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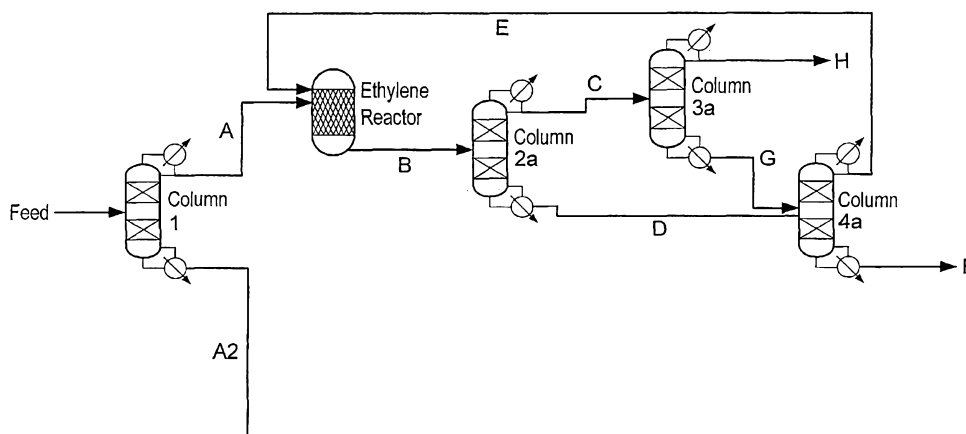
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(54) Title: PROCESS FOR PRODUCING ETHYLENE



(57) Abstract: The present invention relates to a process for the production of ethylene from a feedstock comprising ethanol.



For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Process for producing ethylene

The present invention relates to a process for the production of ethylene from a feedstock comprising ethanol.

5 Olefin(s) have traditionally been produced by steam or catalytic cracking of hydrocarbons. However, inevitably as oil resources decrease the price of oil will continue to increase; making light olefin(s) production a costly process. Thus there is an ever-growing need for non-petroleum routes to produce C₂+ olefin(s), essentially ethylene and propylene. Such olefin(s) are useful starting materials for numerous chemical products
10 including polymeric products such as polyethylene and polypropylene.

In recent years the search for alternative materials for C₂+ olefin(s) production has led to the use of alcohols such as methanol, ethanol and higher alcohols. The said alcohols may be produced by the fermentation of, for example, sugars and/or cellulosic materials.

15 Alternatively, alcohols may be produced from synthesis gas (also known as "syngas"). Synthesis gas refers to a combination of hydrogen and carbon oxides produced in a synthesis gas plant from a carbon source such as natural gas, petroleum liquids, biomass and carbonaceous materials including coal, recycled plastics, municipal wastes, or any organic material. Thus, alcohol and alcohol derivatives may provide non-petroleum based routes for the production of olefin(s) and other related hydrocarbons.

20 Generally, the production of oxygenates, primarily methanol, takes place via three process steps. The three process steps are: synthesis gas preparation, methanol synthesis, and methanol purification. In the synthesis gas preparation step, an additional stage maybe employed by where the feedstock is treated, e.g. the feedstock is purified to remove sulfur and other potential catalyst poisons prior to being converted into synthesis gas. This
25 additional stage can also be conducted after syngas preparation, e.g. when coal or biomass is employed.

Processes for producing mixtures of carbon oxide(s) and hydrogen (synthesis gas) are well known. Each has its advantages and disadvantages and the choice of using a particular reforming process is dictated by economic and available feed stream
30 considerations, as well as by the desired mole ratio of H₂:CO in the feedstock resulting from the reforming reaction. The synthesis gas may be prepared using any of the processes known in the art including partial oxidation of hydrocarbons, steam reforming, gas heated

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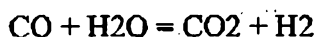
reforming, microchannel reforming (as described in, for example, US 6,284,217), plasma reforming, autothermal reforming and any combination thereof. A discussion of these synthesis gas production technologies is provided in "Hydrocarbon Processing" V78, N.4, 87-90, 92-93 (April 1999) and "Petroleum Techniques", N. 415, 86-93 (July-August 1998).

- 5 It is also known that the synthesis gas may be obtained by catalytic partial oxidation of hydrocarbons in a microstructured reactor as exemplified in "IMRET 3: Proceedings of the Third International Conference on Microreaction Technology", Editor W Ehrfeld, Springer Verlag, 1999, pages 187-196. Alternatively, the synthesis gas may be obtained by short contact time catalytic partial oxidation of hydrocarbonaceous feedstocks as described in EP
- 10 0303438. Typically synthesis gas is obtained via a "Compact Reformer" process as described in "Hydrocarbon Engineering", 2000, 5, (5), 67-69; "Hydrocarbon Processing", 79/9, 34 (September 2000); "Today's Refinery", 15/8, 9 (August 2000); WO 99/02254; and WO 200023689.

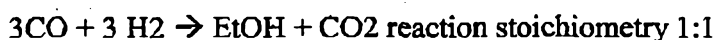
- Typically, for commercial syngas production the pressure at which the synthesis
- 15 gas is produced ranges from approximately 20 to 75 bar and the temperature at which the synthesis gas exits the reformer ranges from approximately 700 DEG C. to 1100 DEG C. The synthesis gas contains a molar ratio of hydrogen to carbon oxide – which is dependent on the syngas feedstock - ranging from 0.8 to 3.

- Alcohol synthesis from syngas requires a H₂:CO molar ratio which is typically
- 20 between 1:1 and 2:1.

- The applicants believe that the reaction of producing alcohol, such as ethanol, from synthesis gas can be written as so: $2\text{CO} + 4\text{H}_2 \rightarrow \text{EtOH} + \text{H}_2\text{O}$ reaction stoichiometry 2:1. However, in addition to this the water gas shift reaction can also readily occur and thus the equilibrium under typical alcohol synthesis conditions strongly favours carbon dioxide and
- 25 hydrogen production.



So the overall alcohol synthesis can be written as so:



- In addition to this the water gas shift reaction allows CO₂ and H₂ to substitute for
- 30 CO. So the required molar syngas ratio for alcohol synthesis can be written in terms of (H₂-CO₂):(CO+ CO₂) and in this case the required ratio is 2 .

However, the H₂:CO molar ratio used in practice is typically higher due to by-product formation, such as alkanes. The synthesis gas preparation, also known than those stated above, as reforming may take place in a single-step wherein all of the energy consuming and generating reforming reactions are accomplished. For example, in a single
5 tubular steam reformer the reaction is overall endothermic whereas in autothermal reforming combustion of some of the feed and product is used to balance the heat duty. The single-step steam reformer usually results in the production of surplus hydrogen. In a preferred alternative, the synthesis gas preparation may take place in a two-step reforming process wherein the primary reforming in a tubular steam reformer is combined with an
10 oxygen-fired secondary reforming step which if used in isolation produces a synthesis gas with a deficiency in hydrogen. With this combination it is possible to adjust the synthesis gas composition used, in order to obtain the most suitable composition for methanol synthesis. As an alternative, autothermal reforming results in a simplified process scheme with a lower capital cost. Autothermal reforming is where a stand-alone, oxygen-fired
15 reformer first produces a hydrogen deficient synthesis gas, and then removes at least a portion of the carbon dioxide present, in order to obtain the desired molar ratio of hydrogen to carbon oxides.

