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(54) Title: SYSTEMS AND PROCESSES FOR THE PRODUCTION OF OLEFIN PRODUCTS FROM HYDROCARBON FEEDSTOCKS

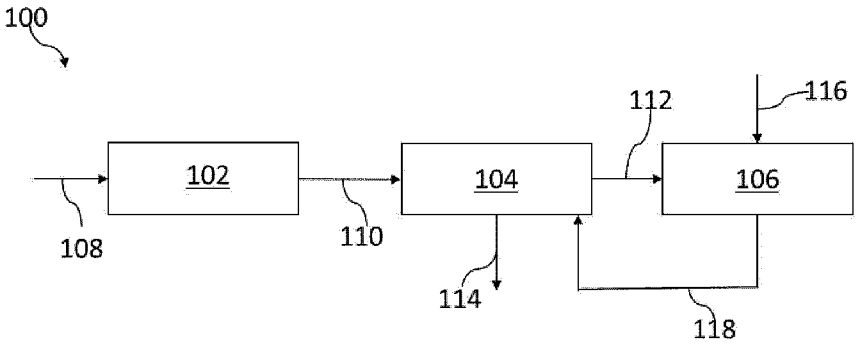

FIG. 1

(57) Abstract: A system and method for production of olefin products from a hydrocarbon feedstock is disclosed. The system can include a mixed feed steam cracking unit coupled to an ethane steam cracking unit where the mixed feed steam cracking unit produces olefins and ethane. The ethane can be further processed in the ethane steam cracking unit to produce ethylene and C2+ hydrocarbons. The C2+ hydrocarbons can be recycled to the mixed feed steam cracking unit.

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SYSTEMS AND PROCESSES FOR THE PRODUCTION OF OLEFIN PRODUCTS FROM HYDROCARBON FEEDSTOCKS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] None.

BACKGROUND OF THE INVENTION

A. Field of the Invention

[0002] The invention generally concerns systems and methods for producing olefin products from a hydrocarbon feedstock. A system can include a mixed feed steam cracking unit coupled to an ethane steam cracking unit where the mixed feed steam cracking unit produces olefins and ethane. The ethane can be further processed in the ethane steam cracking unit to produce ethylene and C2+ hydrocarbons. The C2+ hydrocarbons can be recycled to the mixed feed steam cracking unit.

B. Description of Related Art

[0003] Olefins (*e.g.,* ethylene), are basic building blocks for a variety of commercially valuable polymers. Naturally occurring sources of olefins do not exist in commercial quantities. Therefore, polymer producers rely on methods for converting the more abundant lower alkanes into olefins. The method of choice for today's commercial scale producers is steam cracking, a highly endothermic process where steam-diluted alkanes are subjected briefly to a temperature of at least 800 °C. The fuel demand to produce the required temperatures and the need for equipment that can withstand that temperature add significantly to the overall cost. Also, the high temperature promotes the formation of coke which accumulates within the system, resulting in the need for costly periodic reactor shut-down for maintenance and coke removal.

[0004] Processes and systems to produce olefins from crude oil have been described. For example International Patent Application No. WO 2017/133975 to Ward *et al.*, describes an integrated process to convert crude oil into petrochemical products that includes crude oil distillation, hydrocracking and steam cracking to produce petroleum products. Some processes use a Mixed Feed Cracker (MFC). A MFC can handle from light hydrocarbons such as ethane,

propane, and butane through naphtha up to heavy liquid feedstocks such as gas oils and hydrocracker residues to produce gasoline and a majority of petrochemical industry products. A MFC process can be operated depending on the optimized downstream value chain between the oil or gas availability as feedstock and the market prices in high added value hydrocarbon products. However, mixed feed steam cracker suffer in that they do no convert all material to olefins. Optimal performance of cracking units occurs when fed with compatible feeds. In most steam cracking units, a dedicated furnace is usually required for optimal ethane cracking. This results in different types and sizes of furnaces. Steam cracking can result in the slow deposition of coke, a form of carbon, on the reactor walls. Decoking requires the furnace to be isolated from the process and then a flow of steam or a steam/air mixture is passed through the furnace coils. This converts the hard solid carbon layer to carbon monoxide and carbon dioxide. Once this reaction is complete, the furnace is returned to service. Due to the amount of coking that occurs in the MRC when ethane is cracked, the MRC generally requires at least two compatible furnaces for the cracking of ethane, which can compromise the size of the furnaces in the MRC and make the process less efficient and more cost intensive.

