The Chemical Engineering Design of a Commercial Citrus Evaporator for the Production of 6,539.86 kg/hr Orange Juice Concentrate in Lagos, Nigeria, West Africa

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***Abstract* — Chemical engineers are high in importunity by industries in a wide range of sectors for the following impetus: Based on nominally defined problem statements, such as a client need or a set of experimental ramifications, chemical engineers can devise and gain a profound understanding of fundamental physical science relevant to the enigma, and harness this apprehension to excogitate a comprehensive action plan and a set of detailed specifications that, if implemented, will lead to forecasted financial dividends. In this treatise, as chemical engineers, apply our scientific and mathematical knowledge, specifically chemistry, applied mathematics, and engineering concepts, to translate experimental or conceptual ideas into value-added products in a lucrative, safe (environmentally friendly), and industry-leading manner. *Citrus sinensis* is the scientific name for orange, a savory and aromatic fruit from the *Rutaceae* family. The annual global citrus production increased dramatically over the last few decades, from around 30 million metric tonnes in the late 1960s to an estimated total of more than 105 million metric tonnes from 2000 to 2004, with oranges accounting for more than half of total global citrus production. Evaporation is a principle habituated in the processing industry to concentrate aqueous liquid streams by vaporizing the quantity of water content in a solution. The curtailment of energy consumption for evaporation reckoned on multitudinous components, such as evaporation capacity, number of effects, operation efficiency, and annual operation hours. We emphasized burgeoning efficient strategies to curtail the energy consumption of evaporators and alluded that monitoring the rate of energy dissipation guarantee the sustainability of an industrial enterprise. We betokened the heat transfer area was the indispensable criterion in the design of an evaporator and delineated correlations for estimating the size of the tube bundle. Ideally, a well-designed evaporator should be able to transfer heat adeptly at a high flow rate, have the minimum valuation of installation, operation, and maintenance, be able to bifurcate vapors from liquid concentrates, meet the conditions required by the product under treatment, produce a product of a quality required, and, if possible, be energy efficient. The peculiar grade of evaporator adopted was the 5-effect, 8-stage Thermally Accelerated Short Time Evaporator. We embraced the genre of evaporators after investigating their benefits relative to other evaporators used in food processing. In addition, it is fundamental to institute governance to identify benchmarks for optimal distribution based on results obtained by all segments of the production chains and orange juice exporters. This input will benefit the collective national interest and is pivotal for the orange juice industry.**

***Keywords* — Chemical Engineering, Citrus, Evaporation, Design, Orange Juice Concentrate.**

I. Introduction

This synopsis intends to enable individuals with an opportunity to explore the activities in which modern chemical engineers are involved, the competencies necessary for these activities, and how these activities and skills resonate with their interests and capabilities. Chemical Engineering encompasses a range of applications, from biomedicine to energy generation. The discipline began as an amalgamation, combining chemistry with an industrial emphasis on the mechanical design of manufacturing equipment. The early triumphs, which defined the profession in the eyes of the public, were related to the ubiquitous production of essential chemicals. How does chemical engineering make a difference in our lives? Chemical Engineers now maneuver significant roles in every industry and service profession in which Chemistry is paramount, including Semiconductors, Nanotechnologies, Agriculture, Environmental monitoring, Pharmaceuticals, Energy, Finance, Medicine, Conventional chemicals, and Petrochemical products. Chemical Engineers uncover, devise, and establish innovative solutions to solve global problems and implement methodologies to benefit humanity. Chemical Engineers make invaluable contributions in a wide range of areas, from food processing to the manufacturing of semiconductors, to energy production and the development of artificial organs. How did Chemical Engineering become such a big part of our society?

II. Significant Achievements in the Field of Chemical Engineering

1) *Semiconductor Fabrication*

Chemical Engineers have designed and perfected a technology for converting semiconductors into dynamic solid-state systems, which resulted in powerful computers, mobile phones, portable music players, and electrical appliances. No one has had more influence on this evolving technology than Andrew Grove, a Chemical Engineer who served as Intel Corporation's three founding directors and chief executive officer for 11 years. Grove was delegated "Time Magazine Man of the Year" in 1997.

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2) Environmental Protection

Chemical Engineers have long been interested in environmental management by developing "environmentally friendly" processes and improving techniques for monitoring air and water quality. Chemical Engineers are actively involved in environmental technology to solve existing issues and prevent future pollution. In 1972, Chemical Engineer, John Seinfeld, and his colleagues developed the first mathematical models of air pollution, and they remained at the forefront of urban and regional models of atmospheric pollution. To gain hands-on experience in a real-world manufacturing facility as a chemical engineer, which would provide a better educational perspective from the perception of research and experimentation regarding the brewing process, Osaretin Ebuehi worked at Nigerian Breweries Plc as a Beer sommelier. He conducted routine maintenance and monitored laboratory maintenance measures to prevent contamination of processing equipment and microbial proliferation. He also sterilized the sampling sites of Bright beer tanks, conditioning tanks with alcohol water, and the brewery's cleaning systems to assure uniformity in beer taste, avoid the formation of undesirable byproducts, and decrease the danger of unintentional food poisoning in the final product.

3) Research and Development

T. W. Fraser Russell headed a research and development team for the continuous manufacture of solar cells and designed reactors that continually deposited the semi-conductor over a movable substrate [1]. To be considered an invaluable asset in each discipline of Chemical Engineering, Osaretin Ebuehi worked at The University of Lagos Consultancy Services as a Quality Control Analyst. He performed innovative research and development activities, inspected product quality, implemented quality control processes to ensure that products comply with specified existing standards and improvements, and investigated biological specimens' surfaces, such as shrimps and fishes.