The reaction from synthesis gas to oxygenates such as methanol is an exothermic equilibrium limited reaction. The conversion per pass to methanol is favored by low
20 temperatures but a balance between rate and conversion must be maintained for economic considerations. It also requires high pressures over a heterogeneous catalyst, as the reactions which produce methanol exhibit a decrease in volume. As disclosed in U.S. Pat. No. 3,326,956, low-pressure methanol synthesis is based on a copper oxide-zinc oxide-alumina catalyst that typically operates at a nominal pressure of 5-10 MPa and
25 temperatures ranging from approximately 150 DEG C. to 450 DEG C. over a variety of catalysts, including CuO/ZnO/Al₂O₃, CuO/ZnO/Cr₂O₃, ZnO/Cr₂O₃, Fe, Co, Ni, Ru, Os, Pt, and Pd. Catalysts based on ZnO for the production of methanol and dimethyl ether are preferred. The low-pressure, copper-based methanol synthesis catalyst is commercially available from suppliers such as BASF, ICI Ltd. of the United Kingdom, and Haldor-
30 Topsoe. Methanol yields from copper-based catalysts are generally over 99.5% of the converted CO+CO₂ present. Water is a known by-product of the conversion of the synthesis gas to oxygenates. A paper entitled, "Selection of Technology for Large

Methanol Plants," by Helge Holm-Larsen, presented at the 1994 World Methanol Conference, Nov. 30-Dec. 1, 1994, in Geneva, Switzerland, and herein incorporated by reference, reviews the developments in methanol production and shows how further reduction in costs of methanol production will result in the construction of very large
5 plants with capacities approaching 10,000 metric tonnes per day.

U.S. Pat. No. 4,543,435 discloses a process for converting an oxygenate feedstock comprising methanol, dimethyl ether or the like in an oxygenate conversion reactor into liquid hydrocarbons comprising C2 -C4 olefin(s) and C5+ hydrocarbons. The C2 -C4 olefin(s) are compressed to recover an ethylene-rich gas. The ethylene-rich gas is recycled
10 to the oxygenate conversion reactor. U.S. Pat. No. 4,076,761 discloses a process for converting oxygenates to gasoline with the return of a hydrogen-rich gaseous product to a synthesis gas plant or the oxygenate conversion reaction zone.

U.S. Pat. No. 5,177,114 discloses a process for the conversion of natural gas to gasoline grade liquid hydrocarbons and/or olefin(s) by converting the natural gas to a
15 synthesis gas, and converting the synthesis gas to crude methanol and/or dimethyl ether and further converting the crude methanol/dimethyl ether to gasoline and olefin(s).

International Patent Application No. 93/13013 to Kvisle et al relates to an improved method for producing a silicon-alumino-phosphate catalyst which is more stable to deactivation by coking. The patent discloses that after a period of time, all such catalysts
20 used to convert methanol to olefin(s) (MTO) lose the active ability to convert methanol to hydrocarbons primarily because the microporous crystal structure is coked; that is, filled up with low volatility carbonaceous compounds which block the pore structure. The carbonaceous compounds can be removed by conventional methods such as combustion in air.

EPO publication No. 0 407 038A1 describes a method for producing dialkyl ethers comprising feeding a stream containing an alkyl alcohol to a distillation column reactor into a feed zone; contacting the stream with a fixed bed solid acidic catalytic distillation structure to form the corresponding dialkyl ether and water, and concurrently fractionating the ether product from the water and unreacted materials.
25

U.S. Pat. No 5,817,906 describes a process for producing light olefin(s) from a crude oxygenate feedstock comprising alcohol and water. The process employs two reaction stages. Firstly, the alcohol is converted using reaction with distillation to an ether.
30

The ether is then subsequently passed to an oxygenate conversion zone containing a metalaluminosilicate catalyst to produce a light olefin stream.

There is a well known chemistry that can be employed to produce olefin(s) from alcohol(s), i.e. the Methanol to olefin(s)- MTO- process (as described in Handbook of
5 Petroleum refining processes third edition , Chapter 15.1 editor R.A. Meyers published by McGraw Hill).

This said MTO Process can be described as the dehydrative coupling of methanol to olefin(s). This mechanism is thought to proceed via a coupling of C1 fragments generated by the acid catalysed dehydration of methanol, possibly via a methyloxonium
10 intermediate. However the main disadvantage of the said MTO process is that a range of olefin(s) are co-produced together with aromatic and alkane by-products, which in turn makes it very difficult and expensive to recover the desired olefin(s) at high purity.

Molecular sieves such as the microporous crystalline zeolite and non-zeolitic catalysts, particularly silicoaluminophosphates (SAPO), are known to promote the
15 conversion of oxygenates by methanol to olefin (MTO) chemistry to hydrocarbon mixtures. Various patents describe the various types of these catalysts that may be used in this process, such as: U.S. Pat. Nos. 3,928,483, 4,025,575, 4,252,479 (Chang et al.); 4,496,786 (Santilli et al.); 4,547,616 (Avidan et al.); 4,677,243 (Kaiser); 4,843,183 (Inui); 4,499,314 (Seddon et al.); 4,447,669 (Harmon et al.); 5,095,163 (Barger); 5,191,141
20 (Barger); 5,126,308 (Barger); 4,973,792 (Lewis); and 4,861,938 (Lewis).

The MTO reaction has a high activation energy, possibly in the methanol or dimethyl ether activation step so in order to achieve reasonable rates there is often a need for high temperatures e.g. 300-450°C. However, unfortunately operating at these said high temperatures leads to major problems such as catalyst deactivation, coking and significant
25 by-product formation. In order to minimize these problems the reactions may be operated at lower temperatures, but this necessitates larger reactors in addition to a large expensive recycle of intermediates and reactants.

Another major disadvantage associated with the MTO process is that the aromatic and alkane by-products are co-produced together with the olefin(s) and are both difficult
30 and expensive to separate from the desired products, e.g. separating ethylene and ethane is an expensive process.

These and other disadvantages of the prior art show that there is a need for an improved and/or alternative process for the production of C2 and C3 olefins from alcohols.

