification No. 4 980 053 describes trials made by using heavy hydrocarbon fractions, such as vacuum gas oil, as feed, under more severe operating conditions than FCC and milder than those of steam cracking, which results in a higher yield of propylene and butylenes than ethylene. This process, known as the Deep Catalytic Cracking process (DCC), has been studied in pilot units and in a commercial, revamped FCC unit. The unit is practically a FCC unit, with different operating parameters and a modified catalyst.

A process for converting saturated hydrocarbons to light olefins, in particular propylene, by using a zeolite catalyst and reaction temperatures in the range of 500 to 700 °C with low hydrocarbon partial pressures, is disclosed in EP Patent Application No. 395 345. In the examples of the said reference, the process has been implemented using fixed bed reactors, which makes it possible to keep the residence times short. The process can, however, also be carried out in fluidized bed systems. The prior art process is claimed to have lower capital costs and to be more selective for propylene and butylenes than conventional steam cracking.

However, the above mentioned reactor systems have serious limitations restricting their utilization particularly in processes, wherein short residence times and high solids concentrations in the reactor are required. In such a process, the riser should be low compared to the regenerator. The problem is even worse if, at the same time, there is a large pressure difference between the regenerator and the riser. In that situation the regenerator cannot be connected to the riser cyclone. Instead, complicated systems to circulate the catalyst are needed. In practice the reactor riser would have to be designed unpractically high, and in that case the gas velocity would grow too high and the catalyst volume fraction in the riser would be too low for optimum process conditions. The FCC system has the limitation that the catalyst volume fraction cannot be freely controlled without affecting other process variables.

Summary of the Invention

It is, therefore, an object of the present invention to overcome the above-mentioned deficiencies of the prior art and to provide a novel process and reactor system for preparing light olefins from a hydrocarbon feedstock.

The invention is based on the concept of carrying out the catalytic conversion of the hydrocarbon feedstock in a circulating fluidized bed (CFB) reactor using short residence times. Preferably, the spent catalyst is also regenerated in a circulating fluidized bed (CFB) regenerator and all the thermal energy needed for the endothermic conversion reaction is supplied by the recycled regenerated catalyst particles.

Therefore, in accordance with the present invention, there is provided a process for catalytically converting hydrocarbons to light olefins, comprising the steps of:

- feeding a hydrocarbon feedstock into a reaction zone containing a solid catalyst,
- contacting the hydrocarbon feedstock in the reaction zone with the catalyst under conditions which favour catalytic conversion of hydrocarbons into light olefins,
- separating reaction products obtained from the reaction zone after catalytic conversion,
- recovering the catalyst, and
- regenerating a deactivated catalyst in a regenerator,

characterized by

- contacting the hydrocarbon feedstock with the catalyst in a circulating fluidized bed reactor at a residence time in the range of 0.1 to 3 seconds,
- withdrawing at least a part of a spent catalyst from the circulating fluidized bed reactor and feeding it into a circulating fluidized bed regenerator for regeneration by combustion,
- recycling a part of the regenerated catalyst back to the regenerator, and
- recycling the rest of the regenerated catalyst into the circulating fluidized bed reactor,

whereby practically all of the heat needed for the catalytic conversion of the hydrocarbon feedstock is being provided by the recycled catalyst regenerated in the circulating fluidized bed regenerator.

The reactor system according to the invention comprises at least one circulating fluidized bed unit (reactor) for catalytic conversion of hydrocarbons, provided with feed nozzles for the hydrocarbon feedstock and for the recycled catalyst particles. The CFB reactor is also provided with a cyclone or similar separator for separating the spent catalyst from the product stream, said cyclone having a product outlet for the light olefins and a solids outlet for the separated catalyst particles. Furthermore, the reactor system comprises at least one circulating fluidized bed unit for catalyst regeneration by combustion, provided with feed nozzles for the spent catalyst to be regenerated and a cyclone or similar separator for separating the regenerated catalyst from the flue gases of the combustion process. The feed nozzle of the regenerator unit is connected to the solids outlet of the cyclone of the reactor unit.