4) Drug Discovery/ Medicine

To obtain a deeper grasp of the function of chemical engineering in modern society, chemical engineers have always been active in chemical synthesis, and the new domain of synthetic biology is fundamentally different. Among the pioneers in this burgeoning field is Chemical Engineer, Jay Keasling. Keasling's accomplishments included the construction of a convenient and inexpensive synthetic biology pathway to artemisinin, which is the drug of choice for treating quinine-resistant malaria, and its variants. In developing countries, particularly in sub-Saharan African countries, many women do not have access to qualified personnel during delivery. To achieve a substantial decrease in maternal and infant mortality, skilled professionals and a supportive environment will be required to offer crucial obstetric and neonatal care [2]. The Keasling synthesis procedure is being adopted on a large scale, promising universal access to a drug that will save millions of lives each year in the world's poorest regions.

Fig. 1. Osaretin Ebuehi sterilized the sampling sites of Bright beer tanks with alcohol water to prevent contamination of Treatment equipment components and microbial proliferation at Nigerian Breweries Plc, Lagos, Nigeria.

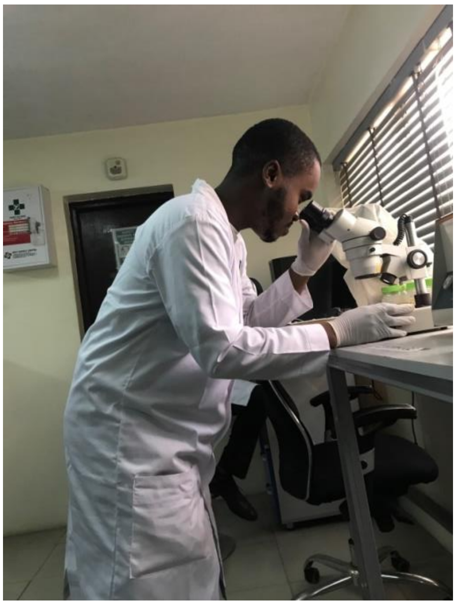

Fig. 2. Osaretin Ebuehi conducted product evaluations to ensure that the products conformed to specific standards at The University of Lagos Consultancy Services, Lagos, Nigeria.

5) Food

Chemical Engineers have contributed to the production of fertilizers, such as phosphate and urea, and pesticides that protect crops. They are also at the forefront of endeavors to enhance food processing technologies, such as freeze-drying and microwave processing [3].

6) Separation and Use of Isotopes

Chemical Engineers have devised processes that separate isotopes from each other. Chemical Engineers have contributed to sophisticated diagnostic and therapeutic mechanisms incorporating fission isotopes in nuclear medicine [2].

B. Background, Global Distribution, and Nutritional Significance of Citrus Fruits

Citrus was referred to in ancient Chinese annals during the reign of Ta Yu (about 2205-2197 BC), when citrus fruit, particularly mandarins and pummelos, were regarded as exceedingly valuable offerings and were exclusively available at the Imperial Court [4]. Current research suggests that, while some commercial species such as oranges, mandarins, and lemons originated from Southeast Asia, the veridical origins of citrus fruits are Australia, New Caledonia (off the east coast of Australia), and New Guinea. Citrus fruits, which have a distinct aroma and delightful taste, have long been recognized as an essential fruit and have become an integral part of our daily diet, providing energy, supplying nutrients, and health promotion [3]. With a low protein content and little fat, citrus fruits mainly provide carbohydrates such as sucrose, glucose, and fructose. As well as being a legitimate source of dietary fiber, citrus fruits are associated with a decrement in cholesterol levels and a diminution in gastrointestinal diseases. Epidemiological studies indicated a 40-50% reduction in the risk of certain cancers due to increased citrus consumption [5]. Oranges are abundant in macronutrients, such as simple sugars and dietary fiber, and sources of numerous micronutrients such as folate, thiamine, niacin, vitamin B_6, potassium, calcium, phosphorus, and magnesium, which are mandatory for virtuous health and natural growth [4]. In addition to traditional morphological identification, chemical features of citrus, such as enzymes, fatty acids, hydrocarbon profiles, flavonoid schemes, and carotenoid composition, were employed to develop systems for investigating the citrus genus [6]. Fruits can vary in form (for example, round, rectangular, or elongated) and size (from 3.8 to 14.5 cm in diameter) [7]. A single orange provides 12.5 percent of the daily fiber requirement, which has proven to lower high cholesterol levels and aided the prevention of atherosclerosis. Fiber has helped keep blood glucose levels in check, and oranges are a highly nutritious snack for patients with diabetes. According to Food and Agriculture Organization of the United Nations (FAO) figures from 2009, China, Brazil, the United States, India, Mexico, and Spain are the world's major citrus growers, accounting for about two-thirds of global output. Even though many citrus fruits, such as oranges, tangerines, and grapefruits, may be consumed fresh, around one-third of the world's citrus fruit is processed, and orange juice manufacturing accounts for over 85% of total treated handled. Due to the delightful flavor, delicious taste, affordable economic range, and consumer awareness of more and more widely recognized potential health properties, citrus fruits and products are very common with a significant nutritional and economic impact in developed and developing countries [8].

