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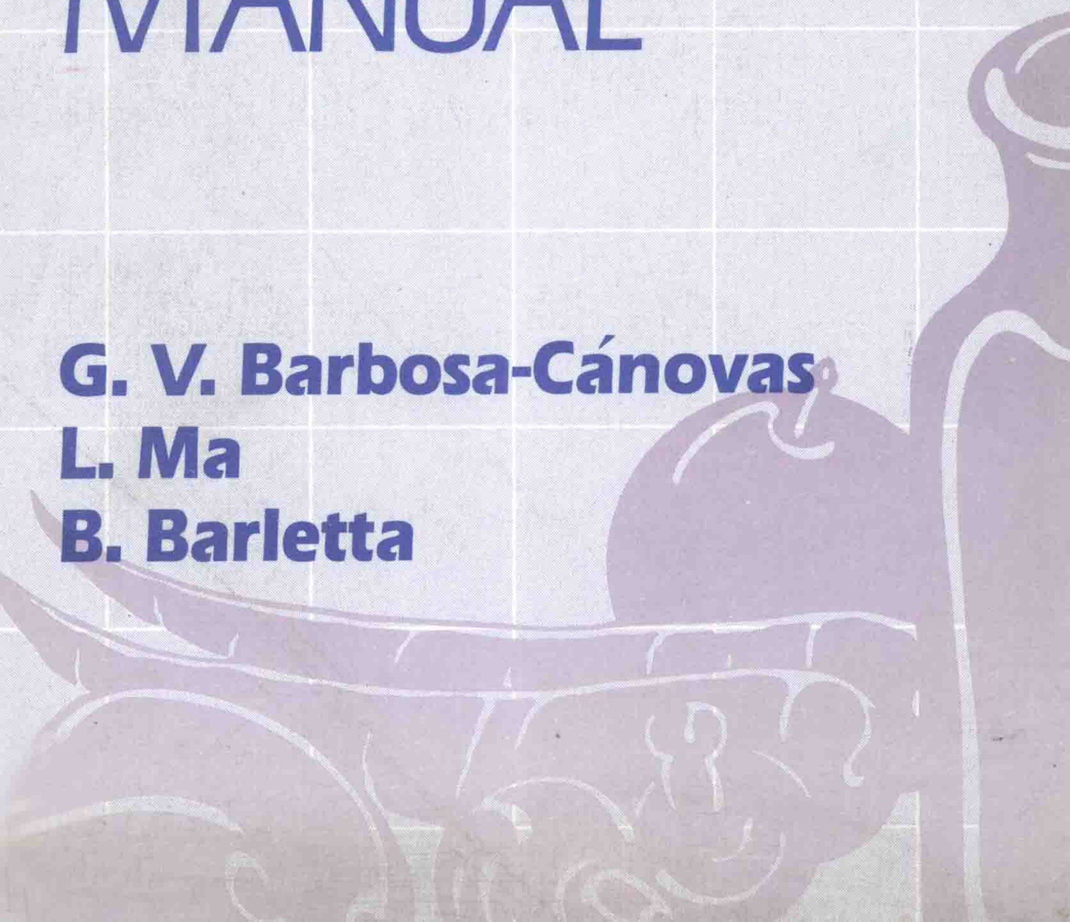

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To our families

PREFACE

The purpose of this laboratory manual is to facilitate the understanding of the most relevant unit operations in food engineering. The first chapter presents information on how to approach laboratory experiments; topics covered include safety, preparing for a laboratory exercise, effectively performing an experiment, properly documenting data, and preparation of laboratory reports. The following eleven chapters cover unit operations centered on food applications: dehydration (tray, spray, and freeze dehydration), thermal processing, friction losses in pipes, freezing, extrusion, evaporation, and physical separations. These chapters are systematically organized to include the most relevant theoretical background pertaining to each unit operation, the objectives of the laboratory exercise, materials and methods (materials, procedures, and calculations), expected results, examples, questions, and references. The experiments presented have been designed for use with generic equipment to facilitate the adoption of this manual by all institutions teaching food process engineering.

We sincerely hope this book will be a valuable addition to the food engineering literature and will promote additional interest in this fascinating field.

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CHAPTER 1

Planning Experiments

1.1 INTRODUCTION

The principles governing the engineering aspects of food processing are the same as those applied in any engineering field in that engineers are educated to analyze, synthesize, design, and operate complex systems that manipulate mass, energy, and information to transform materials and energy into useful forms, which, in this case, are food products or food ingredients. This book is designed to give food engineering and/or food science students an understanding of the engineering principles and hands-on experiences involved in the processing of food products. With a clear understanding of the engineering basic principles of food processing, it is possible to develop new food processes and modify existing ones. Because an essential component of any laboratory exercise is to receive proper laboratory orientation, follow safety guidelines, and prepare laboratory reports, this chapter deals with fundamental engineering aspects related to specific laboratory exercises, how to get ready for an experiment, and how to report it.

