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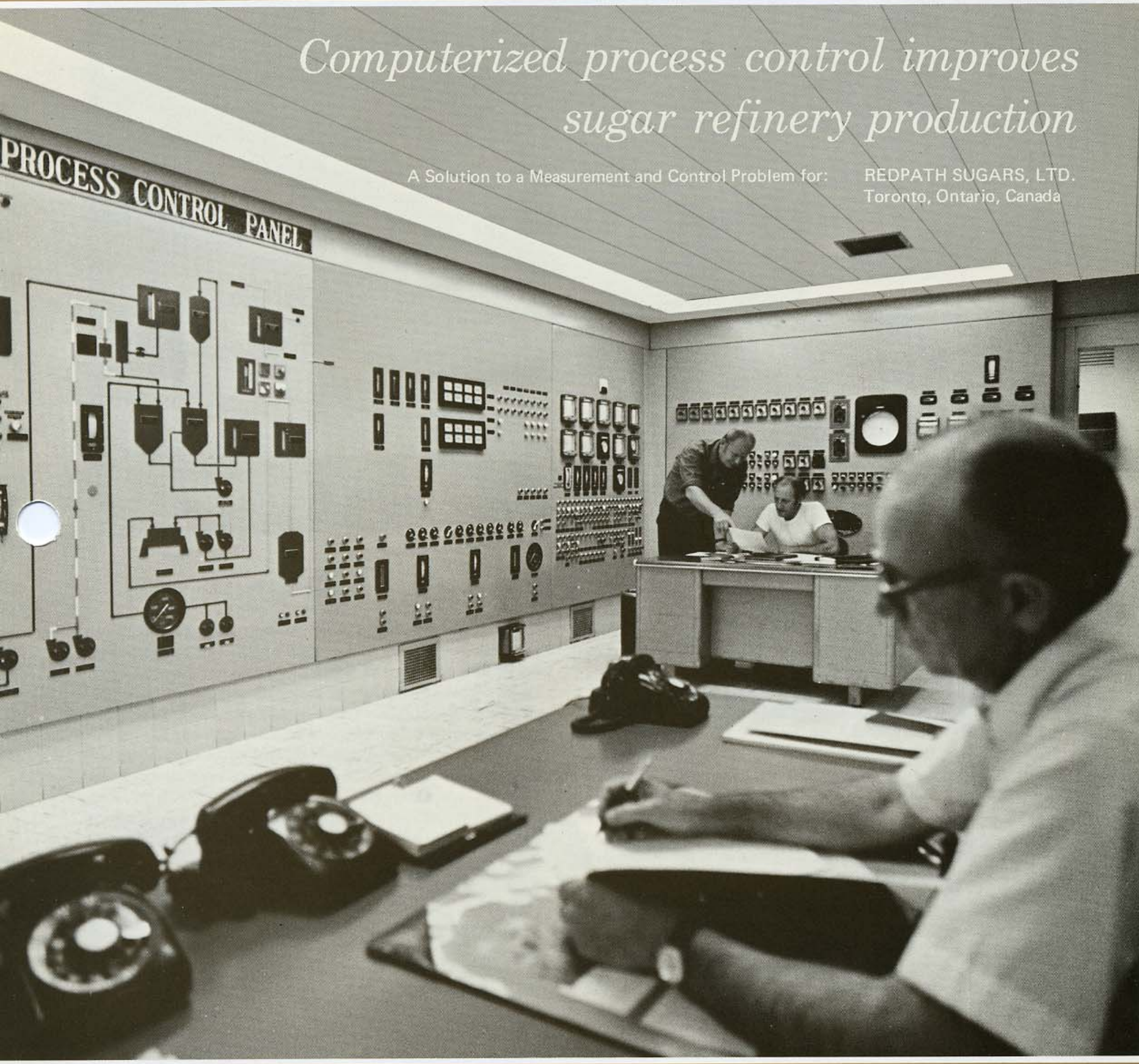
APPLICATIONS OF COMPUTERIZED DIGITAL DATA ACQUISITION SYSTEMS

Computerized process control improves sugar refinery production

A Solution to a Measurement and Control Problem for: REDPATH SUGARS, LTD. Toronto, Ontario, Canada



The main control room of Redpath's process control system shows at a glance the status of each stage in the process control stream. An HP computerized system (in the computer room) keeps the sugar refining processes running smoothly and at peak output.

