Java Sugar Industry and Sugar Cane Engineering in Nineteenth Century

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1. Introduction

Historically, Indonesia is one of the oldest sugar cane growing areas. The botanists Artschwager and Brandes believe sugar cane (Saccharum Offinarum, L.) was first domesticated in New Guinea around 8,000 B.C. Then, 2,000 years later, the cane "migrated" eastward through Micronesia to Hawaii, and westward through the East Indies to the Asian land mass. From there it was carried the east coast of Asia to China and along the southern coast to India, Persia, the Middle East and on to the Mediterranean.

Some references in Indian literature, such as Mahabhashya of Patanyali, the first grammar of a language ever written (around 400-350 B.C) mentions sugar repeatedly in particular food combinations. Historians get first evidence of sugar making in Indian literature, *Budhagosa*, (Discourse on Moral Consciousness) written about 500 A.D. The Hindu religious document describes by way of analogy the boiling of juice, the making of molasses, and the rolling of a ball of sugar. The historian of food, R. J. Forbes, said that sugar became known to the Roman world in Plini's day, about 100 A.D. Only after the eighth century was sugar known and consumed in Europe.

Arab expansion in the seventh and eighth centuries marked a milestone in the European experience of sugar. Sugar making spread in the Mediterranean basin after that conquest, in Sicily, Cyprus, Malta, Rhodes, Morocco, and Spain. The Arabs brought with them the sugar cane, its cultivation, the art of sugar making, and a taste for this different sweetness. The Arab conquerors were synthesists and innovators, transporting the diverse cultural riches of the land they subjugated back and forth across different portions of land combining, intermixing and inventing, and creating new adaptations. The Arabs also disseminated to phalanxes of non-Arab subordinate administrators, policies of administration and taxation, technologies of irrigation, production and processing, and the impulse to expand sugar cane production.

A turning point in sugar technology came with the invention of the vertical three-roller mill, powered by water or animal traction. The origins and exact ages of such mills are still vague. But there is sure evidence of the use of water power for cane milling at an early time in Morocco and Sicily. The sugar engineer and historian Noel Deerr attributes their invention to Pietro Specialle, chief administrative official in Sicily, in 1449.

Non-centrifugal sugar was the basic sweetener of commerce, until the mid-1800's brought the modern equipment and methods that reduced the artisan product. By the end of nineteenth century, crude sugar was no longer accepted in the commercial world. It was eliminated to the status of providing a sweetener suitable for small-scale, low-capital-input production in underdeveloped parts of the world.

2. Java Sugar Industry

The earliest record of sugar in Indonesia is found in the account of the travels of the Chinese traveller, Fahian who visited Java in 424 A.D. and I-Tsing 695 A.D. They mention the presence of sugar cane and the manufacture of gur from cane and palm juice. In 846 A.D., the manufacture of sugar cane is mentioned by Ibn Kordhbeh. The beginning of a large-scale manufacturing of sugar is to be attributed to Chinese immigrants, who by 1400 had established in Java a wealthy trading community. The Dutch connection with sugar in Java dates from 1619.

During 1619-1830, the Vereenigde Oost-Indische Compagnie (VOC, Dutch East India Company) monopolized the sugar trade until their supersession by the Dutch crown in 1798. In this period, sugar was produced by Chinese settlers, who were obliged to deliver sugar to the company at fixed rates. The sole technology applied was that of the traditional small-scale Chinese type. The Chinese used heavy mill-stones and vertically-erected wooden or stone cylinders; propulsion was effected by buffaloes or human power, or both. The cane-juice that was extracted was boiled on furnaces in open cauldrons, the syrup being sold on the domestic market and the raw unrefined sugar exported by VOC. Four grades of sugar were made at this time. The best was exported to Europe, the second to British India, and the third, or brown, to Japan. The fourth grade, "much less dry and very brown from being served out by the dispenser from warehouses for use on board ship." In 1828, two sugar manufacturers made use of iron cylinders for the first time in the production process. The final years of this period were taken up by the French occupancy, the English domination, and the Dutch administration of du Bus de Gisignies, 1826-1830. Before the du Bus administration nearly all trade in Java was in the hands of German merchants. In 1825, the Netherlandsche Handelsmatschappij (N.H.M) had been founded, under which the administration secured a monopoly on all of the Java trade.

