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Simultaneous saccharification and fermentation process for ethanol production from steam-pretreated softwood: Recirculation of condensate streams

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HIGHLIGHTS

- Effect of condensate streams recirculation on the ethanol yield was investigated.
- Recycling of condensate stream exhibits no effect on ethanol yield or productivity.
- Recycling of condensate stream replaced totally the addition of fresh water.
- The proposed configuration diminishes the problem of lactic acid production.

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ABSTRACT

Wastewater from fuel ethanol production plant represents a considerable potential pollutant. Treatment is an essential operation in the overall conversion of lignocellulosic to ethanol. This significantly reduces the effluent volume, and reduces the need of fresh water. Present work concerns a simultaneous saccharification and fermentation (SSF) process for ethanol production from steam-pretreated softwood. Within this process, the effect of recirculation of the condensate from the evaporation of the stillage stream was investigated. The condensate employed in this study represents the condensate of four evaporators connected in series, with each evaporator producing a condensate corresponding to 14% of the process stream after distillation of the SSF broth. The investigation demonstrated that it was possible to replace 100% of the fresh water used in the process (except for the steam used in the pretreatment), by recirculation of all the condensate fractions together, without affecting the ethanol yield and the productivity in SSF. A significant factor was the absence of lactic acid production, which is sometimes observed when the pretreated material is diluted with fresh water. The prospect of using condensate to replace fresh water offers an attractive means of reducing the cost of wastewater management and thereby improving the overall economic feasibility of the process.

1. Introduction

The search for a low-cost, high-yield process for producing renewable fuel has been the subject of intensive research over the past two decades. Fuel ethanol derived from lignocellulosic materials, such as softwood, has been shown to be an attractive substitute for fossils fuels [1]. A wide variety of process parameters, such as enzyme and substrate loading, has been optimised to achieve high ethanol yield resulting in lower production costs [2–5]. However, despite the significant industrial development and tremendous research work on biofuel production from lignocellulosic feedstock, the process is not yet at a commercial scale. Successful biofuel enterprise depends very much on multiple factors such as technology innovation, technical feasibility, economical possibility, governmental policy and environmental regulations [6]. Technical evaluation of detailed process specification is the first step to be considered including various process step such as feedstock logistics, pre-treatment, chemical conversion, biological conversion, and downstream processing [7]. Synergy and possible integration of all step is very essential to make full demonstration of the whole process such as integration of process stream [8]. Validation of demonstration process, with solid economical modelling is inevitable step prior lunching the biofuel production in the industrial scale [9]. There are a number of key-demo plants for biofuel production from cellulosic feedstock; however, the process

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economic viability remains the main challenge. Commercially, ethanol/butanol is produced from edible sugars and there is a hope there will be a feedstock transition to cellulosic in a couple of years.

It is possible technically to produce ethanol/butanol from sugar obtained from pretreatment of lignocellulosic feedstock. However, reaching the highest product yield is governed by multiple factors such as physical and chemical structure of feedstock, pre-treatment conditions and fermentation process configuration [10]. The bottle neck of the whole process is the pretreatment process which still not matures and it exists only in a demo or pilot scale facility. The main challenge of this technology is the lose/degradation of sugars which subsequently decrease the final yield and the generation of inhibiting substances which influence the fermentability of the given feedstock and subsequently increase the operation cost [11]. The technology also require addition of fresh water in the form of steam to heat up the reactors, as well as addition of fresh water to dilute the generated sugar solution in order to obtain the proper concentration for microbial fermentation. This will lead defiantly in accumulation of a considerable wastewater amount within the process.

The wastewater from fuel ethanol production plant represents a considerable potential pollutant; it must therefore be treated before being discharged [12]. The largest wastewater stream is that obtained as a stillage from the distillation step. This stream contains water-soluble inhibitors, which are generated mainly during the pretreatment of the raw material, including sugar degradation compounds and lignin-based compounds, comprising furans, e.g. furfural and hydroxymethylfurfural (HMF) and aromatic compounds [13–16]. Aromatic compounds obtained in the steam-explosion pretreatment step have been identified as being potentially inhibitory to yeast fermentation [13]. The nature of these inhibitors and their inhibition potential vary greatly with pretreatment conditions, and the chemical structure of the raw material. Wastewater treatment is an essential operation in the overall conversion of lignocellulosic to ethanol. This significantly reduces the effluent volume, and reduces the need of fresh water.

