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(81) **Designated States** (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

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[Continued on next page]

(54) **Title:** REACTOR WITH IMPROVED RESISTANCE TO FOULING

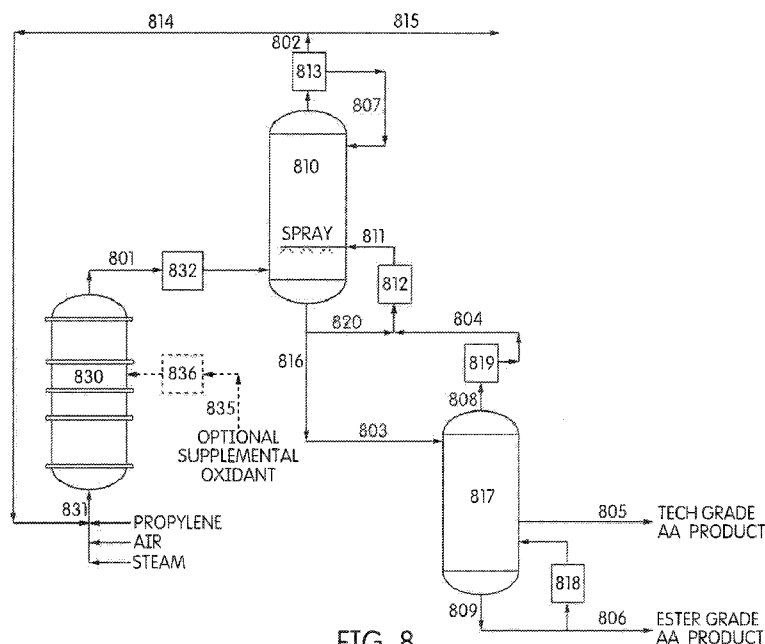


FIG. 8

(57) **Abstract:** The present disclosure relates to a single shell open interstage reactor ("SSOI"). The SSOI comprises a first reaction stage, an interstage heat exchanger, an open interstage region, and a second reaction stage. The SSOI may be configured for upflow or downflow operation. Further, the open interstage region of the SSOI may comprise a supplemental oxidant feed. When the open interstage region comprises a supplemental oxidant feed, the SSOI may further comprise a supplemental oxidant mixing assembly. Processes for producing acrylic acid through the oxidation of propylene are also disclosed.



— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US13/55689

A. CLASSIFICATION OF SUBJECT MATTER

IPC(8) - B01J 8/06; C07C 45/28 (2014.01)

USPC - 422/638, 652, 659

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)

IPC(8): B01J 8/04, 8/06; C07C 45/28 (2014.01)

USPC: 422/105, 600, 630, 631, 638, 641, 644, 646, 652, 659; 562/545

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)

MicroPatent (US-G, US-A, EP-A, EP-B, WO, JP-bib, DE-C,B, DE-A, DE-T, DE-U, GB-A, FR-A); Google Scholar; ProQuest; IP.com; multistage, reactor, catalyst, tubes, heat exchange, shell, oxidizing, acrylic acid, interstage, open

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2008/0021242 A1 (TANIMOTO, M et al.) 24 January 2008; figures 5-6; paragraphs [0011], [0014], [0026]-[0030], [0037]-[0038], [0046]-[0057], [0067], [0070], [0084], [0094]	1-117
Y	US 4,518,574 A (OSMAN, RM et al.) 21 May 1985; figure 5; column 8, lines 4-51; column 9, lines 21-64; column 18, lines 17-37; column 19, lines 9-31; column 24, lines 25-42	1-54, 74-117
Y	US 4,873,368 A (KADOWAKI, K et al.) 10 October 1989; column 9, lines 20-23; column 10, lines 49-56; column 12, lines 40-52	16-17, 41, 48-50, 55-73, 80
Y	US 6,384,274 B1 (ELDER, JE et al.) 07 May 2002; figures 2-3; column 7, lines 28-39; column 9, lines 1-10	3
Y	US 2006/0099131 A1 (SINGH, SP et al.) 11 May 2006; figure 1; paragraph [0039], [0047]	23-24, 51-52, 67
Y	US 2010/0015017 A1 (HA, KS et al.) 21 January 2010; paragraph [0069]	27-28
Y	US 2009/0253934 A1 (HO, F et al.) 08 October 2009; figures 1, 5; paragraphs [0009], [0012], [0017]-[0019], [0021], [0032], [0047], [0051]-[0052], [0063], [0073], [0076]	93, 113-117



Further documents are listed in the continuation of Box C.