The solution to these and other disadvantages is provided by the present invention, which relates specifically to a new non-MTO process which proceeds via the dehydration of ethanol into olefins. This dehydration reaction is characterized in that carbon-carbon double bonds are formed by elimination of water only and does not include the coupling of carbon fragments as is the case in MTO chemistry. It should be noted that for the dehydration of ethanol, by-products are formed. These can be formed by coupling of alkyl fragments e.g. acid catalysed olefin oligomerisation, such as:

10 2 propylene $\rightarrow$ Hexene

The by-products can also be formed by alcohol dehydrogenation, e.g.
Ethanol $\rightarrow$ Acetaldehyde + H₂ (J.Catalysis 1989,117, pp135-143
Y.Matsumura,K.Hashimoto and S.Yoshida).

The state of the hydrogen liberated may not be as free hydrogen but as chemisorbed hydrogen. Of particular relevance is the transfer hydrogenation reaction e.g.
Ethylene + H₂ $\rightarrow$ ethane

2 Ethanol $\rightarrow$ Acetaldehyde + ethane + water

The formation of same carbon number alkanes is known to add significantly to the complexity and cost of producing purified olefins for polymer manufacture. For example the industrially practiced catalytic cracking of hydrocarbon feedstocks to produce olefins for polymer manufacture is a capitally intensive process with a significant proportion of the cost involved in same number olefin and alkane separation. That is separation of ethane from ethylene and propane from propylene (as described in Handbook of Petroleum refining processes third edition , Chapter 3 editor R.A. Meyers published by McGraw Hill). This is also a disadvantage for the MTO process, (Ibid chapter 15.1). Dehydration of ethanol to ethylene has been commercially practiced in places such as Brazil, and India, albeit at a small scale. The reported reaction conditions are such that high conversion per pass to olefin is achieved at e.g. 1-2 barg, >350C. It is a high selectivity process but produces unacceptable levels of alkanes for direct use in the preparation of polyethylene. Acceptable levels are often quoted as less than 500ppm combined ethane and methane. Current practice of dehydration leads to olefins which need expensive purification before use in current polymerization processes, as is also the case with MTO.

U.S. Pat. No 5,475,183 describes a process for producing light olefins by dehydrating lower alcohols having 2-4 carbon atoms on a alumina catalyst in the vapour phase. The typical reaction conditions given in the examples are 300-400C at 8 to 18 Barg with reported olefin selectivities between 65 and 97%.

5 GB Pat No 2094829 describes how ethylene can be produced in a plurality of vapour phase adiabatic reactors with parts of the liquid products containing unconverted alcohol being recycled. The reaction conditions are described as the feed charge is at 400-520C and a pressure 19-39 barg. The outlet product being kept at least 18 barg prior to being cryogenically purified. No examples were given of the predicted selectivity. US Pat
10 No 4,232,179 also describes how ethanol can be dehydrated in adiabatic reactors. The examples, with silica /alumina, and alumina show that the ethane content in the ethylene product is above 923-100000ppm wt on ethylene. This is unacceptable for polyethylene production without additional purification.

DD Pat No 245866 describes how C2 to C4 olefins can be obtained from syngas-
15 derived alcohol mixtures by vapour phase treatment with a zeolite catalyst between 300-500C and 200-1000kPa. Analysis of the examples has shown that significant conversion to C5 and higher hydrocarbons occurred. The examples describe the dehydration of mixtures of C1 to C7 alcohols. Example 1 describes the dehydration of a mixture of 76% methanol, 7.1% ethanol, 4.3% ethanol, 0.5% isopropanol, 4.3% n-propanol, 3.9% iso-butanol, 2%
20 butanols, 2.1% amyl alcohol, 0.9% hexanols, 0.2% heptanols + balance other oxygenates to give 143.2g ethylene, 96.8g propene, 77.9 g butene, 174.3 g C5+ hydrocarbons. Clearly significant conversion of lower carbon moieties to higher carbon fragments is occurring on the modified zeolite catalyst.

US Pat No 4398050 describes the synthesis of a mixed alcohol stream and
25 purification to give a mixture of ethanol and propanol which is subsequently dehydrated at 0.5-1 bar, 350-500C (example 1). The primary claim mentions the removal of methanol prior to dehydration, but not the removal of C4 and higher alcohols.

US Pat No 4,423,270 describes the atmospheric pressure vapour phase dehydration of ethanol over a supported phosphoric acid catalyst with additional water and an alkyl
30 substituted phosphoric acid. The reaction temperatures employed are between 300-400C and the experiments were conducted at atmospheric pressure in a glass tube. The reported

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yields of ethylene ranged from 88-101% , no details of by-product formation was disclosed.

5 US Pat No 4727214 describes the dehydration of ethanol over a crystalline aluminosilicate zeolite. The conditions claimed are between 1 and 10 bar and 126 and 526C. Details of by-product formation are supplied to one decimal place and a selectivity to ethylene of 100% is reported. It is, however unclear from the patent if material suitable for polymer grade ethylene can be made without additional purification for removal of ethane.

0 Limited experimental information is available for n-propanol dehydration (Journal of Catalysis 169, 67-75 (1997) G.Larsen et al, J. Phy. Chem B 109/8 3345-3354), we have found that the dehydration proceeds in a similar manner to that reported for ethanol, with similar by-product formation e.g. alkanes, aldehydes, ketones, oligomers. The rate of oligomer formation is however more significant.

5 The present invention relates to a process for the production of ethylene from ethanol.

Figure 1 represents one embodiment of a process scheme according to the present invention. This said embodiment comprises optional and/or preferred process steps according to the present invention. The letter references in Figure 1 correspond to those used in the present description and appending claims.

0 The present invention relates to a process for the production of ethylene from an ethanol feedstock A characterised by the following steps;

1. the ethanol feedstock A is reacted in a vapour phase reactor wherein the ethanol is converted at a temperature comprised between 160 and 270°C and at a pressure of above 0.1 MPa but less than 4.5 MPa, into a product stream B comprising ethylene, diethyl ethers, water and unconverted ethanol,
- 25 2. the said product stream B is cooled,
3. the said cooled product stream B is disengaged in a separation unit to give a first stream C comprising ethylene and diethyl ethers, and a second product stream D comprising water, diethyl ethers and unconverted ethanol,
- 30 4. the said product stream D is fed to a dewatering unit wherein the water stream F is separated from the diethyl ethers and unconverted ethanol stream E,
5. the said stream E is recycled into the dehydration reactor of step 1,
6. the said product stream C is cooled,

7. the said cooled product stream C is fed to a purification unit wherein the diethyl ethers stream G is separated from the ethylene stream H, and
8. optionally, the ethyl ethers stream G is recycled to either the dewatering unit of step 4 or directly to dehydration reactor of step 1.

5 According to a preferred embodiment, the present invention provides a process for the conversion of hydrocarbon to ethylene wherein the ethanol feed A of the hereabove step 1 come from the separation of a mixed ethanol and propanol oxygenates feedstock.