Computerized process control improves sugar refinery production

Figure 1. A mountain of raw sugar just waiting to be processed. Redpath's Toronto refinery processes 78,000 pounds per hour.

Sugar in its many finished forms – granulated, powdered, cubed, brown, and others – is undoubtedly one of the most commonly available products today. Yet, sugar continues to be in ever-increasing demand on a world-wide level. The needs are being met through technical advances in agriculture and by improving the efficiency of sugar refining techniques. The amount of acreage sown to sugarcane and sugar beets has steadily increased and, at the same time, the yield per acre has increased. Techniques in the sugar refining processes have also undergone change – ranging from the all-manual methods of a few years ago to highly automated closed-loop computer control. A particularly noteworthy approach to the feasibility and implementation of process automation was undertaken at the Toronto, Ontario sugar refinery of Redpath Sugars, Ltd. The product is well-known under the name Redpath Sugar.

Approximately six years ago Redpath initiated a full-scale, plant-wide investigation into computerized process control for the purpose of optimizing individual stages in the refining process and the overall process itself. Important among the project objectives was the establishment of closed-loop control of only those stages where a computer could make a significant improvement. *The project, then, was not intended to be one of completely automating the refinery at all costs, but rather, a planned step-by-step approach based on sound engineering principles.*

INSIDE THE REFINERY

A cane sugar refinery, such as Redpath, receives as its input a product called raw sugar, some of which is shown in Figure 1. It is manufactured from sugarcane in raw sugar mills usually located close to the cane fields. Raw sugar is generally 96 to 98% sucrose. The refining process yields a finished product which is 99.9+% pure sucrose, by removing the impurities from the raw sugar. The chief impurity is a film of molasses which adheres to each raw sugar crystal; some wax and gum are also present. While sugar is available in other forms (fructose, dextrose, maltose, etc.), sucrose is accepted as the world-wide sugar of commerce, with the major source being sugarcane.

Raw sugar goes through a number of processing stages before attaining the high purity and white color of the end product. The first step consists of weighing the raw sugar as a means of determining plant capacity and rate control. Refining begins with mingling a syrup with the raw sugar to loosen the film of molasses, waxes, and gums that coat the raw sugar crystal, then washing this magma in four affination centrifugal machines. This has the primary function of removing these impurities, and is known as affining. The washed raw sugar from the affination machines is then melted, passed through carbonatation tanks through Sweetland filters where solid impurities are removed, passed over char cisterns removing the melted-in impurities (in the form of color) to give the clear, sparkling pure liquid sucrose, which is boiled back into a crystal in the form of granulated sugar.

THE APPROACH TO AUTOMATION

After establishing the objectives for its process control project, Redpath determined the best approach should be: (a) develop a mathematical model of the complete sugar refining process, and (b) determine from the model (a series of interrelated equations) which stages to automate, the order of implementation, and the degree of control required to achieve a steady flow and high efficiency.

Initially, Redpath purchased a non-computer-controlled HP digital data acquisition system to handle the many measurements that would be required to formulate the mathematical model. The system consisted of scanning and digitizing instruments, with punched tape and printed tape output recorders, plus a special interface system to accept inputs from the existing sensors located at the various process stages. The interface was used to convert pneumatic signals to voltage levels acceptable to the scanner-digitizer. It converted the input signals so that the output was in normal engineering units. For example, a depth gage signal of 16 mA, representing the 3/4-full level of a tank, was converted so that the scanner received a 7.5-volt signal, representing the 75% level. The interface also integrated the input from selected instruments such that the system input was a signal representing total flow, although the flow meters used produced a signal which was proportional to flow rate.

