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SAN LUIS VALLEY, COLORADO; A REGION OF HIGH POTENTIAL FOR GEOTHERMAL DEVELOPMENT

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ABSTRACT

The geothermal resources of the San Luis Valley, Colorado, have been evaluated on the basis of available geological and geophysical data. The technical and economic feasibilities of using 300°F brine from the Valley, or from any other geothermal source, to provide process heat for beet sugar processing and barley malting, were analyzed. Costs of overland trans-shipment of hot water from the Valley to front range cities were estimated parametrically. This study was performed under the auspices of the U.S. Department of Energy, Contract No. EG-77-C-07-1626.

I. Introduction

The San Luis Valley is located in south-central Colorado, spanning the Colorado-New Mexico border. It is a part of the Rio Grande Rift system, bounded by the Sangre de Cristo Mountains on the east side and the San Juan Mountains on the west. Within Colorado it is about 90 miles north to south, and 30 miles east to west at its widest point. The Valley is estimated to be as much as 20,000 to 30,000 feet deep; it is filled with porous sediment with interlacing, lenticular layers of low permeability clay in the upper strata. The porous sediment is largely water-filled, with the water table reaching the surface in some areas. Thus, there is an immense aquifer present. There are various natural hot springs in the Valley and numerous shallow wells have produced warm water.

The principal industry in the area is agriculture, producing mainly barley, potatoes, and livestock, with barley being the largest single crop. Sugar beets were once grown in the Valley and they remain a major crop in other parts of Colorado.

This study was designed to analyze the economic feasibility of industrial use of the San Luis Valley geothermal reservoir, and was conducted in three phases. First, the diverse data and studies on the Valley's hydrology were thoroughly evaluated. Second, two industrial process applications of geothermal heat were analyzed in great detail: beet sugar processing and barley malting, with the objective of determining if low temperature waters could be economically used in new plants. Third, the cost of trans-shipment of hot water across the mountains to front range cities was evaluated.

It has been concluded that even a low temperature heat source (less than 300°F) can be an economical heat source for complex processing plants. The beet sugar industry, which normally uses heat in the form of steam at about 290°F, can derive its energy needs from 302°F geothermal brines at very nearly competitive operating costs compared to fossil fueled steam systems. Barley malting also shows favorable costs at even lower brine temperatures. The concept of pipelining hot water over long distances was considered parametrically. The delivered cost of heat in different quantities was estimated. These costs are then matched against potential user heat loads at the delivery end. At low flow rates of only a few thousand acre feet per year, the physical pipeline itself is very expensive for the amount of delivered heat available from 302°F source water. Conversely, in this region of sparse population, the large volumes of water that would be delivered by large pipelines (for example, 100,000 acre feet per year from a 60-inch line) provide vastly more heat energy than needed.

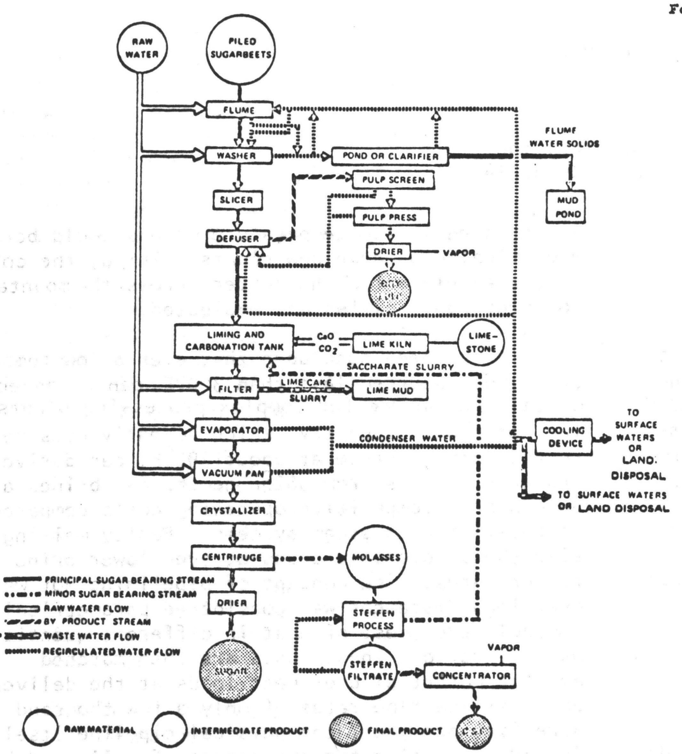
The beet sugar refining industry is currently at a depressed point in its economical cycle, and the construction of new sugar factories is unlikely in the near future. Nevertheless, the results of this study can be applied to other industrial users of energy, even in complex systems as exemplified by the sugar refinery, where normal top steam temperatures approach the temperature of the geothermal waters. The primary value of the present study is the demonstration it provides that with a little innovative process design engineering, low temperature geothermal brines can be an energy source. It is also important to note that a higher source temperature can reduce costs significantly; for example, geothermal waters in the range of 350 to 400°F are expected to reduce delivered energy costs by 40 to 60%.

