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PREDICTION OF PHYSICAL PROPERTIES OF FOODS FOR UNIT OPERATIONS

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Abstract

The engineering design of food processes and equipments requires the knowledge of basic physico-chemical and engineering properties of food materials. Due to the complex physical and chemical structure of foods, theoretical prediction is not possible. There is a need for more and reliable data on the engineering properties of foods in design and simulation of food processes. A computer program was developed at the Budapest University of Technology and Economics based on the computer program COSTHERM. The property models were determined based on our experiments, and some of them based on data published in the literature. The data were organised and processed to make them suitable for use in computer aided design packages.

Keywords: foods, physical properties, computer program.

1. Predicting the Engineering Properties of Foods

Computer Aided Design has been elaborated in the petrochemical industries, where sufficient physical property data and prediction models are available, especially for liquids and gases. Process engineers routinely use computer packages both to design individual unit operations, such as distillation columns and heat exchangers, and to model the behaviour of the flowsheets. They can also optimise process control strategies and energy recovery. These programs are based on mathematical descriptions of the physical and chemical processes that take place in the chemical plant.

Computer aided techniques have been suggested for food technology applications too. The engineering design of food processes and equipments requires the knowledge of basic physical and engineering properties of food materials. In contrary to the extensive physico-chemical databases for chemical processes and operations, only limited data bases and computer programs have been published for foods. The lack of appropriate values of properties of foods has limited the wider applications of these techniques. Due to the complex physical and chemical structure of foods, theoretical prediction is not possible. Most of these properties are determined experimentally. There is a need for more and reliable data on the engineering properties of foods in design and simulation of food processes. The need of accurate data is particularly manifest in processes dealing with the safety and sensory quality of process sensitive foods.

Two co-operative research projects, COST 90 and COST 90bis were carried out in the European Union on the physical properties of interest to the food industry [1]. It was concluded that the physical properties of foods depend not only on the specific food material, but also on the processing of the food and the method of measurement. A computer program COSTHERM [2] was developed for the thermal properties of foods. Tables of physical and engineering properties of foods have been published in handbooks, e.g. [3].

A computer program was developed at the Budapest University of Technology and Economics based on the computer program COSTHERM. The property models were derived mainly from our experiments, and partly from data published in the literature.

The original computer program has been developed in two directions. On the one hand properties of new food products were added, especially those of liquid products, e.g. milk products oils, and fruit juices. On the other hand the program was improved to predict further characteristics, mainly engineering properties. The data were organised and processed to make them suitable for use in computer aided design packages. The physico-chemical properties were described by polynomials using the method of regression analyses. The independent variables of the polynomials are the composition and the temperature.

2. The Structure of the Developed Program

The program is written in Turbo Pascal, it is menu driven and works in dialog mode, it is user-friendly.

In order to execute the computer program the following input variables are required:

- composition (x_i the mass fraction)
- density (ρ kg/m^3)
- initial freezing point (t °C)

The output variables are:

- specific heat (C_p kJ/kg °C)
- enthalpy (h kJ/kg)
- thermal conductivity (λ W/m K)
- thermal diffusivity (α m^2/s)
- viscosity of Newtonian fluids / consistency of non-Newtonian fluids (μ Pas)
- consistency coefficient (κ Pas^n at non-Newtonian fluids)
- flow behaviour index (n)

The specific heat of the food can be predicted in most cases accurately from the chemical composition of the major food components weighted by the mass fractions (1).

$$C_p = \sum x_i C_{pi}. \tag{1}$$

The thermal conductivity can be predicted from the chemical composition of the major food components weighted by the volume fractions ε_i (2).

$$\lambda = \sum \varepsilon_i \lambda_i. \tag{2}$$

The thermal diffusivity is usually determined the thermal conductivity, from the density and the specific heat (3).

$$\alpha = \lambda / C_p \rho. \tag{3}$$

Fluid food materials often exhibit non-Newtonian behaviour, so the power law model (4) may be applied e.g. at planning heat transfer. In the case of non-Newtonian fluids instead of viscosity the consistency coefficient and the flow behaviour index are important engineering properties. In *Eq.* (4) $\mathrm{d}v/\mathrm{d}y$ means the shear rate.

$$\mu = \kappa (\mathrm{d}v/\mathrm{d}y)^{n-1}. \tag{4}$$

The flow behaviour index was determined by the help of capillary rheometer curves. In the figures shear stress versus shear rate the slope of the curve gives the flow behaviour index.

The program contains a set of regression polynomials for predicting the data. The relationship between viscosity, solid material content and temperature is described by the help of multiple regression. In the case of whey we use the *Eq.* (5).

$$\mu = 0.0638(9/5t + 32)^{0.9982}(1.0042 + 3.11x + 14.7x^2). \tag{5}$$

For whey protein dispersion the functions between the flow behaviour properties and the solid content are given in (6) and (7). The equation was calculated based on measured data in the interval of 4–20 m/m%.

$$\kappa = 0.004 \exp(32.33x), \tag{6}$$

$$n = 0.9956 + 0.9556x - 11.11x^2. \tag{7}$$

We prefer to predict the given engineering property, – if it is available, – by polynomial regression based on measured data instead of calculating them by the help of the summation of the individual properties of the food components.