[0005] Overall, while the technologies of producing olefins, namely ethylene, exist, they can be energy inefficient and expensive.

SUMMARY OF THE INVENTION

[0006] A discovery has been made that provides a solution to at least one of the problems associated with production of olefinic products, namely ethylene. In one aspect, the discovery can include a system that provides an ethane cracking unit downstream of a mixed feed cracking unit. Ethane is diverted from the mixed feed cracking unit and provided to the ethane cracking unit. This set-up can reduce costs associated with upgrading the cracker feeds due to reducing the amount of energy needed to process ethane in the mixed feed steam cracking unit. Also, this setup up allows an increase in the amount of liquid hydrocarbons that can be fed to the mixed feed steam cracking unit.

[0007] In one aspect of the present invention, systems and processes to produce olefin products are described. One system can include a mixed feed steam cracking unit capable of producing an olefin product stream and an ethane (C2) product stream, an ethane steam cracking unit capable of

producing a C2+ stream, and a first conduit coupled to the mixed feed steam cracking unit and the ethane steam cracking unit, and a second conduit coupled to the ethane steam cracking unit and the mixed feed stream cracking unit. The first conduit can be capable of receiving the C2 product stream from the mixed feed steam cracking unit and providing the C2 product stream to the ethane steam cracking unit. The second conduit can be capable of receiving the C2+ stream from the ethane steam cracking unit and providing at least a portion of (e.g., 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, or 95 wt. % or more or any range therein) or all of the C2+ stream to the mixed feed stream cracking unit. The first and second conduits can each directly couple the mixed feed steam cracking unit to the ethane steam cracker. The system can also include a feed conduit coupled to the mixed feed steam cracking unit. In some aspects, the system can include an ethane feed conduit coupled to the ethane steam cracking unit. The ethane feed conduit can be configured to provide additional ethane to the ethane steam cracking unit. In a preferred aspect, the ethane cracking unit is not comprised in the mixed feed steam cracking unit. The C2+ stream can include propane, propylene, butane, butylene, pentane, pentylene, and/or C6+ products. In some aspects, the C2+ stream can also include ethane and/or ethylene.

[0008] Processes to produce olefins are also described. In one aspect, a process can include step (a) where in a mixed feed steam cracking unit, a mixed hydrocarbon feed stream is subjected to conditions sufficient to produce olefin products and ethane (C2) hydrocarbons. Non-limiting examples of the mixed hydrocarbon feed stream can include naphtha, gas oil, middle distillate, or a combination thereof. The conditions in step (a) can include a temperature and pressure such that a majority of ethane present is not cracked. For example, the conditions in step (a) can include a temperature of 600 °C to 770 °C and/or a pressure of 0.2 MPa to 0.3 MPa In step (b), the C2 hydrocarbons can be separated from the olefin products to produce a C2 hydrocarbon stream and an olefin products stream. In step (c), the C2 hydrocarbon stream can be subjected to an ethane steam cracking unit under conditions sufficient to produce a C2+ hydrocarbons stream. Ethylene can be produced in addition to the C2+ hydrocarbons stream. The ethylene can be stored, transported or provided to other processing units. The conditions in step (c) can include a temperature of 775 °C to 860 °C and/or a pressure of 0.2 MPa to 0.3 MPa In step (d) the C2+ hydrocarbons stream can be subjected to the mixed feed steam cracking unit. In some aspects, a second ethane feed stream can be provided to the ethane steam cracking unit.