II. Hydrology of the San Luis Valley

Various studies have been conducted to define the deep, geologic character of the San Luis Valley, including gravity and resistivity studies, geochemical analyses, heat flow compilations, and actual drilling.

Figure I

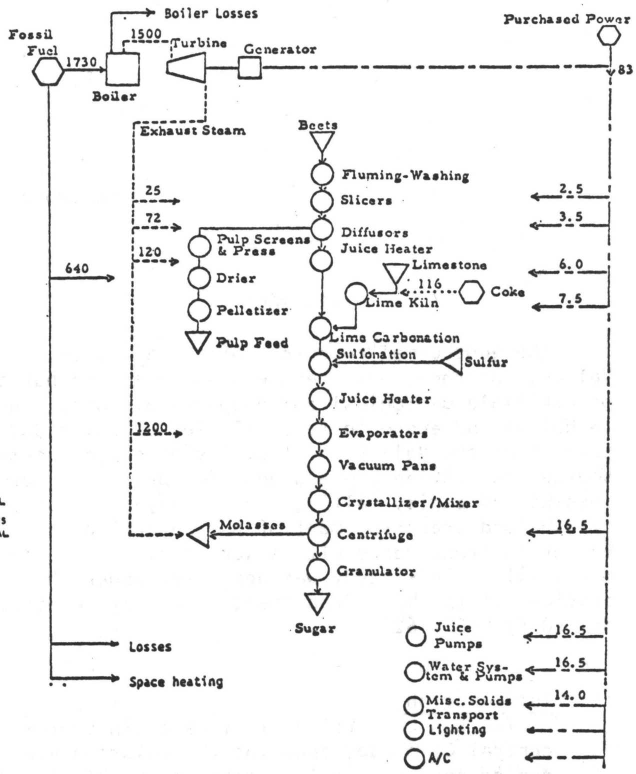
MATERIALS FLOW IN BEET SUGAR PROCESSING PLANT WITH TYPICAL WATER UTILIZATION AND WASTE DISPOSAL PATTERN



As taken and modified from Beetsugar Technology, Second Edition, Edited by R.A. McGinnis, Beetsugar Development Foundation, Fort Collins, Colorado (p 645), 1971, (65)

Figure II

Material and energy flow for a typical beet sugar processing plant. (Energy inputs in units of thousands of Btu /ton beets sliced.)



The geophysical data indicate the existence of a major aquifer in the northeastern portion of the Valley, paralleling the Sangre de Cristo range. A similar, smaller zone exhibiting anomalously low-gravity values occurs in the northernmost portion of the Valley, and there is speculation that the two may be part of one huge aquifer.

Mapco State Well #1-32 was drilled as an exploratory geothermal well northeast of Alamosa near the Sand Dunes National Monument, which directly overlies the large predicted aquifer along the northeast perimeter of the Valley. Temperature measurements taken projected an equilibrium temperature of 250°F at a depth of about 8,000 feet. Porosity at that depth was about 25 percent. Bouguer gravity data led to an estimated surface area of 225 square miles. Above the 8,600-foot depth, frequent layers of low permeability clay or shale were encountered.

At the maximum depth of the Mapco Well of 9,500 feet, temperatures are expected to be about 300°F. Based on the above surface area, the aquifer contains at least 30 million acre-feet of water at depths from 8,600 to 9,500 feet. The temperature measurements from the Mapco well were also in agreement with extrapolations of local temperature gradients, and within the range of numerous geochemical temperature estimates.

Water qualities were measured by potentiometric methods, and the dissolved solids content was found to be about 2,000 parts per million. This is interpreted to indicate a substantial amount of circulation, so that the water hasn't enough residence time to be seriously degraded by dissolution of minerals.