Accordingly, also in accordance with the present invention, there is provided an apparatus for catalytically converting hydrocarbons to light olefins, comprising a combination of

- at least one circulating fluidized bed reactor,
- feed nozzles for feed of a hydrocarbon feedstock and a recycled catalyst to a lower part of the circulating fluidized bed reactor,
- a first catalyst separation cyclone on an outlet of the fluidized bed reactor for separating a spent catalyst from a product stream of the reactor, said cyclone having a product outlet and solids outlets for the spent catalyst,
- one circulating fluidized bed unit regenerator for catalyst regeneration, provided with a recycle pipe for recycling of a part of a regenerated catalyst back to the regenerator,

- a nozzle for the spent catalyst to be regenerated on a lower part of the circulating fluidized bed regenerator, and
- a second catalyst separation cyclone for separating the regenerated catalyst from regenerator flue gases.

Brief Description of the Drawing

The attached drawing shows, in schematic fashion, a simplified process scheme for a preferred embodiment of the invention.

Detailed Description of the Invention

Definitions

Within the scope of the present invention, the terms "spent catalyst" and "deactivated catalyst" are interchangeably used to designate catalyst particles deposited with coke or other impurities, which lower the catalytic activity of the catalyst.

The abbreviation "CFB" is used to denote a "circulating fluidized bed", in which solids are transported vertically in a vertical pipe by a high-velocity gas stream. The CFB is preferably equipped with a cyclone, in which solids are separated from gas flow. Often there is also a return pipe connected to the cyclone for recycling of the solids. Such a return pipe represents a preferred embodiment of a CFB according to the invention, but the CFB units described below are also operable without return pipes. The superficial gas velocities in the CFB reactor are typically in the range of about 2 to about 10 m/s. The throughput of the solids (catalysts particles) is very large at these gas velocities which minimizes the required reactor diameter. The superficial gas velocity in the CFB regenerator is not critical, because the catalyst can be recycled to achieve the desired recidence time for catalyst regeneration.

"Light olefins" mean olefins comprising 1 to 6 carbon atoms, preferably ethylene, propylene, butylenes and pentenes.

When used with reference to feedstock-to-catalyst contact the term "short contact" indicates residence times in the range of 0.1 to 3 seconds. Residence times of less than 2 seconds or less than 1 second, in particular of less than even 0.5 s are possible.

Process Description

The process for catalytically converting hydrocarbons to light olefins comprises the conventional steps of feeding a hydrocarbon feedstock into a reaction zone containing a solid catalyst. In the reaction zone, the hydrocarbons are contacted with the catalyst under conditions which favour catalytic conversion of hydrocarbons into light olefins. After the

reaction, the light olefins produced and unreacted feedstock are separated from the catalyst particles. The spent, deactivated catalyst is recovered and regenerated in a regenerator by burning off the coke deposited on the catalyst particles.

According to the invention, the hydrocarbon feedstock is contacted with the catalyst in a circulating fluidized bed (CFB reactor), the residence time being in the range of 0.1 to 3 seconds. The CFB system according to the invention differs from the conventional FCC system in the respect that: 1) the vast volumetric reactor is replaced by a riser with a small external cyclone, and the reactions occur only in the riser pipe; 2) the bubbling bed regenerator is replaced by a CFB regenerator. Both of these improvements allow for enhanced residence time control and improved reactor construction.

To date, circulating fluidized bed reactors (CFBR) have primarily been used for noncatalytic processes. Known in the art is, however, also a circulating fluidized bed reactor (CFB) intended for maleic anhydride production based on catalytic oxidation of butane [Pugsley, T. et al., Ind. Eng. Chem. Res. 31 (1992), 2652-2660]. As a disadvantage of the known CFB construction, it should be mentioned that the catalyst volume fraction of the reactor cannot be freely controlled without affecting other process variables. Furthermore, there is no suggestion in the prior art that the same equipment could be used for cracking reactions or for the preparation of light olefins.

According to the invention, the spent catalyst is separated from the products and the hydrocarbon feedstock in an external cyclone connected to the CFB reactor. Preferably the regenerator comprises a similar piece of equipment as the reactor, so that the regeneration of the spent catalyst can be carried out in a second circulating fluidized bed. However, other types of regenerators can be used, as well.

According to the invention, it is possible to arrange two (or more) reactor units in series by using the product stream of the previous reactor as the feed of the following reactor. The reactors of this embodiment can be operated at different temperatures and pressures, which makes it possible to adapt the process to hydrocarbon feedstocks of most varying kind.