* Special categories of cited documents:

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

"E" earlier application or patent but published on or after the international filing date

"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)

"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

"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

"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

"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

"&"

document member of the same patent family

Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US13/55689

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:

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 examined, the appropriate additional examination fees must be paid.

Group I: Claims 1-33 are directed toward an upflow single shell open interstage reactor.

Group II: Claims 34-54 are directed toward a single shell open interstage stage reactor.

Group III: Claims 55-73 are directed toward another single shell open interstage stage reactor.

Group IV: Claims 74-90 are directed toward an additional single shell open interstage stage reactor.

-Please 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.:

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.

-***-Continued from Box III Observations where unity of invention is lacking -***-

Group V: Claims 91-117 are directed toward a method of producing acrylic acid from propylene.

The inventions listed as Groups I-V 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: the special technical features of Group I include wherein said interstage heat exchanger is positioned between said first reaction stage and said open interstage region, and wherein said reactor is configured for upflow operation, which is not present in Groups II-V; the special technical features of Group II include an integrated interstage heat exchanger comprising a plurality of tubes coaxially continuous with the plurality of reaction tubes of the first reaction stage, which are not present in Groups I and III-V; the special technical features of Group III include wherein the reaction tubes of the second reaction stage have a diameter greater than a diameter of the reaction tubes of said first reaction stage, which are not present in Groups I-II and IV-V; the special technical features of Group IV wherein the reaction tubes of the second reaction stage have a diameter greater than 22.3 mm (0.878 in), which are not present in Groups I-III and V; the special technical features of Group V include a mixed metal oxide catalyst, which is not present in Groups I-IV.

The common technical features of Groups I-V are a single shell open interstage reactor; a first reaction stage; an integrated interstage heat exchanger; an open interstage region; a second reaction stage; a first shell-and-tube reaction stage comprising a plurality of reaction tubes; a second shell-and-tube reaction stage comprising a plurality of reaction tubes; a first and second catalyst; oxidizing propylene to produce acrolein; oxidizing acrolein to produce acrylic acid; and an upflow through a reactor.

These common technical features are disclosed by US 2008/0021242 A1 to Tanimoto, et al. (hereinafter 'Tanimoto'). Tanimoto discloses a single shell open interstage reactor (a fixed bed shell-and-tube reaction apparatus comprising a single reactor; figure 6; paragraph [0011]); a first reaction stage (in figures, 1 is a reaction tube, wherein reaction tubes in the first reaction zone are filled with a suitable catalyst; paragraphs [0026], [0029]); an integrated interstage heat exchanger (gas temperature control section; figure 6; paragraph [0026]); an open interstage region (between the two reaction zones a space is provided; figure 6; paragraph [0014]); a second reaction stage (in figures, 1 is a reaction tube, wherein reaction tubes in the second reaction zone are filled with a suitable catalyst; paragraphs [0026], [0029]); a first shell-and-tube reaction stage comprising a plurality of reaction tubes (in figures, 1 is a reaction tube, wherein reaction tubes in the first reaction zone are filled with a suitable catalyst; paragraphs [0026], [0029]); a second shell-and-tube reaction stage comprising a plurality of reaction tubes (in figures, 1 is a reaction tube, wherein reaction tubes in the second reaction zone are filled with a suitable catalyst; paragraphs [0026], [0029]); a first and second catalyst (in figures, 1 is a reaction tube, wherein reaction tubes in the reaction zones are filled with a suitable catalysts; paragraphs [0026], [0029]); oxidizing propylene to produce acrolein (reaction tubes in the first reaction zone are filled with a suitable catalyst to convert propylene into acrolein; paragraph [0029]); oxidizing acrolein to produce acrylic acid (second reaction zone are filled with a suitable catalyst to convert acrolein into acrylic acid; paragraph [0029]); and an upflow through a reactor (the starting gas for the reaction is fed from above the reactor, but the flowing direction of the starting gas is not particularly limited, but can be suitably selected depending on the circumstances; paragraph [0028]).

Since the common technical features are previously disclosed by Tanimoto, these common features are not special and so Groups I-V lack unity.