[0009] Other embodiments of the invention are discussed throughout this application. Any embodiment discussed with respect to one aspect of the invention applies to other aspects of the invention as well and vice versa. Each embodiment described herein is understood to be embodiments of the invention that are applicable to other aspects of the invention. It is contemplated that any embodiment or aspect discussed herein can be combined with other embodiments or aspects discussed herein and/or implemented with respect to any method or composition of the invention, and vice versa. Furthermore, compositions of the invention can be used to achieve methods of the invention.

[0010] The following includes definitions of various terms and phrases used throughout this specification.

[0011] The term "C# hydrocarbons", wherein "#" is a positive integer, is meant to describe all hydrocarbons having # carbon atoms. Moreover, the term "C#+ hydrocarbons" is meant to describe all hydrocarbon molecules having # or more carbon atoms. Accordingly, the term "C2+ hydrocarbons" is meant to describe a mixture of hydrocarbons having 2 or more carbon atoms. The term "C2+ alkanes" accordingly relates to alkanes having 2 or more carbon atoms.

[0012] "Cracking" refers to a process involving decomposition and molecular recombination of organic compounds to produce a greater number of molecules than were initially present. In cracking, a series of reactions take place accompanied by a transfer of hydrogen atoms between molecules. For example, naphtha may undergo a thermal cracking reaction to form ethene and hydrogen.

[0013] "Hydrocarbons" are generally defined as molecules formed primarily by carbon and hydrogen atoms. Hydrocarbons may also include other elements such as, but not limited to, halogens, metallic elements, nitrogen, oxygen, and/or sulfur. Hydrocarbon fluids may include, entrain, or be entrained in non-hydrocarbon fluids such as hydrogen, nitrogen, carbon monoxide, carbon dioxide, hydrogen sulfide, water, and/or ammonia.

[0014] The terms "about" or "approximately" are defined as being close to as understood by one of ordinary skill in the art. In one non-limiting embodiment, the terms are defined to be within 10%, preferably within 5%, more preferably within 1%, and most preferably within 0.5%.

[0015] The terms "wt.%", "vol.%", or "mol.%" refers to a weight percentage of a component, a volume percentage of a component, or molar percentage of a component, respectively, based on the total weight, the total volume of material, or total moles, that includes the component. In a non-limiting example, 10 grams of component in 100 grams of the material is 10 wt.% of component.

[0016] The term "substantially" and its variations are defined to include ranges within 10%, within 5%, within 1%, or within 0.5%.

[0017] The terms "inhibiting" or "reducing" or "preventing" or "avoiding" or any variation of these terms, when used in the claims and/or the specification includes any measurable decrease or complete inhibition to achieve a desired result.

[0018] The term "effective," as that term is used in the specification and/or claims, means adequate to accomplish a desired, expected, or intended result.

[0019] The use of the words "a" or "an" when used in conjunction with any of the terms "comprising," "including," "containing," or "having" in the claims, or the specification, may mean "one," but it is also consistent with the meaning of "one or more," "at least one," and "one or more than one."

[0020] The words "comprising" (and any form of comprising, such as "comprise" and "comprises"), "having" (and any form of having, such as "have" and "has"), "including" (and any form of including, such as "includes" and "include") or "containing" (and any form of containing, such as "contains" and "contain") are inclusive or open-ended and do not exclude additional, unrecited elements or method steps.

[0021] The systems and processes of the present invention can "comprise," "consist essentially of," or "consist of" particular ingredients, components, compositions, *etc.* disclosed throughout the specification. With respect to the transitional phrase "consisting essentially of," in one non-limiting aspect, a basic and novel characteristic of the systems and methods of the present invention are their abilities to produce olefin products (e.g., ethylene) in a cost and energy efficient manner by having an ethane steam cracker unit capable of receiving ethane from a mixed feed steam

cracker unit and feeding the C2+ products produced by the ethane steam cracker unit to the mixed feed steam cracker unit.