Establishing the mathematical model required measurement of about 80 variables consisting of flows, temperatures, tank levels, tank weights, pH, brix (amount of sugar in a solution), etc. These measurements, plus concurrent laboratory measurements, were recorded on punched tape. The data were then taken to a large computer facility where non-linear regression analyses were performed. Results from the experiments, which were conducted over a 2-year period, showed that relatively simple models (mass flow equations) were adequate for rate control purposes. On the other hand, much more complex models were needed for quality control, and the degree of accuracy would not be as high.

Figure 2. Seated at a teleprinter in the computer room, the operator is entering changes into the process control system by calling the variable number assigned to the particular function, and inserting the new figure. In between printouts, the computer handles non-process jobs via the teleprinter in the rear.

While conducting the experiments, it became quite apparent that variations in throughput rate were of sufficient magnitude to reduce the validity of the acquired results. Thus, the second element in the refinery automation study was put into effect, viz., automatic rate control over certain stages in the refinery process. The next step was selection of a computer to perform the control function.

THE COMPUTER CONTROL SYSTEM

Redpath engineers selected an HP 2115A Computer with 8K (16-bit words) of memory as the main control element in the refinery process control system. The system, as set up inside the computer control room, is shown in Figure 2. Among the many factors considered important from both an economical and operational standpoint was that of compatibility with existing equipment. The input scanner and digital voltmeter from the non-computer system are compatible with computer operation and are performing the same functions in the computer-controlled system. (The input sensor interface system is also used with the computer system.) The complete computer process control system is shown in the block diagram of Figure 3.

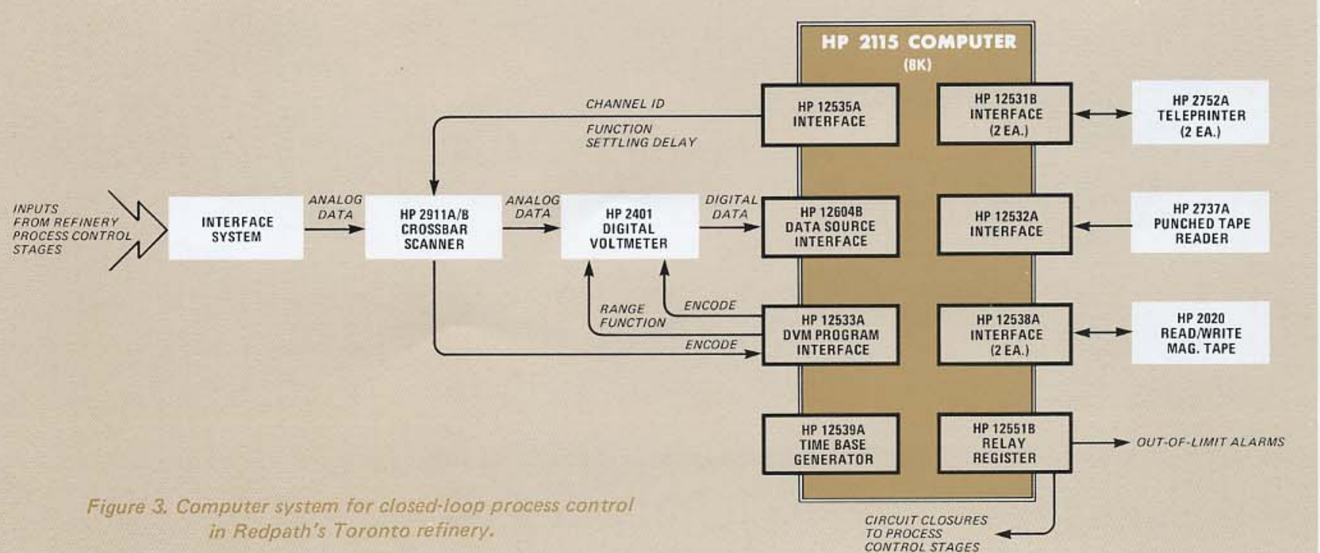


Figure 3. Computer system for closed-loop process control in Redpath's Toronto refinery.