The density of the grape juice in the function of solid content and temperature is calculated by multiple regression. In *Eq.* (8) the solid content and the temperature are the independent variables and the density is the controlled (dependent) one.

$$\rho = 969 + 5.72x - (25 + 0.42x)t/100. \tag{8}$$

3. Application of the Program

1. Predict the properties of the whey protein dispersion at 20 °C and 10000 Pa!

Input data:

milk product; composition: water 93.7 w/w%, protein 0.8 w/w%, carbohydrate 4.8 w/w%, fat 0.1 w/w%, minerals 0.6 w/w%; density unknown, initial freezing point unknown.

Output data:

density kg/m^3	1022.6
freezing point °C	−1
specific heat kJ/kg °C	4.03
enthalpy kJ/kg	48.4
the thermal conductivity W/m K	0.56
the thermal diffusivity m^2/s*10^{-7}	1.358
the viscosity Pas	0.001

2. Predict the consistency coefficient and the flow behaviour index of the 15% tomato juice at 50 °C and 10000 Pa!

Input data:

fruit juices, tomato, 15% solid content, 50 °C, 10000 Pa

Output data:

consistency coefficient Pas:	2.68*10^{-3}
flow behaviour index:	0.53

These properties are important phenomena of non-Newtonian fluids. Fluid food materials with higher solid content often exhibit non-Newtonian behaviour. The model design, e.g. of heat exchanger incorporates this factor into the design.

The plate heat exchanger is becoming a widely used apparatus for heat transfer in food processing. The efficiency of heat transfer in plate exchangers is considerably higher than that in conventional heat exchangers. The higher efficiency is attributable to the pattern of the heat transfer plates, which produce turbulence at low fluid velocities. The induced turbulence is produced by the plate pattern because the fluids flow in narrow streams with many abrupt changes in direction and velocity. This turbulence, created by the shape of the plate pattern, reduces the liquid film resistance to heat transfer more efficiently than turbulence created by high flow rates and pressures in conventional exchangers.

Plate heat exchangers are used extensively in the food beverage industries, as they can be rapidly taken apart for cleaning and inspection.

Because of the nature of the flow patterns in a plate heat exchanger the conventional log-mean rate equation for the design of heat transfer equipment does not hold in most cases.

Prediction of heat transfer coefficients is based on the Nusselt-type equation [4]

$$(hD_e/K)(\mu_w/\mu_a) = 1.86(D_e^2 G C_p/KL)^{1/3}, \tag{9}$$

where h film coefficient of heat transfer, J/m^2 h °C
D_e equivalent diameter for non-round cross section, m
K thermal conductivity of liquid, J/m h °C
μ_w viscosity of liquid at wall temperature, kg/m h
μ_a viscosity of liquid at wall temperature, kg/m h
G mass velocity, kg/m^2 h
C_p heat capacity, J/kg °C
L lengths of heat surface in direction of flow, m^2

The factor Δ is used to correct *Eq.* (9) for the effect of non-Newtonians on heat transfer as follows

$$(hD_e/K\Delta^{1/3})(\mu_w/\mu_a) = 1.86(D_e^2 G C_p/KL)^{1/3}, \tag{10}$$

where Δ is the ratio of heat transfer coefficients, non-Newtonian/Newtonian

$$\Delta = (2n + 1)/3n,$$

where n flow behaviour index.

Based on the predicted physical characteristics, the area needed for plate heat exchangers can be determined.

The solution to the problem, because of the iteration steps (first assuming an exchanger with one thermal plate), is adaptable to computer use.

3. The hot stream inlet and outlet temperatures and flow-rate (milk, 85 °C, 15 °C, 2500 kg/h), the cold stream inlet temperature and flow-rate (water, 10° C, 2500 kg/h), and the physical characteristics of the type of heat exchanger plate (area 0.37 m^2) are given. Determine the area of the plate heat exchanger!

Input data:
hot stream: milk, solid content: 12.5 w/w%, protein: 3.3 w/w %, carbohydrate: 4.6 w/w%, fat: 3.8 w/w%, minerals: 0.8 w/w%. Inlet temperature: 85 °C, outlet temperature: 15 °C, flow-rate: 2500 kg/h.
cold stream: water, inlet temperature: 10 °C, flow-rate: 2500 kg/h.

Output data:
heat exchanger area: 9.5 m^2
number of thermal plates: 26.

4. Conclusion

This work presents the use of a computer program for predicting engineering properties of foods and the applications of it in a plate heat exchanger model.

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