According to another preferred embodiment, the present invention provides a process for the conversion of hydrocarbons to ethylene comprising the steps of

- 10 a. converting hydrocarbons in a syngas reactor into a mixture of carbon oxide(s) and hydrogen,
- b. converting the said mixture of carbon oxide(s) and hydrogen from step (a) in the presence of a particulate catalyst in a reactor under a temperature comprised between 200 and 400°C and a pressure of 5 to 20 MPa into a feedstock comprising
- 15 ethanol,
- c. using at least part of said feedstock comprising ethanol as the ethanol feed A and proceeding according to steps 1 to 8 described hereinabove and according to the present invention to produce the said ethylene.

Any hydrocarbon-containing feed stream that can be converted into a feedstock

20 comprising carbon monoxide and hydrogen, most preferably a synthesis gas (or "syngas"), is useful in the processes of the invention.

The hydrocarbon feedstock used for syngas generation is preferably a carbonaceous material, for example biomass, plastic, naphtha, refinery bottoms, smelter off gas, municipal waste, coal, coke and/or natural gas; coal and natural gas being the preferred

25 carbonaceous material and most preferably the hydrocarbon feedstock is natural gas.

Feedstocks comprising carbon monoxide and hydrogen, e.g. synthesis gas may undergo purification prior to being fed into any of the reaction zones. Synthesis gas purification may be carried out by processes known in the art. See, for example, Weissmehl, K. and Arpe H.-J., Industrial Organic Chemistry, Second, Revised and

30 Extended Edition, 1993, pp. 19-21.

According to the present invention the method for the production of olefins from alcohols proceeds via the dehydration of the said alcohols. These dehydration reactions are

distinguished from the aforementioned MTO process in that although no coupling of carbon fragments is required in the dehydration process a C-C double bond is formed during the elimination of water and as a result high selectivity can be achieved. In general the conditions employed in the MTO process are much more severe than those employed in alcohol dehydration described herein.

The dehydration of the feedstock according to the present invention is believed (Chem.Eng Comm. 1990 vol 95 pp27-39 C.L.Chang,A.L. DeVera and D.J.Miller) to proceed by either the direct dehydration to olefin(s) and water;

Equation 1

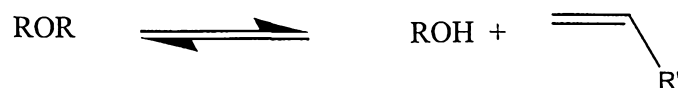


or via an ether intermediate;

Equation 2



Equation 3



where R is an ethyl group. R' is hydrogen.

The direct conversion of the ether to two moles of olefin and water has also been reported (Chem.Eng.Res and Design 1984 Vol 62 pp81-91).

All of the reactions shown above are typically catalysed by Lewis and/or Bronsted acids. Equation 1 shows the endothermic direct elimination of alcohol to olefin(s) and water; competing with Equation 1 are Equations 2 and 3 i.e. the exothermic etherification reaction (Equation 2), and the endothermic elimination of ether(s) to produce olefin(s) and alcohol (Equation 3). However the dehydration reaction of alcohols to olefin(s) is overall said to be endothermic.

As mentioned hereabove, the process according to the present invention preferably starts with an oxygenated feedstock comprising ethanol and propanol, for example a mixture of ethanol and n-propanol and/or iso-propanol.

Said oxygenate feedstock can comprise homo and mixed ethers of these alcohols, for example diethyl ether, n-propyl ether, ethyl n-propyl ether, ethyl isopropyl ether, n-propyl isopropyl ether and iso-propyl ether.

The oxygenates feedstock preferably comprises as alcohols a mixture of ethanol and n-propanol only.

According to the present invention, the molar ratio of ethanol to n-propanol in the oxygenates feedstock to be separated into the ethanol feed A is preferably higher than 1:2 but lower than 20:1 and is more preferably higher than 1:1 but lower than 10:1, most preferably higher than 2:1 and lower than 5:1.

According to a preferred embodiment of the present invention, the oxygenates feedstock and/or the feedstock A have an iso-propanol content of less than 5wt%, preferably less than 1wt%, most preferably less than 0.1wt% and ideally contain no iso-propanol.

A preferred characterizing feature according to the present invention is that the oxygenates feedstock and/or the feedstock A have a total C3+ alcohol (defined as alcohols having at least 4 carbon atoms e.g. n-butanol, iso-butanol, pentanol) content of less than 5wt%, preferably less than 1wt%, most preferably less than 0.1wt% and ideally contain no C3+ alcohols. Conventional distillation can be used according to the present invention in order to reduce/eliminate the C3+ from the corresponding feedstock A.

Indeed the Applicants have unexpectedly discovered that the presence of C3+ alcohols to be detrimental towards the olefin(s) production process of the present invention, e.g. the Applicants believe that they are responsible for an increase in alkane make during the olefin production.

Another preferred embodiment according to the present invention is that the oxygenates feedstock and/or the feedstock A have a methanol content of less than 5wt%, preferably less than 2wt%, most preferably less than 0.5wt% and ideally there is no methanol. Corresponding advantages may accrue from eliminating methanol, i.e.

- (i) Prevention of dimethyl ether formation – DME is hard to separate from propylene and ethylene compared to diethyl ether

- (ii) Prevention of MTO chemistry
- (iii) Prevention of alkylation of olefins e.g. propylene to butene
- (iv) Prevention of formation of the methyl ethyl ether (which is harder to separate from ethylene)
- 5 (v) Less waste
- (vi) Lower toxicity
- (vii) Lower vapour pressure – easier to ship
- (viii) A better C:O ratio in the feedstock for shipping i.e. less water production

Conventional distillation can be used according to the present invention in order to
10 reduce/eliminate the methanol and C3+ alcohols from the corresponding feedstock.

When a mixed ethanol and propanol feedstock is obtained from hereinabove step b), then a separation of the ethanol and propanol feedstock into an ethanol feedstock A and a propanol feedstock A2 is preferably performed. Said separation is preferably performed in a conventional distillation column.

15 The separation is preferably performed in such a way that the resulting ethanol feedstock can tolerate the presence of some propanol. Hence, the propanol content of feedstock A is preferably of at least 50ppm, more preferably at least 0.1wt% of propanol or at least 1wt% of propanol. According to a preferred embodiment of the present invention, the feedstock A comprises less than 10 wt%, more preferably less than 2wt% of propanol.

20 The preferred reaction conditions of the vapour phase dehydration according to step 1 of the present invention are such that moderate conversion to olefin occurs in the reactor. The liquid product stream after olefin removal comprises mostly unreacted alcohols, ethers and water. It is preferred to recycle the major portion of the alcohols and ethers to the dehydration reactor after water by-product removal.

25 For the purpose of the present invention and appending claims, moderate conversion of the ethanol feedstock A into ethylene means that 10 to 80%, and more preferably 20 to 60%, of the said ethanol introduced into the dehydration reactor is converted per pass. Where “conversion” is defined as being, the ratio between the number of moles of ethylene produced, versus, the number of moles of ethanol (and ethanol
30 derived fragments in ethers) that are fed into the said vapour phase dehydration reactor(s).