According to one particularly preferred embodiment, wherein the reactor system comprises a CFB reactor and a CFB regenerator, at least a part of the separated deactivated catalyst is conducted to the regenerator via a first pipe (the "spent catalyst pipe"), which is connected to the lower end of the regenerator. The feed of deactivated catalyst into the regenerator is preferably controlled by a valve connected to the feed nozzle of the pipe in such a way that there is at least a minimum amount of catalyst in the pipe in order to keep the pipe essentially gas tight. The "plug" formed by the catalyst in the pipe will prevent any gases emanating from the reaction zone from being conducted to the regenerator. This will eliminate the risk of explosions.

Within the scope of the invention, it is possible to conduct all of the separated deactivated catalyst to the regenerator, without any internal reactor recycle.

The deactivated catalyst is advantageously regenerated by combusting coke gathered on its surface in the second circulating fluidized bed at a temperature in the range of 650 to 800 °C preferably by introducing hot air and optionally hot flue gas from additional fuel into the regenerator. As already mentioned above, it is also possible to use other types of regenerators, such as the conventional bubbling bed type regenerators.

An important advantage of the present reactor system, which will be described in more detail below, resides in the fact that the concentration of the catalyst in the reactor can be maintained at a high level, thus ensuring large catalytic surface contact with the hydrocarbon reactants. The reactor system according to the invention is, therefore, preferably equipped with a second pipe (the "catalyst recycle pipe"), for recycling of the catalyst separated by the cyclone back to the reactor.

The flow ratio of spent catalyst to be regenerated and recycled depends on the hydrocarbon feedstock, feed rate, catalyst used and the processing conditions.

As is the case with the CFB reactor, a part of the catalyst is preferably recycled back to the CFB regenerator via a recycle pipe, whereas the rest of the catalyst, i.e. the regenera flows to the CFB reactor through the catalyst recycle pipe, which is connected to the bottom of the

CFB reactor.

The invention can be used for converting hydrocarbons into light olefins under cracking as well as under dehydrogenation conditions. The hydrocarbon feedstock to be used for catalytic cracking in the present invention can consist of light gas oil (LGO), heavy gas oil (HGO), vacuum gas oil (VGO) or naphtha. Steam or another gas can be used as a diluent. The light olefins produced comprise ethylene, propylene, butylenes, amylenes, and a high octane, low benzene gasoline fraction. As solid catalysts, conventional (FCC) cracking catalysts and improved cracking catalysts are used. The catalyst types can be exemplified by natural and synthetic aluminium silicates, zeolites, clay etc. Conventional zeolites including X and Y zeolites, which may be stabilized with rare earth metals, are possible. The process conditions for catalytic cracking in a reactor system according to the present invention are the following: reaction temperature: 520 to 700 °C; pressure: 105 to 500 kPa; residence time: 0.1 to 3 s, in particular 0.2 to 1 s. Residence times of less than 0.5 s (e.g. 0.2 - 0.49 s) are possible.

The invention can also be used for dehydrogenation of a hydrocarbon feedstock, such as propane, isobutane and light condensate to convert the feedstock to propylene, isobutylene and mixed butylenes, respectively. The reaction temperature is typically in the range of 580 to 750 °C. The same residence times as mentioned above can be used. Dehydrogenation catalysts known in the art, such as chromium/alumina, can be employed.

According to the invention air can be fed into the reactor in order to enhance the reaction, the amount of air feed being 0 to 50 %. If additional air is fed into the reactor, the amount thereof is preferably about 0.1 to about 50 %, in particular 10 - 40 %, calculated on the basis of the weight of the hydrocarbons.

The most important benefits of the invention, compared with the known processes are:

A short residence time and high catalyst volume fraction can be sustained without using complicated mechanical or pneumatic transport systems to carry catalyst from one unit to another.

All of the heat needed for the catalytic conversion of the hydrocarbon feedstock is being provided by the recycled catalyst regenerated in the circulating fluidized bed regenerator, except when air is also injected into the reactor and the resulting oxidation of the feedstock and the reaction products caused by air injection provides some heat into the reactor.