1.2 MASS BALANCE

The law of conservation of mass states that mass cannot be created nor destroyed, so a mass balance in any process can be written as follows:

$$\text{Input} - \text{Output} = \text{Accumulation}$$

In a continuous process at steady state, the accumulation is zero. Therefore, a simple rule that "what goes in must come out" holds. For example, in the concentration process of milk, whole milk is fed into an evaporator. Under the law of conservation of mass, the total number of pounds of material (whole milk) entering the evaporator per unit time must equal the total number of pounds of concentrated milk and evaporated moisture that leave the evaporator. When solving the mass balance, four key steps must be followed:

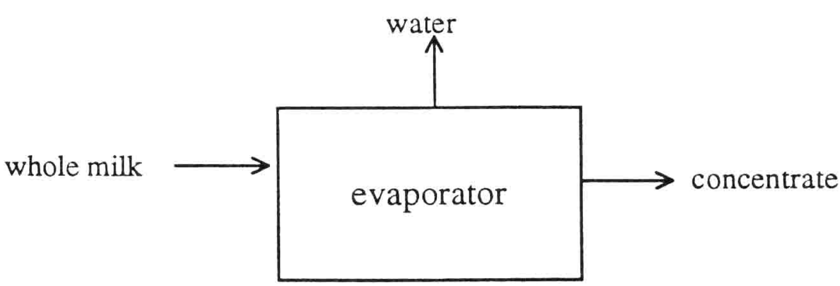
(1) Select a system and draw a diagram representing the process (including all pertinent information on stream rate and compositions).
(2) Select an appropriate basis for calculation.
(3) Write the mass balance relationships for the various constituents in terms of the known and unknown quantities.
(4) Solve the resulting algebraic equations for the unknown quantities.

1.2.1 Example

A milk concentrate is to be made by evaporating water from whole milk. The whole milk contains 13% total solids (*TS*), and the concentrate should contain 49% *TS*. Calculate the amount of product and the water that needs to be evaporated.

1.2.1.1 SOLUTION

- *Step 1:* Select the evaporator to be a target system, and draw a diagram representing the process as follows:



- *Step 2:* Select a basis for the calculation of 100 kg of incoming whole milk.
- *Step 3:* Write up the equations for the mass balance:
  (1) The balance for the total material:

$$100 \text{ (kg whole milk)} = W \text{ (kg water evaporated)} + C \text{ (kg concentrate)} \quad (1.1)$$

(2) The balance of total solids *(TS)*:

$$100(0.13)\ (\text{kg}\ TS) = W(0)\ (\text{kg TS}) + C(0.49)\ (\text{kg}\ TS) \qquad (1.2)$$

- *Step 4:* Solve the equations. Note that Equation (1.2) has only one unknown and should therefore be solved first. The result is:

$$C = 26.5\ \text{kg}$$

Substituting the C value into Equation (1.1), we get:

$$W = 73.5\ \text{kg}$$

- *Step 5:* Appropriate answer: From every 100 kg of whole milk, we can manufacture 26.5 kg of the concentrated milk, and thus 73.5 kg of water must be evaporated.

1.3 ENERGY BALANCE

The law of conservation is also applied to energy, where its balances are employed in much the same manner as material balances:

Total energy entering system = Total energy leaving the system

Energy may appear in many forms; some of the more common are heat, work, internal energy, enthalpy, mechanical, and electrical. Heat and work are considered transitory. An additional complexity of energy balances is the need for various material property data (specific heats, latent heats of vaporization and fusion, freezing or boiling points, and process-related data such as temperatures). The following example provides an illustration of an energy balance:

1.3.1 Example

A still retort containing 1000 cans of apple sauce was sterilized at 121°C. After sterilization the cans need to be cooled down to 37°C before leaving the retort. The specific heats of the apple sauce and the can metal are 3730 and 510 J/kg K, respectively. Each can weighs 50 g and contains 450 g of apple sauce. The retort wall is made of cast iron and weighs 3000 kg. It is assumed that cooling by the surrounding air is negligible. Calculate the amount of cooling water required if it enters at 20°C and leaves at 30°C.

1.3.1.1 SOLUTION

- *Step 1:* Define the operation: The operation is cooling, and the desired result is the amount of cooling water needed.
- *Step 2:* Determine the basis of calculation: In this problem, 1000 metal cans that contain apple sauce are selected as the basis.
- *Step 3:* Write the energy balance equation: This will balance the total heat (Q) leaving the system against all the heat forms entering the system.

The heat entering the system consists of four parts: (1) heat in the cans, (2) heat in the apple sauce, (3) heat in the cooling water, and (4) heat in the retort wall. For calculation convenience, the reference temperature datum is selected at 37°C.