C. Micro-Nutrients and Phytochemicals

1) Water-soluble vitamins

The high concentration of vitamin C (ascorbic acid) is the most vital contribution of citrus fruits to human health and nutrition. Although citrus fruits are not the sole source of vitamin C, they are a copious and prominent food source among vegetables and fruits, with a mean concentration of vitamin C ranging from 23 to 83 mg/100 g fresh weight. Besides ascorbic acid, citrus fruits also supply a vitamin B complex, especially thiamine (vitamin B_1) and phosphate pyridoxal (vitamin B_6).

Fig. 3. Monsieur and Madame Smith savor the soothing orange juice in Calgary, Canada.

2) Fat-soluble vitamins

Vitamin A is the unique fat-soluble vitamin discovered in sufficient quantities in citrus fruits in the form of provitamin A carotenoids, with carotenes and β-cryptoxanthin serving as the dominant vitamin A precursors. Citrus fruits are the eminently concentrated dietary source of β-cryptoxanthin in the diet.

D. Macronutrients

1) Carbohydrates

Following ethanol extraction of 80%, supplementary investigations discovered citrus fruits entailed soluble and insoluble constituents. Sucrose, glucose, and fructose, in a 2:1:1 ratio, are the primary elements of citrus carbohydrates and are responsible for the juice's smoothness [9].

2) Fiber

In the case of Citrus fruits, dietary fibers generally refer to the alcohol-insoluble compounds listed above, which usually consist of cellulose, lignin, and pectin. In addition to the ability of dietary fiber to reduce the transit time of food through the digestive tract and prevents digestive disorders [10], [11].

III. An Overview of the Nigerian Orange Juice Production Industry

Orange juice is one of Nigeria's colossal production lines, with an estimated 17.8 million tonnes produced annually. In 2009, 1.0 million tonnes of orange juice were manufactured, which accounted for 57% to 80% of global exports in Nigeria. Brazil is the world's leading producer of oranges and maneuvers more than 70% of harvested fruit for juice production. The United States, Canada, Japan, and China are the world's prominent importers of orange juice. The astronomical preponderance of frozen orange juice concentrate manufactured in Brazil was set aside for commutation. Notably, the pre-eminent manufacturers of orange juice concentrate in Nigeria are Chivita Limited, United Africa Company Limited, Frutta Juice & Services Limited, and Dansa Foods Limited. The juice of oranges is usually extracted mechanically and concentrated; this truncates shipping and warehousing costs. The commercial processes of concentrating orange juice typically involved the evaporation of water at elevated temperature followed by recovery and concentration of volatile savor and their inclusion back in the concentrated product. Orange juice can be frozen and marketed as frozen concentrated orange juice, or it can be kept and supplied in bulk at a remote distribution point where it is diluted, heated, and packed. The variation in commercial juices differ due to the combined effects of cultivars and ripeness, time-temperature conditions used to stabilize the liquor, the number of times it was heated, and the extent of volatile matter vanished during concentration. In addition, temperature conditions, storage duration, and vessel type cause significant impacts on the flavor of the juice when consumed. Despite the development of alternative processes, almost all commercially produced orange juice is heat-treated because it is the most cost-effective way to reduce microbial populations and enzymatic activity. However, heat treatment will diminish the concentrations of some of the original juice fluids and induce a complex series of chemical reactions, which may eventually produce extraneous odors to freshly expressed juice. Other phases in the orange juice treatment process may affect the flavor of the juice. One of the fundamental quality aspects of commercial juice is the mechanical pressure employed to extract the juice from the fruit. De-pulping reduced some of the volatile matter associated with the pulp, thereby regenerating its flavor. Packaging materials, storage time and weather conditions, and microbial contamination can also significantly alter the taste of the juice. The diagram below is a process flow diagram depicting the relationships between the major components of an orange juice concentrate industrial facility. A process flow diagram entails an array of symbols and notations to construe a process. It is employed to document, enhance, or design a new chemical process.

Among the blueprints used by 3 senior chemical engineering students to manufacture orange juice concentrate in my research group were extraction, juice finishing, deaeration, thermal processing, and concentrated juice.

1) Extraction of Juice

Oranges (*Citrus sinensis*) are fragrant fruit with a juicy inside. The skin has two layers: an orange outer layer known as flavedo, which includes glands and greasy pigments, and a white spongy interior layer known as albedo. The fleshy or endocarpal interior is composed of wedge-shaped portions (segments) packed with multiple liquid-filled bags or vesicles. These juice bags are the edible section of citrus fruit and the predominant source of citrus juice. When the juice vesicles rupture during physical extraction, the extract is released. As a result, the type of commercial extractor and the puller pressures will dictate the relative quantities of peel compared to the juice oils, the composition of the juice volatiles, and the comprehensive flavor of the juice. Mechanically crushed orange juice contained more aldehydes (octanal, nonanal, and decanal) and terpenes (mostly limonene, myrcene, and linalool) than fresh juice extracted by hand, as well as present in peel oil.

2) Juice Finishing

Immediately after extraction, the commercially produced juices are passed through a stainless-steel filter to separate the supervenient cells and the segment wall, and embryo seeds from the extract. A screw press separated as much juice as possible from the undesired solid particles. This procedure is known as finishing, and the pressure required to separate the juice from the pulp is finishing pressure.