Catalyst volume fraction in the reactor can be set at desired value by internal catalyst recirculation, independently of other flows within the process.

The pressure levels of the reactor and the regenerator can be controlled independently from each other. This also gives a possibility to combine more than one reactor, operating with its own optimal process parameters and feedstock, with one common regenerator.

In comparison with the conventional cracking processes, the process of present invention provides high light olefin yield, good quality gasoline fraction, high conversion and simple, inexpensive reactor design.

In comparison with the current dehydrogenation processes, the present invention provides a very simple, inexpensive reactor/regenerator design.

In comparison with FCC type units, the regenerator is small and the catalyst loading is lower. This gives a possibility, with a proper design, to avoid current heavy refractory assemblies and use easy maintenance, lightweight, simple, inexpensive, externally insulated constructions.

The average cracking temperature across the CFB reactor can be increased without increasing the reactor inlet temperature and, as a result, the yield of light olefins is increased with the use of air as a prefluidization gas due to exothermic combustion taking place simultaneously with endothermic cracking in the reaction zone.

The attached drawing shows a preferred embodiment of the present invention. A short contact reactor/regenerator system is used to get desired process conditions. The basic principle governing the interaction of two CFB units is described in more detail in the

PCT Publication No. WO94/08194 published on April 14, 1994 (Einco Oy, Finland).

According to the invention, a hydrocarbon feedstock mixed with heated catalyst is cracked in a short contact CFB reactor 1 at temperatures in the range of 520 to 700°C. The hydrocarbons are fed through a feed nozzle (24). The operating pressure of the reactor is 105 to 500 kPa(a) and the residence time from 0.1 to 3 s, preferably from 0.2 to 2 s. The catalyst-to-oil ratio can vary from 1 to 120, preferably from 10 to 50. The partial pressure of hydrocarbon feed can be decreased with the addition of steam or other diluent gases like recycle gas from the unit, but the use of diluent gas is not a prerequisite for the operation of the process. The feedstock enters from a pipe 17 and the prefluidization gas is injected through pipe 18.

After the cracking reaction, spent catalyst is separated from the products in a cyclone 2 located outside of the fluidized bed reactor. Hydrocarbons adsorbed in the spent catalyst will either remain in the spent catalyst and burn in the regenerator 3 or can be stripped off in the stripping zone below the cyclone with steam 21, if stripping is economically justifiable. Products exit through the pipe 19. A part of the spent catalyst is transferred from the cyclone 2 to the generator 3 via the spent catalyst pipe 16, the flow of catalyst particles being regulated by a valve 8 on the pipe close to the feed nozzle 8' connected to the bottom of the regenerator 3. A part of the spent catalyst can be returned to the reactor as internal recycle via a control valve 6 on the catalyst recycle pipe 12 which is provided downstream with a nozzle 6'. By controlling the catalyst recycle rate with the valve 6, the catalyst volume fraction and temperature profile in the reactor can be adjusted. In order to prevent mixing of reactor and regenerator gases, the valve 8 controls the catalyst particle flow in such a manner that the pipe 16 is always filled with catalyst. The surface level control is indicated with an L.

The regenerator 3 is essentially a circulating fluidized bed reactor. The regenerator serves two purposes: Heat for the endothermic cracking reaction is supplied to the reactor by the catalyst heated in the regenerator and coke deposited on spent catalyst particles is burned off. Regeneration of the catalyst takes place at temperatures in the range of 650 to 800 °C by blowing preheated air through an air inlet pipe 22 and injecting additional fuel through a pipe 23 to the lower end of the regenerator. Alternatively the additional fuel can be burned in a separate combustion chamber, from where the hot flue gases are led to the lower end of the regenerator through the pipe 22. Regenerated hot catalyst is separated from combustion gases, which exit through outlet pipe 20 in the regenerator cyclone 4 and the regenerated catalyst is returned to the reactor 1 via a regenerated catalyst pipe 15, the flow being controlled by the control valve 10. The rest of the regenerated catalyst is returned as an internal recycle to regenerator via a catalyst recycle pipe 14.

At steady state conditions the catalyst flow rates through pipes 15 and 16 are equal. Catalyst is added to the system through pipe 13 and valve 5, which is controlled by the pressure difference between the top and bottom of the regenerator.

