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SHORT NON-REFEREED PAPER

SUGARCANE JUICE CONCENTRATION USING GAS HYDRATE TECHNOLOGY

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Introduction

Various treatment methods (evaporation (Madaeni and Zereshki, 2010), membrane (Gul and Harasek, 2012) and freezing separation technologies (Sahasrabudhe *et al.,* 2012)) are used to concentrate sugarcane juice. In the processing of sugarcane to produce sugar crystals, the clarified juice is concentrated in a multi-effect evaporator train to 60°Brix sucrose; however, the juice is very sensitive to heat, which can alter its colour and flavour. The use of membranes is a developing technology whereby juice can be concentrated up to 70°Brix sucrose, however, capacity and downtime for cleaning and maintenance are some of the drawbacks. Freezing is another developing technology, applicable to sensitive materials, with reported concentrations of up to 20-40°Brix solids. This, however, results in high energy costs and lengthy processing time.

Clathrate hydrates are crystalline water-based solids physically resembling ice, in which small non-polar molecules (typically gases) or polar molecules with large hydrophobic moieties are trapped inside 'cages' of hydrogen bonded, frozen water molecules. The host molecule is water and the guest molecule is typically a gas or liquid. By creating a clathrate, the initial feed is concentrated with solids, thereby reducing the water content (Sloan Jr and Koh, 2007).

Gas hydrate separation is an emerging technology which concentrates fruit juice by trapping the moisture in water cages. The advantages, drawbacks, and feasibility of the different separation methods of juice concentration have been investigated. Few researchers have investigated sucrose concentration using gas hydrate-based technology. Chun and Lee (1999) studied the phase equilibria of the sucrose and fructose solution in the presence of R22 and CO_2, showing the inhibition effect of sugar species by 0.8 K. Andersen and Thomsen (2009) constructed a test rig which showed a concentration effect of 35 (from 12) °Brix feed. The deficiencies in the study were inadequate sample withdrawal and inefficient stirring. Smith *et al*. (2016) performed an experimental and modelling study on the phase equilibria of sucrose in the presence of several refrigerants confirming the inhibition effect of the sugar species.

This short paper presents the design of a new hydrate reactor for the formation of hydrate crystals in sugar solutions, followed by the removal of a sample of concentrated solution for analysis. The concentration of sucrose solutions and sugarcane juice was investigated using the gas hydrate of CO_2. In both cases, samples were withdrawn, and brix analyses performed, and the pH of the sugarcane juice samples measured.

Materials and method

Carbon dioxide (CO_2; CAS Number: 124-38-9) and sucrose ($C_{12}H_{22}O_{11}$; CAS Number: 57-50-1) were purchased from Afrox and Sigma Aldrich, respectively and sugarcane juice was supplied by the Sugar Milling Research Institute NPC (SMRI). Distilled water was used to prepare the sucrose solution.

Results and discussion

Phase equilibria and kinetic measurements of CO_2 and sucrose (up to 35°Brix) + water system were measured to obtain the phase boundary and hydrate formation rate. This was followed by concentration measurements with sample withdrawal of the concentrated juice. The effects of several parameters including initial temperature and pressure, mixer speed, and mesh size were tested on the concentration of sucrose to obtain the optimum conditions. These three stages were required to concentrate the sucrose from 12 to 59.98°Brix at the temperature, pressure, and mixer speed of 1.5°C, 3.7 MPa, and 130 rpm, respectively. The mesh size used in first two stages to separate the juice form crystals was 26 µm with four hours of process time required while the last stage was performed using 10 µm mesh size and 12 hours of process time.

Thereafter concentration measurements were performed using sugarcane juice supplied by the SMRI. Regarding the sensitivity of the materials to storage time, experiments were carried out as quickly as possible with samples being stored in the fridge when unused. The experiments were performed in the optimum operating conditions obtained from previous tests on sucrose. The results from these concentration measurements showed that a four-stage hydrate process can achieve a final product concentration of 56.20°Brix at the temperature, pressure, mesh size, and mixer speed of 1.5°C, 3.7 MPa, 26 µm, and 130 rpm, respectively. The times required for the stages 1 to 4 were 4, 4, 7 and 15 hours, respectively.

