COMMUNICATION
Mass Transfer in a Closed-cycle Solid-liquid Extraction Unit

B. A. Asbi

Department of Food Technology
Faculty of Food Science and Biotechnology
Universiti Pertanian Malaysia
43400 Serdang, Selangor, Malaysia.

ABSTRAK

Pengekstrakan pepejal-cecair merupakan satu proses yang utama dalam industri gula di mana sukros dari bit gula diluluh larutkan dengan menggunakan air panas sebagai pelarut. Dalam kajian simulasi ini, pekali pemindahan jisim pepejal-kepada-bendalir ditentukan dengan mengukur kadar pengesktrakan gula dalam sebuah pengekstrak berkitar tertutup. Pengukuran dilakukan bagi empat kadar aliran: 3.0, 3.5, 4.0 dan 4.5 ml/s pada julat suhu 45 - 65°C pada tekanan atmosfera. Kesan suhu dan halaju pelarut ke atas pekali pemindahan haba adalah positif dan tenaga keaktifan yang dihitung bagi proses pengekstrakan didapati berada dalam julat 4.0 - 5.4 kJ/kmol K.

ABSTRACT

Solid-liquid extraction is a very important process in the sugar industry, in which sucrose from sugar beets is leached by utilizing hot water as a solvent. In this simulation study, solid-to-fluid mass transfer coefficients were determined by measuring extraction rates of sugar in a closed-cycle extractor. Measurements were made for four flowrates: 3.0, 3.5, 4.0 and 4.5 ml/s over a temperature range of 45 - 65°C at atmospheric pressure. The effects of temperature and solvent velocity on mass transfer coefficients were found to be positive, and the calculated activation energies for the extraction process were found to be in the range of 4.0 to 5.4 kJ/kmol K.

INTRODUCTION

Solid-liquid extraction is a very important process in the sugar industry, in which sucrose from sugar beets is leached by utilizing hot water as a solvent (Madsen 1990). There are many types of extractors used in the sugar industry but many use the counter-current arrangement (Chen 1985). To the food process engineer, the major problems associated with the extraction process are the factors affecting the rate of extraction and the establishment of process conditions which ensure the optimum extraction rate (Brennan *et al.* 1990).

The objective of this study was to simulate the leaching process and report on the effect of temperature and solvent flowrate on the solid-to-fluid mass transfer coefficients, which were determined by measuring extraction rates of sugar in a batch closed-cycle extractor.

THEORY

The rate of extraction, dN/dt, of a mass component, N, is described by equation (1):

$$\frac{dN}{dt} = K_L A (C_s - C) \tag{1}$$

where $K_L A$ represents the overall mass-transfer coefficient across an effective external surface area, A, and C and C_s represent the concentrations of the solute in the solvent at any time, t, and at the saturation condition respectively (Heldman and Singh 1981). If the solid-liquid extraction is carried out in a batch process in which the total volume, V, of solution is kept constant, the following expression is obtained:

$$dN = V dC \tag{2}$$

which leads to the integrated solution in the form:

$$C = C_s \left[1 - \exp\left(-\frac{K_L A}{V} t \right) \right] \tag{3}$$

Equation (3) implies that the mass-transfer coefficient, the interfacial area between the solid particles and the solvent and the total volume of the solution used will influence the rate at which the solvent approaches the saturation concentration.

MATERIALS AND METHODS

The leaching process was carried out in a closed-cycle extraction unit (Armfield, England, Model UOP4) which is shown diagrammatically in *Fig. 1*. In this study, sugar-impregnated vermiculite of fixed weight was placed in a removable retaining bag inside a small solid-liquid extractor vertical column. Solvent was drawn from a feed tank solvent vessel by a meter pump at a known and constant feed rate and delivered to the extraction column. In this manner the sugar-impregnated sample was washed with a constant volume of hot water. Samples were taken at the outlet stream and the amount of soluble sugar extracted in the system was monitored periodically with a refractometer (Atago, Japan, Model N20) and reported in concentration units of Brix.

Measurements were made at four different solvent flowrates: 3.0, 3.5, 4.0 and 4.5 ml/s over a temperature range of 45-65°C at atmospheric pressure.

