US2015328610 discloses a mixing device mounted between two catalyst beds in a multi-bed catalytic reactor with a cylindrical shape. The mixing device has a circular outer rim which corresponds to the inner wall of the reactor and includes a collecting section for collecting fluid from an up-stream catalytic bed, a mixing section for mixing the collected fluid, and a discharging section for discharging the mixed fluid to a down-stream catalytic bed. The collecting section, the mixing section and the discharging section are disposed outside the centre of the circular cross-section of the reactor.

Accordingly, there is a need for an effective distribution device providing free space for cleaning and service which solves the problem of fouling of the feed due to temperature rise of the feed especially present in renewables hydroprocessing.

Therefore, a need exists to provide catalytic reactor with an improved and efficient distributor providing free space for service and cleaning and solving the problems of fouling due to elevated feed temperatures.

SUMMARY

The new multi-bed reactor with a cylindrical shape comprising at least one distribution device according to the disclosure distribute fresh feed over a catalyst bed independently of recycle oil and gas, allowing the feed to remain at low temperature during distribution, thus at a low or no risk of polymerization, coking or other means of fouling. Recycle oil and gas is homogenized independently (and each phase separately) in order to combat any maldistribution effects on temperature of composition from the previous catalytic bed. The elimination of a dedicated two-phase mixer reduces space requirements and cost. The increased free space improves accessibility for cleaning the internals.

According to this disclosure the distribution device comprises a novel principle of distributing the feed in separate feed distribution channels covering the entire cross section. In an example, soaking gas, which enters the reactor with the feed, is used to shield the feed channel from ambient heat. Feed and soaking gas is distributed evenly over the reactor cross section using the excess pressure (for instance 1.5 bar) in the feed inlet, which gives it an extremely uniform distribution as compared to normal VLT's. Recycle oil and gas is homogenized independently (each phase separately) in order to combat any maldistribution effects on temperature of composition from the previous bed.

This has the effect that the separate feed distribution system keeps the highly reactive feed at low temperatures until it meets the catalyst bed. This reduces the risk of polymerization in the bed, and ensures that when the feed is finally heated up, is does so in a hydrogen rich environment, which also lowers the risk of polymerization.

The recycle streams in the reactor are used as dilution and as a heat sink in the example. Contrary to the existing solutions the recycle gas and oil will first be mixed with the feed inside the next bed, and not inside the quench zone internals.

The new multi-bed reactor with a cylindrical shape according to the disclosure comprises at least one distribution device for distribution of fluids. It is to be understood that fluids means either liquid(s), gas(ses) or vapour(s) or a mixture of two or more of the mentioned. The distribution device comprises at least one recycle fluid inlet and distribution tray (the recycle fluid is a more or less processed fluid which is recycling within the reactor or derives from downstream the reactor). This recycled fluid enters the distribution tray via the recycle fluid inlet of that specific distribution tray, and the distribution tray then passes the recycle fluid throughout the distribution tray to distribute the recycle fluid evenly over the area of a catalytic bed below the distribution device. How well and even the distribution tray is able to distribute the recycle fluid depends on

several factors, such as number of distribution points, pressure loss over the distribution device, how level the distribution tray is among other. According to the disclosure, the distribution device further comprises a separate feed distributor. The separate feed distributor comprises at least one feed inlet and a plurality of feed outlets. It may be sufficient with one feed inlet as long as the feed inlet has the necessary capacity for the fluid flow, however a plurality of feed outlets are necessary to ensure an even distribution of feed over the catalytic bed below as will also be discussed later on. The feed distributor has means to distribute the feed fluid from the at least one feed inlet to the plurality of feed outlets. This may be done by any means known in the art such as pipes or channels connecting the one or more feed inlet and manifolding out to the plurality of feed outlets. The feed distributor is separated from fluid connection to the mentioned recycle fluid within the distribution device, i.e. within the distribution device, the feed fluid does not come into contact with the recycle fluid. This is important to gain the effect that the feed fluid is protected against the higher temperatures of the recycle fluid in a time before the feed fluid contacts the catalytic bed which is long enough to risk polymerisation and fouling as mentioned in the description earlier.

In one aspect, the present disclosure provides a multi-bed catalytic reactor with a cylindrical shape comprising at least one distribution device, said distribution device comprises at least one recycle fluid inlet and distribution tray adapted to distribute recycle fluid, wherein said distribution device further comprises a separate feed distributor comprising at least one feed inlet and a plurality of feed outlets and adapted to distribute a feed fluid from said at least one feed inlet to said plurality of feed outlets, wherein said feed distributor is separated from fluid connection to said recycle fluid within the distribution device.