III. Beet Sugar Processing

Viewed in its totality, the beet sugar refining process is a straightforward operation. The general process is depicted in Figure 1. Given the raw materials and the end products of this process, there are few changes that can be made that significantly affect the basic flowsheet of a beet sugar plant. Indeed, in the past 100 years the major process modifications have been due to advances in the technology of heat transfer equipment and purification chemistry. The details of the refining process, highlighting modifications to enable the use of a 302°F hydrothermal energy source, are discussed below.

A. General Process Description

Sugar beets are cleaned and sliced into thin strips, which are then steeped in warm, low-salinity water in the diffuser battery. The sugar and various impurities enter into solution by osmosis through the beet cell walls. These solutes and suspended impurities also pass directly into the water from cells that have been broken or crushed.

Two product streams leave the diffuser. The insoluble beet pulp is washed, pressed, and then dried in a fossil-fuel fired kiln. This dryer consumes a significant fraction of the energy needs of the sugar refinery. Temperature requirements for pulp drying are normally in the range of 1200°F, which led to the exclusion of this process step from the present geothermal design. The second stream leaving the diffuser is the raw juice, a dilute and impure sugar solution. Its dissolved solids concentration is in the range of 10 to 16 Brix (that is, approximately 10 to 16 percent solids by weight), of which about 90% is sucrose.

The raw juice passes through three basic purification stages, with intermediate filtration and settling operations, to produce a pure thin juice with about the same solids concentration. The water is then evaporated from thin juice until a solution between 60 to 70 Brix (thick juice) is obtained. The sugar solution has been processed on a continuous basis to this point. Thick juice then enters the "pan section" of the plant, consisting of two to four vacuum crystallizers operated in series-batch mode. The sugar solution is first concentrated to a labile, but not self-seeding condition. Seed crystals are added and allowed to grow with gradual addition of more juice. The pans are operated so that, when finally filled to capacity, the magma of crystals and liquor is at 90 to 95 Brix. Crystals and liquor are separated by centrifugation and the crystals are washed.

Sugar is crystallized from the so-called liquor fed to the pans in as many as three or four successive stages or "strikes," each stage producing a lower purity batch of crystals and residual liquor. Only the first-strike sugar, sometimes blended with a portion of the second, leaves the process as product sugar at 99-100 percent purity. The low-purity sugars are melted and blended back with the thick juice from the evaporators. The various impurities taken into solution with the sugar cannot be economically totally eliminated in the purification section. Consequently, as in many other processes, the practice of recycling streams raises the recovery rate of the desired product, and final impurities are removed in a byproduct stream at the end of the process.

The liquor from the last strike is molasses. It is the byproduct stream mentioned above; it will be in the range of 70 to 90 Brix, with a sugar purity of about 60 percent. The molasses may be further refined to extract sugar and may be used in making MSG (monosodium glutamate), or it may be applied directly to stock feed for its significant nutrient content.

B. Sugar Process Energy Utilization

Four primary energy inputs to a beet sugar plant can be identified. These consist of electrical energy for mechanical equipment (most of which is generated in-house in some plants); coal, gas, or oil to produce steam for the evaporators and heaters (this steam is taken from the turbine exhaust for plants that generate their own electricity); coke for the lime kiln that supplies the juice purification system; and gas or oil for the pulp and sugar driers. Figure 2 is a schematic drawing of typical energy inputs for sugar processing. The values presented are approximate industrial averages.

Despite the overall simplicity of the beet sugar process, much of the chemistry related to side reactions, degradation of sucrose to other unwanted sugars, impurity removal, and crystal formation is still not completely understood. In addition, many aspects of the sugar production process remain an art, not amenable to standardization. Many old factories using low-pressure steam and inefficient evaporating systems are still in service. Thus, it is not easy to develop a single, model plant to be compared with a geothermally heated refinery. Nevertheless, the basic evaporation principles and energy usage schemes in all sugar refineries are similar and are described below.

The important differences to be noted when comparing existing plants with, first, a representative "typical" plant, and then with a plant using geothermal energy, would be found in the schemes of heat utilization. In the extreme of inefficiency, older sugar plants used low-pressure steam and three- or four-effect vacuum evaporators. These plants made single-pass usage of steam to all the various heaters, crystallizing pans, and the diffuser, as well as to the evaporators. Heat efficiency is expressed as a weight percent of pounds of steam per pound of beets, so that a low value represents high efficiency. Older plants typically had a "percent steam on beets" value of the order of 80 percent. Modern plants, on the other hand, tend to use higher temperature steam feeding a five-effect evaporator system. In addition, vapors leaving the evaporators are reused in other heat-consuming operations, such that the evaporator vapors supply in excess of 95 percent of all other process heat loads, exclusive of those for the sugar and pulp driers and lime kiln. Such plants can achieve efficiency values near 40 percent steam on beets.