The juice composition was modified depending on the finisher pressure employed. By squeezing the pulp hard enough, the liquid portion of the pulp was apprehended and reckoned to the juice. Solid particles actuate through the finisher screen and are dispersed into smaller particles by homogenizers. The finely suspended particulates which gave the juice its gloomy appearance was called clouds. The juice was clarified to eliminate finely dispersed particles, ensuing in the liberation of a tremendous amount of aromatic compounds and a modification in the flavor of the extract.

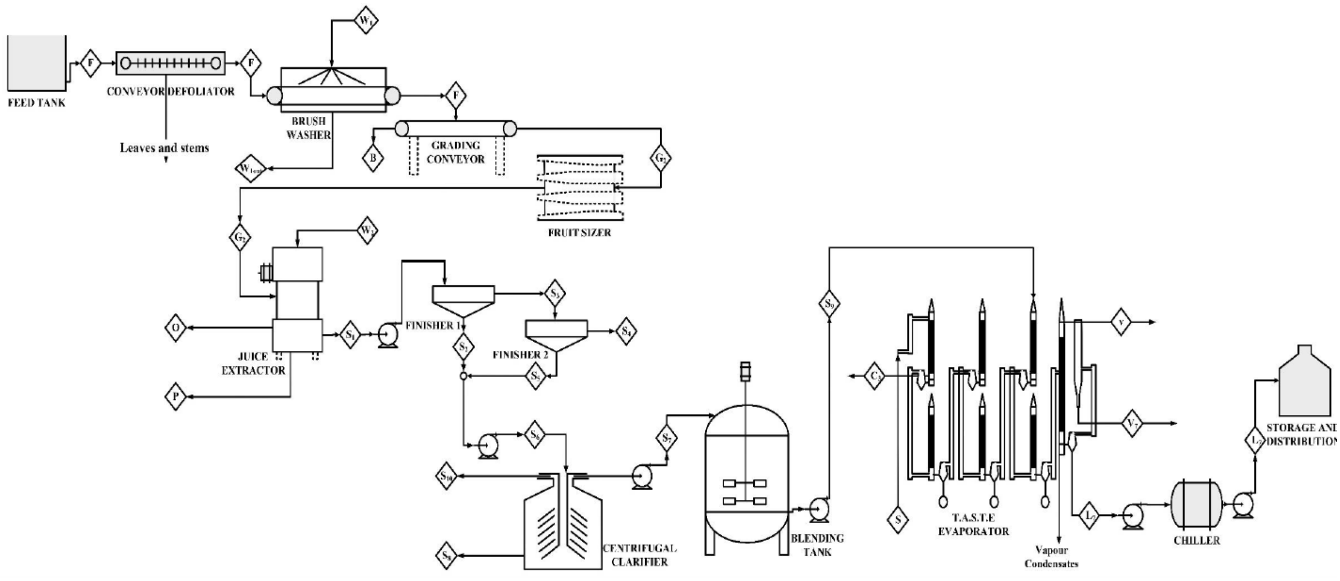

Fig. 4. Process flow diagram of an orange juice concentrate plant.

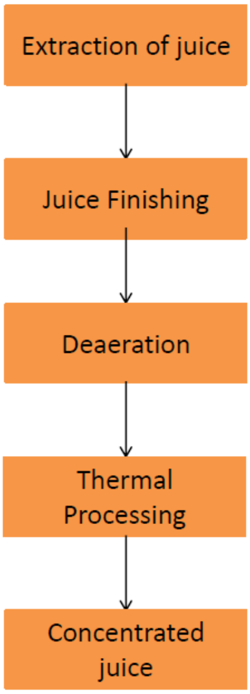

Fig. 5. Selected process route for orange juice concentrate production.

3) De-aeration

De-aeration is the process of abbreviating the air hauled from the juice right before heat treatment, which may perturb the caliber of juice. The resultant air caused foam-related filling challenges during the packing step and expedited vitamin C disintegration during storage. De-aeration was procured only for those juices that will not endure concentration as the concentration modus operandi abolished entrained air transported with water and volatile flavors. If not competently supervised, de-aeration can radically depreciate quantities of the most volatile alcohols, aldehydes, and terpenes. Although de-aeration will not influence ester and ketone enthrallment, research established that de-aeration contributed to the significant variances in orange juice liquids juxtaposed to pasteurization.

4) Thermal Processing

Heating eradicated spoilage bacteria and immobilized enzymes that destabilized the juice cloud and diminished juice quality during storage. Subsequently, elevated temperatures were ineffective in preserving the flavor of juice, ensuing in the fatality of nonpareil aromatic compounds (mostly aldehydes and esters) and the evolution of novel volatile compounds or their precursors.

5) Concentrated Juices

Most orange juices were yanked and concentrated mechanically to abbreviate transport and warehousing valuations. Commercial techniques for concentrating orange juice entailed the removal of water at elevated temperatures using a light vacuum for a short duration, followed by the recovery and concentration of volatile flavors and their incorporation into the concentrated product. The concentrated orange juice was packaged either as warm juice to disinfect the container or as refrigerated juice under aseptic conditions in a sterilized container and vessel. The concentration processes of producing frozen orange juice concentrate liberated essence oil as a byproduct. Essentially a flavoring additive, essence oil was widely employed as a principal flavoring additive and conveyed desirable flavors to frozen concentrated orange juices.

IV. Literature Review

Wakil *et al*. [13] contended that falling film evaporators surpassed vertical and flooded tubes in terms of efficiency, procuring them the utmost prospect for industrial application. They silhouetted a meticulous heat transfer correlation for falling film evaporators that could consummately ensnare both subordinated temperature evaporation and salt concentration. The propounded correlation harnessed saturation temperatures which deviated from 280 to 305 K, and feed water concentrations contrasted from 35,000 to 95,000 ppm.