Initially, the computer system was used for rate control of raw sugar input; at the present time it controls all stages prior to the char filters. Forty separate production points in the refinery are now monitored and twelve functions are computer controlled.

The movement of sugar through the process is governed by two factors: (a) the required overall throughput rate and (b) any unusual conditions that may develop at any stage in the process. Rate control is the most important control in the process since all stages respond immediately to a change in the throughput rate. *This effectively eliminates surges that can occur with conventional controls in response to a change in rate or a bottleneck in the process.* The computer also monitors the levels of several tanks along the stream and automatically reduces the throughput rate if any are too high. As the level returns to its normal working range, the throughput rate is restored to its previous value.

Examples of some of the process stages under computer control are:

- Raw sugar weigher shown in Figure 4. The computer trips the weigher at intervals determined from the current values of throughput rate and weigher batch weight.
- Mingling syrup dosing. A timed dose of mingling syrup is added to each batch of raw sugar. The volume of syrup added to each batch is adjusted for variations in the batch weight. Any changes in the flow rate of the syrup are compensated for by adjustment of the duration of the dose. The brix of the magma is inferred from the properties of the sugar and syrup inputs and controlled to within +0.05 of the selected value.
- Affination machine starts and washes. The four affination machines (two are shown in Figure 5) are started at intervals determined from the required throughput rate and the feed-through level. The calculated start time is compared with a stipulated minimum cycle time to ensure that a start pulse is not sent to a machine until it has completed the previous cycle. The affination washes are timed so as to maintain a constant water volume per cycle. The duration of the wash is thus adjusted for changes in wash water brix or flow rate in a manner similar to that for the mingling syrup control.
- First crop machine starts. The first crop machine is started at a rate calculated to remain constant at least until the next first crop pan strike. When the next pan is "dropped", the rate will be adjusted as necessary to maintain a steady rate.
- Melter flow control. The melter (Figure 6) throughput rate is controlled by a valve on the exit side. This is adjusted by the computer to correspond to the overall throughput rate, modified according to the level in the pre-melter tank.
- Sweetland filter starts. The Sweetland filters (Figure 7) are operated so as to remove a chosen weight of cake (calcium carbonate precipitate which collects between the leaves of the filter and removes the solid impurities) in each filter cycle. The filter flow rate is calculated to correspond to the overall rate, allowing for the number of filters on duty and the downtime required for sluicing and recharging. The computer prints a recommended setting for the filter flow regulators.

ADDITIONAL COMPUTER CAPABILITIES

Besides its function as the central controller in the process control system, the computer also: (a) controls the acquisition of data from all instruments, (b) controls printout of summary reports, (c) controls printout of shift reports, and (d) handles non-process control applications.

Under computer control, all data points in the system are scanned at 5-minute intervals. For any out-of-range conditions, alarm messages are printed on the teleprinter, accompanied by an audible warning. A brief log entry is printed which tabulates the current weigher, mingling syrup dose, and affination centrifugal start times. At the end of each hour, a summary line of production data is printed. This shows the raw sugar input and the total flows of affination wash, raw syrup, washed sugar liquor, and filtered liquor. Every four hours the affination and crop machine basket factors (weight of sugar from centrifugals) are printed together with the magma brix. At midnight, 8 am, and 4 pm a shift report is printed. This contains the summary lines previously printed plus an average for the complete shift. Also printed is a tally of the alarm messages that were printed during the preceding shift. While not taking instrument readings, the computer is used for non-process control applications. Non-process programs are stored on magnetic tape and called into memory when required. Also, the output from these programs is stored on magnetic tape and printed between succeeding scans.

