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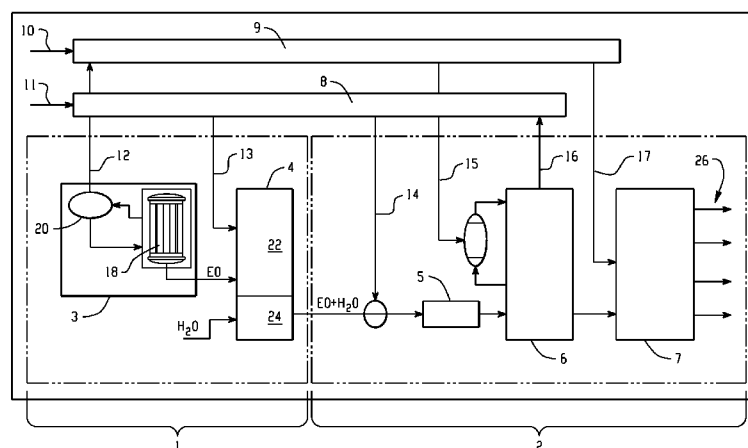


FIG. 1

(57) Abstract: The present disclosures and inventions relate to methods and apparatus for the conversion of ethylene and oxygen to ethylene oxide, conversion of the ethylene oxide to ethylene glycols, and improving the efficiency of such processes. In some aspects, the inventions relate to methods for the production of ethylene glycols, wherein the method comprises: providing a front end section and a back end section, wherein the front end section comprises the production of ethylene oxide and the back end section comprises the production of ethylene glycol; converting ethylene and oxygen to ethylene oxide, wherein the conversion uses a high selectivity catalyst in the front end section; converting ethylene oxide to ethylene glycol in the back end section; and transferring steam generated in the front end section to the back end section and using the steam to heat the back end section.

METHOD AND APPARATUS FOR IMPROVED EFFICIENCY IN AN ETHYLENE OXIDE/ETHYLENE GLYCOL PROCESS

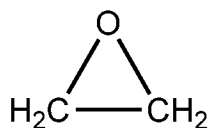
TECHNICAL FIELD

[0001] The present disclosure and invention relates to methods and apparatuses for the conversion of ethylene and oxygen to ethylene oxide, conversion of the ethylene oxide to ethylene glycols, and improving the efficiency of such processes.

BACKGROUND

[0002] Ethylene glycol, HO-CH₂-CH₂-OH, (often also called “EG” or “MEG”) is liquid at room conditions, and is used as a large volume commodity chemical in making many downstream chemicals and in many industrial applications throughout the world. MEG is used as a monomer for the production of polymers such as polyethylene terephthalate polyesters (PET), as automotive anti-freeze, and as a solvent. Diethylene glycol, HO-CH₂-CH₂-O-CH₂-CH₂-OH, (“DEG”) a dimeric ether of ethylene glycol, is also used in many industrial applications as a monomer or solvent, as is triethylene glycol, HO-CH₂-CH₂-O-CH₂-CH₂-O-CH₂-CH₂-OH, (“TEG”). Even higher oligomers and/or polyethers of ethylene glycol (such as tetraethylene glycol) also have industrial applications. Thus, ethylene glycol and its oligomeric/polymeric ethers, which can be collectively termed the “ethylene glycols” have many industrial applications, and worldwide markets and demands for these various ethylene glycols are large and competitive.

[0003] The ethylene glycols are made and supplied by several global manufacturers, typically by processes which share some basic features, but differ significantly in details. Ethylene gas, CH₂=CH₂, is produced in oil refineries worldwide, and oxidized with air over supported silver catalysts to produce ethylene oxide:



ethylene oxide
"EO"

[0004] The ethylene oxide, after synthesis from ethylene and oxygen, and purification, is hydrolyzed with excess water, often in the presence of acidic catalysts, to produce aqueous mixtures of MEG, DEG, TEG, and higher ether oligomers and/or polymers of EG, which are then separated from the excess water, and then separated from each other by various refining

systems that often involve vacuum distillations. Nevertheless, there can be considerable variation in the proportions of water, MEG, DEG, TEG etc., depending on the conditions and catalysts employed for the hydration of the EO, and the separations and purifications of the ethylene glycols from each other, to give high purity polymer grade materials, can be complex, energy intensive, and expensive.

[0005] Hence, there remains a continuing need in the art for improved methods and apparatuses for making the various ethylene glycols, and optimizing those processes and apparatus so as to increase the efficiency of such processes and apparatus, and decrease the consumption of raw materials and energy required to make the ethylene glycols. The objects of the various inventions described and claimed herein are to provide such improved methods and apparatus.

SUMMARY

[0006] Some aspects of the various inventions described and/or claimed herein relate to methods for the production of ethylene glycols, wherein the method comprises:

- a) providing a front end section and a back end section, wherein the front end section comprises the production of ethylene oxide and the back end section comprises the production of ethylene glycol;
- b) converting ethylene and oxygen to ethylene oxide in the front end section, wherein the conversion uses a high selectivity catalyst in the front end section;
- c) converting ethylene oxide to ethylene glycol in the back end section; and
- d) transferring steam generated in the front end section to the back end section and using the transferred steam to heat at least a portion of the back end section.

[0007] Related aspects of the inventions described herein relate to an apparatus for the production of ethylene glycols, wherein the apparatus comprises:

- a. a front end section comprising a catalytic reactor, wherein the catalytic reactor comprises a high selectivity catalyst, wherein the high selectivity catalyst converts ethylene and oxygen to ethylene oxide;
- b. a first conduit, wherein the first conduit transfers the ethylene oxide to a back end section;

- c. a back end section comprising a glycol reactor, wherein the glycol reactor converts the ethylene oxide with water to ethylene glycol;
- d. a second conduit to transfer steam generated in the front end section to the back end section.

[0008] Related aspects of the inventions described herein relate to an improved method for the efficient production of ethylene glycols, wherein the method comprises:

- a. providing an apparatus comprising a front end section and a back end section, wherein
 - i. the front end section comprises an ethylene oxidation reactor and ethylene oxidation catalyst for converting ethylene and oxygen to ethylene oxide, and an EO Purification Subsystem for the crude ethylene oxide produced; and
 - ii. the back end section comprises a glycol reactor for converting water /ethylene oxide mixture to a mixture of ethylene glycol and oligomeric or polymeric ethylene glycol ethers, and a dehydration system for separating water/steam from the ethylene glycol and oligomeric or polymeric ethylene glycol ethers;
- b. reacting ethylene and oxygen in the front end section, and producing water/ethylene oxide mixtures; and
- c. reacting the water/ethylene oxide mixtures in the back end section to produce ethylene glycol and oligomeric or polymeric ethylene glycol ethers;
- d. wherein the heat of reaction between ethylene and oxygen produces steam, and transferring the steam produced to the back end section to supply process heat to the back end section;

wherein the water/ethylene oxide molar ratio of the water/ethylene oxide mixture fed to the glycol reactor is greater than 19, and wherein steam produced by the dehydration system is transferred to the front end section, to provide process heat to the front end section.