Statistics are available for sugar factories and sugar production in Java 1596-1797. These are collected below.

Table 1. Factories and Production in Java, 1596-1797

Year	*Factories*	*Production (tons)*
1596	2 or 3	60-120
1602	4 or 5	185
1619	6 or 7	
1650	20	425
1710	43	2,800
1745	95	1,900
1750	105	1,410
1757	102	
1779	90	4,950
1786	44	5,150

Dutch Governor-General van den Bosch took measures to make Java produce for the Netherlands. These measures include one known by the name of the "Cultivation System" (Cultuur Stelsel). This system under van den Bosch was successful as a source of great wealth to Holland. The output of the sugar industry in Java was nearly all exported. In 1879/1888, for example, only an estimated 3% of the production was sold in the Netherlands-Indies itself. Value of sugar exports to the Netherlands rose from 1,558,000f (12.2% of total value of exports) in 1830, to 80,592,000f (36% of total value exports) in 1895. The development of the Java sugar industry under the culture system can be seen in the following table.

Table 2. Java Sugar Production and Number of Factories (1830-1896)

Year	*Factories*	*Production*	*Ton per Factory*
1830	30	6,467	216
1838	68	44,589	657
1856	95	125,101	1,318
1868	97	178,784	1,834
1879	105	233,302	2,219
1893	192	479,600	2,498
1896	187	534,390	2,858

One outcome of this system in the production of sugar was a notable improvement in technology. In 1836 the open cauldrons were replaced for the first time by vacuum apparatus designed to accelerate the evaporation/reduction process. Animal power was replaced by water mills; these in their turn gave way to steam engines. From 1841 onwards, new factories used production technology derived from the European sugar-beet industry only. The first centrifugal plant for the efficient separation of sugar and syrup was imported into Java in 1853. In 1840 N.H.M. set up a model sugar factory. The output of sugar rose from less than 15 pikols per bouw in 1830, to about 50 pikols per bouw in 1850. The hand-presses of early days had given way to steam plants, but in the 1880's these were out of date, and manufacturers spent large sums on replacing them. Statistics of output and export show that the improvements in technology enabled the manufacturers to hold their own, and even to make rapid progress, even while encountering a steady fall in prices due to the sugar crisis of 1884.

The sugar industry was by far the most important factor in the process of mechanization. For example, in 1891 the value of machinery imported for the sugar industry was over 50% of the total value of all imported machinery. In 1875, for example, as much as 93% of all steam boilers in industrial enterprises were used in sugar factories. The Sugar Act of 1870 was a particularly important stimulus for the sugar enterprises to use steam-driven appliances in their factories instead of water mills. The compulsory surrender of land and compulsory labour of the Cultivation System came to an end under this Act. As a consequence, sugar factories were confronted with a supply of cane which needed harvesting from a limited and often changing area. This forced the sugar industry to aim at a sharp increase in productivity, in which respect, factory mechanization played a decisive part. A new wave of mechanization then followed this Act. In 1873 the first 'double action evaporation/reduction equipment' was put into commission; two years later a similar piece of equipment, this time the 'triple effect machine', was installed. In 1877 pans were introduced for improved purification of the cane juice.

The sugar crisis of 1884 did not bring the mechanization of the sugar industry to a halt. Although the number of working factories nearly stabilized, output per factory rose by over 80% between 1880 and 1885. Simultaneously with this crisis, a new sugar cane disease appeared, called Sereh (from sereh grass Androgon schoenanthus). The sereh disease was reported for the first time in 1881. Within a few years it had infected sugar cane plants all over Java. Around 1885 the sugar research stations were established in Cirebon, Tegal, Semarang, Pasuruan. The stations carried out research into the processing of sugar cane, the manufacture of by- and residual products, the construction and operation of plant and equipment in sugar factories.

