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Review

Challenges and opportunities in improving the production of bio-ethanol

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ABSTRACT

Bio-ethanol, as a clean and renewable fuel, is gaining increasing attention, mostly through its major environmental benefits. It can be produced from different kinds of renewable feedstock such as e.g. sugar cane, corn, wheat, cassava (first generation), cellulose biomass (second generation) and algal biomass (third generation). The conversion pathways for the production of bio-ethanol from disaccharides, from starches, and from lignocellulosic biomass are examined. The common processing routes are described, with their mass and energy balances, and assessed by comparing field data and simulations. Improvements through 5 possible interventions are discussed, being (i) an integrated energy-pinch of condensers and reboilers in the bio-ethanol distillation train; (ii) the use of Very High Gravity (VHG) fermentation; (iii) the current development of hybrid processes using pervaporation membranes; (iv) the substitution of current ethanol dewatering processes to >99.5 wt% pure ethanol by membrane technology; and (v) additional developments to improve the plant operation such as the use of microfiltration of the fermenter broth to protect heat exchangers and distillation columns against fouling, or novel distillation concepts.

Whereas the benefits of introducing these techniques are recognized, extensive research is still needed to scientifically and economically justify their application. The paper finally presents a tentative economic assessment, with production costs not only depending on the extent of applying process improvements, but also on the raw material used in the process.

Contents

1. Bio-ethanol: characteristics and worldwide potential 61
1.1. Ethanol and its characteristics 61
1.2. Worldwide production and research importance 62
1.2.1. The recognized potential of bio-ethanol 62
1.2.2. The different “generations” of bio-ethanol production 63
2. The uses of bio-ethanol 64
2.1. Generalities 64
2.2. The uses of bio-ethanol as fuel and feedstock in chemicals' synthesis 67
3. Bio-ethanol production 68
3.1. Major raw materials 68
3.2. Main steps in biomass-to-ethanol processes 70
3.3. Bioethanol from disaccharides- and starch 70
3.4. Lignocellulosic biomass-to-ethanol 70
3.5. Fermentation of hexoses and pentoses 71

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0360-1285/

3.6. The problem of ethanol-inhibition in the first generation feedstock fermentation 72
4. Traditional processing routes 73
4.1. Integrated saccharification/fermentation processes versus two-step processes 73
4.2. Basic data and energy requirement of the process 75
4.2.1. Fermentation broth 75
4.2.2. Simulation in Aspen Plus of the basic concept (no internal energy recycle) 75
5. Process improvements 75
5.1. Energy integration within the current production processes 75
5.2. The use of VHG fermentation: principles and application results 75
5.2.1. Introduction of very high gravity (VHG) fermentation 75
5.2.2. Effect of implementing VHG on the distillation thermal requirements 76
5.3. The development of hybrid (pervaporation) systems 77
5.3.1. Introduction of hybrid operations 77
5.3.2. Effect of implementing pervaporation on the distillation thermal requirements 77
5.4. Overall assessment 77
5.5. The process of final ethanol dewatering to fuel grade 78
5.5.1. Introduction 78
5.5.2. Major processes 79
5.5.3. Production of anhydrous ethanol using hydrophilic membranes 80
5.6. Additional developments 81
5.6.1. Cross-flow microfiltration of bio-ethanol fermentation broth 81
5.6.2. Novel distillation concepts 82
5.6.3. The improved bio-ethanol production plant 83
6. Preliminary economic assessment 83
7. Conclusions 83
Acknowledgments 84
References 84

1. Bio-ethanol: characteristics and worldwide potential

1.1. Ethanol and its characteristics

Ethanol or ethyl alcohol (CH_3CH_2OH) is a colorless, volatile and flammable liquid, with molecular weight of 46.07 g and density of 789 kg/m^3 at 294 K. Thermal properties are given in Table 1.

It burns with a smokeless blue flame, generally invisible in normal light.

The auto-ignition temperature is the lowest temperature at which ethanol will spontaneously ignite in a normal atmosphere without an external source of ignition, such as a flame or spark.

Mixtures of water and ethanol are important throughout the bio-ethanol process. The knowledge of mixture flash points, as presented in Fig. 1, is needed for their safe handling, storage and transportation: the flash point is one of the most important physical properties used to determine the potential for fire and explosion hazards of liquids, used for the classification and labeling of dangerous substances and preparations. The flash point of a given liquid is the experimentally determined temperature adjusted to standard temperature and pressure at which a substance emits sufficient vapor to form a combustible mixture with air. A lower flash point value indicates that a given liquid is more hazardous relative to a different liquid with a higher value.

The physical properties of ethanol result from the presence of both the hydroxyl group and the shortness of the carbon chain. The hydroxyl group is prone to hydrogen bonding, making ethanol more viscous and less polar than organic compounds of similar molecular weight. Ethanol is moreover miscible with water (unlike > C_3 alcohol) and with many organic solvents, e.g. acetic acid, acetone, ether, ethylene glycol, glycerol, and toluene [1,2]. It is also miscible with light aliphatic liquids, such as C_5H_{12} and C_6H_{14}, and with chlorinated aliphatics such as CH_3CCl_3 and $Cl_2CH{-}CHCl_2$ [2]. Mixing ethanol and water is slightly exothermic, releasing ~0.78 kJ/mol [3] at 298 K. Mixtures of ethanol and water at atmospheric pressure form an azeotrope of ~89 mol% ethanol and ~11 mol% water [4] at a temperature of 351 K. This azeotropic behavior is a pronounced function of temperature and pressure and vanishes at temperatures below 303 K or pressures below about 10 mbar [5].

Table 1
Primary properties of ethanol.

Boiling point	351.37 K
Flash point	289.6 K
Auto-ignition temperature	698 K
Heat of combustion	26,800 kJ/kg

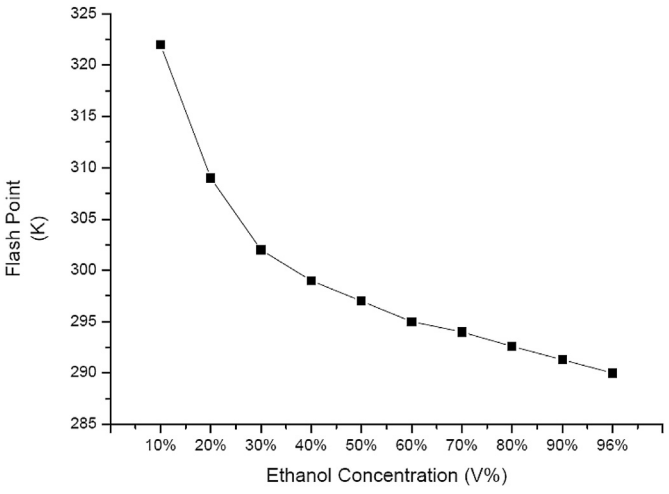

Fig. 1. Flash points of ethanol–water mixtures.