Sorour *et al.* [14] explored two disparate recompression schemes: mechanical compression and thermal compression. They anatomized and appraised the cost of distinct economic constituents, such as the disbursement of steam and electricity, the fixed value of a compressor, the valuation of an evaporator, and the annual market value for each component of the system. They accentuated that evaporation should purport from the perspective of energy and process efficiency.

Chen *et al*. [12] examined and evaluated profuse energy-saving mechanisms for evaporation. Furthermore, they ascertained evaporation was one of the enormous energy-consuming units employed by the food processing industry. They investigated and enumerated the steam economy ratios for a 6-effect TASTE evaporator which was 4.63 for manual control and 4.94 for automated control, corroborating that automatic control proceedings piloted energy savings of 6.7% in this sophisticated industrial device. They concerted that transformation from manual to computer-assisted automatic control effectuated substantial energy savings.

Crandall *et al.* [15] explored the prerequisite of a proficient methodology for viscosity decrement by inaugurating a commercial homogenizer between the third and fourth stages of a pilot plant TASTE evaporator. They contended that viscosity control was clamorous for effectual evaporation and vacuation of citrus concentrates. They concentrated the juice at 65° Brix with and without homogenization. They ascertained that the mean non-homogenized values were 279 mPa.s (s.d. = 7.5) on the 65° Brix control and 242 mPa.s (s.d. = 10) on the homogenized concentrate, adjudged at 3.50 established to be the shear rate of orange juice concentrates within the third stage of a pilot plant TASTE evaporator.

Zimmer *et al.* [16] investigated the transformation of fruit into fruit juice concentrate and asserted that evaporation was the stage of the proceeding that mandated enormous energy dissipation. They ascribed mechanical vapor recompression technology with extensively abbreviating the energy consumption of fruit juice evaporators. They contended a flexible design of the plant would be imperative for the transformation of various varieties of fruit, which would reckon on seasonal availability and plant capacity, and should be adopted based on the quantities of raw materials provided at the facility.

V. Methodology

As one of the colossal energy hellacious processes harnessed in the dairy and chemical industries, it was peremptory to substantiate evaporation from the outlook of economic energy utilization and process efficiency. During evaporation, a solvent, typically water, is evanesced to achieve the concentration of the product. Many solids content in the recovered penultimate product conformed to the output quality and operating economy. The evaporator achieved a net separation of vapors from feed and condensate. A comprehensive selection of evaporation technology and systems were procurable from the equipment purveyor, designed to anchorage varied product characteristics, the degree of concentration enforced, and regional energy valuations. The evaporator consisted of a heat exchanger, valves, collectors, controllers, pumps, and condensers. Many designs and variations of evaporators are applicable, and which evaporators were condign for a specific operation conjectured on the product characteristics and desired outcomes. Although the design conceptions of evaporators are the same delinquent of industries concerned, two conundrums usually arise: is the equipment the best suited to the task, and is it engineered for the most efficient and cost-effective use? Consequently, multitudinous variations of evaporators have been devised over time to contend with deviating product characteristics and operating parameters in the processing industry. We designated the evaporator best suited to the duty on hand based on viscosity, product fouling propensity, utility and operator requirements, and cost of production. The espoused classifications of evaporators were natural circulation, rising film tubular, falling film tubular, forced circulation, thermally accelerated short-time evaporator, and plate evaporators.

VI. The Description of the 5-Effect, 8-Stage Thermally Accelerated Short Time Evaporator

The typical juice output of oranges during commercial transactions ranged from 43% to 55%, with solid content ranging from 9% to 15% and concentrations ranging from 60% to 65% via evaporation. The profound design platitudes of citrus evaporators were known as the 5-effect, 8-stage Thermally Accelerated Short-Time Evaporator.

The 5-effect, 8-stage thermally accelerated short-time evaporator was indispensable in manufacturing orange juice concentrate. The 5-effect, 8-stage thermally accelerated short-time evaporators smothered the feed material to elevated temperatures in a curtailed period to preclude detriment to the food and to guarantee optimum heat transfer from the heating medium to the feed. We achieved *modus operandi* by accelerating a turbulent mist of the substance in a high-temperature, single-pass, and multiple-effect evaporator. The 5-effect, 8-stage thermally accelerated short-time evaporator transubstantiated orange juice into orange juice concentrate, distinguishing our proceeding from conventional orange juice manufacturing methods. The design of this equipment was critical to the effectiveness of the overall process and performed congruously.