RESULTS AND DISCUSSION

The calculated mass transfer coefficients ($K_L A/V$) were found to be in the range of $0.020 - 0.043$ min^{-1} and these were correlated with the solvent
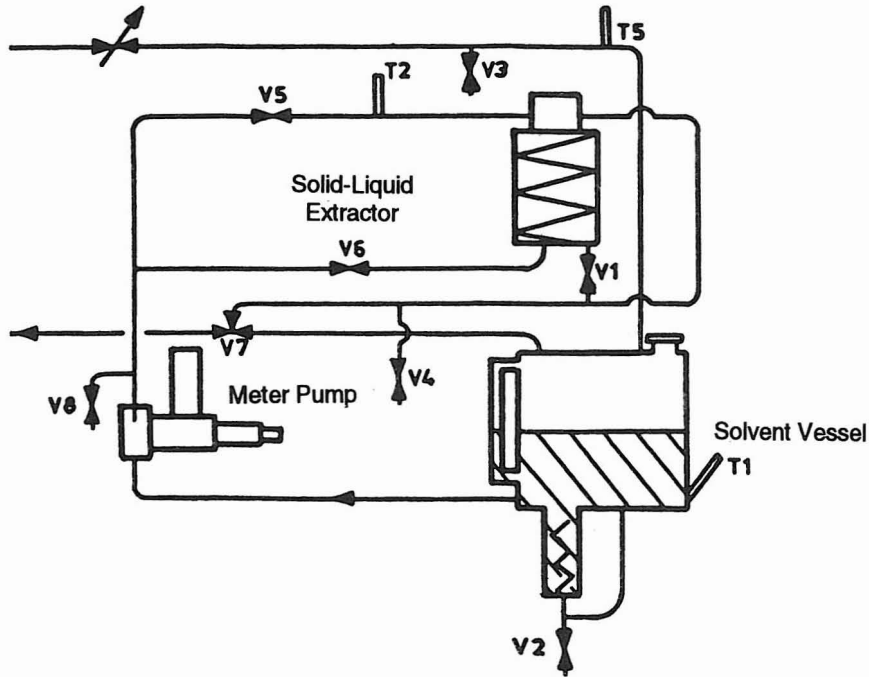
Fig. 1. Schematic diagram of solid-liquid extraction unit where V are valves and T are thermometers
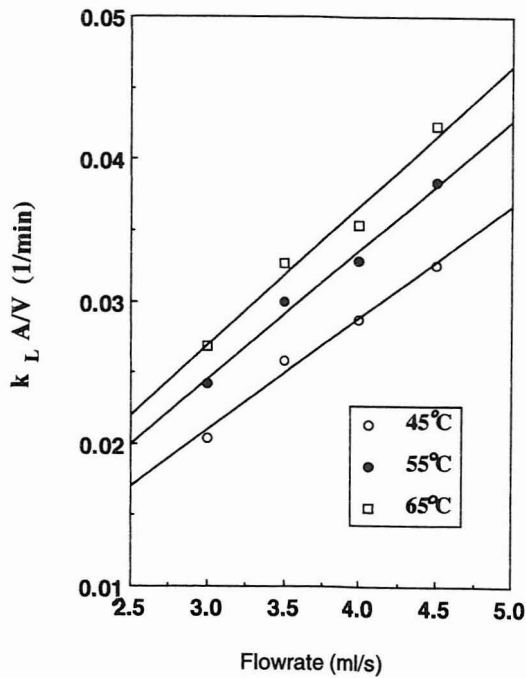

Fig. 2. Mass transfer coefficients with varying solvent flowrates at various temperatures

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flowrate of the solvent in the closed-cycle extractor resulted in the corresponding increase in the mass transfer coefficient. This could be attributed to the increased agitation of the solid-liquid system which had improved the diffusion rate of the solute.

Fig. 2 also shows that as the temperature of the solvent used was increased, the mass transfer coefficients increased for all solvent circulation flowrates. The effect of temperature on the rate of extraction is to increase the solubility of the solute and, therefore, cause an overall improvement in the leaching rate. When the effect of temperature, T, on the mass transfer coefficient, K, is expressed in the form of Arrhenius equation:

$$K = K_o \exp [- E_a / RT] \qquad (4)$$

the calculated activation energies, E_a, for the extraction process were found to be in the range of 4.0 to 5.4 kJ/kmol K (*Fig. 3*).
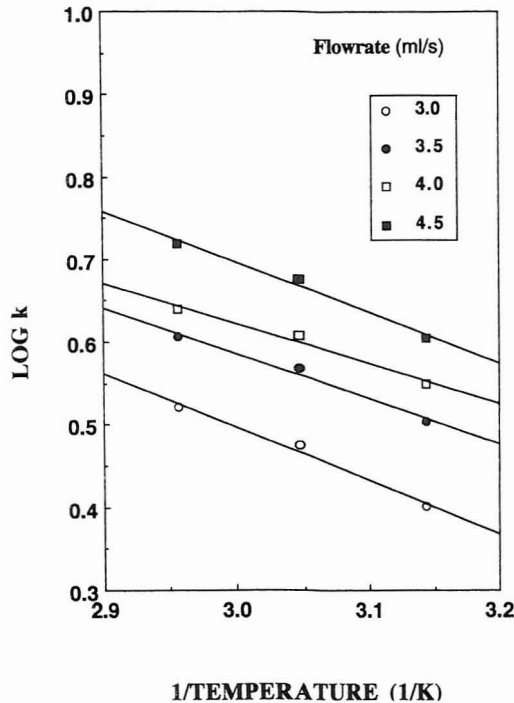

Fig. 3. Arrhenius plot of mass transfer coefficients at various solvent flowrates

NOMENCLATURE

A = effective external surface area for mass transfer
C = concentration
C_s = concentration at equilibrium conditions
E_a = activation energy
K = mass transfer coefficient

K_o = constant
K_L = solid-to-fluid mass transfer coefficient
N = mass component being tranferred
R = gas constant
t = time
T = absolute temperature
V = volume

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