[0009] Such methods and apparatuses can provide for the unexpectedly improved and highly efficient production and purification of ethylene glycols, and allow the use of highly efficient and improved catalysts so as to improve process rates and selectivities to ethylene oxide and/or ethylene glycols, and decrease the undesirable conversion of ethylene to CO₂. Such methods and apparatuses can also decrease the need for large excesses of water during

EO hydrolysis, which saves energy inputs (which are often internally and/or externally supplied in the form of steam) in the processes for dehydrating and purifying the product ethylene glycols. Such methods and apparatuses can also provide for increases in capacity for producing the product ethylene glycols.

[0010] Additional advantages will be set forth in part in the description which follows, and in part will be obvious from the description when read in light of the knowledge of those of ordinary skill in the art, or may be learned by practice of the various aspects of the inventions described below. The advantages described below will be realized and attained by means of the methods, apparatus, and combinations thereof particularly pointed out in the appended claims. It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not intended to be restrictive of the claims, unless otherwise clearly indicated herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The accompanying drawings, which are attached heretobelow, which are incorporated in and constitute a part of this specification, illustrate several aspects described below. Like numbers represent the same elements throughout the figures.

[0012] Figure 1 shows a schematic process flow diagram for one aspect of the methods and apparatuses described herein, and exemplifying and illustrating multiple features of the apparatuses and methods described herein.

DETAILED DESCRIPTION

[0013] Disclosed herein are compositions, methods, apparatus, and various aspects thereof that can be used for the invention and, can be used in conjunction with, the disclosed methods and apparatus. It is to be understood that when combinations, subsets, interactions, groups, etc. of these methods and apparatuses are disclosed, that while specific reference to each individual and collective combinations and permutation of these methods and apparatus may not be explicitly disclosed, each of the individual and collective combinations and permutation is hereby contemplated and described as if it had been explicitly described. For example, if a catalyst component is disclosed and discussed, and a number of alternative solid state forms of that component are discussed, each and every combination and permutation of the catalyst component and the solid state forms that are possible are specifically contemplated unless specifically indicated to the contrary. This concept applies to all aspects of this disclosure including, but not limited to, steps in the methods and components of the apparatus. Thus, if there are a variety of additional steps that can be performed it is understood that each

of these additional steps can be performed in any order or simultaneously with any specific aspect or combination of aspects of the disclosed methods, and that each such combination is hereby contemplated and should be considered disclosed.

Methods and Apparatuses for the Production of Ethylene Glycols

[0014] Generally described herein, and more specifically described here are apparatuses and methods for producing ethylene glycols, including ethylene glycol itself (“EG” or “MEG”), as well as diethylene glycol (“DEG”), triethylene glycol (“TEG”), and higher molecular weight oligomeric and/or polymeric di-hydroxy ethers comprising repeating units derived from the condensation of ethylene oxide and/or ethylene glycol.

[0015] Some aspects of the various inventions described herein relate to methods for the production of ethylene glycols, wherein the method comprises:

- a) providing a front end section and a back end section, wherein the front end section comprises the production of ethylene oxide and the back end section comprises the production of ethylene glycol;
- b) converting ethylene and oxygen to ethylene oxide in the front end section, wherein the conversion uses a high selectivity catalyst in the front end section;
- c) converting ethylene oxide to ethylene glycol in the back end section; and
- d) transferring steam generated in the front end section to the back end section and using the transferred steam to heat at least a portion of the back end section.

[0016] Related aspects of the inventions described herein relate to an apparatus for the production of ethylene glycols, wherein the apparatus comprises:

- a. a front end section comprising a catalytic reactor, wherein the catalytic reactor comprises a high selectivity catalyst, wherein the high selectivity catalyst converts ethylene and oxygen to ethylene oxide;
- b. a first conduit, wherein the first conduit transfers the ethylene oxide to a back end section;
- c. a back end section comprising a glycol reactor, wherein the glycol reactor converts the ethylene oxide with water to ethylene glycol; and
- d. a second conduit to transfer steam generated in the front end section to the back end section.

[0017] The descriptions of both the methods and the apparatuses generally referenced above comprise and/or relate to at least two broadly and somewhat arbitrarily defined “sections” of the apparatuses suitable for carrying out the methods described herein, the front

end section of the apparatuses being related to the conversion / oxidation of ethylene, with oxygen and/or air as oxidant, to form and/or then purify ethylene oxide.

[0018] Reference to Figure 1 attached hereto, which is intended to be directed to only a single exemplary subset of the many combinations of aspects of the inventions disclosed and described herein, is nevertheless likely to be generally useful to the reader for understanding the general statements above, and many more specific verbal descriptions below, without any intent that Figure 1 or any references to Figure 1 in this written description is intended to or should limit any particular claims directed to differing aspects of the many aspects of the inventions described herein.

The Front End Section

[0019] The front end section of the apparatus can comprise various equipment and/or various devices designed and connected to enable the oxidation of ethylene with oxygen or air (and optional additional carrier or diluent gases) to form crude ethylene oxide, and then separate the ethylene oxide from the crude reaction product stream, and then purify the ethylene oxide.

[0020] The portions of the equipment and/or apparatus contained in the front end section that are necessary to produce the crude reactor product (i.e., crude ethylene oxide) can be termed the "EO Reaction System." In one aspect, the EO Reaction System comprises an Ethylene Oxidation Reactor that comprises a catalyst for the oxidation of ethylene to ethylene oxide. Many types of Ethylene Oxidation Reactors and Ethylene Oxidation Catalysts can be employed. However, in many aspects of the inventions, the oxidation of ethylene with oxygen and/or air is carried out in the vapor phase, with the vapors in contact with a solid Ethylene Oxidation Catalyst. In one aspect, the Ethylene Oxidation Reactor has inlets for ethylene, oxygen or air, and/or mixtures thereof. In another aspect, the Ethylene Oxidation Reactor also can comprise an outlet for the crude reaction product gases, which can comprise the crude ethylene oxide; the un-reacted gases, such as ethylene and oxygen or air; or other gases, such as CO₂, water, and smaller amounts of various other byproducts (such as low molecular weight carboxylic acids and aldehydes), as will be further discussed below.

[0021] In one aspect, any Ethylene Oxidation Catalyst can potentially be employed in the methods and apparatuses described herein, but it is known and often commercially practiced in the art to employ ethylene oxidation catalysts that comprise silver dispersed on a solid support (for example alumina or silica) along with other promoter materials such as alkali metals, see for example US Patent No. 4,368,144. The supported ethylene oxide catalysts can

also be formed or shaped into particles, tablets, and various other desirable shapes, see for example US Patent Publication 2008/0015393. US Patent No. 4,368,144 and US Patent Publication 2008/0015393 are incorporated by reference in their entirety herein for their teachings regarding the compositions, preparation, and desirable conditions for the use of Ethylene Oxidation Catalysts for producing ethylene oxide.

[0022] In one aspect, different types of Ethylene Oxidation Reactors and Ethylene Oxidation Catalysts can be employed, so long as the reactors and catalysts can maintain the elevated reaction temperature, while simultaneously removing and capturing the heat generated by the oxidation of ethylene (i.e., the heat of reaction, ΔH , to be further discussed herein). In one aspect, the system shown in Figure 1 can be a suitable reactor design, wherein the catalyst is packed into the tubes, and the reacting gases passed down the tubes, while a temperature control/coolant liquid is circulated around the tubes, so as to maintain a suitable temperature in the tubes, while simultaneously removing the heat of reaction.