The use of steam power had made some progress in the first half of the nineteenth century after Indisch-Staats'blad 185, 1836, No. 10 was drawn up. This regulation was aimed at the prevention of fire in built-up areas, and avoiding annoyance and danger to inhabitants in the environment. In 1852, regulations concerning safety measures in the use of steam engines in the Netherlands-Indies was introduced. These regulations stipulated that a licence was required for the use of a steam engine, steam boiler or steam appliance. At the end of 1853, 70 license certificates for the use of steam power had been granted, of which 62 were for private use and eight for Government use. In the Colonial Report for the year 1859, the sugar industry used by far the highest number of steam engines, namely 151 of the total 185 steam engines in private (and 19 in Government) use. The number of steam boilers was much higher than the number of steam engines up to the end of 1873.

Use of Steam Power in the Sugar Industry,
Manufacturing Industry, Private Enterprise
1871-1897 (selected years)

Year	*Sugar Industry*	*Number of Boilers Manufacturing Industry*	*Private Enterprise*
1871	342	378	677
1875	808	866	954
1881	998	1,200	1,256
1886	984	1,230	1,366
1892	1,011	1,392	1,596
1897	1,038	1,589	1,955

The machine factories and construction workshops also existed in the Netherlands-Indies. The metal industry is considered to be the oldest industrial branch in the country. Most machine factories and construction firms often started out as workshops. For example, the firms were De Nederlandsch-Indische Industrie (1823), Constructiewerkplaats De Vries Robbe-Lindeteves (1860), Machinefabriek en Scheepswerf Batavia (1875), and De Maatschappij tot Exploitatie van den Constructiewinkel de Bromo te Pasuruan (1889). However, in nineteenth century the majority of these industries were still simple workshops. The Netherlands-Indies machinery industry never did anything more than just repair machinery until the First World War.

3. Sugar Cane Engineering

Manual cane harvesting, as practiced at the beginning of the establishment of the Java sugar industry, is still in practice. The progress on methods of cane harvesting in Indonesia has occured in line with the conditions, the environment, the cane quality required, and the labour. To reduce cane trash, the harvesting was frequently done after the cane was burnt, followed by manual or mechanical harvesting, as whole stalk cane or chopped cane. The cane was once transported by carriages or lorries drawn by cow or buffaloes. Later, the cane was transported by lorries or drawn by steam locomotives, for in the cane fields, loose rails can be used. The first in use was at the Kaliwungu sugar factory in 1870 and this was connected to the main railroad. The first steam locomotives were used at the Purwodadi sugar factory in about 1876. In the cane fields, both permanent railroads and loose railroads were in use.

Extraction of juice from cane has always been effected by pressure. At some unknown early date, primitive two-roller mills were in use. These were replaced by vertical three-roll mills, the three rollers being set vertically in a straight line. Such mills were driven by animal, wind or water power, the type in general use until the latter part of the eighteenth century. In 1871, Rousselot introduced three roller mills with horizontal rollers which have been constructed the most since. The three-roller mill consists of cast iron shells mounted on heavy steel shafts and these are arranged to rotate. The top roller is driven from the prime mover through reduction gearing, and the two lower rollers are driven by pinion meshing with a pinion mounted on the top roller.

Until recent times, the extraction of the cane juice was done by mills only, or with a preparation unit. The Krajewski crusher, patent 12,012 of 1886, was probably the first type of cane preparation plant used in very wide application. A crusher consists of a pair of heavy rollers with deeply grooved surfaces, rotating at slow speed, with the ridges of one roller meshing with the grooves of the other. The ridges run the length of the roller following a longitudinal zigzag line, and are separated by a trough shaped as an arc. In the Java sugar industry, the three-roll mills with the Krajewski crusher have generally been in use since 1894.

The sugar industry is unique among industries in obtaining all its fuel requirements from its raw material, bagasse. Bagasse is the residue of cane after it has been crushed in the mill. Bagasse has long been used as fuel in the sugar factory, both for sugar boiling and for power generation. The boiler consists of two main parts: the heat generator, where the fuel is burnt to generate the heat, and the heat absorber, in which the heat generated is transmitted to the water in the boiler, so generating steam. Before the twentieth century, the fire tube boilers were favoured in the sugar industry on account of their higher water capacity and the supposed improved heat storage which could cope with the fluctuation of steam demand. However, fire tube boilers are restricted to low pressures and small units. The first application of the use of steam power to the operation of cane-crushing plants was made in Cuba around about 1797. In Java, the introduction was later than 1838. In 1857, of the 178 factories, 118 had steam boilers and machines.