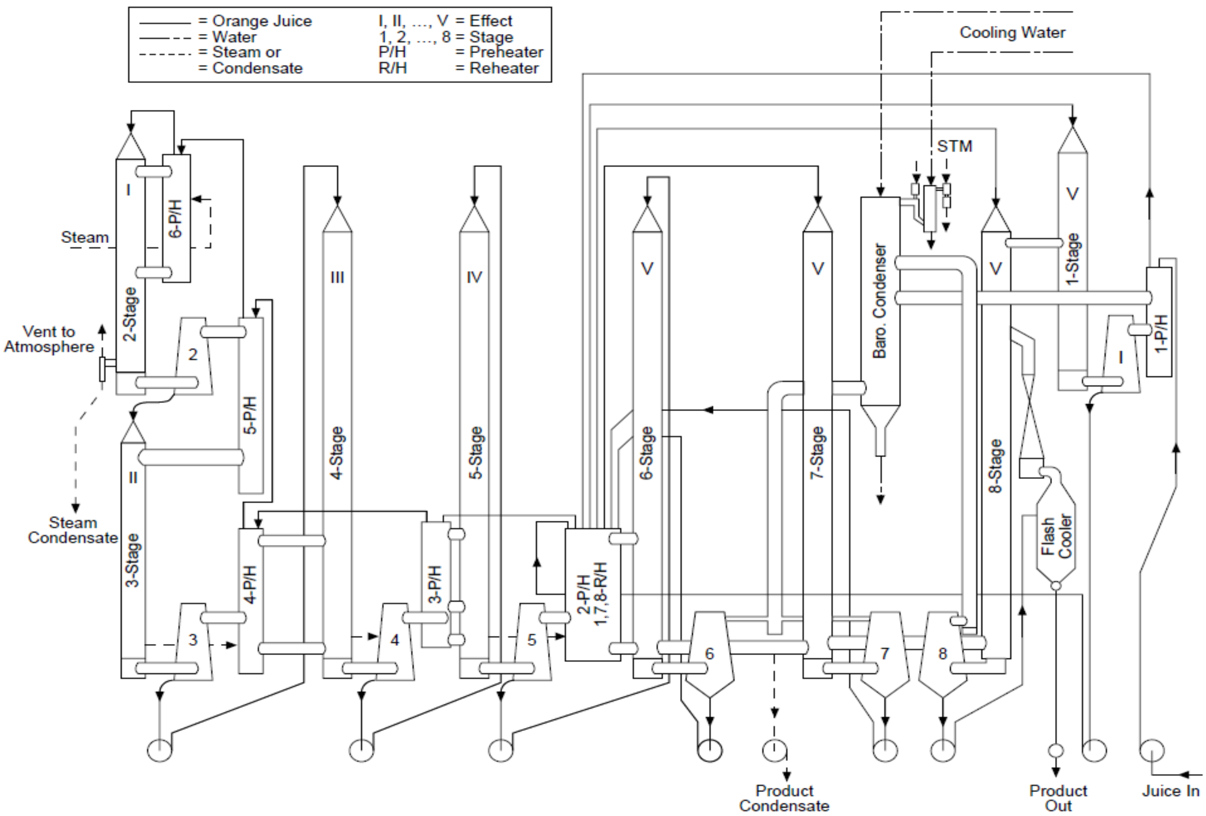

Fig. 6. A schematic diagram of a typical 5-effect, 8-stage citrus TASTE evaporator system [12].

A. 2nd Effect- 3rd Stage

1) Heat Balance

$$V_2\lambda_2 = Q_5(F_1 - V_2)C_2\ (T_2 - T_3) = V_3\lambda_3 \quad (1)$$

$$Q_5 = F_1C_1(T_{f5} - T_{f4}) \quad (2)$$

2) Mass balance

$$V_3 = (F_1 - V_2)(1 - X_2/X_3) \quad (3)$$

3) Heat transfer coefficients for evaporator

$$U_3 = (V_2\lambda_2 - Q_5)/(A_3 \times (T_2 - T_3 - B_3) \quad (4)$$

4) For Preheater (5)

$$U_5^* = Q_5/(A_5^* \times LMTD) \quad (5)$$

B. 3rd Effect - 4th Stage

1) Heat Balance

$$V_3\lambda_3 = Q_4 + (F_1 - V_2 - V_3)C_3(T_3 - T_4) + V_2C(T_3 - T_4) = V_4\lambda_4 \quad (6)$$

$$Q_4 = F_1C_1(T_{f4} - T_{f3}) \quad (7)$$

2) Mass balance

$$V_4 = (F_1 - V_2 - V_3)(1 - X_3/X_4) \quad (8)$$

3) Heat transfer coefficients for evaporator

$$U_4 = (V_3\lambda_3 - Q_4)/(A_4 \times (T_3 - T_4B_4)) \quad (9)$$

4) For Preheater (4)

$$U_4^* = Q_4/(A_4^* \times LMTD) \quad (10)$$

C. 4th Effect - 5th Stage

1) Heat Balance

$$V_4\lambda_4 - Q_3 + (F_1 - V_2 - V_3 - V_4)C_4(T_4 - T_5) + (V_2 + V_3)C(T_4 - T_5) = V_5\lambda_5 \quad (11)$$

$$Q_3 = F_1C_1(T_{f3} - T_{f2}) \quad (12)$$

2) Mass Balance

$$V_5 = (F_1 - V_2 - V_3 - V_4)(1 - X_4/X_5) \quad (13)$$

3) Heat transfer coefficients for evaporator

$$U_5 = (V_4\lambda_4 - Q_3)/(A_5 \times (T_4 - T_5 - B_5)) \quad (14)$$

4) For Preheater (3)

$$U_3^* = Q_3/(A_3^* \times LMTD) \quad (15)$$

D. 5th Effect - 6th Stage

1) Heat Balance

$$M_1 \times V_5\lambda_5 - Q_2 - Q_{r1} - Q_{r8} + (F_1 - V_2 - V_3 - V_4 - V_5)C_5 \quad (16)$$

$$(T_5 - T_6) + (V_2 + V_3 + V_4)C(T_5 - T_6) = V_6\lambda_6 \quad (17)$$

$$Q_2 = F_1C_1(T_{f2} - T_{r1}) \quad (18)$$

$$Q_{r1} = F_oC_o(T_{r1} - T_{f1}) \quad (19)$$

$$Q_{r7} = (F_1 - V_2 - V_3 - V_4 - V_5 - V_6)C_6(T_6 - T_{r7}) \quad (20)$$

$$Q_{r8} = (F_1 - V_2 - V_3 - V_4 - V_5 - V_6 - V_7)C_7(T_7 - T_{r8}) \quad (21)$$