The described distribution device may in some cases be located in the top of the catalytic reactor, entirely above the catalytic bed or beds of the reactor, ensuring distribution of recycle fluid and ensuring safe (with regard to potential overheating) distribution of feed over the catalytic bed below the distribution device. In an example of the disclosure, the described distribution device is mounted between two catalyst beds in the reactor. In this case, the distribution device further comprises a collection tray which is adapted

to collect fluid coming down from the catalytic bed above the distribution device. To enable the collected fluid to pass to the distribution tray, the collection tray comprises at least one recycle fluid inlet. In an example, the collection tray may comprise an at least partially fluid tight plate which is mounted level above the distribution tray and the recycle fluid inlet may be at least one hole or drain in the collection tray.

In an example of the disclosure, the mentioned plurality of feed outlets is adapted to distribute the feed fluid below the mentioned collection tray. Accordingly, the feed fluid is distributed below the zone where the recycle fluid is collected, thus, the discharged feed fluid is not in contact with the recycle feed in a zone where the recycle feed is collected with the temperature/time exposure this would entail. The plurality of feed outlets is in a further example adapted to distribute the feed over at least 90% of the entire cross section of catalytic bed located below the distribution device and said plurality of feed outlets. The ability for the feed outlets to distribute the feed evenly over as large a part of the below catalytic bed is dependent on several factors such as number and pattern of feed outlets, outlet design, feed pressure, distance from feed outlets to the below bed, cross-sectional area of the bed to mention some. Regarding the present disclosure comprising the at least one distribution device, especially the number and pattern of the feed outlets are to be considered. It is to be understood that the plurality of feed outlets may also distribute the feed to almost 100% of the entire cross section of the catalytic bed located below the distribution device or to a lesser part of the cross-sectional area, such as more than 80% or more than 60% of the entire cross section of the catalytic bed below the distribution device.

To fluidly connect the at least one feed inlet to the plurality of feed outlets, the feed distributor may in a further example comprise feed channels. It is to be understood that fluidly connect means that a connection is provided which allows fluid (a gas, liquid or vapour) to flow from the at least one feed inlet to the plurality of feed outlets. In a further example of the disclosure, the distribution device comprises cooling channels which are adapted to protect the feed fluid from ambient temperatures. This may be accomplished in different ways; the cooling channels may be in any kind of contact with the feed channels which allows for a cooling fluid to cool down the feed. In an example of the disclosure, each feed channel is at least partly surrounded by at least one of the cooling channels. This may be the case in a smaller or larger part of the length

of the feed channels, as well as in intermittent parts of the length of the feed channels. Also, each feed outlet may be at least partly surrounded by a cooling channel or a cooling channel outlet, thereby even cooling the feed when it exits the feed outlet(s), which has the effect that the feed is protected against degrading temperatures and fouling.

In an example of the disclosure, the feed distributor further comprises a feed phase separator to separate a liquid feed phase from a gas feed phase of the feed fluid. The feed phase separator may be located between said at least one feed inlet and the plurality of feed outlets, and the separated gas feed phase may have a fluid connection from a feed gas phase outlet of the feed phase separator to at least one of the cooling channels, thus, the gas phase of the feed may be utilized to cool and/or protect the liquid phase of the feed while the liquid phase of the feed is flowing in at least a part of the feed distributor, as the liquid phase of the feed which has the risk of fouling. (It is to be understood that a separate cooling fluid, for instance a cooling gas may also be added from outside the reactor to cool and/or protect the liquid phase of the feed.) In a further example of the disclosure, the feed distributor also comprises a cooling fluid inlet adapted to provide a cooling fluid to the feed distributor, as it may be necessary or beneficial to ensure cooling of the feed also by an extra cooling fluid, which may flow in the above described cooling means.

In an example of the disclosure, the at least one recycle fluid inlet may comprise both a recycle gas inlet and separate from this a recycle liquid inlet if beneficial. In an example of the disclosure, the recycle gas may by-pass the distribution device via a recycle gas mixer and a recycle gas by-pass channel, while the recycle liquid flowing from the recycle liquid inlet in a further example flows through a recycle liquid mixer and a recycle liquid distributor which is adapted to distribute the recycle liquid from the collection tray and the recycle liquid mixer onto the distribution tray, from where it is to be further distributed onto the below catalytic bed. This may in an example be accomplished by means of some further recycle liquid fine distributors which are

in liquid connection to the recycle liquid mixer and are adapted to distribute the recycle liquid from the distribution tray onto the catalytic bed below as described above. These recycle liquid fine distributors may in an example be of a chimney type as can be further seen and described in the drawings.