According to the present invention, for the ethylene generating reactor some ethanol and optionally limited amounts of propanol derived ether(s) such as diethyl ether,

n-propyl ether, ethyl n-propyl ether, ethyl isopropyl ether, n-propyl isopropyl ether and isopropyl ether, are produced during the dehydration stage. It is preferred according to the present invention to proceed with an additional separation stage; thus, preferably at least 80 wt %; more preferably at least 90 wt %; most preferably at least 99 wt %; even more preferably at least 99.9 wt % of the ether(s) are separated from the olefin(s). At least part - preferably all - of the ether(s) separated are then preferably recycled into the respective vapour phase dehydration reactor(s).

According to a preferred embodiment of the present invention at least part, preferably all of the said ether recycle is pre-mixed with the fresh ethanol feed (stream A) prior to entering the vapour phase dehydration reactor of step 1.

The formation of ethers is thermodynamically favorable. This ether formation facilitates separation of water from the recycle. Ethanol, n-propanol and iso-propanol are all fully or significantly water miscible and readily form water azeotropes, which thus hinders the separation of water, a by-product of the reaction, from the recycle streams. However, the formation of ethers, such as diethyl ether and di-n-propyl ether (which both have a limited water miscibility and a very low water content azeotrope), allows the recovery of water by use of a decanter, even in the presence of unreacted alcohols.

According to the present invention, water is permissible in the ethanol and propanol feedstocks A to be dehydrated; the said feedstock may comprise up to up to 50 wt % of water but preferably the said feedstock comprises less than 25 wt% water, and most preferably the feedstock comprises less than 20 wt % of water.. However due to processing costs such as the reactor size, heat of vaporization and heat capacity of water, it is preferred to operate with feedstocks containing lower levels of water for example less than 10wt%, preferably less than 5wt% of water. When Heteropolyacids are used as catalysts the level of water in contact with the catalyst can affect the catalyst stability and activity. For example heteropolyacids show a diminished catalyst stability at low levels of water (<1wt%) and a diminished activity at high levels of water (>50wt%). To one skilled in the art it is apparent that the optimum water level will depend on the interaction of a complex set of variables including, alcohol feed composition, pressure, temperature and nature of the heteropolyacid employed. That said, this process has a good ability to separate water out and hence facilitates the use of bioethanol and other bioalcohol(s). The operation at medium conversion with water removal during recycle has the advantage in

that it allows convergence towards the optimum reaction conditions of the process. The presence of water in the feed can also increase the difficulty of the alcohol separation due to the presence of alcohol water azeotropes which serves to narrow the boiling point difference for separation.

According to the most preferred embodiment of the present invention the ethanol and diethyl ether together with the water represent at least 90 wt% and preferably at least 99 wt% of the feedstock A introduced into vapour phase dehydration reactor.

Additional sources of ethanol can be added to either the alcohol separation column or directly to the reactor feeds e.g. bioethanol to stream A.

The vapour phase reactor used for dehydrating the ethanol feedstock A according to the present invention is preferably operated at a temperature comprised between 180 and 270°C, more preferably between 190 and 260°C and most preferably between 200 and 250°C.

The vapour phase reactor used for dehydrating the ethanol feedstock A according to the present invention is preferably operated at a pressure of above 1.5 MPa but less than 3.5 MPa and more preferably at a pressure of above 1.8 MPa but less than 2.8 MPa.

According to the present invention the operating conditions are such that the dehydration process is always operated in a vapour phase state. It is a preferred embodiment that the dehydration process operating pressure is always at least 0.1 MPa, preferably 0.2 MPa, below the dew point pressure and/or that the dehydration process operating temperature is at least 10°C above the dew point temperature of the feed entering the vapour phase dehydration reactor (the alcohol feed mixture and/or the mixture resulting from addition of the recycle) and the product composition that is present inside the dehydration reactor. The latter will depend on factors such as the initial feed composition and the degree of conversion in the reactor.

For the purposes of the present invention, the 'dew point temperature' is defined as being a threshold temperature. For example, for a given mixture, at a given pressure, if the system temperature is raised to above the dew point temperature, the mixture will exist as a dry gas. Likewise below the dew point temperature, the mixture will exist as a vapour containing some liquid. And similarly the 'dew point pressure', is defined as being a threshold pressure. For example, for a given mixture, at a given temperature, if the system

pressure is below the dew point pressure, the mixture will exist as a dry gas; above the dew point pressure, the mixture will exist as a vapour containing some liquid.

The reactors are engineered to cope with the exothermic ether formation and the endothermic dehydration to olefins. The reaction temperature is preferably maintained within a small temperature range, as too low a temperature reduces the rate of olefin manufacture and can lead to condensation of reactants and too high a temperature can lead to the olefin being contaminated by unacceptable levels of by-products such as same carbon number alkanes. Preferably the temperature profile of the catalyst bed is less than 30C more preferably less than 15C and most preferably less than 10C. For a single bed adiabatic reactor the overall endothermic reaction if allowed to go to thermodynamic equilibrium could result in a theoretical temperature drop of 180C. Obviously the problem is one of heat management by reactor design. Suitable reactor designs include those capable of handling heat fluxes such as fixed bed, fluidised bed, multitubular and multiple fixed bed reactors with inter stage heaters. Optionally the heat management can be improved by injecting preheated fresh alcohol feed at several points in the reactor bed, at which point the exothermic etherification reaction can partially counteract the overall endotherm. The feed can also be heated further to above the reaction temperature, in order to provide an additional source of heat. A portion of the recycle stream also can be added at several points along the reactor with additional heating but it is preferred to add the main proportion of this stream to the front end of the reactor.

According to another embodiment of the present invention, the dehydration process, described by the present invention, is not conducted in a reactive distillation column. Where a "reactive distillation column" refers to a combined distillation column and reactor.

Surprisingly it has been found by the applicants that the use of a mixed ether and alcohol feed results in a higher yield and selectivity to olefins. This surprising discovery has shown that operating the process of the present invention with a recycle is advantageous to the productivity and selectivity of the olefin production process. In addition to this, the option of conducting the separate etherification on the alcohol feedstock prior to dehydration is also one embodiment of this invention.

Thus, according to a preferred embodiment of the present invention, the ethanol feedstock A comprises at least 10wt%, preferably at least 15 wt%, preferably at least

30wt%, and most preferably at least 50wt% ethers but less than or equal to 85wt% ethers. Said ethers are preferably ethanol derived ether(s) such as diethyl ether for the feedstock A. As propanol can also be tolerated in the ethanol feedstock A, said ethers can also be propanol derived ether(s) such as di n-propyl ether, n-propyl isopropyl ether, di iso-propyl ether, n-propyl ethyl ether and iso-propyl ethyl ether. Said ethers can be produced during the dehydration stage, during the alcohols synthesis stage, during a separate etherification additional stage or simply added to the feedstock(s).