[0022] Other objects, features and advantages of the present invention will become apparent from the following figures, detailed description, and examples. It should be understood, however, that the figures, detailed description, and examples, while indicating specific embodiments of the invention, are given by way of illustration only and are not meant to be limiting. Additionally, it is contemplated that changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description. In further embodiments, features from specific embodiments may be combined with features from other embodiments. For example, features from one embodiment may be combined with features from any of the other embodiments. In further embodiments, additional features may be added to the specific embodiments described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0023] Advantages of the present invention may become apparent to those skilled in the art with the benefit of the following detailed description and upon reference to the accompanying drawings.

[0024] **FIG. 1** illustrates an embodiment of a system to produce olefin products from a hydrocarbon feed provided to a mixed hydrocarbon feed steam cracking unit.

[0025] While the invention is susceptible to various modifications and alternative forms, specific embodiments thereof are shown by way of example in the drawings. The drawings may not be to scale.

DETAILED DESCRIPTION OF THE INVENTION

[0026] A discovery has been made that provides a solution to at least one of the problems associated with steam cracking a mixed hydrocarbon feed. In one aspect, the mixed hydrocarbon feed can be fed to a mixed hydrocarbon steam cracking unit to produce petroleum products and ethane. The ethane can be provided to an independent ethane cracking unit to produce ethylene and/or a C2+ hydrocarbons stream, which can be recycled to the mixed hydrocarbon steam

cracking unit. An advantage of this set-up is that the mixed hydrocarbon steam cracking unit can be operated at optimal conditions for C2+ cracking while the ethane steam cracking unit can be operated at optimal conditions to crack ethane. These and other non-limiting aspects of the present invention are discussed in further detail in the following sections with reference to the Figure.

[0027] Referring to FIG. 1, system 100 for producing olefin products is described. System 100 can include a feed preparation unit 102, a mixed feed steam cracking unit 104, and an ethane steam cracking unit 106. Crude oil 108 enters feed separation 102. Crude oil can be the petroleum extracted from geologic formations in its unrefined form. The term crude oil can also include petroleum that has been subjected to water-oil separations and/or gas-oil separation and/or desalting and/or stabilization. Non-limiting examples of crude oil include Arabian Heavy, Arabian Light, other Gulf crudes, Brent, North Sea crudes, North and West African crudes, Indonesian, Chinese crudes, West Texas crude, and mixtures thereof, but also shale oil, tar sands, gas condensates and bio-based oils. The crude oil used as feed to the process of the present invention preferably is conventional petroleum having an API gravity of more than 20° API as measured by the ASTM D287 standard. In one aspect, the crude oil used in the process of the present invention is a light crude oil having an API gravity of more than 30° API. In another aspect, the crude oil used in the process of the present invention can include Arabian Light Crude Oil. Arabian Light Crude Oil typically has an API gravity of between 32-36° API and a sulfur content of between 1.5-4.5 wt. %.

[0028] In feed preparation unit, the crude oil can be separated into different crude oil fractions based on a difference in boiling point. For example, the crude oil can be distilled using a fractionating column, or a combination of more than one fractionation column, that is used to separate crude oil into fractions by fractional distillation. The resulting crude oil can be processed in an atmospheric distillation unit to separate gas oil and lighter fractions from higher boiling components to produce a mixed hydrocarbon feed 110. Mixed hydrocarbon feed can include hydrocarbons having a boiling point above 560 °C. Non-limiting examples of various distillate hydrocarbon feeds having a boiling point above 560 °C include vacuum gas oil, middle distillate, naphtha, kerosene, liquid petroleum gas, or a blend thereof.