In an example of the disclosure, the recycle gas by-pass channel will by-pass the recycle gas from the collection tray to exit below the distribution tray, thus, the recycle gas will not contribute notably to a temperature increase within the distribution device. In another example of the disclosure, the recycle gas by-pass channel is adapted to by-pass the recycle gas from the collection tray to the distribution tray and further to said recycle liquid fine distributors, where it may have the effect of enhancing the liquid fine distribution.

In an example of the disclosure a method of distributing a process fluid and a feed fluid inside a multi-bed catalytic reactor with a cylindrical shape is provided. The process fluid comprises a gas phase and a liquid phase and possibly also a vapour phase. The feed fluid is mixed with the process fluid between an upper catalyst bed and a lower catalyst bed of the multi-bed catalytic reactor, or entirely above a catalyst bed of the multi-bed catalytic reactor. The method of distributing is performed in a distribution device comprising a collection tray with at least one recycle fluid inlet; a distribution tray adapted to distribute recycle fluid and located below the collection tray; and a separate feed distributor comprising at least one feed inlet and a plurality of feed outlets. A specific feature of the disclosure is that the feed distributor is separated from fluid connection to the recycle fluid within the distribution device, which protects the feed fluid from the higher temperatures of the recycle fluid that may cause fouling of the feed fluid. The feed fluid may even be further protected or cooled when flowing inside the distribution device. The method comprises the steps of constricting the cross-sectional area of the flow of recycle fluid from the upper catalyst bed the at least one recycle fluid inlet by means of the collection tray. The collection tray may be a metal plate which blocks the entire cross-sectional area of the catalytic reactor except for flow through the at least one recycle fluid

inlet which allows flow of recycle fluid through that specific point(s) of the collection tray. In a further step of the method, the recycle fluid flows within the distribution device or is partly by-passing the distribution device, as also discussed above. At least a part of the recycle fluid is then distributed onto the distribution tray and from the distribution tray over the catalytic bed located below the distribution device. As for the feed fluid, a step of the method is to provide the feed fluid from at least one feed inlet to the feed distributor. The feed distributor is separated from fluid connection to the recycle fluid within the distribution device, which protects the feed fluid from the higher temperatures of the recycle fluid within the distribution device, which could otherwise lead to fouling of the feed as also discussed in the above. In a further step of the method, the feed fluid is then distributed from the at least one feed inlet to a plurality of feed outlets, while still keeping the feed fluid separated from fluid connection to the recycle fluid.

In another aspect, the present disclosure provides a method of distributing a process fluid comprising a gas phase and a liquid phase and possibly a vapour phase, and a feed fluid inside a multi-bed catalytic reactor with a cylindrical shape between an upper catalyst bed and a lower catalyst bed thereof, said method is performed in a distribution device comprising a collection tray comprising at least one recycle fluid inlet; a distribution tray adapted to distribute recycle fluid and located below said collection tray; a separate feed distributor comprising at least one feed inlet and a plurality of feed outlets, wherein said feed distributor is separated from fluid connection to said recycle fluid within the distribution device, the method comprising the steps of,

- constricting the cross-sectional area of the flow of recycle fluid from the upper catalyst bed to the at least one recycle fluid inlet by means of the collection tray
- flowing the recycle fluid within or partly by-passing the distribution device,
- distributing at least a part of the recycle fluid on to the distribution tray and evenly distributing at least a part of the recycle fluid from the

distribution tray over the catalytic bed located below the distribution device,

- providing a feed fluid from a feed inlet to the feed distributor separated from fluid connection to the recycle fluid within the distribution device,
- distributing the feed fluid from the feed inlet to a plurality of feed outlets while keeping the feed fluid separated from fluid connection to the recycle fluid.

In a further example of the disclosure, the distributing process of fluid further comprises feed channels which connects the at least one feed inlet with the plurality of feed outlets and further comprises a step of cooling the feed fluid by a cooling fluid provided by cooling channels which are at least partly surrounding the feed channels in at least a part of their length. Separating the recycle fluid and the feed fluid within the distribution device is protecting the feed fluid from the higher temperatures of the recycle fluid, but this active cooling of the feed fluid within the distribution device even further contributes to the temperature protection of the feed fluid within the distribution device and hence contributes to the avoidance of feed fouling.

In a further example of the disclosure, the multi-bed catalytic reactor with a cylindrical shape comprising at least one distribution device according the above described is used for renewables hydroprocessing, where the risk of fouling is particularly present.

In another aspect, the present disclosure provides use of a multi-bed catalytic reactor with a cylindrical shape comprising at least one distribution device as described herein for renewables hydroprocessing.