[0023] In many aspects of the methods and apparatuses, water and/or aqueous solutions can be employed as a coolant liquid, and the heated water or aqueous solutions are then circulated to external boiler device which can be considered part of the EO Reaction System, where the heated water vaporizes into steam. The steam generated (which can be high pressure steam, e.g., steam at a pressure greater than or equal to 15 bar (1.5 MegaPascals MPa)), can be transferred out of the EO Reaction System to provide heat to other devices in the apparatus, including the various equipment and devices in Back End Section of the apparatus. For example, high pressure steam can generally be referred to as steam greater than or equal to 15 bar (1.5 MPa), for example, greater than or equal to 20 bar (2.0 MPa), for example, greater than or equal to 30 bar (3.0 MPa), for example, greater than or equal to 35 bar (3.5 MPa), and for example, greater than or equal to 40 bar (4.0 MPa).

[0024] Existing Ethylene Oxidation Catalysts can however vary significantly in both activity (ethylene conversion rate) and selectivity for the production of ethylene oxide. The major chemical reactions and side reactions that can occur over modern ethylene oxidation catalysts are shown below, along with the associated heat of reaction (ΔH) for that reaction.

1. $\text{CH}_2=\text{CH}_2 + \frac{1}{2} \text{O}_2 \rightarrow \text{EO}$ $\Delta H = -138 \text{ kJ/k-mole}$ (desirable)
2. $\text{CH}_2=\text{CH}_2 + 3 \text{O}_2 \rightarrow 2 \text{CO}_2 + 2\text{H}_2\text{O}$ $\Delta H = -1609 \text{ kJ/k-mole}$ (undesirable)
3. $\text{EO} + \frac{5}{2} \text{O}_2 \rightarrow 2 \text{CO}_2 + 2 \text{H}_2\text{O}$ $\Delta H = -1471 \text{ kJ/k-mole}$ (undesirable)

[0025] In the practice of the inventions described herein, significant amounts of all

three reactions of equations 1, 2, and 3 can occur. Accordingly, it is desirable to employ a high selectivity ethylene oxidation catalyst, so as to maximize the conversion of ethylene to the desired EO product (Equation 1), and minimize the wasteful side reactions of equations 2 and 3, so as to avoid the conversion of relatively expensive ethylene to undesirable carbon dioxide.

[0026] It should also be noted however that the heat of reaction of the side reactions 2 and 3 are much higher than the heat of reaction for desired reaction 1. Accordingly, the heat of reaction generated from the side reactions of equations 2 and 3 is very substantial in practice, and must be removed from the ethylene oxidation reactor. In the apparatuses and methods described herein, the heat of reaction is recovered and converted into the form of steam, often high pressure steam, and the steam generated from the ethylene oxidation reaction can be employed to provide process heat required to operate other parts of the methods and apparatuses, such as the Back End Section. Applicant has observed that in practice, a 1% improvement in EO selectivity obtained by employing a higher selectivity ethylene oxidation catalyst reduces the amount of high pressure steam produced in the Front End Section by about 4%, or more.

[0027] The Front End Section of the apparatus described herein also typically comprises an "EO Purification Subsystem" for separating and/or purifying EO away from the crude reaction gases transferred from the ethylene oxidation reactor. Many variations and/or combinations of devices and arrangements thereof can be employed in the EO Purification Subsystem (e.g., Distillation Column, EO-Reabsorber Column, etc.) of the Front End Section. Nevertheless, many combinations of devices in the EO Purification Subsystem typically comprise one or more CO₂ Strippers, for removing CO₂ from the reaction gases and removing them from the apparatus and process.

[0028] The EO Purification Subsystems also often comprise an EO Stripper or EO absorber, for separating and/or condensing crude EO away from the reaction gases. EO absorbers typically work by contacting a vapor stream comprising EO vapor with liquid water, so as to form aqueous solutions comprising dissolved EO, and then separate the aqueous EO solutions from the other reaction gases. The EO Purification Subsystem also often comprises one or more distillation columns, for dehydrating/separating the EO from the water, and/or then further separating the EO from other heavy or light organic byproducts, and/or finally purifying the EO to produce ethylene oxide (as either a vapor or a liquid) at a purity sufficient for its transfer to and/or utilization in the Back End Section.

[0029] Many of the gases and the EO that are processed in the EO Purification

Subsystem are volatile, and gas-liquid phase separations are employed in many of the devices in the EO Purification Subsystems. The phase transitions can occur at relatively low temperatures, so that any heat that must be supplied to the EO Purification Subsystem can often be supplied by low pressure steam, (i.e., steam at pressures less than 15 bar (1.5 MPa)).

[0030] In one aspect, the low pressure steam can be greater than or equal to 0.1 bar to less than 15 bar (0.01 MPa to less than 1.5 MPa). For example, the low pressure steam can be 0.5 bar less than 15 bar (0.05 MPa to less than 1.5 MPa), for example, 2.5 bar to less than 15 bar (0.25 MPa to less than 1.5 MPa), for example, 4 bar to less than 15 bar (0.4 MPa to less than 1.5 MPa), for example, 6 bar to 10 bar (0.6 MPa to 1.0 MPa), for example, 10 bar to 14 bar (1.0 MPa to 1.4 MPa).

[0031] In some optional aspects of the apparatuses and methods described herein, purified EO vapor output from the EO Purification Subsystem can be passed into an EO Absorber Column (e.g., an EO-Reabsorber Column), which typically percolates EO vapor upwards through a column which also comprises a downward countercurrent flow of liquid water, so that EO is absorbed (in controllable proportions and/or water/EO ratios) into the downward flowing water, to provide a liquid stream from the bottom of the EO absorber column comprising pure water and dissolved EO in controllable water/EO ratios, which can be suitable for transfer to and/or utilization in the Back End Section of the apparatus.

The Back End Section

[0032] The Back End Section of the apparatus can comprise various combinations of equipment and/or devices designed and connected so as to enable the hydrolysis of ethylene with water, to form crude ethylene glycol (MEG) and higher oligomeric or polymeric ethylene glycol ethers, such as DEG, TEG, and the like, and then separate the ethylene glycols from the crude reaction product stream, and purify the ethylene glycols to provide pure and saleable MEG, DEG, TEG, and the like.

[0033] The equipment and/or apparatuses ordinarily employed in the Back End Section can be subdivided into three subsections, a Glycol Reaction Subsection, a Dehydration Subsection, and a Refining Subsection.

[0034] In one aspect, the Glycol Reaction Subsystem comprises devices and/or equipment necessary to either transfer in or optionally make a new mixture of water and ethylene oxide in a desired water/ethylene oxide ratio, and optionally pre-heat that water/ethylene oxide mixture to a desired reaction temperature, then transfer the water/ethylene oxide mixtures to a Glycol Reactor, which can optionally comprise an ethylene

oxide hydrolysis catalyst. In the Glycol Reactor, the water/ethylene oxide mixtures and optional catalyst are reacted at a temperature and pressure and residence time sufficient to substantially hydrolyze the ethylene oxide, to form a mixture of ethylene glycols.

