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Process intensification in lactic acid production: A review of membrane based processes

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ABSTRACT

Lactic acid the most widely occurring hydroxy-carboxylic acid has traditionally been used as food preservative and acidulent. So long, it has been produced through either chemical synthesis route or fermentation route the latter being the dominating one. Despite its tremendous potential for large scale production and use in a wide variety of applications, cost-effective production of high purity lactic acid has remained a challenge for decades, mainly due to high downstream processing cost. In the recent years, possibility of integration of highly selective membranes with the conventional fermentors has opened a golden opportunity for full commercial exploitation of the tremendous application potential of this wonder chemical. This paper discusses recent developments of such membrane-based processes representing process intensification in production of monomer grade lactic acid while suggesting a very promising production scheme.

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1. Introduction

The chemical and the allied process industries all over the world are now confronted with the big challenges of developing innovative products and processes for survival in an era of emaciated profit margins amidst highly globalized trade competition and fast growing environmental constraints. Thus process intensification through revolutionary development of new products and processes that ensure reduced material and energy consumption and reduced environmental impacts while offering greater flexibility in scale of operation are the need of the hour. Production of monomer grade lactic acid (2-hydroxypropanoic acid) a traditionally used food preservative and acidulent has over the last few decades, attracted attention of the world researchers.

By virtue of unique presence of both hydroxyl and carboxylic acid groups, lactic acid can participate in a wide variety of chemical reactions like esterification, condensation, polymerization, reduction and substitution and this has contributed to its tremendous potential as a platform chemical for a whole range of products that have very large-volume uses for industrial production and consumer products. Biodegradable thermoplastics (polylactic acid), green solvents (ethyl, propyl, butyl lactates) and oxygenated chemicals (propylene glycol) are a few examples of lactic acid-derived products, market demands of which are growing exponentially over the years [1]. Exploitation of its full potential, however, depends largely on how cost-effectively it can be produced with high levels of purity. The major technology barrier in cost-effective production of high purity lactic acid is its down-stream separation and purification. And this is where; membrane-based processes are stepping in. Being modular in design, membrane-based processes offer great flexibility in scale of production depending on market demand. By virtue of high selectivity, membranes can ensure high levels of separation and purification. As membranes of chosen selectivity and permeability can easily be integrated with conventional fermentors, membrane-based processes permit simultaneous production and purification in the same unit. This eliminates the need for separate purification units and results in compact design with reduced capital investment. Membrane-based separation and purification (barring pervaporation) involves no phase change ensuring reduced energy consumption. Thus such processes can meet all the goals of process intensification. In this paper, we first briefly discuss the traditional processes to highlight the major problems associated with these processes and then review the developments in membrane-based processes which have attempted to overcome the problems of traditional processes. The objective is to identify an environmentally benign, simple, economically viable and continuous manufacturing scheme capable of producing monomer grade lactic acid with high productivity.

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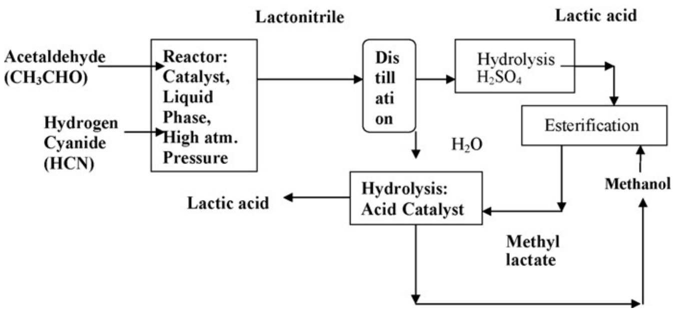

Fig. 1. Lactic acid production scheme in chemical synthesis route using acetaldehyde feed.

2. Traditional production process

Traditionally lactic acid has been produced through either chemical synthesis route or fermentation route. Chemical synthesis route as shown in Fig. 1 uses by-products like lactonitrile from other industries. Hydrogen cyanide (HCN) is added to acetaldehyde (CH_3CHO) in liquid phase in presence of a base catalyst under high pressure when lactonitrile is produced. Crude lactonitrile is then purified by distillation and subsequently hydrolyzed to lactic acid by hydrochloric acid or sulphuric acid [2]. The process is often dependent on other by-product industries and, considered expensive where petroleum based raw material is the major cost-contributor. Moreover, chemical synthesis route produces a mixture of L-lactic acid and D-lactic acid whereas in most of the cases, L-lactic acid is the desirable product. The problems of high cost of raw materials, impurity of the product and dependence on other industries for raw materials could be overcome in fermentation based process. Thus majority of the big lactic acid manufacturing industries like Musahino chemical in Japan,

Table 1
Widely used substrates in fermentation-based lactic acid production.