(1) Heat in the cans = (weight of cans)(specific heat of can)(temperature above the datum). Mathematically:

$$Q_1 = 1000\ (\text{can}) \cdot \frac{50\ (\text{g/can})}{1000\ (\text{g/kg})} \cdot 510\ \left(\text{J/}[\text{kg} \cdot \text{K}]\right) \cdot (121 - 37)\ (\text{K})$$

$$= 2,142,000\ \text{J}$$

$$= 2142\ \text{kJ}$$

(2) Heat in the contents = (total weight of apple sauce)(specific heat of apple sauce)(temperature above the datum). Mathematically:

$$Q_2 = 1000\ (\text{can}) \cdot \frac{450\ (\text{g/can})}{1000\ (\text{g/kg})} \cdot 3730\ \left(\text{J/}[\text{kg} \cdot \text{K}]\right) \cdot (121 - 37)\ (\text{K})$$

$$= 1.410 \times 10^8\ \text{J}$$

$$= 1.410 \times 10^5\ \text{kJ}$$

(3) Heat in the water = (weight of water)(specific heat of water)(temperature above the datum). Mathematically:

$$Q_3 = W\ (\text{kg}) \cdot 4180\ \left(\text{J/}[\text{kg} \cdot \text{K}]\right) \cdot (20 - 37)\ (\text{K})$$

$$= -71,060W\ (\text{J})$$

$$= -71.06W\ (\text{kJ})$$

(4) Heat in the retort wall:

$$Q_4 = 3000 \text{ kg} \cdot 450 \left(\text{J/}[\text{kg}\cdot\text{K}]\right) \cdot (121-37) \text{ (K)}$$

$$= 113,400,000 \text{ J}$$

$$= 113,400 \text{ kJ}$$

Therefore, the total heat entering the system is:

$$Q_E = Q_1 + Q_2 + Q_3 + Q_4$$

$$= 2142 + 1.410 \times 10^5 + (-71.06W) + 113,400$$

$$= 229,542 - 71.06W \text{ (kJ)}$$

The heat leaving the system also consists of four parts: (1) heat in the cans, (2) heat in the apple sauce, (3) heat in the cooling water, and (4) heat in the retort wall.

(1′) Heat in the cans = (weight of cans)(specific heat of can)(temperature above the datum). Mathematically:

$$Q_1' = 1000 \text{ (can)} \cdot \frac{50 \text{ (g/can)}}{1000 \text{ (g/kg)}} \cdot 510 \left(\text{J/}[\text{kg}\cdot\text{K}]\right) \cdot (37-37) \text{ (K)}$$

$$= 0$$

(2′) Heat in the can contents = (total weight of apple sauce)(specific heat of apple sauce)(temperature above the datum). Mathematically:

$$Q_2' = 1000 \text{ (can)} \cdot \frac{450 \text{ (g/can)}}{1000 \text{ (g/kg)}} \cdot 3730 \left(\text{J/}[\text{kg}\cdot\text{K}]\right) \cdot (37-37) \text{ (K)}$$

$$= 0$$

(3′) Heat in the water = (weight of water)(specific heat of water)(temperature above the datum). Mathematically:

$$Q_3' = W \text{ (kg)} \cdot 4180 \left(\text{J/}[\text{kg}\cdot\text{K}]\right) \cdot (30-37) \text{ (K)}$$

$$= -39,260W \text{ (J)}$$

$$= -39.26W \text{ (kJ)}$$

(4′) Heat in the retort wall:

$$Q'_4 = 3000\ \text{kg} \cdot 450\big(\text{J}[\text{kg} \cdot \text{K}]\big) \cdot (37 - 37)(\text{K})$$

Therefore, the total heat leaving the system is:

$$Q_L = Q'_1 + Q'_2 + Q'_3 + Q'_4$$

$$= 0 + 0 + (-39.26\text{W}) + 0$$

$$= -39.26\text{W (kJ)}$$

According to the law of conservation:

$$Q_E = Q_L$$

$$229{,}542 - 71.06W\ (\text{kJ}) = -39.26W$$

- *Step 4:* Solve the energy balance equation:

$$W = 7218\ \text{kg}$$

- *Step 5: Appropriate answer:* To cool down the apple sauce from 121°C to 37°C, 7218 kg cool water (20°C) is needed.

1.4 LABORATORY ORIENTATION

1.4.1 Laboratory Safety

Laboratory participants need a suitable orientation to equipment and procedures to provide a safe and profitable learning experience. The safety of all persons involved is of utmost importance in laboratory exercises, which means that everyone must have knowledge of basic safety principles, work alertly, and support one another in safe laboratory practices. Before beginning any laboratory exercise, each person must be oriented to the guidelines for safe use of laboratory equipment and emergency response procedures. A checklist suggested for laboratory safety orientation is given below:

(1) Identify locations of safety equipment:
- fire extinguishers, fire blankets, fire alarms
- first aid kit
- emergency showers and eye wash stations