More than one reactor can be arranged in series with the hydrocarbon stream, or more than one reactor can be arranged in parallel, each having its own feed.

Products separated from the catalyst in the reactor cyclone can further be processed into intermediate product fractions using a standard or modified FCC process product recovery system.

As examplifying embodiments of the present invention, the results of pilot plant tests on the conversion of gas oils to olefins are presented in the following.

Example 1

The system consisted of one CFB reactor and one CFB regenerator. The regenerated catalyst entering the reactor was prefluidized with nitrogen. Light gas oil (LGO) was fed through a nozzle with a small flow of distribution air in the reactor. No internal catalyst recycle was used in this test. The main parameters were the following:

Reactor:

Height	1.85 m
Diameter	0.030 m

Oil mass flow rate	1.13 g/s
External catalyst/oil ratio	27 g/g
Internal catalyst/oil ratio	0 %
Catalyst volume fraction	2 to 7 %
Height of prefluidization pipe	0.25 m
Diameter of prefluidization pipe	0.018 m

Regenerator:

Height	3.1 m
Diameter	0.08 m
Exit gas O_2 concentration	4 to 5 %
Catalyst volume fraction	4 %

Example 2

The reactor configuration and feedstock were the same as in example 1, with the exception that the internal and external catalyst/oil ratios were both about 15. The internal catalyst recycle inlet on the reactor was just above the oil injection point.

Example 3

The reactor configuration and feedstock were the same as in example 2, except that no air was used for the feed distribution and the internal catalyst recycle fraction was about 8.

Example 4

The reactor configuration and the feedstock were equal to those of example 1, except that air was used for prefluidization, but no feed distribution gas. Riser diameter in this run was 0.042 m.

Table 1. Results of the tests of Examples 1 to 4

	Example 1	Example 2	Example 3	Example 4
Mass balance				
Feed, g				
Oil	4,073	3,802	4,248	8,780
Nitrogen	3,323	2,620	2,618	0
Air	593	428	0	2,962
Total	7,989	6,850	6,866	11,742
Products, g				
Gas	5,593	4,563	4,406	7,164
Condensate	2,132	1,594	2,234	3,555
Coke	407	380	425	1,300
Total	8,132	6,537	7,065	10,719
Difference	-143	313	-199	-277
Difference of feed	-2 %	5 %	-3 %	-2 %
Process				
Yields, wt-%				
C_1 to C_4 alkanes	5.8	6.4	5.9	13.8
$C_2^=$ to $C_4^=$	26.2	24.2	21.2	26.0
Gasoline	28.3	30.8	37.1	30.4
Gas oil	23.9	23.1	20.3	12.5
Bottoms	4.3	4.0	3.7	0.4
Coke	10.7	9.9	11.5	14.3
CO_2, H_2, H_2O	0.8	0.8	0.2	2.5
Total	100.0	99.8	99.7	99.9
Conversion, wt-%				
Reactor temperature, °C	588	587	585	591
Regenerator temp., °C	760	755	786	762
Int. Catalyst/oil ratio	0	15	8	0
Ext. Catalyst/oil ratio	27	15	15	22
Residence time, s	0.25	0.31	0.32	0.83

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A process for catalytically converting hydrocarbons to light olefins, comprising the steps of:

- feeding a hydrocarbon feedstock into a reaction zone containing a solid catalyst,
- contacting the hydrocarbon feedstock in the reaction zone with the catalyst under conditions which favour catalytic conversion of hydrocarbons into light olefins,
- separating reaction products obtained from the reaction zone after catalytic conversion,
- recovering the catalyst, and
- regenerating a deactivated catalyst in a regenerator,

characterized by

- contacting the hydrocarbon feedstock with the catalyst in a circulating fluidized bed reactor at a residence time in the range of 0.1 to 3 seconds,
- withdrawing at least a part of a spent catalyst from the circulating fluidized bed reactor and feeding it into a circulating fluidized bed regenerator for regeneration by combustion,
- recycling a part of the regenerated catalyst back to the regenerator, and
- recycling the rest of the regenerated catalyst into the circulating fluidized bed reactor,

whereby practically all of the heat needed for the catalytic conversion of the hydrocarbon feedstock is being provided by the recycled catalyst regenerated in the circulating fluidized bed regenerator.