Substrates	Reference
Whole-wheat powder	[3]
Starch	[4]
Cucumber juice	[5]
Cheese whey	[6]
Sugarcane bagasse cellulose	[7]
Molasses	[8]
Sugar cane juice	[9]

CCA Biochemical BV of the Netherlands, Natureworks LLC etc. have switched over to fermentation based technology as presented in Fig. 2. The scheme consists of a number of downstream treatment schemes like precipitation, conventional filtration, acidification, carbon adsorption, evaporation etc. Though possible carbon sources may be numerous, mainly the cheap and renewable carbohydrates as shown in Table 1 are used as the source of carbon and produces optically pure form of lactic acid [3]. The substrates are chosen on the basis of their cost, levels of contaminants, fermentation rate, lactic acid yields, by-product formation, and ability to be fermented with little or no pretreatment and year round availability. Substrate cost is one of the major current problems. Downstream purification needs are closely related to the nature of these substrates, their degree of conversion and the reagents or microbes involved in the conversion process along with other factors. The most widely used substrates for production of lactic acid are glucose, sucrose and lactose which are soluble carbohydrates [4]. Cucumber juice (CJ) is also a good substrate for production of lactic acid as it contains malic acid with glucose and fructose where malic acid is very rapidly converted to lactic acid. Molar yield of lactic acid from CJ were found to be 11.2 [5]. Cheese whey, a by-product from cheese manufacturing industry is also used as substrate for production of lactic acid as it contains huge

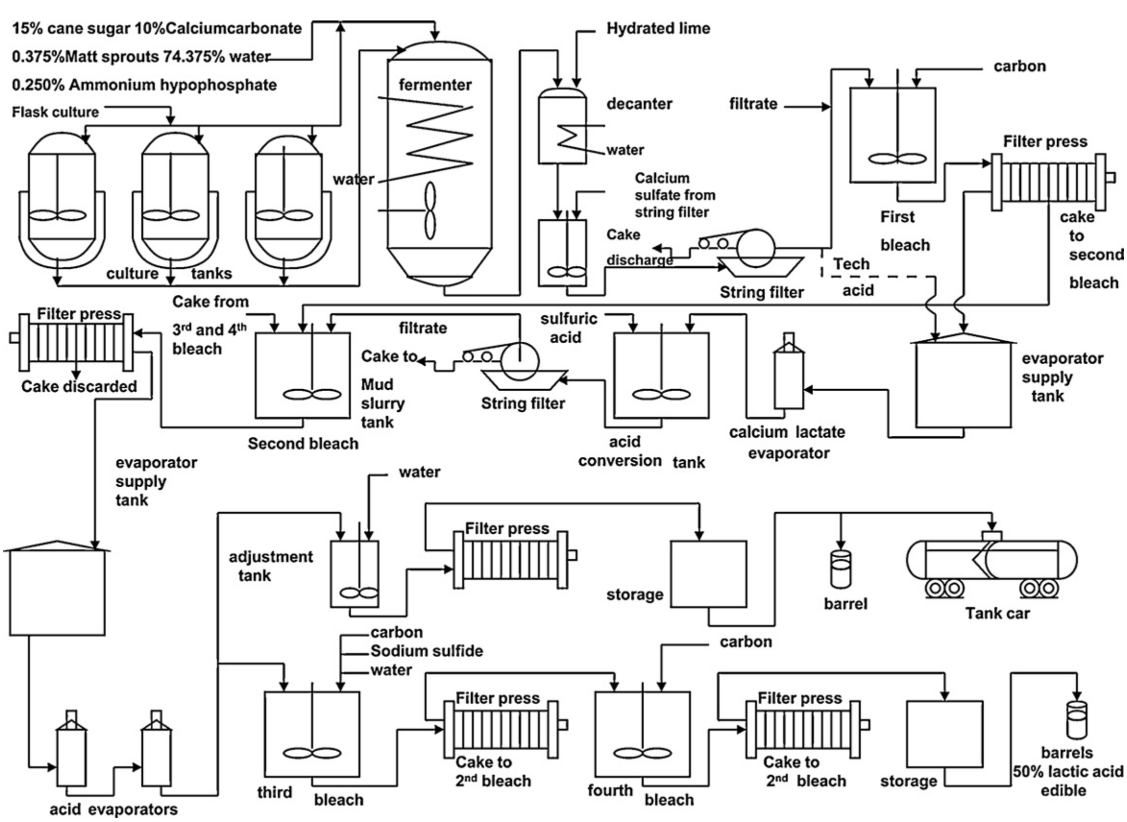

Fig. 2. Typical conventional fermentation-based lactic acid production scheme.

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