A preferred characterizing feature according to the present invention is that feedstock A has a C1 ether (e.g. methyl ethyl ether, methyl propyl ether) and C3+ (defined as having at least one 4 carbon atom chain e.g. n-butyl ethyl ether, butyl propyl ether) derived ethercontent of less than 5wt%, preferably less than 1wt%, most preferably less than 0.1wt% and ideally there are no C1 and/or C3+ derived ethers present.

According to another embodiment of the present invention, the presence of aldehydes in the oxygenates feedstock and/or the feedstock A has been found to be detrimental to the catalyst lifetime. Accordingly the aldehydes content in the said feedstocks is preferably less than 1wt%, more preferably less than 0.1wt%. In order to achieve the required absence of aldehydes, it is preferred to remove the said aldehydes from the alcohols feedstocks to be dehydrated by subjecting the said alcohols feedstocks to any one of the following treatments: a bisulphite wash: a borohydride hydrogenation, a hydrogen hydrogenation or a distillation treatment. The distillation treatment can be combined with a chemical treatment such as caustic catalysed Aldol condensation or borohydride treatment to improve its efficiency for aldehyde removal. The dehydration reaction may also produce small quantities of aldehydes which can be preferably similarly removed by treatment.

According to another embodiment of the present invention, the oxygenates feedstock and/or the feedstock A and/or the recycle streams should preferably be substantially free of volatile bases and metal ions which can cause catalyst deactivation. Transition metals ions such as common corrosion metals e.g. Cu, Fe and Ni, can also catalyze hydrogen transfer reactions and lead to loss of quality of the olefin streams due to increased aldehyde and alkane make. Volatile amines can be conveniently removed by treatments such as distillation and/or use of guard beds (typically acidic ion-exchange resin

beds). Metal ions can also be conveniently removed by the use of guard beds but careful design of the feed and vaporization unit(s) can afford significant protection.

Olefins such as ethylene and propylene used in polymer manufacture by virtue of the high activity and turnover numbers of the catalysts employed for polymerisation are susceptible to the presence of low amounts of impurities; these can be removed by well known treatments for the olefin. Alternatively some of these impurities such as sulphur compounds which may be present in bio-ethanol can be removed by pre-treatment of the feedstock.

According to a preferred embodiment of the present invention the alcohols present in the oxygenates feedstock are transported from a remote location prior to being separated and dehydrated to olefin(s) via the above process. For the purpose of this invention and the appending claims the term 'remote location' refers to a location that is more than 100 kilometers from the alcohol dehydration units.

According to a preferred embodiment of the present invention the catalyst used for the dehydration of the ethanol feedstock A are heterogeneous catalyst(s). It includes but is not limited to heteropolyacids, sulphonated supports (e.g. Nafion and ion exchange resins, Sulphonated zirconia, Pt sulphonated zirconia), Niobia, phosphoric acid on siliceous supports (silica, Kieselguhr, clays), zeolites, metal modified zeolites, mordenites and mixtures thereof; preferably heteropolyacids and ion-exchange resins; more preferably heteropolyacids; and most preferably 12-tungstosilicic acid, 12-tungstophosphoric acid, 18-tungstophosphoric acid and 18-tungstosilicic acid and partial salts thereof.

The term "heteropolyacid", as used herein and throughout the description of the present invention, is deemed to include inter alia; alkali, alkali earth, ammonium, free acids, bulky cation salts, and/or metal salts (where the salts may be either full or partial salts) of heteropolyacids. Hence, the heteropolyacids used in the present invention are complex, high molecular weight anions comprising oxygen-linked polyvalent metal atoms. Typically, each anion comprises 12-18, oxygen-linked polyvalent metal atoms. The polyvalent metal atoms, known as peripheral atoms, surround one or more central atoms in a symmetrical manner. The peripheral atoms may be one or more of molybdenum, tungsten, vanadium, niobium, tantalum, or any other polyvalent metal. The central atoms are preferably silicon or phosphorus, but may alternatively comprise any one of a large variety of atoms from Groups I-VIII in the Periodic Table of elements. These include

copper, beryllium, zinc, cobalt, nickel, boron, aluminium, gallium, iron, cerium, arsenic, antimony, bismuth, chromium, rhodium, silicon, germanium, tin, titanium, zirconium, vanadium, sulphur, tellurium, manganese nickel, platinum, thorium, hafnium, cerium, arsenic, vanadium, antimony ions, tellurium and iodine. Suitable heteropolyacids include

- 5 Keggin, Wells-Dawson and Anderson-Evans-Perloff heteropolyacids. Specific examples of suitable heteropolyacids are as follows:

18-tungstophosphoric acid	-	$H_6[P_2W_{18}O_{62}].xH_2O$
12-tungstophosphoric acid	-	$H_3[PW_{12}O_{40}].xH_2O$
12-molybdophosphoric acid	-	$H_3[PMo_{12}O_{40}].xH_2O$
10 12-tungstosilicic acid	-	$H_4[SiW_{12}O_{40}].xH_2O$
12-molybdosilicic acid	-	$H_4[SiMo_{12}O_{40}].xH_2O$
Cesium hydrogen tungstosilicate	-	$Cs_3H[SiW_{12}O_{40}].xH_2O$

and the free acid or partial salts of the following heteropolyacids:

Monopotassium tungstophosphate	-	$KH_5[P_2W_{18}O_{62}].xH_2O$
15 Monosodium 12-tungstosilicic acid	-	$NaK_3[SiW_{12}O_{40}].xH_2O$
Potassium tungstophosphate	-	$K_6[P_2W_{18}O_{62}].xH_2O$
Sodium molybdophosphate	-	$Na_3[PMo_{12}O_{40}].xH_2O$
Ammonium molybdodiphosphate	-	$(NH_4)_6[P_2Mo_{18}O_{62}].xH_2O$
Potassium molybdodivanado phosphate	-	$K_5[PMoV_2O_{40}].xH_2O$

- 20 In addition mixtures of different heteropolyacids and salts can be employed. The preferred heteropolyacids for use in the process described by the present invention is any one or more heteropolyacid that is based on the Keggin or Wells-Dawson structures; more preferably the chosen heteropolyacid for use in the process described by the present invention is any one or more of the following: silicotungstic acid, phosphotungstic acid, 25 silicomolybdic acid and phosphomolybdic acid; and most preferably the chosen heteropolyacid for use in the process described by the present invention is any one or more silicotungstic acid.

- The heteropolyacids employed according to the present invention may have molecular weights of more than 700 and less than 8500, preferably more than 2800 and 30 less than 6000. Such heteropolyacids also include dimeric complexes.

