How Sugar Became a Readily-Available Commodity

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Introduction

"Sugar in the morning, sugar in the evening, sugar at suppertime." Sugar is everywhere – in little packets on café tables, in pastries and desserts, in juices and energy drinks, and in a host of other common foods. In 2007, the U.S. produced 7,665,000 metric tons of sugar while domestic consumption was 9,342,000 metric tons.[1] Although sugar is now used extensively, it was not always a readily-available commodity. Many years ago, the value of sugar was close to that of gold, and sugar was considered the "sweet" salt.[2] However, sugar prices declined as mechanization made sugar production more efficient and as cultivation of sugar crops expanded to more geographical areas. In the U.S., the development of the multi-effect evaporator revolutionized the sugar production process. Following its success in sugar-refining, the multi-effect evaporator was soon used to make other products. During the last 150 years, it has become a well-known and ubiquitous unit operation in chemical engineering.

History of Sugar Production

The earliest source of sugar was sugar cane. The first process for crystallizing sugar was developed around 350 CE in India.[2] Heavily-grooved rolls were used to crush the cane and extract the juice, which was then boiled to produce sugar in solid form[3]. Over the centuries, the means of production spread to other parts of Asia and Europe, including Persia, China, the Philippines, and Spain, where sugar cane --which grows best in warm climates-- could be cultivated. Europeans used the by-then conventional production techniques in their colonies,

thereby further expanding the sugar industry. In the 17th through 19th centuries, the Caribbean islands (e.g., Cuba, Jamaica, Puerto Rico) produced the most sugar cane.[2]

In 1747, sugar was found in beets by the German chemist Andreas Margraf.[2] Unlike sugar cane, beets grow in regions with cooler climates. Although at first the beet-processing industry was not economically attractive, it boomed during the Napoleonic Wars. At that time, because France and much of Europe were cut off from Caribbean imports by a British naval blockade, continental Europe had to produce its own sugar. Today, 30% of worldwide sugar production comes from beets.

Original Sugar Production Process

In the U.S., during the early 1800s, much of the sugar production occurred in the Southern states, where slaves provided cheap labor. At that time, the process was highly labor-intensive and dangerous. The process began with harvesting and cutting the sugar cane. Next, the sugar cane was milled into smaller particles by animal power to yield cane juice. By 1830, with the Industrial Revolution underway, steam-generated power replaced animal power. Next came the evaporation process, which was not only labor-intensive but very dangerous given the high temperatures required. Four open kettles, the largest holding up to 500 gallons, were ordered from largest to smallest; as this row of kettles resembled a train, the process was called the "Jamaica train."[4] The juice was brought close to its boiling point in the first kettle. As the water boiled off, groups of slaves poured the concentrated sugar syrup into the second kettle. This process of transferring increasingly concentrated sugar syrup continued until it had all been poured into the last kettle. As soon as one kettle was emptied, it would be refilled with the juice from the previous one. Each step in this process -- transferring, refilling, and maintaining the kettles-- required intensive labor. When the syrup reached the desired quality, density and

temperature in the last kettle, the sugar manufacturer would make the "strike": Once the boiled syrup began to produce sugar crystals, the syrup was put into large containers for cooling. Timing the "strike" perfectly was essential for the syrup to crystallize. Otherwise, the syrup would cool into amorphous molasses, not achieving the desired quality.[4]

The Jamaica train required manpower from teams of slaves to provide the necessary heavy and dangerous manual labor. The slaves needed to handle scalding liquids in between kettle transfers. The process also lost sugar during the transfer of cane syrup between kettles and wasted energy because each kettle required its own source of unregulated heat (usually from burning wood). Some sugar manufacturers attempted to increase efficiency by using the energy of steam rising from one kettle to heat the liquid in the next kettle, but with limited success.