C. Design Considerations

The entire sugar refining process was studied in detail in preparation for specifying a conversion to geothermal energy. It was ascertained that the operating parameters of the process are fairly narrowly constrained by either simple economics or by considerations of sugar quality and purity, so that complete freedom cannot be used in the redesign of a plant to use geothermal brines. Temperatures in the evaporators, the hottest section in the process, must be kept as high as possible to facilitate high temperature driving forces between vapors from each effect and the juices in subsequent effects, or other heating devices. High temperatures also effect high heat

TABLE 1

Incremental Beet Sugar Plant Capital Costs for a Geothermal Steam-Powered Plant

Bases: Geothermal Brine available at 302°F; 5°F brine transport losses; 5000 Tons/Day Sliced Beets

Brine Production	Costs ($1000)
2.8×10^6 lb/hr	
7 Production Wells (10,000 feet)	$4,550
3 Brine Disposal Wells (10,000 feet)	$1,950
Heat Transfer Surface Area	
Geothermal 161,670 ft^2	
Conventional 76,110 ft^2	
Additional Cost	$1,610
Additional Equipment for Geothermal Plant	
Air Compressor (Beet Knife Cleaning)	$ 50
Vacuum Pump (Replaces Air Ejectors)	100
Net Incremental Capital Costs for a Geothermal Plant	$8,310

TABLE 2

Unit Cost of Geothermal Energy
(Based on Replacement of Fossil Energy)

Geothermal Sugar Plant Energy Requirements for Conventional Fossil Fuel-Fired Plant	
Steam to Plant	177 MM Btu/hr
Furnace Efficiency	85%
Fossil Fuel to Furnace	209 MM Btu/hr
Cost of Geothermal System	
A. Annual amortized capital costs at 15%	$1,247,000/year
B. Hourly amortized cost, based on 120-day campaign	$433/hour
C. Brine treatment cost	$ 70/hour
D. Additional electricity costs	$ 10/hour
E. Total geothermal generating cost	$513/hour
Cost of Geothermal Energy	
$513/hour ÷ 209 MM Btu/hr	$2.46/MM Btu

TABLE 3

Amortized Capital Costs for Geothermally-Heated Barley Malted Plant

Brine Temp. (°F)	Brine Flow Range (1000 lb/hr)	Wells* No.	Wells* Annual Cost**	Capital***	Brine Treatment	Total
				(Dollars per Million Btu)		
300	297 to 510	3	$292,500	1.21	0.19	1.40
260	368 to 596	4	$330,000	1.36	0.25	1.61
220	600 to 1,600	7	$473,000	1.95	0.57	2.52

* Including spare production well and reinjection wells.
** 15% amortization rate
*** Includes 25% added charges for pumps, heat exchangers, etc.

transfer coefficients by reducing liquid viscosities. These factors tend to minimize the needed heat transfer surface area. Contrarily, the sucrose can be degraded or discolored by high temperatures, with the upper temperature limit for dilute sugar solutions being about 270°F. Thus, when using a geothermal source for process heat, the plant design will be very similar to any existing plant, and the plant efficiency will be strongly dependent on the geothermal resource temperature.

Because much of the sugar process remains an art, as was previously discussed, the geothermal sugar plant design was developed without changing the purification or the crystallization sections. Typical process designs and heat loads were developed for these operations, which comprise the front and back end, respectively, of the process. A considerable effort was devoted to developing an efficient design for the evaporator section. Several different flow sheets were analyzed, ranging from two- to five-effect evaporator systems operating at various temperature levels. The source of "rob" vapors, that is, vapors taken from one of the evaporators to be reused in other heaters, was another parameter to be adjusted. Various vapor recompression schemes were analyzed in an attempt to reduce energy consumption. The final flow sheet developed is not optimized, because of the large amount of effort required to arrive at an optimized system, but is believed to be close to the best design. Preliminary calculations indicate that geothermal brine requirements could be reduced by an additional 10 to 30%.

Detailed flow sheets for the sugar process, using a geothermal heat source, are presented at the end of this paper without further discussion. It may be noted this preliminary design has an efficiency of 84% steam on beets.