The supported catalyst may be conveniently prepared by dissolving the chosen heteropolyacid in a suitable solvent, where suitable solvents include polar solvents such as

water, ethers, alcohols, carboxylic acids, ketones and aldehydes; distilled water and/or ethanol being the most preferable solvents. The resulting acidic solution has a heteropolyacid concentration that is preferably comprised between 10 to 80 wt %, more preferably 20 to 70 wt% and most preferably 30 to 60 wt%. This said solution is then added to the chosen support (or alternatively the support is immersed in the solution). The actual volume of acidic solution added to the support is not restricted, and hence may be enough to achieve incipient wetness or wet impregnation, where wet impregnation (i.e. preparation using an excess acidic solution volume relative to pore volume of support), is the preferred method for the purposes of the present invention.

The resulting supported heteropolyacid may be modified, and various salts of heteropolyacid may then be formed in the aqueous solution either prior to, or during, impregnation of the acidic solution onto the support, by subjecting the supported heteropolyacid to a prolonged contact with a solution of a suitable metallic salt or by addition of phosphoric acid and/or other mineral acids.

When using a soluble metallic salt to modify the support, the salt is taken in the desired concentration, with the heteropolyacid solution. The support is then left to soak in the said acidic solution for a suitable duration (e.g. a few hours), with periodic stirring or shaking, after which time it is filtered, using suitable means, in order to remove any excess acid.

When the salt is insoluble it is preferred to impregnate the catalyst with the HPA and then tritrate with the salt precursor. This method can improve the dispersion of the HPA salt. Other techniques such as vacuum impregnation may also be employed.

The impregnated support may then be washed and dried. This may be achieved using any conventional separation technique, including, for example, decantation and/or filtration. Once recovered, the impregnated support may be dried, preferably by placing the support in an oven at elevated temperature. Alternatively, or additionally, a desiccator may be employed. On a commercial scale this drying stage is often achieved by a purge of hot inert gas such as nitrogen.

The amount of heteropolyacid impregnated on the resulting support is suitably in the range of 10 wt % to 80 wt % and preferably 20 wt % to 50 wt % based on the total weight of the heteropolyacid and the support.

The weight of the catalyst on drying and the weight of the support used, may be used to obtain the weight of the acid on the support by deducting the latter from the former, giving the catalyst loading as 'g heteropolyacid/kg catalyst'. The catalyst loading in 'g heteropolyacid /litre support' can also be calculated by using the known or measured bulk density, of the support. The preferred catalytic loading of heteropolyacid is 150 to 600g HPA / kg Catalyst

It should be noted that the polyvalent oxidation states and hydration states of the heteropolyacids stated previously and as represented in the typical formulae of some specific compounds only apply to the fresh acid before it is impregnated onto the support, and especially before it is subjected to the dehydration process conditions. The degree of hydration of the heteropolyacid may affect the acidity of the supported catalyst and hence its activity and selectivity. Thus, either or both of these actions of impregnation and dehydration process may change the hydration and oxidation state of the metals in the heteropolyacids, i.e. the actual catalytic species used, under the process conditions given, may not yield the hydration/oxidation states of the metals in the heteropolyacids used to impregnate the support. Naturally therefore it is to be expected that such hydration and oxidation states may also be different in the spent catalysts after reaction.

Suitable catalyst supports may be in a powder form or may be granules, pellets, spheres or extrudates and include, but are not limited to, Mordenites e.g. montmorillonite, clays, bentonite, diatomous earth, titania, activated carbon, alumina, silica-alumina, silica-titania cogels, silica-zirconia cogels, carbon coated alumina, zeolites, zinc oxide, flame pyrolysed oxides. Supports can be mixed oxides, neutral or weakly basic oxides. Silica supports are preferred, such as silica gel supports and supports produced by the flame hydrolysis of SiCl_4 . Preferred supports are substantially free of extraneous metals or elements which might adversely affect the catalytic activity of the system. Thus, suitable silica supports are at least 99% w/w pure. Impurities amount to less than 1% w/w, preferably less than 0.60% w/w and more preferably less than 0.30% w/w. The pore volume of the support is preferably more than 0.50ml/g, preferably more than 0.8 ml/g. The average pore radius (prior to use) of the support is 10 to 500Å, preferably 30 to 175Å, more preferably 50 to 150 Å and most preferably 60 to 120Å. The BET surface area is preferably between 50 and 600 m²/g and is most preferably between 150 and 400 m²/g. The preferred support has an average single particle crush strength of at least 1 kg force,

suitably at least 2 kg force, preferably at least 6 kg force and more preferably at least 7 kg force. The bulk density of the support is at least 380 g/l, preferably at least 395 g/l.

The single particle crush strength was determined by using a Mecmesin force gauge which measures the minimum force necessary to crush a particle between parallel plates.

5 The crush strength is based on the average of that determined for a set of 50 catalyst particles.

The BET surface area, pore volume, pore size distribution and average pore radius were determined from the nitrogen adsorption isotherm determined at 77K using a Micromeritics TRISTAR 3000 static volumetric adsorption analyser. The procedure used
10 was an application of British Standard methods BS4359:Part 1:1984 'Recommendations for gas adsorption (BET) methods' and BS7591:Part 2:1992, 'Porosity and pore size distribution of materials' - Method of evaluation by gas adsorption. The resulting data were reduced using the BET method (over the pressure range 0.05-0.20 P/Po) and the Barrett, Joyner & Halenda (BJH) method (for pore diameters of 20-1000 Å) to yield the surface
15 area and pore size distribution respectively.

Suitable references for the above data reduction methods are Brunauer, S, Emmett, P H, & Teller, E, J. Amer. Chem. Soc. 60, 309, (1938) and Barrett, E P, Joyner, LG & Halenda P P, J. Am Chem. Soc. , 1951 73 373-380.

Samples of the supports were out gassed for 16 hours @120°C under a vacuum of
20 5x10⁻³ Torr prior to analysis.

Suitable silica supports include, but are not limited to, GraceDavison G57, GraceDavison 1252, Grace Davison 1254, Fuji Silysia CariAct Q15, Fuji Silysia CariAct Q10, Aerolyst 3045 and Aerolyst 3043. The average diameter of the support particles is 2 to 10 mm, preferably 3 to 6 mm. However, these particles may be crushed and sieved to
25 smaller sizes of, for example, 0.5-2 mm, if desired.

A further embodiment of the said invention is where the chosen catalyst support is first treated with a fluorinating agent; the applicants believe that by fulfilling this said embodiment the catalyst will become more inert and/or acidic thus improving the selectivity and/or effectiveness of the catalyst during the aforementioned dehydration
30 process.

Figure 1 represents one embodiment of a process scheme according to the present invention. This said embodiment comprises optional and/or preferred process steps according to the present invention.

The letters used to depict the respective feedstocks/product streams correspond to the definitions given in the above text and appending claims.

In the claims which follow and in the preceding description of the invention, except where the context requires otherwise due to express language or necessary implication, the word "comprise" or variations such as "comprises" or "comprising" is used in an inclusive sense, i.e. to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the invention.

It is to be understood that, if any prior art publication is referred to herein, such reference does not constitute an admission that the publication forms a part of the common general knowledge in the art, in Australia or any other country.