Norbert Rilliex and the Multi-effect Evaporator

In Louisiana, cane sugar was one of the leading cash crops by the 1790s. Norbert Rillieux, a Louisiana native familiar with the sugar production process (his father owned a sugar refinery), sought a more efficient way of refining sugar. The talented son of a French plantation owner and a slave mother, Rillieux caught his father's eye as a young boy. Because his father knew that Rillieux's mixed-racial background would prevent social advancement in the U.S., he sent him to France to study engineering. There, Rillieux learned how latent heat could be repeatedly used in refining sugar and how juice can be heated more efficiently (i.e., at lower temperature) under reduced pressure.[5] That knowledge would provide the basis of Rilleux's engineering work, especially in his invention of the multi-effect evaporator.

Rillieux devised the revolutionary multi-effect evaporator in the 1830s (it was patented in 1843). Instead of using kettles, Rillieux discovered that sending vapor from one pan to another through condensing coils in a vacuum chamber allowed the vapor from the juice heated in the first pan to retain almost all of the latent heat of the original steam. His invention utilizes a series of three to four closed evaporating pans in which vapor from boiling juice in the bottommost pan could be used to heat the juice in the next pan. The heating process would repeat until the topmost pan. The vapor from the last pan then went to a condenser. The entire system operated at partial vacuum (pans after the first were under vacuum), with the pressure decreasing successively in each pan.[6] That procedure also corresponded to successively lower temperatures, creating a driving force for heat transfer from the temperature difference established between the boiling vapor and the juice to be heated for evaporation.[7]

Fig. 1. Basic Multi-effect Evaporator Diagram[3]

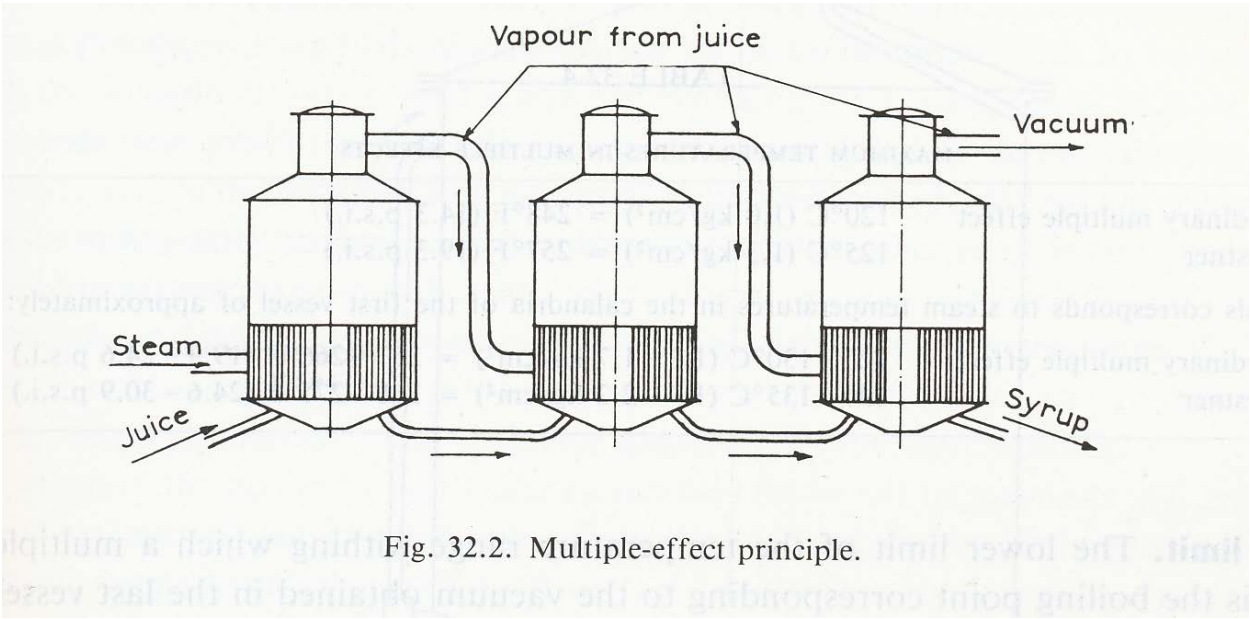

Fig. 32.2. Multiple-effect principle.