2. A process according to Claim 1, wherein all of the spent catalyst from the circulating fluidized bed reactor is withdrawn and fed into the regenerator for regeneration by combustion.

3. A process according to Claims 1 or 2, wherein the spent catalyst is separated from the circulating fluidized bed reactor in an external cyclone connected to the reactor, at least a part of that catalyst is led to the regenerator via a spent catalyst pipe, which is connected to a lower end of the circulating fluidized bed regenerator.

4. A process according to Claim 3, wherein all of the separated catalyst is led to the regenerator.

5. A process according to Claims 3 or 4, wherein the spent catalyst flow into the regenerator via the spent catalyst pipe is controlled by a valve on the spent catalyst pipe in such a way that the spent catalyst pipe is at all times filled with catalyst in order to keep the reactor and the regenerator gases from mixing with each other.

6. A process according to any of Claims 2 to 5, wherein a catalyst concentration in the reactor and temperature profile across the reactor is controlled by adjusting the catalyst recycle rate through a first catalyst recycle pipe to the reactor.

7. A process according to any of Claims 1 to 6, wherein the regenerated catalyst is separated from the circulating fluidized bed regenerator in a regenerator cyclone external to the regenerator, a part of the catalyst is recycled to the circulating fluidized bed regenerator via a second catalyst recycle pipe, whereas the rest of the catalyst is led to a lower end of the reactor via a regenerated catalyst pipe for regenerated catalyst.

8. A process according to Claim 1, wherein the hydrocarbon feedstock includes one of light gas oil, heavy gas oil, vacuum gas oil and naphtha, and is treated under catalytic cracking conditions with no diluent gas or using steam or other gas as a diluent to convert the hydrocarbon feedstock to light olefins comprising propylene, butylenes, amylenes, and high octane, low benzene gasoline.

9. A process according to Claim 8, wherein a solid catalyst is used which can be either conventional cracking catalyst or improved cracking catalyst.

10. A process according to any of Claims 1 to 9, wherein the feedstock is contacted with the catalyst in the circulating fluidized bed reactor at a temperature in the range of 520 to 700°C, at a pressure of 105 to 500 kPa and with a residence time of 0.1 to 3.0 s.

11. A process according to Claim 1, wherein the hydrocarbon feedstock comprises one of propane, isobutanes and light condensates, and is treated under dehydrogenation conditions in the presence of a dehydrogenation catalyst in order to convert the hydrocarbon feedstock to propylene, butylenes or amylenes.

12. A process according to Claim 11, wherein the feedstock is contacted with the catalyst in the circulating fluidized bed reactor at a temperature in the range of 580 to 750°C with a residence time of 0.1 to 3.0 s.

13. A process according to any of Claims 1 to 12, wherein 0.1 to 50% of air, calculated on the basis of the weight of the feedstock hydrocarbons, is fed into the reactor.

14. A process according to any of Claims 1 to 13, wherein the deactivated catalyst is regenerated by combusting coke deposited on its surface in the circulating fluidized bed regenerator at a temperature in the range of 650 to 800°C with hot air and optionally additional fuel.