Claims

1. Process for the production of ethylene from an ethanol feedstock A characterised by the following steps;

1. the ethanol feedstock A is reacted in a vapour phase reactor wherein the ethanol is converted at a temperature comprised between 160 and 270°C and at a pressure of above 0.1 MPa but less than 4.5 MPa, into a product stream B comprising ethylene, diethyl ethers, water and unconverted ethanol,
2. the said product stream B is cooled,
3. the said cooled product stream B is disengaged in a separation unit to give a first stream C comprising ethylene and diethyl ethers, and a second product stream D comprising water, diethyl ethers and unconverted ethanol,
4. the said product stream D is fed to a dewatering unit wherein the water stream F is separated from the diethyl ethers and unconverted ethanol stream E,
5. the said stream E is recycled into the dehydration reactor of step 1,
6. the said product stream C is cooled,
7. the said cooled product stream C is fed to a purification unit wherein the diethyl ethers stream G is separated from the ethylene stream H, and
8. optionally, the ethyl ethers stream G is recycled to either the dewatering unit of step 4 or directly to dehydration reactor of step 1.

2. Process for the conversion of hydrocarbon to ethylene comprising the steps of

- a) converting in a syngas reactor hydrocarbons into a mixture of carbon oxide(s) and hydrogen,
- b) converting the said mixture of carbon oxide(s) and hydrogen from step (a) in the presence of a particulate catalyst in a reactor under a temperature comprised between 200 and 400°C and a pressure of 5 to 20 MPa into an oxygenates feedstock comprising ethanol, and
- c) using at least part of said feedstock comprising ethanol as the ethanol feed A and proceeding according to steps 1 to 8 of claim 1 to produce the said ethylene.

3. Process according to any of the preceding claims wherein the oxygenates feedstock and/or the feedstock A have an iso-propanol content of less than 5wt%, preferably less than 1wt%, most preferably less than 0.1wt% and ideally contain no iso-propanol.
4. Process according to any of the preceding claims wherein the oxygenates feedstock and/or the feedstock A have a C3+ alcohols content of less than 5wt%, preferably less than 1wt%, most preferably less than 0.1wt% and. ideally contain no C3+ alcohols.
5. Process according to any of the preceding claims wherein the oxygenates feedstock and/or the feedstock A have a methanol content of less than 5wt%, preferably less than 2wt%, most preferably less than 0.5wt% and ideally contain no methanol.
6. Process according to any of the preceding claims wherein the ethanol, the di-ethyl ether and the water represent at least 90 wt %, preferably at least 99wt% of the ethanol feed A introduced into the vapour phase dehydration reactor.
7. Process according to any of the preceding claims wherein the ethanol feed A comprise at least 10wt%, preferably at least 15 wt%, preferably at least 30wt%, and most preferably at least 50wt% ethers but less than or equal to 85wt% ethers; said ethers being diethyl ether and optionally di n-propyl ether, and/or n-propyl isopropyl ether and/or di iso- propyl ether.
8. Process according to any of the preceding claims characterized in that the ethanol feed A comprises less than 5wt%, preferably less than 1wt%, most preferably less than 0.1wt% of Cl ethers and/or C3+ derived ethers and ideally there are no Cl and/or C3+ derived ethers present.
9. A process for the production of ethylene from an ethanol feedstock A substantially as herein described with reference to Figure 1.

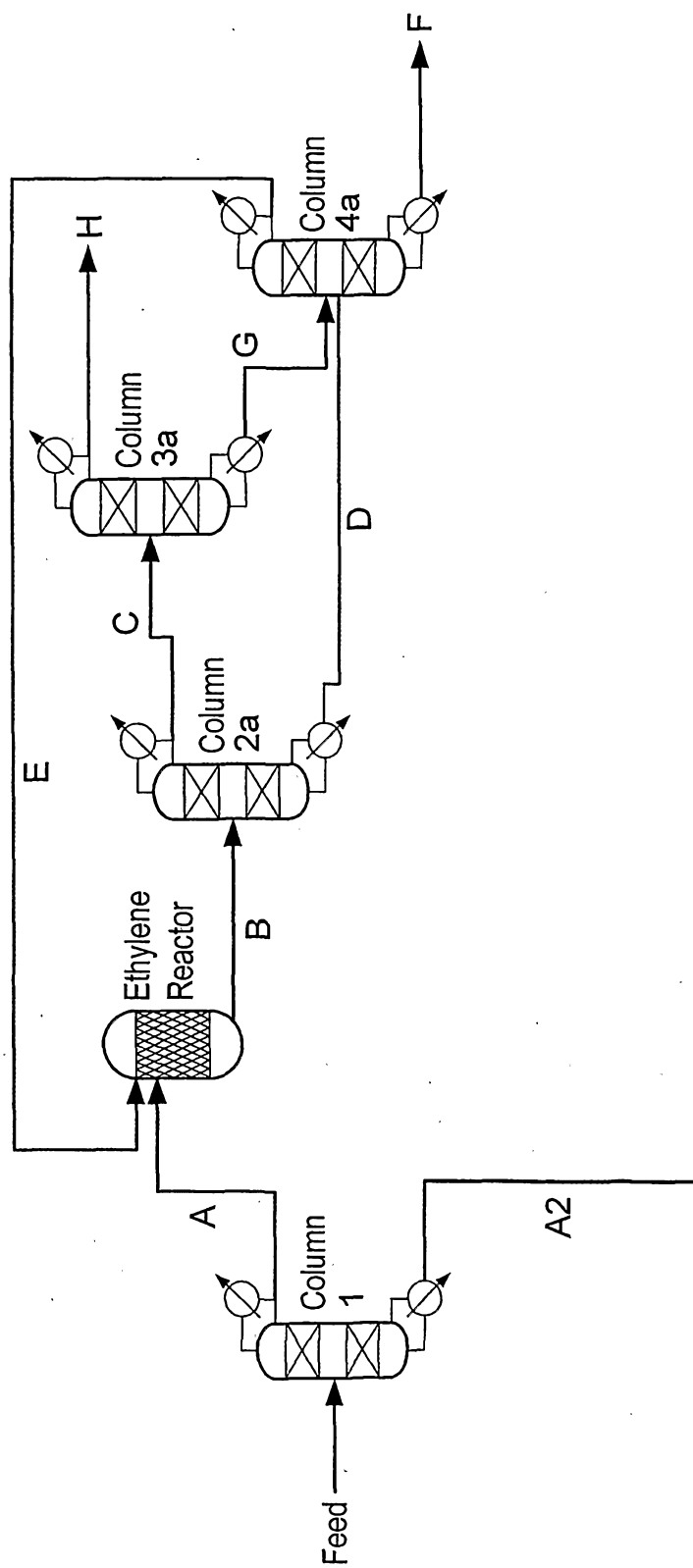


Fig.1