Increases in Efficiency, Reduction in Cost

The multi-effect evaporator greatly benefited the sugar industry. First, the evaporator drastically reduced the amount of required energy; by conserving fuel, primarily wood, production costs declined. Instead of having to supply energy to all four kettles, the evaporator only required the energy necessary to boil the liquid for the first pan. Each successive pan utilized the latent heat from the previous pan to boil the liquid. The multi-effect evaporator also required less expensive raw materials; Rillieux used dried cane stalk instead of expensive wood as a fuel source for the production process.[8]

Improvement in Quality

Second, the quality of sugar improved because the sugar was produced in pure crystalline form. Whereas the traditional Jamaica train produced a dark sugar due to the large amount of sugar burned during the process, in the new evaporator, the controlled heat prevented the sugar from burning, resulting in white sugar. Judah P. Benjamin and Theodore Packard's company was the first to begin producing sugar via the multi-effect evaporator. Packard and Benjamin individually received the first and second prizes, respectively, for best quality sugar in Louisiana in 1846.[6]

Federal economic policy also promoted improvement of sugar quality via the Tariff of 1842, which increased the duty on white sugar. Higher duty meant increased consumers prices, so sugar plantations would receive higher profits for producing higher quality sugar. The tariff encouraged more investment in the sugar industry and, subsequently, more use of the multi-effect evaporator to produce white sugar.[9]

Humanistic Influence

With lower production costs, sugar soon became affordable to people in nearly all social levels. Not only did the multi-effect evaporator make sugar more readily available, but it also protected the lives of slaves who no longer needed to transfer boiling liquid between the kettles. As a closed system, the multi-effect evaporator only required one person to operate the valves. It removed much of the manual labor required in the Jamaica-train process.

Although sugar production became less expensive after invention of the multi-effect evaporator, it also introduced new problems, especially for slaves. The increase in profitability of sugar meant that slaves in the fields were expected to harvest more sugarcane. The evaporator created new dangers for operators too, such as equipment explosions. Moreover, if one particular part of the equipment stopped functioning, the entire system would have to shut down and undergo repairs before continuing production.

Unfortunately, despite the multi-effect evaporator's efficiency, only a few were installed in the 1840s and 1850s. Although the multi-effect evaporator reduced fuel consumption by 75%, lack of local institutions to train workers to operate and repair the equipment hindered its widespread use. More importantly, however, planters and sugar refinery owners were suspicious of the effects of such a labor-saving and energy-efficient device on their workforce. Some feared that improvement in skills could lead slaves to question authority and rebel against their owners. Many considered their slaves not capable of handling the new technology; it is a sad irony that an evaporator invented by a black engineer would be considered too complicated for black men to operate. [9]

Conclusion

After Rillieux's death in 1894, the multi-effect evaporator became widespread success. It gained a reputation for providing the best method to lower temperature of all industrial evaporation and for saving fuel.[4] It was also adopted for production of a variety of products. Today, the evaporator is also used to manufacture salt, gelatin, glue, soap, and condensed milk. In addition, the evaporator is used in seawater desalination, paper-making prcesses, and petrochemical production.[8] Recycling processes on the International Space Station use the multi-effect evaporator as well.

The invention of the multi-effect evaporator is considered one of the earliest modern advances in chemical engineering; it is used in all current industrial evaporation processes. On April 18, 2002, the American Chemical Society declared the invention a "National Historic Chemical Landmark," an honor given to 40 other inventions including the discovery of penicillin, Seaborg's research leading to transuranium elements, and Giauque's studies of behavior of substances at very low temperatures. (These last two achievements were conducted by Nobel Prize-winning scientists in Gilman Hall at UC Berkeley.[10)]

Charles A. Browne, a sugar chemist from the U.S. Department of Agriculture noted, "I have always held that Rillieux's invention is the greatest in the history of American chemical engineering, and I know of no other invention that has brought so great a saving to all branches of chemical engineering."[10]

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