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(54) Title: THERMOCHEMICAL CONVERSION METHODS, AND REACTOR SYSTEMS FOR THERMOCHEMICAL CONVERSION

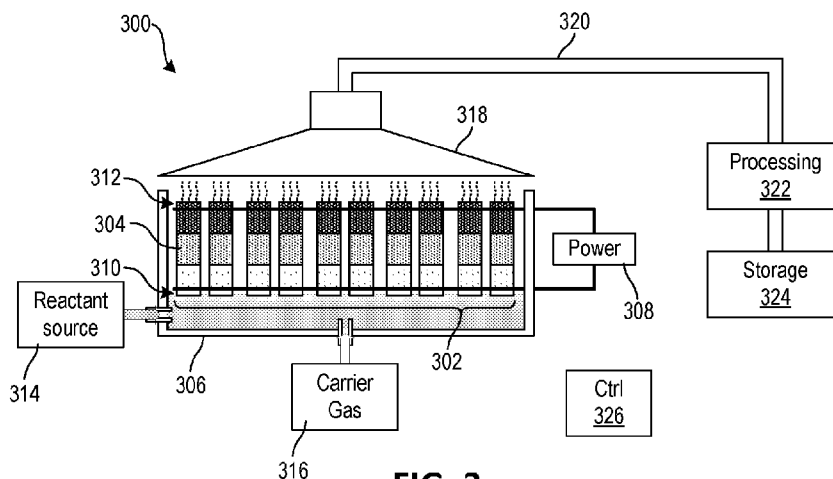


FIG. 3

(57) Abstract: An organic polymer can be converted to one or more lower molecular weight products by subjecting to one or more heating cycles in a porous reactor. The reactant can be provided to an inlet end of the reactor, and the products can be provided from an outlet end of the reactor. A first reactor portion at the inlet end of the reactor can have a pore size or porosity greater than that of a second reactor portion at an outlet end of the reactor. In some embodiments, the different pore sizes or porosities of the reactor portions can modulate mass transport and/or heat transfer behavior of intermediates to select for particular products at the outlet end with high yield.



DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT,
LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE,
SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN,
GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

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27 March 2025 (27.03.2025)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 24/33986

A. CLASSIFICATION OF SUBJECT MATTER
 IPC - INV. B01J 6/00, B01J 15/00, C01B 3/26 (2024.01)
 ADD. B01J 19/00 (2024.01)

CPC - INV. B01J 6/008, B01J 15/005, C01B 3/26

ADD. B01J 19/0013

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)
 See Search History document

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
 See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2023/0144856 A1 (University of Maryland, College Park) 11 May 2023 (11.05.2023) Abstract, para [0009], [0065]-[0071], [0073]-[0075], [0079]-[0080], [0082], [0179]-[0180], [0182], Figure 1A; Figure 1B; Figure 2.	1, 10-22, 28, 30 ----- 2-9, 23-27, 29, 31-32
Y	US 6,666,909 B1 (TeGrotenhuis et al.) 23 December 2003 (23.12.2003) Abstract, col 5 In 52-65; Claim 30; Figure 1.	2-9
Y	Ajibola, et al. "Comparative Study of the Chemical Compositions of Liquid Fuel from Thermal Cracking of Low and High-Density Polyethylene Plastic Waste." IOP Conference Series: Materials Science and Engineering. Vol. 413. No. 1. IOP Publishing, 1 September 2018. Abstract.	23-25, 29, 31-32
Y	US 2012/0310023 A1 (Huang et al.) 6 December 2012 (06.12.2012) Abstract, para [0061], [0068].	26-27 8
Y	US 8,277,743 B1 (Ramberg et al.) 2 October 2012 (02.10.2012) Abstract, col 9 In 5-33; Figure 7.	1-32
A	WO 2023/059622 A1 (University of Maryland, College Park et al.) 13 April 2023 (13.04.2023) Entire Document.	1-32
A	US 5,344,553 A (Shih) 6 September 1994 (06.09.1994) Entire Document.	1-32

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	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"D" document cited by the applicant in the international application	"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
"E" earlier application or patent but published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 9 October 2024	Date of mailing of the international search report OCT 31 2024
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Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-8300	Authorized officer Kari Rodriguez Telephone No. PCT Helpdesk: 571-272-4300
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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 24/33986

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

- 1. Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

- 2. Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

- 3. Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:
(See Supplemental Page)

- 1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
- 2. As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
- 3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
- 4. No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-32

Remark on Protest

- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.

Box III Lack of Unity of Invention:

This application contains the following inventions or groups of inventions which are not so linked as to form a single general inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I: Claims 1-32, directed to a method comprising converting a reactant in a porous reactor.

Group II: Claims 33-58, directed to a system comprising a porous reactor.