Furthermore, considering just the first concentration step, (at a temperature of 1.5°C and pressure of 3.7 MPa) a final brix of 30.10°Brix from 12°Brix sugarcane juice was achieved. Comparing this to the evaporation multi-effect process, the concentration effect over the first three effects yields 28°Brix (Hugot, 2014). Figure 1 shows the conceptual hydrate process for sugarcane juice concentration using CO_2 gas hydrate formation at the optimum operating condition.

Concluding remarks

In conclusion, new experimental equipment was designed and commissioned that was able to withdraw a sample from the hydrate juice. Experimental measurements were performed for sucrose solution at the concentrations up to 60°Brix with optimum conditions for temperature, pressure, mesh size, and mixer speed of 1.5°C, 3.7 MPa, 26 µm, and 130 rpm, respectively. Thereafter, measurements were performed with cane juice solution at the same conditions. The experimental results demonstrate the use of hydrate technology to concentrate the cane juice up to approximately 56.20°Brix in four stages.

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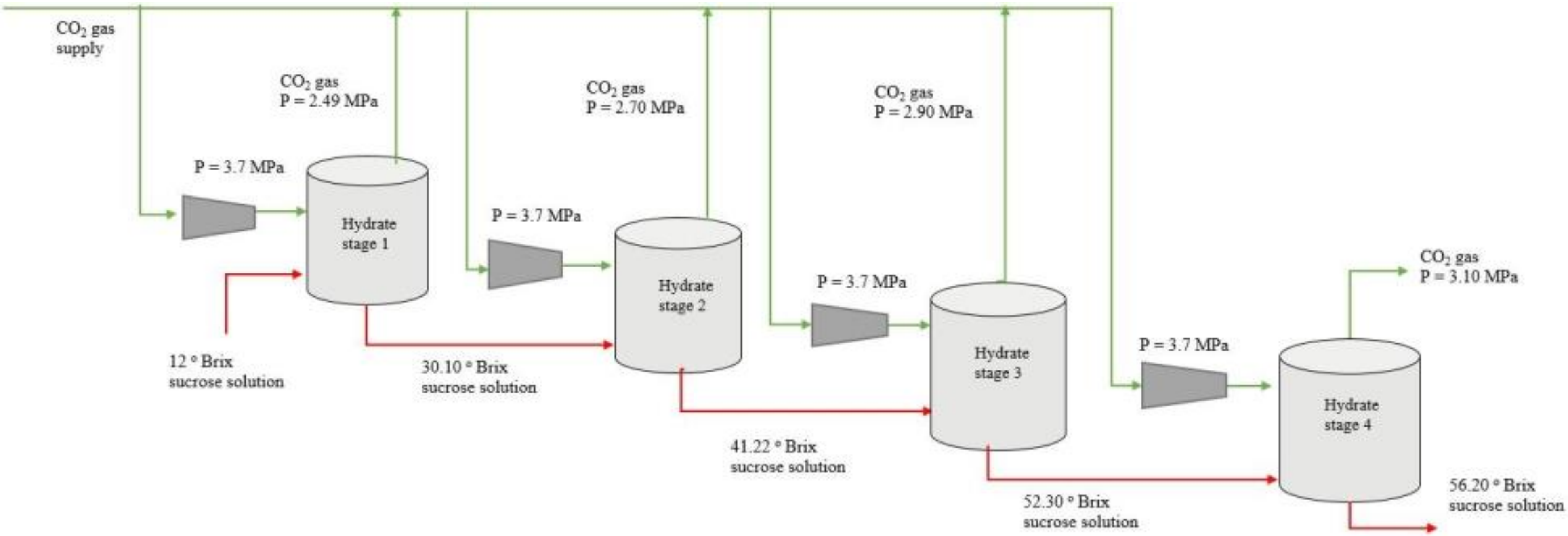

Figure 1. Conceptual hydrate process for sugarcane juice concentration using CO_2 gas hydrate formation carried out at the optimum operational condition in the four stages and at the optimum temperature, pressure, mesh size, and mixer speed of 1.5°C, 3.7 MPa, 26 µm, and 130 rpm, respectively.