Journal of Environmental Management xxx (2017) 1–6

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Process model economics of xanthan production from confectionery industry wastewaters

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A R T I C L E I N F O

Article history:
Received 30 December 2016
Received in revised form
19 August 2017
Accepted 30 August 2017
Available online xxx

Keywords:
Economic analysis
Process model
Xanthan
Wastewater treatment
SuperPro Designer

A B S T R A C T

In this research a process and cost model for a xanthan production facility was developed using process simulation software (SuperPro Designer®). This work represents a novelty in the field for two reasons. One is that xanthan gum has been produced from several wastes but never from wastewaters from confectionery industries. The other more important is that the aforementioned software, which in intended exclusively for bioprocesses, is used for generating a base case, i.e. starting point for transferring the technology to industrial scales. Previously acquired experimental knowledge about using confectionery wastewaters from five different factories as substitutes for commercially used cultivation medium have been incorporated into the process model in order to obtain an economic viability of implementing such substrates. A lower initial sugar content in the medium based on wastewater (28.41 g/L) compared to the synthetic medium (30.00 g/L) gave a lower xanthan content at the end of cultivation (23.98 and 26.27 g/L, respectively). Although this resulted in somewhat poorer economic parameters, they were still in the range of being an investment of interest. Also the possibility of utilizing a cheap resource (waste) and reducing pollution that would result from its disposal has a positive effect on the environment.

1. Introduction

Xanthan gum, as the first industrially produced biopolymer, was discovered in the late 1950s and since then, the demand for the xanthan has progressively increased, at an annual rate of 5–10% (Moshaf et al., 2014). Because of its unique structure, xanthan displays special pseudoplastic properties, high viscosity and solubility, enhanced stability over a wide range of pH values and temperatures, as well as compatibility with many salts, food ingredients and other polysaccharides used as thickening agents. These characteristics contribute to the employment of xanthan in a wide range of applications especially in the food industry cosmetics, paper milling, textiles and the pharmaceutical sector and also in enhanced oil recovery (Xin et al., 2015). The world market of xanthan is expected to rise significantly in the next decade and reach the value of 987.7 million US dollars by the year 2020, according to the *Xanthan gum market size, share, trends, global industry report* (2015) of the *Grand View Research Inc.* due to its increasing use in the aforementioned industries.

For the efficient production of xanthan gum, the producing microorganism, *Xanthomonas campestris* needs several nutrients, including micronutrients (e.g. potassium, iron, and calcium salts) and macronutrients such as carbon and nitrogen (Silva et al., 2009). The synthetic media used for xanthan production contain glucose or sucrose as carbon sources and therefore their cost represents a critical factor in the xanthan production process from an economic perspective (Li et al., 2017). Hence, using a medium with a low cost carbon source can reduce the price of the final product (Yoo and Harcum, 1999), which is why different food industry effluents and agricultural waste have been suggested as alternative carbon sources (Gunasekar et al., 2014).

Keeping in mind the characteristics of processed raw materials and operating conditions, food industry wastewaters, including confectionery industry wastewaters, are most easily utilized for the biotechnological production of several different high value products, such as xanthan gum (Bajić et al., 2014). Many industrial wastewaters contain notably higher organic matter loading and undesirable inorganic and organic pollutants compared to natural aquatic environments. The food processing industry in general

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http://dx.doi.org/10.1016/j.jenvman.2017.08.055
0301-4797/

faces a problem of large amounts of wastewaters, which if not treated have an extremely negative influence on the environment (Yang et al., 2015). Therefore, the reduction of pollution has a high priority, and is achieved by using technologies which maximally utilize raw materials, generate minimal amounts of waste and use secondary raw materials. It is of great importance to reuse and recycle liquid industrial wastewaters in other technological processes, since fresh and unpolluted water resources are limited. Aforementioned approaches are highly beneficial because wastewaters of one industry become useful raw material for another industry (Kosseva, 2013).

Rheological properties and yield of this biopolymer greatly depend on the cultivation medium used for its production (Garcia-Ochoa et al., 2000) and it is necessary to use its adequate composition and operating conditions in order to obtain an economically feasible process.

Niknezhad et al. (2016) examined the effect of xanthan gum production by free and immobilized cells of *Xanthomonas campestris*. Although they came to a conclusion that immobilized cells are advantageous over the free cells, still there is no record of industrial xanthan production by immobilized cells, i.e. the technology is still at the laboratory level. That is why free cell cultivation has been chosen for this work. There have been several attempts on cultivating *Xanthomonas campestris* on different substrates based on waste such as kitchen waste (Li et al., 2017), wasted food and food residues (Oldfield et al., 2016), etc., but there is very little data about producing xanthan from confectionery industry wastewaters (Bajić et al., 2014). There have also been numerous combinations of using starch processing wastewater for generating a plant for fungal biomass protein (Jin et al., 2002), using SuperPro Designer software for generating other biotechnological processes (Innocenzi et al., 2016), but never before has a xanthan production process on confectionery industry wastewaters been modeled by SuperPro Designer.