2) Mass balance

$$V_6 = (F_1 - V_2 - V_3 - V_4 - V_5)(1 - X_5/X_6) \quad (22)$$

3) Heat transfer coefficients for evaporator

$$U_6 = (M_1 \times V_5\lambda_5 - Q_2 - Q_{r1} - Q_{r7} - Q_{r8})/(A_6 \times (T_5 - T_6 - B_6)) \quad (23)$$

4) For Preheater 2

$$U_2^* = Q_2/(A_2^* \times LMTD) \quad (24)$$

5) For re-heater for stage 1

$$U_1^* = Q_{r1}/(A_1^* \times LMTD) \quad (25)$$

6) For re-heater for stage 7

$$U_7^* = Q_{r7}/(A_7^* \times LMTD) \quad (26)$$

7) For re-heater for stage 8

$$U_8^* = Q_{r8}/(A_8^* \times LMTD) \quad (27)$$

E. 5th Effect - 7th Stage

1) Heat Balance

$$M_2 \times V_5\lambda_5 + (F_1 - V_2 - V_3 - V_4 - V_5 - V_6)C_6(T_{r7} - T_7) = V_7\lambda_7 \quad (28)$$

2) Mass Balance

$$V_7 = (F_1 - V_2 - V_3 - V_4 - V_5 - V_6)(1 - X_6/X_7) \quad (29)$$

3) Heat transfer coefficients for evaporator

$$U_7 = (M_2 \times V_5\lambda_5)/(A_7 \times (T_5 - T_7 - B_7)) \quad (30)$$

F. 5th Effect - 8th Stage

1) Heat Balance

$$M_3 \times V_5\lambda_5 + (F_1 - V_2 - V_3 - V_4 - V_5 - V_6 - V_7)C_7(T_{r8} - T_8) = V_8\lambda_8 \quad (31)$$

2) Mass Balance

$$V_8 = (F_1 - V_2 - V_3 - V_4 - V_5 - V_6 - V_7)(1 - X_7/X_8) \quad (32)$$

3) Heat transfer coefficients for evaporator

$$U_8 = (M_3 \times V_5\lambda_5)/(A_8 \times (T_5 - T_8 - B_8)) \quad (33)$$

G. 5thEffect–1stStage

1) Heat Balance

$$M_4 \times V_4\lambda_5 + F_0C_0(T_{r1} - T_1) = V_1\lambda_1 \quad (34)$$

2) Mass Balance

$$V_1 = F_0(1 - X_0/X_1) = F_0 - F_1 \quad (35)$$

$$M_1 + M_2 + M_3 + M_4 = 1 \quad (36)$$

3) Heat transfer coefficients for evaporator

$$U_1 = (M_4 \times V_5\lambda_5)/(A_1 \times (T_5 - T_1 - B_1) \quad (37)$$

4) Heat recovery from the exhaust of effect 5

$$Q_1 = F_oC_o(T_{f1} - T_{fo}) \quad (38)$$

5) Heat transfer coefficients for preheater (1)

$$U_1^* = Q_1/(A_1^* \times LMTD) \quad (39)$$

6) Overall Mass Balance

$$V = V_1 + V_2 + \cdots V_8 \quad (40)$$

7) Feed Requirement

$$F_0 = V(1 - X_0/X_8) \quad (41)$$

8) Flash Cooler

$$V_9 = (F_0 - V)C_8(T_9 - T_0)\lambda_9 \quad (42)$$

Using the equations above, we estimated the heat and mass balance of a 5-effect, 8-stage thermally accelerated short-time evaporator.

TABLE I: THESE ABBREVIATIONS ABOVE ALLOWED US TO ESTIMATE THE HEAT AND MASS BALANCE OF A 5-EFFECT, 8-STAGE THERMALLY ACCELERATED SHORT-TIME EVAPORATOR

ABBREVIATIONS	NOMENCLATURE
A, Ai	Evaporator heat transfer area (m2)
B, Bi,	Boiling-point rise (°C)
C_s	Cost of steam per kg ($/kg)
F, Fi	Feed flow rate (kg/h)
LMTD	Log mean temperature difference (°C)
M_j	Fraction of vapor distribution in parallel stages
Q	Rate of heat transfer (kJ/h)
T	Temperature; liquid temperature (°C)
Ti	Boiling temperature of liquid in stages 1 to n (°C)
Ts	Steam temperature (°C)
T_{fo}	Initial feed temperature (°C)
T_{fi}	Feed temperature at exit of the ith preheater (°C)
T_{ri}	Feed temperature at exit of the reheater (°C)
U, U_i	Overall coefficient of heat transfer for the ith stage (W/m^2/°C)
V	Total water removed; total evaporation rate (kg/h)
V_o	Steam rate (kg/h)
V_i	Vapor flow rate (kg/h)
V_s	Kilogram of live steam (kg)
VT	Total kgs of steam (kg)
W	Compression work per kg of steam (kJ/kg)
X_i	Solids content (°Brix)
X_s	Weight fraction of soluble solids; solids content (°Brix)
Λ	Latent heat of vaporization (kJ/kg)