The original method of concentrating sugar juice to form crystals was the method of boiling in a shallow open pan with direct heating. The juice was placed in the pan farthest from the fire, and after evaporation it was transferred into the pan near the fire, so that the juice nearest the fire gets the most heat. Use of steam as a heating medium was marked by the invention of the vacuum pan by Edward Charles Howard in 1813. This way the juice was boiled at a lower pressure and thus at a lower temperature, so that the inversion as well as caramelization could be kept at a minimum. This vacuum pan was the shallow open pan with the addition of a cover to make it airtight, with a vapour pipe, condenser and vacuum pump, and with a steam jacket around the lower portion (of the pan itself) for heating. By using double, triple or quadruple evaporator bodies in a series (multiple effect evaporator), the steam consumption was much more efficient. In 1836, the open iron cauldrons were replaced for the first time by the vacuum pan in the Java sugar industry with the instalation at Seembul, Probolinggo, East Java.

Multi effect evaporation, employed universally in the sugar industry and in other industries, was invented by Norbert Rillieux, in Louisiana, in 1844. Rillieux's first patent shows two jacketed Howard's original pans coupled together in a double effect. The jacketed pans were soon replaced by evaporators with horizontal steam tubes, and in 1851 the first vertical tube evaporator was introduced from which modern designs have been developed. Double effect evaporations were first introduced and installed at Purwodadi sugar factory by Baron Aloet in 1873, and at Jatiwangi and Wonopringo in 1875.

The operation known in the factory as sugar boiling is the process of crystallization which is carried out in single effect vacuum evaporators. The vacuum pan is an evaporative crystallizer. The vacuum pan provides space for the boiling liquid, a heating element in which heat is supplied by condensation of steam or vapour, a vapour disengaging space and vapour connecting to the condenser and vacuum pump. The Van Vlissingen vacuum pan was developed by Stork-Werks-poor, and was equipped with coils and a double bottom for heating out of copper. At a later stage, the need for a bigger volume pan was felt. Because of this, it was then made of iron plate. The first evapo-crystallization pan with calandria heater was made by Hollesche Haschalaen Fabriek, of Germany.

This pan was the same as evaporators except shorter and with wider pipes which were used because of the higher viscosity of material to be evaporated. Uncondensable gasses were taken from the top of calandria, while the condensed water was taken from the bottom of calandria.

Until the middle of the nineteenth century, separation of syrup from crystal sugar was effected only by gravity. The centrifugal separator has been described by Noel Deer "as one of the world's most far reaching inventions" and, while originally introduced for use with textile goods, its first development was in its application in the sugar industry. The sugar crystals are retained on a perforated basket, while the liquid passes through crystals and holes (diameter 0.26mm) of a batch centrifugal basket. The big advance in the centrifugal basket was the flexible suspension, incorporated in the patents of David McCoy Weston in 1852. The flexible suspension allowed the centrifugal basket to: rotate about the centre of gravity rather than its geometrical centre; and enables high speeds to be used with the load slightly out of balance. In the Java cane-sugar industry, the earliest record of the centrifugal separator use is at Waru, which was installed by Dolder in 1853.

In the beginning of sugar manufacturing, the massecuite (the concentrated syrup or molasses in which the sugar has been crystallized) was blown down to an open container. The massecuite was left unstirred and the crystals formed automatically. This resulted in a small and irregular grain, due to local oversaturation a consequence of the lack of any circulation in mixing. Stirred massecuites could reduce the amount of false and big size crystals. A crystallization-in-motion pan was patented by Wulff in Germany in 1884. The crystallizer generally was a cylindrical or U-shaped vessel with a simple stirrer in the form of a helical ribbon mounted on a longitudinal shaft which rotated at about two minutes/per revolution. The cooling agent could be air or water. Since that date, the use of the crystallizers has gradually became universal in the Java sugar industry.