[0035] Several competing EO hydrolysis reactions occur in the Glycol Reactor, as illustrated in the equations below:



[0036] Such EO hydrolysis reactions are typically performed between about 140-230 °C, and between about 1.5-2.5 MPa (see Li et al., Journal of Catalysis 241(2006) 173-179, incorporated by reference in its entirety herein for its teachings relating to suitable reaction conditions and catalysts for ethylene oxide hydrolysis reactions). The relative rates of these hydrolysis reactions and therefore the relative proportions of MEG, DEG, and TEG, etc. produced vary with a variety of factors, most notably the water/ethylene oxide ratio. Higher molar ratios of water/ethylene oxide tend to favor MEG formation, while lower ratios of water/ethylene oxide tend to favor formation of oligomeric and/or polymeric ethylene glycols such as DEG and TEG. Both the rate and selectivity of MEG production can also be substantially affected by the use of highly active and/or selective ethylene oxide hydrolysis catalysts, which are ordinarily Bronstead and/or Lewis acid catalysts, as disclosed by Li et al., as well as reaction temperature.

[0037] The Glycol Reaction Subsection may comprise one or more Glycol Reactors, either back-mixed or plug flow, which can be arranged in series or in parallel, depending on a combination of factors, circumstances and desired outcomes.

[0038] In one aspect, the water/ethylene oxide molar ratio ranges from 14 to 19.5, including exemplary values of 14.5, 15, 15.5, 16, 16.5, 17, 17.5, 18, 18.5, and 19. The ratio range can be derived from any two of the exemplary values. For example, the water/ethylene oxide ratio can range from 16.5 to 18.5, or can range from 17 to 19.

[0039] An aqueous solution of mixed ethylene glycols from the Glycol Reaction Subsystem is typically transferred to a Dehydration Subsystem, to separate the un-reacted excess water from the mixed ethylene glycols. In many aspects of the methods and apparatuses described herein, the Dehydration Subsystem comprises one or more distillation columns, which remove the excess water vaporization and thereby produce low pressure steam as an upper end product stream of the distillation columns. The much higher boiling ethylene

glycols are produced as a dehydrated liquid bottom stream from the distillation columns. Since molecular weight of water is low, the volume of steam produced is at the top of the distillation columns is large, and the distillation columns must therefore be relatively large and expensive. Moreover, large amounts of heat energy are required by the Dehydration System to vaporize the large quantities of water.

[0040] In many of the methods and apparatuses of the invention, the heat energy input required for the operation of the Dehydration Subsystem is provided by high pressure steam, which can be supplied either externally, or alternatively and partially from internal sources (such as from the EO Reaction System). However, in partial compensation for such usage of high pressure steam, the low pressure steam that is output from the Dehydration Subsystem can be transferred to or recycled to provide process heat to other parts of the apparatuses, such as the Ethylene Oxide Purification system in the Front-End Section, or heat the feed to the Glycol Reactor in the Back-End Section.

[0041] In one aspect, the product stream, which exits the bottom of the Dehydration Subsystem distillation columns, comprises mixtures of the ethylene glycols, and can be transferred to a Refining Subsystem, for separating and purifying the ethylene glycols into the pure components. The Refining Subsystem can comprise one or more distillation columns that separate the ethylene glycols by differences in volatility (nBP of MEG = 197.3 °C, nBP of DEG = 244-245 °C, nBP of TEG = 285 °C, etc.). Although those distillations can be conducted under vacuum, in order to lower the required temperatures, the required heat input is large. High pressure steam can be employed to provide the heat at the required temperatures. The high pressure steam required can be supplied from externally, or recycled at least in part from internal sources, such as high pressure steam generated in the EO Reaction Subsystem in the Front-End Section.

[0042] It is to be noted that the various transfers of steam described above can be accomplished by many combinations of equipment and methods, including those known to those of ordinary skill in the art (such as piping, lines, pressure and flow regulators, etc.). However, it should be noted that unexpected benefits of simplicity, reliability, and economy can be realized if the inputs and outputs of steam from the various sections and devices of the apparatus can be transferred by means of common steam headers within the apparatuses (High Pressure Steam Headers 9 and Low Pressure Steam Header 8), as shown in Figure 1. Outputs of steam from various systems and subsystems within the apparatuses can be transferred into and out of the local common steam headers associated with the apparatuses described herein,

while any additionally required inputs of external high or low pressure steam required for the overall apparatuses and/or methods can be also input to the local common steam headers.

The common local steam headers can be useful to simplify issues of both local and overall steam supply, demand, and control of the apparatus as a whole (i.e. the apparatus is configured to balance the output of steam and an input of steam by balancing the low pressure steam header and the high pressure steam header output of steam and input of steam between the Front End Section 1 and the Back End Section 2).

[0043] Turning now to Figure 1, a method for the production of ethylene glycol is illustrated. As illustrated in Figure 1, the method can include a Front-End Section 1 and a Back-End Section 2. The Front-End Section 1 can include an EO Reaction System 3, an EO Purification Subsystem 4 including a Distillation Column 22 and an EO-Reabsorber Column 24, while the Back End-Section 2 can include a Glycol Reactor 5, a De-hydration System 6, and a Refining System 7. As can be seen from Figure 1, EO feeds from the EO Reaction System 3 into the EO Purification Subsystem 4 along with a feed of Low Pressure Steam 11 from Low Pressure Steam Header 8 via line 13. The Distillation Column 22 for separating and purifying the ethylene glycols into the pure components can include a carbon dioxide (CO₂) stripper, an EO stripper, can conduct EO purification, and can be a CO₂ second stripper.

[0044] From there, the product passes through the EO-Reabsorber Column 24 and along with an input of water (H₂O), exits the EO Purification Subsystem 4 as EO + H₂O and along with the introduction of Low Pressure Steam 11 (e.g., less than 15 bar (1.5 MPa)) via Low Pressure Steam Header 8 via line 14, moves into the Back-End Section 2 into the Glycol Reaction Subsystem 5. In the Glycol Reaction Subsystem 5, the water/ethylene oxide mixtures and optional catalyst are reacted at a temperature and pressure and residence time sufficient to substantially hydrolyze the ethylene oxide, to form a mixture of ethylene glycols. The EO + H₂O passes through the Glycol Reaction Subsystem 5 and into the De-hydration Subsystem 6. More specifically, an aqueous solution of mixed ethylene glycols from the Glycol Reaction Subsystem 5 is transferred to a Dehydration Subsystem 6, to separate the un-reacted excess water from the mixed ethylene glycols. The Dehydration Subsystem 6 can comprise one or more distillation columns, which remove the excess water vaporization and thereby produce low pressure steam 11 as an upper end product stream of the distillation columns. High Pressure Steam 10 is introduced to the De-hydration System 6 through a High-Pressure Steam Header 9 (e.g., greater than or equal to 15 bar (1.5 MPa)) via line 15, while Low Pressure Steam 11 is fed back into Low Pressure Steam Header 8 via line 16. The product then moves

from the De-hydration Subsystem 6 to a Refining System 7 while High Pressure Steam 10 is imported into the Refining Subsystem 7 via line 17 for separating and purifying the ethylene glycols into the pure components. The various end products 26 can be exported from the Refining Subsystem 7, such as MEG, DEG, TEG, and other “Heavies”. Heavies can generally refer to a product having greater than 6 carbon atoms. The Refining Subsystem 7 can comprise one or more distillation columns that separate the ethylene glycols by differences in volatility.