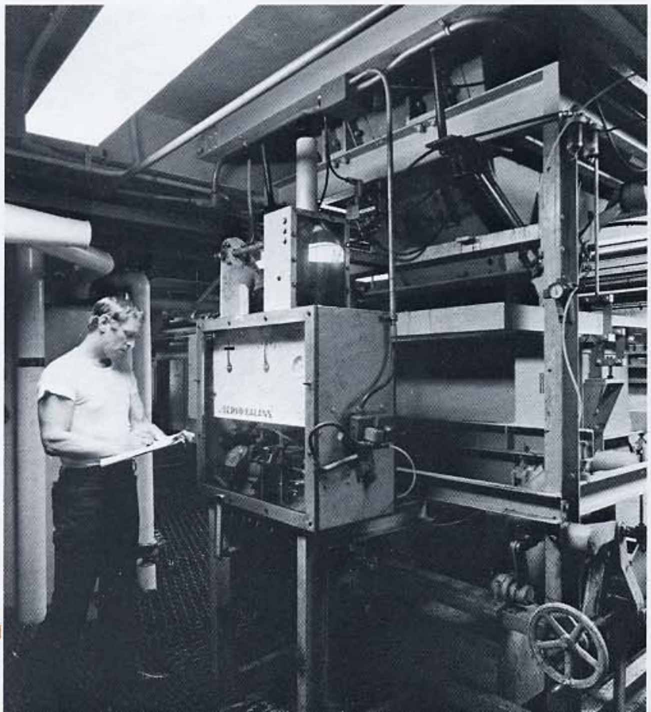


Figure 4. Checking the condition and status of the raw sugar weigher helps to assure proper operation of this very important first stage in the process control system. The raw sugar is then sent to the magma mingler.

QUALITY CONTROL

After successfully implementing rate control in several stages of the refinery, Redpath engineers began to institute some control over the quality of the sugar. A good example of applying computerized techniques in the area of quality control is that which has been incorporated in the affination wash cycle. As mentioned earlier, the purpose of the affination wash is removal of the molasses and other impurities that adhere to the sugar crystal. The problem is to determine how well the film of impurities is being removed and hence how much wash to apply. Data gathered over a period of several years showed, of the various impurities present, the removal of chloride was greatest, on a "percent removal" basis, and that the variation in removal was least for chloride. The chloride content then became a measure of the film. Measurements are made by taking chloride samples from an affination machine whose wash time is varied systematically. The chloride measurement data are then fed to the computer which performs a regression analysis, thereby selecting the optimal wash.

BENEFITS OF COMPUTERIZED PROCESS CONTROL

Computerized process control has proved to be very practical and worthwhile in the Redpath refinery. The improved rate control represents an effective increase in plant capacity estimated at between 3 and 5%. The automatic process control system allows the refinery to operate at close to full capacity on a 24-hour, 5-day week schedule. The maximum output of the refinery is 80,000 pounds per hour, and with the process control system the output is maintained constant at 78,000 pounds per hour. Redpath engineers report the more uniform conditions (elimination of surges, etc.) make possible the evaluation of alternative methods leading to overall refinery operation that is closer to optimal. Additionally, this has allowed the reduction of in-process inventories, permitting decreased tank sizes. Future work is expected to be directed toward full automatic control of the pan boiling, and subsequently to control of the char cisterns.