The sugar juice contains considerable colloidal and fine suspended matter. It is mainly these constituents that have to beremoved. Removing or clarification processes are closely analogous to the treatment of water supplies. The clarification process was developed in such a way that with the addition of lime, SO_2, CO_2 gasses, mixing, heating, settling and screening, the temperature, PH and retention time, can be controlled accurately. This will produce clear juice which is easily processed further. Three types of processes are defacation, sulphitation and carbonatation. The material most used has been from centuries ago, lime. In the cane-sugar industry, the use of a large excess of lime followed by its removal as a carbonate by the action of the carbonic acid gas, was first used by Averbeck at Jatiwangi and at Wonopringo, East Java, in 1876, where it gradually became established as an economic process for making the highest grade of direct-consumption white sugar.

In the past, the organization of sugar experiment stations was only carried out by individual effort. The earliest and most noteworthy example is that of the Marquis de Cazaud, in Grenada, who was colonial born and brought up on a sugar plantation. A paper read by him before the Royal Society in 1779, and expanded into a book, contains an account of the life-history of the cane, of which he gives an accurate analysis of the root system. In the Java sugar cane industry, the first record of agricultural experiments is the experimental work on cane varieties by Fromberg in 1853 and experiments on manures by Krajenbrick and Roost van Toonigan in 1857. The first suggestion for the establishment of experiment stations is from Jonkheer van der Wych in 1860. The Java Proef Stations at Semarang, Cirebon, Tegal and Pasuruan began work in 1806 and 1887. These stations created a wealth of information covering all phases of the Java sugar industry. This resulted in 40 million words, appearing in *Java Archief voor de Suikerindustrie*, published between 1893 and 1934. In the archives can also be found the work of Went and Walker on cane diseases, the original cane breeding work of Kobus, nobilization of the wild type of cane by Jeswiet, the studies of Geerligs embracing all stations in the factory and the cytological studies of Bremer.

4. Epilogue

The early part of the nineteenth century was not a good period for the Dutch economy. The overall politics-economy was affected by wars. In response to the problems, the Cultivation System was introduced. The System was notably successful in raising the Dutch income flow from the Netherlands-Indies: "Java poured forth riches upon riches on the home land as if by a magicians wand". A big part of this income was obtained from the Java sugar industry.

The Java sugar industry in the nineteenth century was boosted by the economic difficulty of the Netherlands and the sharp increase in world sugar consumption. The development of the Java sugar industry closely related and accompanied the progress of science and technology of the sugar cane. The inventions and patents in Europe at once became capital goods in the Java sugar industry. The influx of technology from Europe kept coming to Java only in a one way traffic stream and nearly never flowed back. The content of technology such as management, money, machines and man was completely that of European outcomes. The transfer of technology, if this existed, was distributed and circulated among the Dutch. The sugar cane technology in Java, developed as a spread in quantity rather than in depth of quality.

One or two vocational schools and short-courses in the technical elementaries of sugar cane machinery or cultivation, were at last founded at the end of the nineteenth century at Surabaya, but native pupils were few. Until the early twentieth century, technology courses in high schools and universities did not exist in the Netherlands-Indies. Native labour in the sugar factory were employed because they agreed to work for cheap wages. The native labour were trained and involved in the factory sugar manufacturing process and cultivation process only as operators or foremen at best. The growth of Java machine building and engineering industries in sugar industry was insignificant. Most of the Netherlands-Indies machinery industries were only simple workshops which never more than just repaired machinery until the First World War.

Because the Java sugar industry was destroyed by the sereh disease, the first Java sugar experimental station was built in 1885. The stations were financed by Dutch investors; were managed by Dutch organizers; were activated by Dutch researchers; and benefited Dutch citizens. From the stations, a huge amount of research information was collected. Unfortunately, nearly all of the information was in relation to sugar cane cultivation instead of sugar industry engineering. The engineering information such as engineering design, testing, in-plant facilities, plant lay-out, flow of work, operating practices, maintenance of plant and equipment, conditions of machines received practically no attention al all.

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