[0045] EO Reaction System 3 can further comprise an Ethylene Oxidation Reactor 18 and a Boiler 20. Catalyst can be packed into tubes of the Ethylene Oxidation Reactor 18, and the reacting gases passed down the tubes, while a temperature control/coolant liquid can be circulated around the tubes, so as to maintain a desired temperature in the tubes, while simultaneously removing the heat of reaction. Boiler 20 can vaporize the heated water into steam. The steam generated (which can be high pressure steam, e.g., steam at a pressure greater than or equal to 15 bar (1.5 MPa)) can be transferred out of the EO Reaction System 3 through line 12 to High-Pressure Steam Header 9.

Apparatus

[0046] In some of many aspects, the inventions described herein relate to an apparatus for the production of ethylene glycols, wherein the apparatus comprises:

- a. A front end section comprising a catalytic reactor, wherein the catalytic reactor comprises a high selectivity catalyst, wherein the high selectivity catalyst converts ethylene and oxygen to ethylene oxide;
- b. A first conduit, wherein the first conduit transfers the ethylene oxide to a back end section;
- c. A back end section comprising a Glycol Reactor, wherein the glycol reactor converts the ethylene oxide with water to ethylene glycol; and
- d. A second conduit to transfer steam generated in the front end section to the back end section.

[0047] The Front End Section and Back End Section of the apparatuses above have already been generally described above. In many aspects of the apparatuses, the catalytic reactor in the Front End Section is an ethylene oxidation reactor as described above, which can also include an ancillary apparatus for removal of the heat of reaction from the Ethylene Oxidation Reactor, and converting that heat of reaction into to an output of steam, which can be and often is high pressure steam. In such aspects of the apparatuses, this steam output from the Front End Section can be transferred and/or recycled to provide process heat elsewhere in

the apparatus, including the Back End Section, which often includes a Dehydration Subsystem and Refining Subsystem, which can utilize such high pressure steam.

[0048] In many aspects of such apparatuses, the apparatuses are also configured to transfer and/or recycle steam generated in the Back End Section to the Front End Section. As discussed above, the Back End Section frequently comprises a Dehydration Subsystem for separating water from the mixture of water and glycols produced in the Glycol Reaction Subsystems, which often include distillation columns that produce an output of steam from the water separated from the ethylene glycols. Steam so generated from the Dehydration Subsystem of the Back End Section can be recycled to provide an output of steam for transfer and/or recycle to the Front End Section, including the devices and/or equipment in the Ethylene Oxide Purification Subsystem of the first section, such as distillation columns often employed in the Dehydration Subsystem and/or Refining Subsystems. In many aspects of the Apparatuses, the steam transferred from the Back End Section to the Front End Section is low pressure steam.

[0049] These intra-apparatus transfers of steam between the front and back sections of the apparatuses described herein can provide for unexpected improvements in energy efficiency and unexpected decreases in overall demand for externally supplied energy and/or steam to the apparatuses and methods as a whole, which unexpectedly provides for both economic and environmental benefits.

[0050] In the situations often encountered in commercial plants, where external steam supplies can be limited, improvements in the utilization of available high or low pressure steam can all have the effect of “de-bottlenecking” such commercial plants, so that their production capacity can unexpectedly be increased without requiring additional external steam inputs.

[0051] Moreover, overall energy input requirement of the apparatuses and methods described herein can be further decreased by configuring the apparatuses to employ a reduced water/ethylene oxide ratio in the Back End Section to convert ethylene oxide to ethylene glycol. If lower water/ethylene oxide ratios are employed in feed to the Glycol Reactors, less water needs to be separated from the ethylene glycol products in the Dehydration Subsystem. Less separation of water in the Dehydration Subsystem requires less input of high pressure steam to the Dehydration Subsystems. Less need for water separation in the Dehydration Subsystem can also debottleneck the Dehydration Subsystems, so that more product ethylene glycols can be processed through the large and expensive distillation columns often employed

in the Dehydration Subsystems. However, lower water/ethylene oxide ratios also results significantly less production of low pressure steam as an output from the Dehydration Subsystems, and some additional low pressure steam may be need to be imported from externally. Nevertheless, since high pressure steam is more expensive and typically less available than low pressure steam, decreases in the water/ethylene oxide ratio can improve all of the overall capacity, energy consumption, and economics of the commercial practice of the methods and apparatuses described herein.

[0052] It should however be recognized that in order to decrease the water/ethylene oxide ratios in practice, devices and equipment designed to prepare the water/ethylene oxide mixtures with controllable and selected water/ethylene oxide ratios must be included in either the Front End Section or Back End Section. Accordingly, in many aspects of the apparatuses described herein, ethylene oxide re-absorbers can be present in either the Front-End Section or Back End Sections of the apparatuses, or connecting the front and Back-End Sections. Such ethylene oxide re-absorbers typically comprise an ethylene oxide inlet and a water inlet, then contact and/or mix the water and ethylene oxide, to produce the water/ethylene oxide mixtures in desired water/ethylene oxide ratios.

Method

[0053] In some of many aspects, the invention described herein relates to methods for the production of ethylene glycols, wherein the method comprises:

- a) providing a front end section and a back end section, wherein the front end section comprises the production of ethylene oxide and the back end section comprises the production of ethylene glycol;
- b) converting ethylene and oxygen to ethylene oxide, wherein the conversion uses a high selectivity catalyst in the front end section;
- c) converting ethylene oxide to ethylene glycols in the back end section; and
- d) transferring steam generated in the front end section to the back end section.

[0054] Many of the various aspects of the Front End Section and Back End Section of the apparatuses provided for use in the methods described above have already been generally described above. Generally the Front End Section is employed by the methods to convert ethylene and oxygen to ethylene oxide. It should be noted, as previously described, that the use of high selectivity ethylene oxidation catalysts in the Front End Section can not only

improve the rate and selectivity of EO production, it decreases the amount of relatively expensive ethylene consumed by side reactions that produce CO₂, and thus provides an environmental benefit. However, as selectivity for EO is improved, the amount of process heat and steam produced in the Front End Section decreases production of steam outputs from the Front End Section, which can possibly result in commercial production bottlenecks. As discussed elsewhere herein, any limitations on steam outputs can be at least partially mitigated or balanced by implementing the steps for intra-apparatus steam transfers described elsewhere herein.

[0055] Generally the Back End Section is employed by the methods to convert ethylene oxide to ethylene glycols. However, as previously described, the production of ethylene oxide in the Front End Section also generates process heat, which is used in the methods described herein to generate an output of steam, typically including high pressure steam, which can be typically transferred to the Back End Section to at least partially provide for the energy and process heat requirements of the Back End Section.

[0056] Furthermore, in many aspects of the methods described herein, steam (typically low pressure steam) is generated in the Back End Section, and can be transferred or recycled to the Front End Section to at least partially provide for the energy and process heat requirements of the Front End Section, including the EO Purification Subsystems. The unexpected benefits of such steam transfers have already been described above in connection with the apparatuses described herein.

[0057] In one aspect, the steam transferred to the back end section can be used to heat the back end section. In a further aspect, the steam transferred to the back section can be used to heat the back end section to produce ethylene glycol. In another aspect, the heating provided by the steam is not the sole source of heat.