15. A process according to Claim 1, wherein the residence time is 0.2 to 2 seconds.

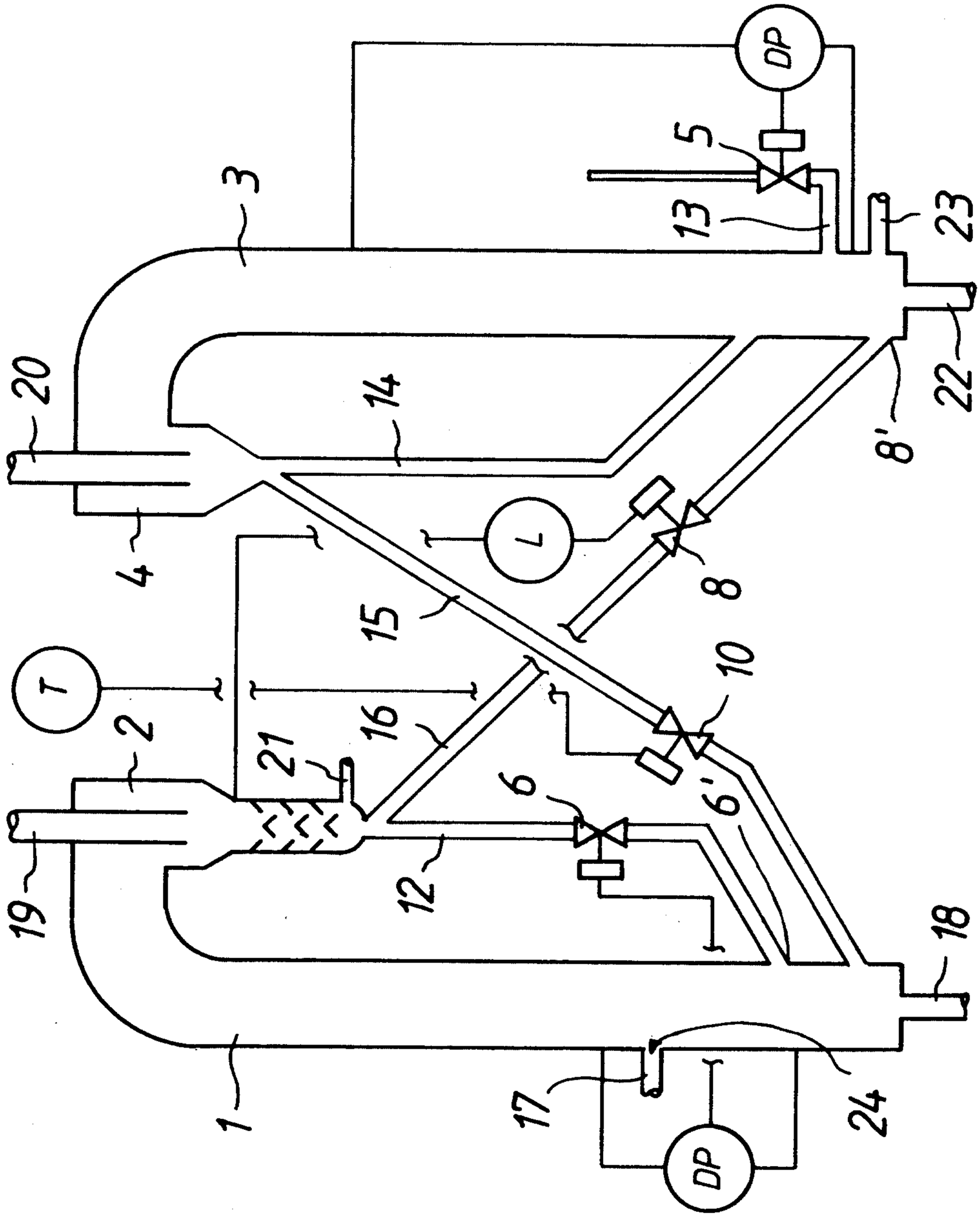
16. A process according to Claim 15, wherein the residence time is 0.2 to 1 seconds.

17. An apparatus for catalytically converting hydrocarbons to light olefins, comprising a combination of

- at least one circulating fluidized bed reactor,
- feed nozzles for feed of a hydrocarbon feedstock and a recycled catalyst to a lower part of the circulating fluidized bed reactor,
- a first catalyst separation cyclone on an outlet of the fluidized bed reactor for separating a spent catalyst from a product stream of the reactor, said cyclone having a product outlet and solids outlets for the spent catalyst,
- one circulating fluidized bed unit regenerator for catalyst regeneration, provided with a recycle pipe for recycling of a part of a regenerated catalyst back to the regenerator,
- a nozzle for the spent catalyst to be regenerated on a lower part of the circulating fluidized bed regenerator, and
- a second catalyst separation cyclone for separating the regenerated catalyst from regenerator flue gases.

18. The apparatus according to Claim 17, wherein the first catalyst separation cyclone on the outlet of the fluidized bed reactor comprises an external cyclone connected to the reactor.

19. The apparatus according to Claim 17, wherein the second catalyst separation cyclone for separating the regenerated catalyst from the regenerator flue gases comprises a cyclone external to the regenerator.


DP
5
13
23
3
20
14
22
8'
4
L
8
15
10
T
2
21
16
6
6'
19
12
18
1
17
24
DP