Group III: Claims 59-60, directed to a system or method comprising a surface coated with a reactant.

The group of inventions listed above do not relate to a single general inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Special Technical Features:

Group I requires the special technical feature of a method comprising: converting a reactant to one or more products by subjecting to one or more heating cycles in a porous reactor; where the reactant is a polymer comprising carbon, not required by groups II-III.

Group II requires the special technical feature of a one or more porous reactors, each reactor having first and second reactor portions; and each porous reactor is configured to convert a reactant, not required by groups I or III.

Group III requires the special technical feature of a system or method comprising: a reactor having one or more surfaces coated with a reactant, the reactant being a thermoset plastic or biomass; loading a reactant onto one or more surfaces of a reactor; subjecting the reactor to heating at a first temperature such that the loaded reactant forms a reactant coating on the one or more surfaces; after the subjecting to heating at the first temperature, converting at least part of the reactant coating to one or more products by subjecting to one or more heating cycles, the one or more heating cycles comprising a peak temperature greater than the first temperature, not required by groups I-II.

Common Technical Features:

Groups I-III share the technical feature of a system or method comprising: converting a reactant to one or more products by subjecting to one or more heating cycles in a porous reactor, the reactant being provided to an inlet end of the reactor, the one or more products being provided from an outlet end of the reactor, a first reactor portion at the inlet end of the reactor having a first pore size or porosity, a second reactor portion at the outlet end of the reactor having a second pore size or porosity, the inlet and outlet ends being separated from each other along an axial direction of the reactor, wherein the second pore size or porosity is less than the first pore size or porosity; and at least some of the one or more products have a molecular weight less than a molecular weight of the reactant.

These shared technical features, however, do not provide a contribution over the prior art, as being anticipated by US 2023/0144856 A1 to University of Maryland College Park (hereinafter Maryland). Maryland teaches a system or method comprising: converting a reactant to one or more products by subjecting to one or more heating cycles in a porous reactor, the reactant being provided to an inlet end of the reactor, the one or more products being provided from an outlet end of the reactor, a first reactor portion at the inlet end of the reactor having a first pore size or porosity, a second reactor portion at the outlet end of the reactor having a second pore size or porosity, the inlet and outlet ends being separated from each other along an axial direction of the reactor, wherein the second pore size or porosity is less than the first pore size or porosity (Figure 1A, 112 and 104 and 106 and 118; and Abstract, One or more reactants are flowed into thermal contact with a heating element in a reactor for a first time period. During a first part of a heating cycle, the one or more reactants are provided with a first temperature by heating with the heating element, such that one or more thermochemical reactions is initiated; and para [0066], FIG. 1A illustrates a generalized thermochemical reaction system 100 according to one or more embodiments of the disclosed subject matter. The reaction system 100 can have a reactor 102, a porous heating element 104, and a control system 108; and para [0068], In some embodiments, the reactor 102 is constructed as a flow-through chamber, with a single inlet 110 for gaseous reactants 112 and/or carrier gas 114 flows, and at least one outlet 116 for gaseous products 118; and para [0073], In some embodiments, the reactor 102 can optionally include a separator 106. For example, the separator 106 can be constructed to receive a flow of products and unreacted reactants from the heating element 104 and to isolate the products from the reactants; and para [0070], The heating element 104 can have a porosity... the heating element 104 can have a pore size of about 1 μm ; and para [0074], the separator 106 is a passive separation mechanism, for example, by being constructed as a size-selective filter membrane... the pore size of the separator filter membrane can be microporous... e.g... 0.3 nm; Note that with reference to Figure 1A, the porous reactor is interpreted as the combination of stages 104 and 106. Porous heating element 104 defines an inlet end of the reactor and a first reactor portion, which has a pore size of about 1 μm . Separator 106 defines an outlet end of the reactor and a second reactor portion, which has a pore size of about 0.3nm, thus teaching "wherein the second pore size or porosity is less than the first pore size or porosity"); and at least some of the one or more products have a molecular weight less than a molecular weight of the reactant (Figure 1A; and para [0080], For example, when the reactants 112 include hydrogen... H₂... and nitrogen... N₂... the reactants can undergo a synthesis reaction to generate products 118 such as ammonia... NH₃; Note that the reactant is interpreted as N₂, and the one or more products are interpreted as NH₃. It is reasonably understood that that molecular weight of N₂ is about 28.02 g/mol, and the molecular weight of NH₃ is about 17.03 g/mol, so therefore this teaches "at least some of the one or more products have a molecular weight less than a molecular weight of the reactant").

As the technical features were known in the art, this cannot be considered a special technical feature that would otherwise unify the groups.

Groups I-III therefore lack unity under PCT Rule 13 because they do not share a same or corresponding special technical feature.