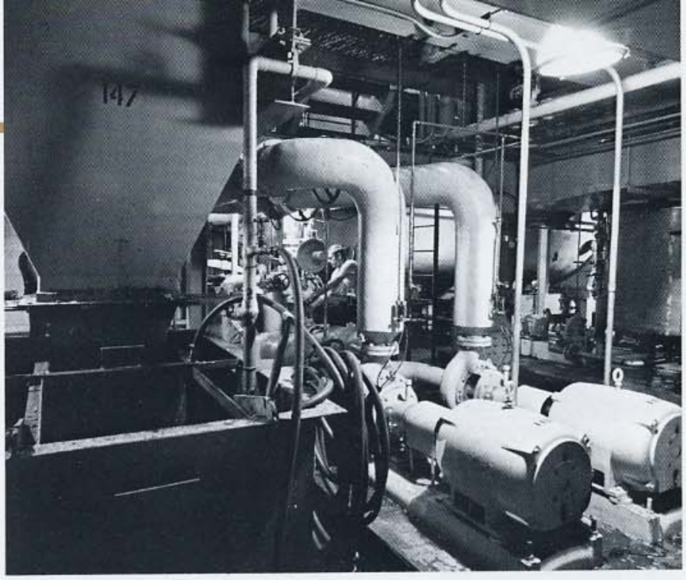


Figure 6. Washed raw sugar is melted in the melter before going on to the Sweetland filters via the carbonatation tanks.

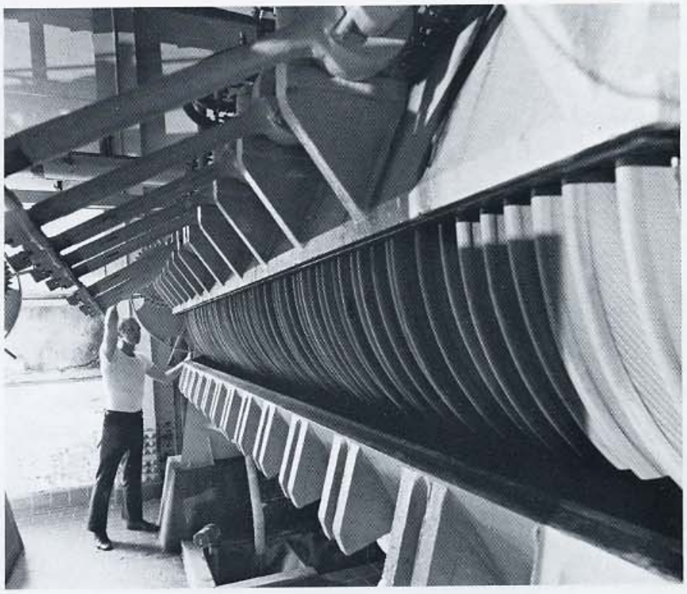


Figure 7. The Sweetland filters remove the solid impurities from the raw sugar before sending it on to the char cisterns for final filtering.

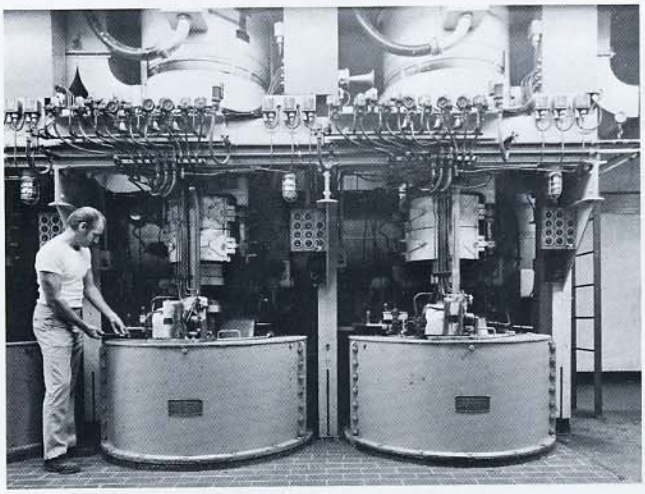


Figure 5. Raw sugar is mixed with a mingling syrup and then washed in these affination machines (two more are not shown) to remove the outer film of impurities from the raw sugar crystals. The washed raw sugar is then sent to the melter.

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