[0029] Mixed hydrocarbon feed 110 can exit feed treatment unit 102 and enter mixed feed cracking unit 104. In mixed feed cracking unit 104, the mixed feed is subjected to steam cracking at a temperature of 600 °C to 770 °C (*e.g.*, 600 °C, 625 °C, 650 °C, 675 °C, 700 °C, 725 °C, 950 °C, 770 °C, or any value or range there between) and/or a pressure of 0.2 MPa to 0.3 MPa (*e.g.*, 0.2 MPa, 0.21 MPa, 0.22 MPa, 0.23 MPa, 0.24 MPa, 0.25 MPa, 0.26 MPa, 0.27 MPa, 0.28 MPa, 0.30 MPa, or any value or range there between). At such a temperature and pressure the ethane may not be cracked. In a steam cracking process, the saturated hydrocarbons are broken down into smaller, often unsaturated, hydrocarbons such as ethylene and propylene by diluting the mixed hydrocarbon feed with steam and heating the mixture in a furnace in the absence presence of oxygen. The steam cracking reaction can have a residence times of 50-1000 milliseconds. Mixed steam cracking unit can have a fractionation unit (not shown) or a gas fractionation unit (not shown) capable of separating ethane from the olefin product stream. Such fractionation units are well known in the art. Ethane stream 112 can exit mixed hydrocarbon feed steam cracking unit 104, and enter ethane steam cracking unit 106. Olefin product stream 114 can exit mixed feed steam cracking unit 104 and be stored, transported or used in other processing units. In some aspects, additional ethane stream 116 can enter ethane steam cracking unit 106. The ethane stream can include other gaseous compounds such as propane and butane. In ethane steam cracking unit 106, gaseous ethane can be diluted with steam and heated to a temperature of 775 °C to 860 °C (*e.g.*, 775 °C, 800 °C, 825 °C, 850 °C, 860 °C, or any value or range there between) and/or a pressure of 0.2 MPa to 0.3 MPa (*e.g.*, 0.2 MPa, 0.21 MPa, 0.22 MPa, 0.23 MPa, 0.24 MPa, 0.25 MPa, 0.26 MPa, 0.27 MPa, 0.28 MPa, 0.30 MPa, or any value or range there between) in one or more furnaces to produce ethylene and/or C2+ hydrocarbons. C2+ hydrocarbons stream 118 can exit ethane steam cracking unit 106 and enter mixed feed steam cracker 104 to be further processed. In some embodiments, C2+ hydrocarbon stream 118 is not recycled to mixed feed steam cracking unit 104.

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[0030] Although embodiments of the present application and their advantages have been described in detail, it should be understood that various changes, substitutions and alterations can be made herein without departing from the spirit and scope of the embodiments as defined by the appended claims. Moreover, the scope of the present application is not intended to be limited to

the particular embodiments of the process, machine, manufacture, composition of matter, means, methods and steps described in the specification. As one of ordinary skill in the art will readily appreciate from the above disclosure, processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed that perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein can be utilized. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

CLAIMS

1. A system for the production of olefins, the system comprising:

a mixed feed steam cracking unit capable of producing an olefin product stream and an ethane (C2) product stream;

an ethane steam cracking unit capable of producing a C2+ stream; and

a first conduit coupled to the mixed feed steam cracking unit and the ethane steam cracking unit, the first conduit capable of receiving the C2 product stream from the mixed feed steam cracking unit and providing the C2 product stream to the ethane steam cracking unit;

a second conduit coupled to the ethane steam cracking unit and the mixed feed stream cracking unit, the second conduit capable of receiving the C2+ stream from the ethane steam cracking unit and providing the C2+ stream to the mixed feed stream cracking unit.

2. The system of claim 1, wherein the first and second conduits each directly couple the mixed feed steam cracking unit to the ethane steam cracker.

3. The system of any one of claims 1 to 2, further comprising a feed conduit coupled to the mixed feed steam cracking unit.

4. The system of any one of claims 1 to 3, further comprising an ethane feed conduit coupled to the ethane steam cracking unit, wherein the ethane feed conduit is configured to provide additional ethane to the ethane steam cracking unit.

5. The system of any one of claims 1 to 4, wherein the ethane cracking unit is not comprised in the mixed feed steam cracking unit.