[0058] The methods described herein can also comprise a step of utilizing reduced water/ethylene oxide ratio in the Back End Section to hydrolyze ethylene oxide to ethylene glycols. The unexpected benefits of such reduced water ethylene oxide ratios have already been described herein in connection with the apparatuses described herein. As used herein, a reduced water/ethylene oxide molar ratio is a ratio that is less than 20. For example, the water/ethylene oxide ratio can range from 14 to 19.5.

[0059] In many aspects of the methods of the inventions, the methods include a step of distilling the ethylene oxide in the Front End Section and/or EO Purification Subsystem.

[0060] In many aspects of the methods of the inventions, the methods include a step of

dehydrating and then refining the glycols in the Back End Section.

[0061] Additional but related aspects of the inventions described and/or claimed herein relate to improved methods for the efficient production of ethylene glycols, wherein the method comprises:

- a. providing an apparatus comprising a front end section and a back end section, wherein
 - i. the front end section comprises an ethylene oxidation reactor and ethylene oxidation catalyst for converting ethylene and oxygen to ethylene oxide, and an EO Purification Subsystem for the crude ethylene oxide produced; and
 - ii. the back end section comprises a glycol reactor for converting water /ethylene oxide mixture to a mixture of ethylene glycol and oligomeric or polymeric ethylene glycol ethers, and a dehydration system for separating water /steam from the ethylene glycol and oligomeric or polymeric ethylene glycol ethers;
- b. reacting ethylene and oxygen in the front end section, and producing water/ethylene oxide mixtures; and
- c. reacting the water/ethylene oxide mixtures in the back end section to produce ethylene glycol and oligomeric or polymeric ethylene glycol ethers;
- d. wherein the heat of reaction between ethylene and oxygen produces steam, and transferring the steam produced to the back end section to supply process heat to the back end section;

wherein the water/ethylene oxide molar ratio of the water/ethylene oxide mixture fed to the glycol reactor is greater than 19, and

wherein steam produced by the dehydration system is transferred to the front end section, to provide process heat to the front end section.

[0062] Many aspects of such improved methods further comprise utilizing a Glycol Refining Subsystem in the Back End Section for separating the ethylene glycol and oligomeric and/or or polymeric ethylene glycol ethers.

[0063] In many aspects of such improved methods, the steam transferred to the Back End Section is high pressure steam. In many aspects of such improved methods, the steam transferred to the Front End Section is low pressure steam. In many aspects of such improved methods, the high pressure steam externally supplied to the apparatus is decreased by at least

1%, as compared to an otherwise similar process conducted without the improvements. In many aspects of such improved methods, the low pressure steam externally supplied to the apparatus is decreased by at least 1%, as compared to an otherwise similar process conducted without the improvements.

[0064] In many aspects of such improved methods, the water/ethylene oxide ratio is decreased by at least 1 %, as compared to an otherwise similar process conducted without the improvements.

[0065] Many aspects of such improved methods further comprise utilizing a more highly selective catalyst for converting ethylene and oxygen to ethylene oxide, with simultaneously decreased production of CO₂.

[0066] By employing the combinations of improvements recited in the improved methods described above many unexpected advantages can be achieved, such as significantly improved ethylene conversion to desirable ethylene glycol products, decreased production of environmentally undesirable CO₂, increased product capacities, improved energy and steam utilization, or decreases in the need for externally supplied energy or steam can be obtained.

[0067] The methods and apparatus disclosed herein include at least the following Aspects:

[0068] Aspect 1: A method for the production of ethylene glycols, wherein the method comprises:

- a) providing a front end section and a back end section, wherein the front end section comprises the production of ethylene oxide and the back end section comprises the production of ethylene glycol;
- b) converting ethylene and oxygen to ethylene oxide, wherein the conversion uses a high selectivity catalyst in the front end section;
- c). converting ethylene oxide to ethylene glycol in the back end section; and
- d) transferring steam generated in the front end section to the back end section and using the transferred steam to heat at least a portion of the back end section.

[0069] Aspect 2: A method according to aspect 1, wherein the method further comprises transferring steam generated in the back end section to the front end section.

[0070] Aspect 3: A method according to any one of aspects 1 an 2, wherein the method comprises transferring low-pressure steam from the back end section to the front end section; wherein the low pressure steam is a pressure less than 15 bar.

[0071] Aspect 4: A method according to any one of aspects 1-3, wherein the method

comprises transferring high pressure steam from the front end section to the back end section; wherein the high pressure steam is a pressure greater than or equal to 15 bar.

[0072] Aspect 5: A method according to any one of aspects 1-4, wherein the method comprises a water/ethylene oxide molar ratio ranging from 14 to 19 in the back end section to hydrolyze ethylene oxide to ethylene glycols.

[0073] Aspect 6: A method according to any one of aspects 1-5, wherein the front end section further comprises distilling the ethylene oxide.

[0074] Aspect 7: A method according to any one of aspects 1-6, wherein the back end section further comprises dehydrating and then refining the glycols.

[0075] Aspect 8: An apparatus for the production of ethylene glycols, wherein the apparatus comprises:

- a. a front end section comprising a catalytic reactor, wherein the catalytic reactor comprises a high selectivity catalyst, wherein the high selectivity catalyst converts ethylene and oxygen to ethylene oxide;
 - b. a line, wherein the line transfers the ethylene oxide to a back end section;
 - c. a back end section comprising a Glycol Reactor, wherein the Glycol Reactor converts the ethylene oxide with water to ethylene glycol;
- wherein the apparatus is configured to transfer steam generated in the front end section to the back end section.

[0076] Aspect 9: An apparatus for the production of ethylene glycols, wherein the apparatus comprises:

- a. a front end section comprising a catalytic reactor, wherein the catalytic reactor comprises a high selectivity catalyst, wherein the high selectivity catalyst converts ethylene and oxygen to ethylene oxide;
- b. a first conduit, wherein the first conduit transfers the ethylene oxide to a back end section;
- c. a back end section comprising a Glycol Reactor, wherein the Glycol Reactor converts the ethylene oxide with water to ethylene glycol; and
- d. a second conduit to transfer steam generated in the front end section to the back end section.

[0077] Aspect 10: An apparatus according to aspect 8 or aspect 9, wherein the apparatus is configured to transfer steam generated in the back end section to the front end section.

[0078] Aspect 11: An apparatus according to aspect 9, wherein the apparatus is configured to transfer steam generated in the front end section to the back end section.

[0079] Aspect 12: An apparatus according to any one of aspects 8-11, further comprising a 3rd conduit to transfer steam generated in the back end section to the front end section.

[0080] Aspect 13: An apparatus according to any one of aspects 8-12, wherein the front end section further comprises a distillation column.

[0081] Aspect 14: An apparatus according to any one of aspects 8-13, wherein the front end section further comprises an ethylene oxide reabsorber.

[0082] Aspect 15: An apparatus according to any one of aspects 8-14, wherein the back end section further comprises a Dehydration Subsystem.

[0083] Aspect 16: An apparatus according to any one of aspects 8-15, wherein the back end section further comprises a Refining Subsystem.

[0084] Aspect 17: An apparatus according to any one of aspects 8-16, wherein the apparatus is configured to comprise a water/ethylene oxide ratio ranging from 14 to 19 in the back end section to convert ethylene oxide to ethylene glycol.