Currently available treatment processes are anaerobic digestion, aerobic biological treatment, evaporation followed by incineration and physical/mechanical separation [6]. However, wastewater treatment technologies for bioethanol plants add additional cost for the process in terms of capital investment and the running cost. Such technologies are limited for bioethanol plants utilising edible sugars feedstock, rather than those based on cellulosic feedstock [17].

Internal process stream recirculation before and after distillation is an interesting option to replace the use of fresh water. This configuration, assuming there is no influence on the ethanol yield, might save energy consumption both in the distillation of the fermentation broth and in the evaporation of the stillage stream [18–20]. However, the problem remains that the consecutive recirculation leads to the accumulation of various substances in SSF. Galbe and Zacchi [19] showed that stream recirculation increases the concentration of non-volatiles tenfold in different locations of the process. Palmqvist et al. [20] showed that the non-volatile substances released during steam pretreatment of willow inhibited the growth of yeast fermentation. A recent study showed that distillery water decreased the ethanol yield, but the problem was tackled by treating the waste stream with bio-flocculation process [21]. It is also possible to combine internal stream recirculation with anaerobic treatment of the stillage [22,23]. In the downstream processing, evaporation is the most conventional and effective way to diminish the build-up of non-volatile inhibitors in the condensate streams. In the evaporation unit, the stillage is concentrated into a relatively small stream containing the non-volatile compounds [12]. The concentrated stillage is taken to an incineration step together with a fraction of the lignin to generate heat and electricity for the process. The condensate streams contain low amount volatile substances [12] and could be used to replace fresh water in various process steps that require water addition, provided they do not affect the process.

The schematic flowsheet in Fig. 1 gives an overview of a simplified description of a possible process configuration for the production of ethanol from softwood. The steam-pretreated,

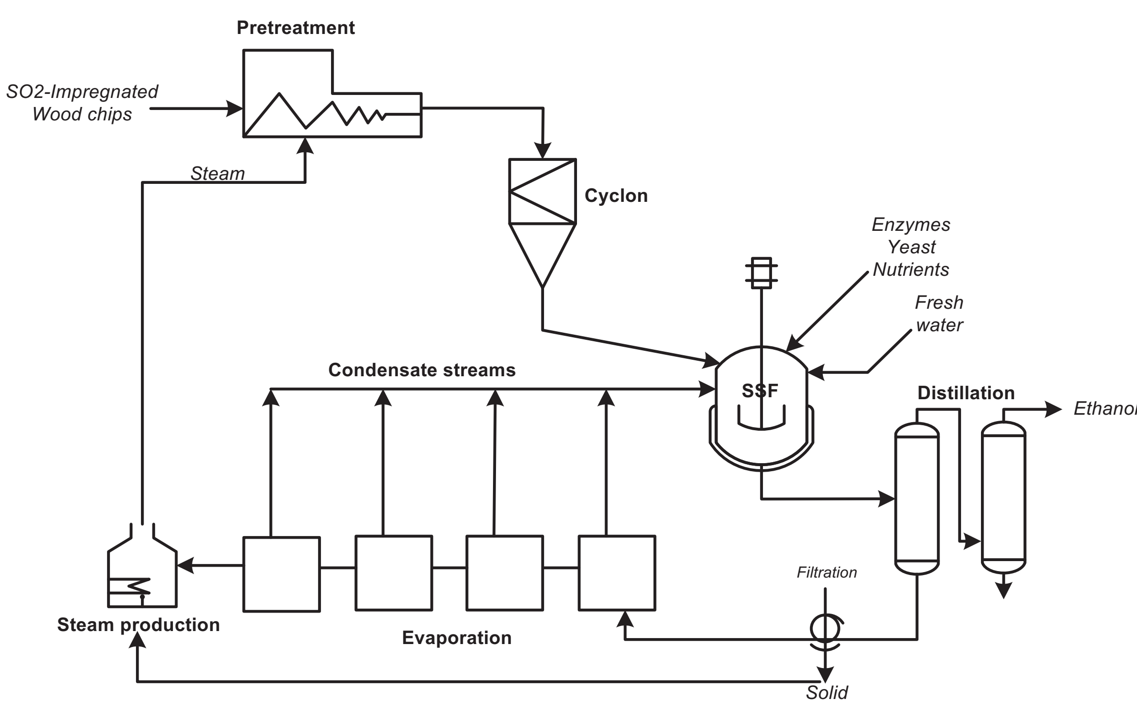

Fig. 1. Schematic flowsheet showing ethanol production based on SSF with recirculation of different condensate fraction.