6. A process for the production of olefins, the process comprising:

(a) in a mixed feed steam cracking unit, subjecting a mixed hydrocarbon feed stream to conditions sufficient to produce olefin products and ethane (C2) hydrocarbons;

(b) separating the C2 hydrocarbons from the olefin products to produce a C2 hydrocarbon stream and an olefin products stream;

(c) subjecting the C2 hydrocarbon stream to an ethane steam cracking unit under conditions sufficient to produce a C2+ hydrocarbons stream; and

(d) subjecting the C2+ hydrocarbons stream to the mixed feed steam cracking unit.

7. The process of claim 6, further comprising providing a second ethane feed stream to the ethane steam cracking unit.

8. The process of any one of claims 6 to 7, wherein the conditions in step (a) comprises a temperature and pressure such that a majority of ethane present is not cracked.

9. The process of any one of claims 6 to 8, wherein the conditions in step (a) comprise a temperature of 600 °C to 770 °C.

10. The process of any one of claims 6 to 9, wherein the conditions in step (a) comprise a pressure of 0.2 MPa to 0.3 MPa.

11. The process of any one of claims 6 to 10, wherein the mixed hydrocarbon feed stream comprises naphtha, gas oil, or a combination thereof.

12. The process of any one of claims 6 to 11, wherein the condition in step (c) comprise a temperature of 775 °C to 860 °C.

13. The process of any one of claims 6 to 12, wherein the conditions in step (c) comprise a pressure of 0.2 MPa to 0.3 MPa.

14. The process of any one of claims 6 to 13, further comprising producing ethylene from cracking of the C2 hydrocarbon stream.

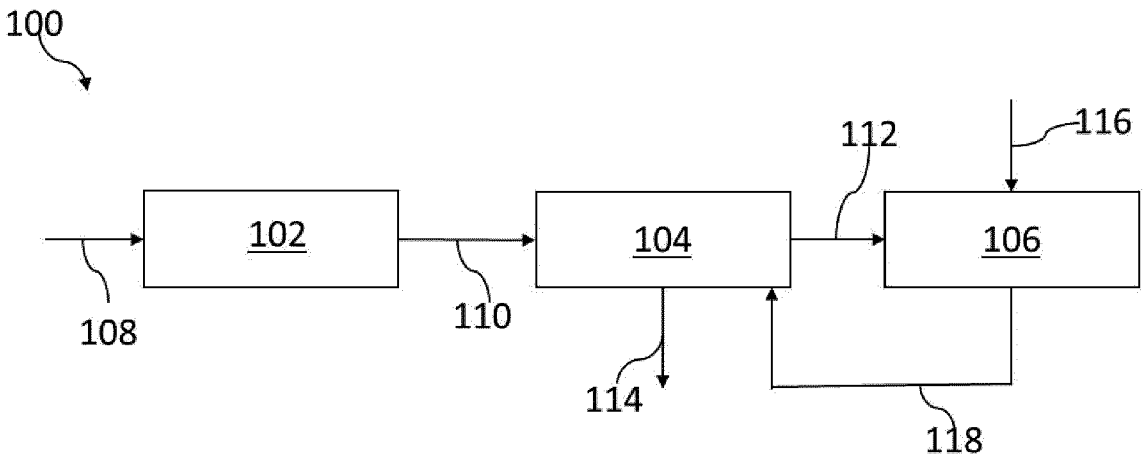

FIG. 1

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2023/068779

A. CLASSIFICATION OF SUBJECT MATTER
INV. C10G9/36 C10G51/02
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
C10G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 9 670 418 B2 (LINDE AG [DE]) 6 June 2017 (2017-06-06) claims 1,11,15; figure 5	1-14
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X	US 2019/177626 A1 (RAMAMURTHY KRISHNA KUMAR [IN] ET AL) 13 June 2019 (2019-06-13) paragraph [0100]; claim 1; figure 4	1-14

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
29 September 2023	10/10/2023

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Deurinck, Patricia

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
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