[0085] Aspect 18: An apparatus according to any one of aspects 8-17, wherein the apparatus is configured to balance the output of steam and an input of steam by balancing the low pressure steam header and the high pressure steam header output of steam and input of steam between the front end section and the back end section.

[0086] Aspect 19: An apparatus according to any one of aspects 8-18, wherein the ethylene oxide reabsorber comprises a water inlet.

[0087] Aspect 20: A method for the efficient production of ethylene glycols, wherein the method comprises:

- a. providing an apparatus comprising a front end section and a back end section, wherein
 - i. the front end section comprises an ethylene oxidation reactor and ethylene oxidation catalyst for converting ethylene and oxygen to ethylene oxide, and an EO Purification Subsystem for the crude ethylene oxide produced; and
 - ii. the back end section comprises a glycol reactor for converting water /ethylene oxide mixture to a mixture of ethylene glycol and oligomeric or polymeric ethylene glycol ethers, and a dehydration system for separating water /steam from the ethylene glycol and oligomeric or polymeric ethylene glycol ethers;
- b. reacting ethylene and oxygen in the front end section, and producing a water/ethylene

oxide mixture; and

c. reacting the water/ethylene oxide mixture in the back end section to produce ethylene glycol and oligomeric or polymeric ethylene glycol ethers;

d. wherein the improvement comprises

i. utilizing the heat of reaction between ethylene and oxygen to produce steam, and transferring the steam produced to the back end section to supply process heat to the back end section;

ii. decreasing the water/ethylene oxide molar ratio of the water/ethylene oxide mixture fed to the glycol reactor,

iii. transferring steam produced by the dehydration system to the front end section, to provide process heat to the front end section.

[0088] Aspect 21: A method for the efficient production of ethylene glycols, wherein the method comprises:

a. providing an apparatus comprising a front end section and a back end section, wherein

i. the front end section comprises an ethylene oxidation reactor and ethylene oxidation catalyst for converting ethylene and oxygen to ethylene oxide, and an EO Purification Subsystem for the crude ethylene oxide produced; and

ii. the back end section comprises a glycol reactor for converting water/ethylene oxide mixture to a mixture of ethylene glycol and oligomeric or polymeric ethylene glycol ethers, and a dehydration system for separating water /steam from the ethylene glycol and oligomeric or polymeric ethylene glycol ethers;

b. reacting ethylene and oxygen in the front end section, and producing a water/ethylene oxide mixture; and

c. reacting the water/ethylene oxide mixture in the back end section to produce ethylene glycol and oligomeric or polymeric ethylene glycol ethers;

d. wherein the heat of reaction between ethylene and oxygen produces steam, and transferring the steam produced to the back end section to supply process heat to the back end section;

wherein the water/ethylene oxide molar ratio of the water/ethylene oxide mixture fed to the glycol reactor is greater than 19, and

wherein steam produced by the dehydration system is transferred to the front end section, to provide process heat to the front end section.

[0089] Aspect 22: The method of aspect 20 or aspect 21, comprising utilizing a more highly selective catalyst for converting ethylene and oxygen to ethylene oxide, with simultaneously decreased production of CO₂.

[0090] Aspect 23: The method of any one of aspects 20-22, wherein the back end section also comprises a Glycol Refining Subsystem for separating the ethylene glycol and oligomeric and/or or polymeric ethylene glycol ethers.

[0091] Aspect 24: The methods of any one of aspects 20-23, wherein the steam transferred to the back end section is high pressure steam.

[0092] Aspect 25: The methods of any one of aspects 20-25, wherein the steam transferred to the front end section is low pressure steam.

[0093] In this specification and in the claims which follow, reference will be made to a number of terms which shall be defined to have the following meanings:

[0094] It must be noted that, as used in the specification and the appended claims, the singular forms “a,” “an” and “the” include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to “an aromatic compound” includes mixtures of aromatic compounds; reference to “a pharmaceutical carrier” includes mixtures of two or more such carriers, and the like.

[0095] “Optional” or “optionally” means that the subsequently described event or circumstance can or cannot occur, and that the description includes instances where the event or circumstance occurs and instances where it does not. For example, the phrase “optionally substituted lower alkyl” means that the lower alkyl group can or cannot be substituted and that the description includes both unsubstituted lower alkyl and lower alkyl where there is substitution.

[0096] Ranges may be expressed herein as from “about” one particular value, and/or to “about” another particular value. When such a range is expressed, another aspect includes from the one particular value and/or to the other particular value. Similarly, when values are expressed as approximations, by use of the antecedent “about,” it will be understood that the particular value forms another aspect. It will be further understood that the endpoints of each of the ranges are significant both in relation to the other endpoint, and independently of the other endpoint.

[0097] References in the specification and concluding claims to parts by weight, of a

particular element or component in a composition or article, denotes the weight relationship between the element or component and any other elements or components in the composition or article for which a part by weight is expressed. Thus, in a compound containing 2 parts by weight of component X and 5 parts by weight component Y, X and Y are present at a weight ratio of 2:5, and are present in such ratio regardless of whether additional components are contained in the compound.

[0098] A weight percent of a component, unless specifically stated to the contrary, is based on the total weight of the formulation or composition in which the component is included.

[0099] It will be apparent to those skilled in the art that various modifications and variations can be made in the present invention without departing from the scope or spirit of the invention. Other aspects of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with a true scope and spirit of the invention being indicated by the following claims.

[00100] The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal languages of the claims.