Therefore, the aim of this research was to design and compare the xanthan production process that utilizes synthetic cultivation media and media based on wastewaters obtained from different parts of the confectionery production process. It is expected that the results of this comparative analysis will indicate the critical points of the production process so further research can be directed toward improving the results of these segments and the productivity of the entire process. This is achieved by using scientific software constructed mainly for this purpose, i.e. for modeling biotechnological processes. This work also describes the economics of the xanthan production process and compares different operating and cost conditions. The model developed can also be used to estimate the production cost of xanthan at various conditions.

2. Materials and methods

2.1. Process overview

The process and cost models were developed using SuperPro Designer® software (Intelligen Inc., Scotch Plains, NJ). The defined process flowsheet of the xanthan production process is shown in Fig. 1.

Among different food and beverage industry wastewaters, wastewaters obtained from the confectionery industry represent a potential raw material for biotechnological production of xanthan, considering their organic and inorganic content suitable for this type of processes. As the cultivation medium in this process, wastewaters obtained from five different domestic confectionery industry factories are blended together in a storage tank (P-07), shown in Fig. 1, from where they are sent to the sterilization (P-08). In order to estimate the efficiency of the xanthan production process using wastewaters as cultivation medium, the same process is evaluated using a synthetic, glucose based cultivation medium. The sterilized cultivation medium (S-10) is then transferred to a bioreactor (P-09) and inoculated with the appropriate amount of *Xanthomonas campestris* inoculum. The inoculum is prepared using one test tube (P-01), two shake flasks (P-02 and P-03) and three reactors (P-04, P-05 and P-06) each containing a ten times higher medium volume than the previous one.

After xanthan biosynthesis, in both processes (with synthetic or wastewater medium), the obtained cultivation broth is first pasteurized (P-10) and then sent to centrifugation (P-11) for the separation of biomass. The liquid fraction (S-12) is precipitated (P-12), using ethanol and saturated solution of KCl, after which the xanthan is separated using a centrifuge (P-13) and spray-dried (P-14) to obtain the final product. The liquid fractions (S-15) of the second centrifugation operation (P-13) as well as the liquid fraction (S-22) obtained in the spray-drier (P-14) are mixed (P-15) and sent to distillation (P-16) in order to recover ethanol that is used for xanthan precipitation (P-12). The solid fraction (S-13) obtained after the first centrifugation (P-11), mostly containing bacterial cells, together with the stillage (S-18) obtained after ethanol distillation (P-16) are mixed (P-17) and sent to further processing in the evaporator (P-18) and dryer (P-19) in order to obtain a value-added product, used as animal feed.

2.2. Process design

Input data and data on operating conditions of the examined process are obtained from experiments and literature, while equipment and process data are obtained directly from the SuperPro Designer software.

The inoculum of *Xanthomonas campestris* ATCC 13951 is prepared in several steps, firstly by using test tubes containing yeast maltose agar (YMA), secondly by using two shake flasks containing 200 mL and 2 L of maltose agar broth (YMB), and finally by using the 20 L and 200 L reactors containing YMB. From there the inoculum is transferred to a reactor containing 2000 L of wastewater as medium and the obtained inoculum is used for inoculating the bioreactor containing confectionary industry wastewater as the cultivation medium. In the process with synthetic medium, the 2000 L inoculum reactor also uses synthetic medium. The initial pH value of all cultivation media used is set to 7.0. Each step in the inoculum preparation phase is carried out on 26 °C with a mixing speed of 200 rpm (flasks with external, while bioreactors with internal mixing – two Rushton 6 blade turbine mixers) during 24 h. Since the producing strain is an aerobic microorganism air is supplied into the flasks and bioreactors of the inoculation section with an aeration rate of 1 vvm. Inoculation of the succeeding vessel (flask or bioreactor) is accomplished by transferring the entire cultivation broth from the previous vessel.

The cultivation medium requirement for the plant is 20,000 L per batch, which is obtained by dividing the available amounts of confectionery industry wastewaters with the maximum number of batches per year predicted by the model. The composition of the cultivation medium based on wastewaters blended together is 28.41 g/L of sucrose and 0.07 g/L of total nitrogen, while the synthetic media contains 30.00 g/L of glucose, 0.2 g/L of nitrogen (yeast extract and $(NH_4)_2SO_4$ in 2:1 ratio), 0.25 g/L K_2HPO_4 and 0.5 g/L $MgSO_4 \cdot 7H_2O$. After necessary preparation in blending/storage tank, the cultivation medium is sent to sterilization (140 °C, 20 min), and then to the bioreactor. Xanthan biosynthesis is conducted in one 27,284 L (6.8 m height and 2.3 m diameter) vessel. The bioprocess is carried at a temperature of 30 °C, mixing speed 200 rpm and the rate of aeration 1 vvm during 72 h. After biosynthesis the obtained xanthan yield is 23.98 g/L and 26.27 g/L for wastewater based