VII. DISCUSSION

Chemical Engineering has been among the consummate remunerated engineering professions worldwide. Many industrial sectors have a requisition for chemical engineers, including conventional manufacturing industries such as chemicals, polymers, fuels, food, pharmaceuticals, and paper, as well as other sectors such as materials and electronics, consumer goods, mining, and metal extraction, biomedical implants, and energy generation. Before embarking on the design of a process, the design framework should be well specified. Engineers should be appertained at the launch of a project in evaluating the design foundations, developing plans and specifications, estimating financial outcomes, and generating possible solutions to the problem for analysis, evaluation, and selection that will effectuate a commercial opportunity, as vaticinated by the sales and marketing consortium. Within these macroscopical pretensions, the chemical engineer should investigate the components and prerequisites of numerous units which constitute the generic process. Many variables affected the chemical engineer's ingenuity to catechize allure methodologies to achieve the goal, which diminished the magnitude of feasible designs. A chemical engineer can collaborate with other engineering disciplines, such as civil engineers for project construction and maintenance, mechanical engineers for vessels and structural constellations, and electrical engineers for instrumentation and controls. Generating ideas for potential solutions to a conceptual problem cannot be isolated from the selection stage of the design process; modicum ideas would repudiate due to impracticability. In the case of constraints, alternative mediums of achieving the pretensions, even improved models, were contingent. External constraints were limitations exceeding the chemical engineer's jurisdiction. Chemical Engineers were granted authority over internal constraints by identifying proficient processes, materials, and equipment and nominating admissible process conditions. To the greatest extent feasible, the Chemical Engineer examined the design requirements (project and equipment specifications) and kept them under evaluation as the design evolved. The pertinent operating and product parameters of the initial orange juice to be evaporated influenced the designation of the prime evaporator classification for the extraction process, such as:

1) Heat sensitivity

Many foods, pharmaceuticals, chemicals, and resins were sensitive to heat and required modest heating temperatures or a brief residence period with prolonged heat exposure. To achieve this, we ensured a constant volume of product in the evaporator, curtailed the duration the evaporator was in operation and abridged the boiling temperature of the bulk product by operating the evaporator at low pressures.

2) Fouling

Particulate matter in the feed precipitates of solids in the concentrate, or product degradation contributed to the conglomeration of undesirable substances on heat transfer surfaces. Gradually, accumulating films on the heat transfer surfaces diminished the global heat transfer coefficient. Ultimately, this preceded process shutdowns and purification of heat transfer surfaces, which obligated extraneous downtime and standard maintenance strategies.

3) Foaming

During evaporation, the product foamed routinely and predominated from a marginal amount of instability that turned into very stable foam that was hellacious to disintegrate into minimal pieces and occupied the comprehensive evaporator system.

4) Appropriate construction materials

Among the critical impetus elements in selecting the evaporator were the appurtenances needed for its construction. The heat transfer surface material was imperative because its thermal conductivity influenced the overall heat transfer coefficient and appropriate surface area.

5) Distillate to concentrate ratio

In most cases, enough fluid flowed through the evaporator to dampen the hot walls. The absence of wall wetting, and the speed of the fluids generated severe fouling and salting of the particles on the heat transfer surfaces, which resulted in reduced heat transmission and product quality degradation owing to smudge on the heating surface.

VIII. Conclusion

As international consumer markets advent saturation, the exposition to the catastrophe in the Nigerian citrus conglomerate will be to enact belligerent public-private gumptions to invigorate the consumption of refined oranges and industrialized orange juice in the Nigerian domestic market. The propounded remunerative models for embracing the domestic and international consortium are: Prioritizing enormous volume distribution catenations to guarantee median emolument margins and repositioning orange juice consortium in the domestic market to incorporate the following peculiarities: utmost nutritional content, aggrandized vitamin C gamut, quality export, job concoction, and revenue generation. Based on a series of surveys, we endorse branding and marketing investments of about US$15 million annually for 100% orange juice distribution and a marketing cadre that can be efficacious. We inferred the implementation of a structured sales corporation with an account executive assigned to distributors and a marketing consultant to facilitate the distribution and wholesale channels. Through investigations, we recommend reverting the enterprise's benefits to national and international campaigns promoting 100% orange juice consumption. The dissemination of premier agricultural management practices to improve productivity and competitiveness of the manufacturing chain as well as diversify distribution channels while expanding the brand "Drink Nigeria," which constitutes empathy and telepathy with the end consumers. The adoption of ordinances facilitates the importation of food and juice commodities (low import taxes, quotas, and elevation of gross domestic product) while maintaining governmental stability and contributing to food security/domestic production. The availability of import distribution channels and workable logistics makes it appealing for international retailers to explore global procurement strategies, import commodities to Nigeria, and assent precedence of benignant exchange rates (local currency appreciated). In addition, marketing evaluations concentrated on recouping product consumption losses in declining markets and propounding financial abetment to citrus manufacturers. With all operational subterfuge perpended, we estimate a purported market of 984 million liters of orange juice at 100% by 2040, which will require 50 million caddies of oranges. In addition, this ingenuity will be fundamental in ensuring the competitiveness of the Nigerian manufacturing consortium, improving the preeminence of individuals, and propagating economic development in Nigeria.

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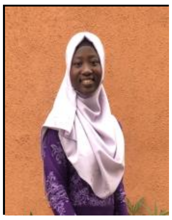

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