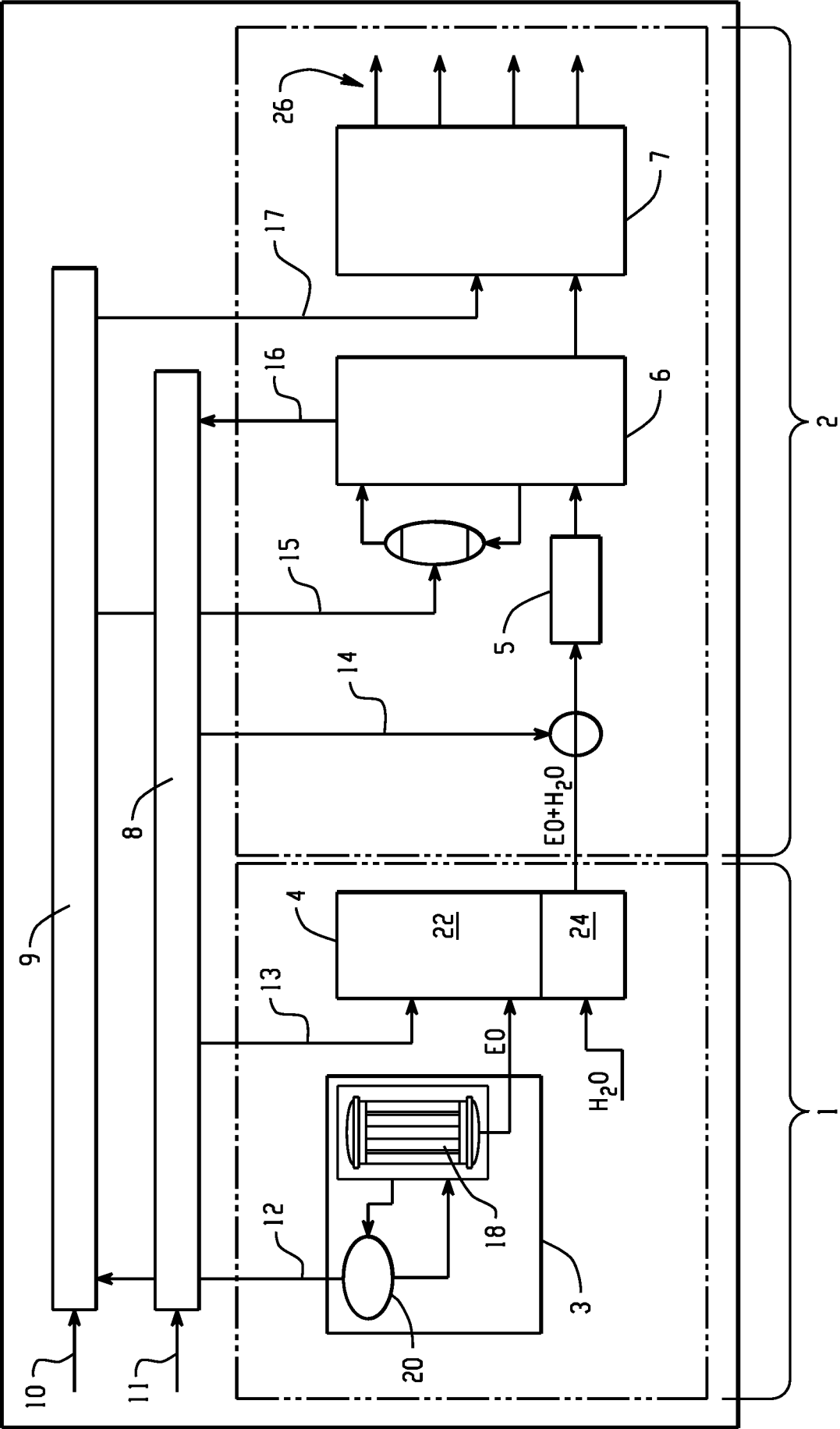
What is claimed is:

1. A method for the production of ethylene glycols, wherein the method comprises:
 - e) providing a front end section and a back end section, wherein the front end section comprises the production of ethylene oxide and the back end section comprises the production of ethylene glycol;
 - f) converting ethylene and oxygen to ethylene oxide in the front end section, wherein the conversion uses a high selectivity catalyst in the front end section;
 - g) converting ethylene oxide to ethylene glycol in the back end section; and
 - h) transferring steam generated in the front end section to the back end section and using the transferred steam to heat at least a portion of the back end section.
2. A method according to claim 1, wherein the method further comprises transferring steam generated in the back end section to the front end section.
3. A method according to any one of claims 1 and 2, wherein the method comprises transferring low-pressure steam from the back end section to the front end section; wherein the low pressure steam is at a pressure lower than 15 bar.
4. A method according to any one of claims 1-3, wherein the method comprises transferring high pressure steam from the front end section to the back end section; wherein the high pressure steam is a pressure greater than or equal to 15 bar.
5. A method according to any one of claims 1-4, wherein the method comprises a water/ethylene oxide molar ratio ranging from 14 to 19 in the back end section to hydrolyze ethylene oxide to ethylene glycols.
6. A method according to any one of claims 1-5, wherein the front end section further comprises distilling the ethylene oxide.
7. A method according to any one of claims 1-6, wherein the back end section further comprises dehydrating and then refining the glycols.
8. An apparatus for the production of ethylene glycols, wherein the apparatus comprises:

- a. a front end section comprising a catalytic reactor, wherein the catalytic reactor comprises a high selectivity catalyst, wherein the high selectivity catalyst converts ethylene and oxygen to ethylene oxide;
 - b. a first conduit, wherein the first conduit transfers the ethylene oxide to a back end section;
 - c. a back end section comprising a Glycol Reactor, wherein the Glycol Reactor converts the ethylene oxide with water to ethylene glycol; and
 - d. a second conduit to transfer steam generated in the front end section to the back end section.
9. An apparatus according to claim 8, further comprising a 3rd conduit to transfer steam generated in the back end section to the front end section.
10. An apparatus according to any one of claims 8-9, wherein the front end section further comprises a distillation column.
11. An apparatus according to any one of claims 8-10, wherein the front end section further comprises an ethylene oxide reabsorber.
12. An apparatus according to any one of claims 8-11, wherein the back end section further comprises a Dehydration Subsystem.
13. An apparatus according to any one of claims 8-12, wherein the back end section further comprises a Refining Subsystem.
14. An apparatus according to any one of claims 8-13, wherein the apparatus is configured to balance the output of steam and an input of steam by balancing a low pressure steam header and a high pressure steam header output of steam and input of steam between the front end section and the back end section.
15. An apparatus according to any one of claims 8-15, wherein the ethylene oxide reabsorber comprises a water inlet.
16. A method for the efficient production of ethylene glycols, wherein the method comprises:
 - a. providing an apparatus comprising a front end section and a back end section, wherein

- i. the front end section comprises an ethylene oxidation reactor and ethylene oxidation catalyst for converting ethylene and oxygen to ethylene oxide, and an EO Purification Subsystem for the crude ethylene oxide produced; and
 - ii. the back end section comprises a glycol reactor for converting water/ethylene oxide mixture to a mixture of ethylene glycol and oligomeric or polymeric ethylene glycol ethers, and a dehydration system for separating water /steam from the ethylene glycol and oligomeric or polymeric ethylene glycol ethers;
 - b. reacting ethylene and oxygen in the front end section, and producing a water/ethylene oxide mixture; and
 - c. reacting the water/ethylene oxide mixture in the back end section to produce ethylene glycol and oligomeric or polymeric ethylene glycol ethers;
 - d. wherein the heat of reaction between ethylene and oxygen produces steam, and transferring the steam produced to the back end section to supply process heat to the back end section;
 - wherein the water/ethylene oxide molar ratio of the water/ethylene oxide mixture fed to the glycol reactor is greater than 19, and
 - wherein steam produced by the dehydration system is transferred to the front end section, to provide process heat to the front end section.
17. The method of claim 16, comprising utilizing a more highly selective catalyst for converting ethylene and oxygen to ethylene oxide, with simultaneously decreased production of CO₂.
18. The method of any one of claims 16-17, wherein the back end section also comprises a Glycol Refining Subsystem for separating the ethylene glycol and oligomeric and/or or polymeric ethylene glycol ethers.
19. The methods of any one of claims 16-18, wherein the steam transferred to the back end section is high pressure steam.

20. The methods of any one of claims 16-19, wherein the steam transferred to the front end section is low pressure steam.



INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2014/061431

A. CLASSIFICATION OF SUBJECT MATTER

INV. C07C29/10 C07C31/20 C07C41/03 C07C43/11 C07C29/80
C07C41/42 C07D301/08

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)

C07C C07D

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)

EP0-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	DE 198 43 654 A1 (BASF AG [DE]) 30 March 2000 (2000-03-30) page 2, lines 3-11 page 2, lines 25-31 page 2, lines 58-68 page 3, lines 14-23; figure 1; table 1 page 2, lines 32-34 page 3, lines 24-34; figures 2,3 -----	1-20

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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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"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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Date of mailing of the international search report

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Kardinal, Siegmars

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/IB2014/061431

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