A brine feed at 302°F (the limit established for this study) was assumed to lose 5°F in temperature before reaching the plant. It then was flashed several times to provide steam for the various units of a four-effect evaporator unit, with the maximum and minimum flashed steam temperatures being 240 and 170°F. By comparison, a modern sugar plant will have a top temperature of about 290°F, and will therefore require much less heat transfer surface area. It should also be noted that the limited flashdown available on the brine (from 297 to 240°F) requires that a large amount of brine be provided per unit steam production.

Despite these problems, the energy cost for the geothermal system is less than $2.50/MM Btu, based on the equivalent fossil fuel energy replaced. This cost is summarized on Tables 1 and 2. These costs are calculated on an incremental basis, and reflect the additional equipment and operating costs incurred by the sugar factory to accommodate the geothermal heat source, as well as the capital and operating costs of the geothermal system itself.

It should be noted that the costs on Tables 1 and 2 do not include a credit for capital cost reductions related to the boiler in a conventional sugar factory, nor does it reflect a penalty for the potential loss of electricity produced in-house. It should also be noted that energy costs will fall rapidly if the brine temperature increases to 350 to 400°F, or for areas where well depths and costs are lower. Finally, it is emphasized that capital costs have been amortized over only 120 days per year.

With respect to the latter factor, the economic feasibility of using geothermal heat for a sugar refinery is strongly affected by a number of operating days per year, or the length of the campaign, which is often as low as 120 days or less. In locations such as southern California where the growing season is long, the campaign can be increased to 200 to 220 days per year. This processing period cannot be stretched out over the year, because rapid processing of beets, once they are harvested, is essential to avoid degradation of the contained sugar during storage. Accordingly, a single-purpose geothermal plant providing only process heat to a sugar refinery would be idle from 1/3 to 2/3 of the year, and the amortized cost of capital is increased by the same factor. Clearly, a multipurpose installation would reduce costs, even if the associated process were an electric power plant, operating at a low efficiency because of the low temperature heat source, but operating all year long.

IV. The Barley Malting Process

Barley malting is a process more readily identifiable as a potential user of geothermal energy than is a sugar factory, for several reasons. Barley malting is a year-around operation with stream factors of over 90%; temperature levels are low, reaching a maximum of about 190°F; and the process is relatively straightforward and uncomplicated. Three primary processing steps are involved:

The barley is first cleaned and is then steeped in cold water in large tanks for time periods that may range from 12 to 48 hours. The object of steeping is to raise the barley moisture content from about 13%w as-received to about 44%w, without promoting germination. Water temperatures in the range of 50 to 60°F are required for steeping. If these temperatures are not naturally available, evaporative refrigeration, an energy intensive operation, of feed water is required.

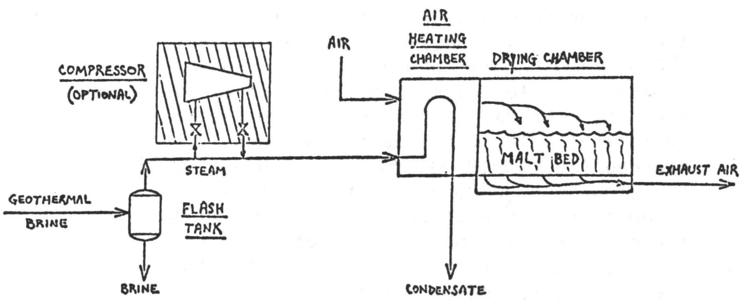
Germination is the second process step that takes place in batches in large bins under controlled environmental conditions. Germination requires about 5 days, and temperatures are maintained at about 65°F by a continuous flow of air through the bed. To prevent drying of the barley, and to replace water lost during the respiration process, the inlet air is sprayed with recirculating water to maintain relative humidity levels at 100%. In warm weather, the natural biochemical germination reactions provide the required heat. In colder weather, supplementary heating of germination air is required. On an annual basis, about 20 to 30% of the energy requirements for a barley plant are consumed in the germination bins and for space heating, with the remaining 70 to 80% being used in the kilns.

The germinated barley is dried in the kilns to produce malt, wherein the moisture content is reduced to 3%w. The malt is thus stabilized and can be stored for long periods before utilization for beer production or other purposes. Drying in the kilns is accomplished in a batch process on a daily cycle. Five or six hours are taken to cool and unload the previous batch and to then charge the kiln with a new batch of germinated barley. Drying then takes place for 18 to 19 hours by passing hot air through the bed, at temperatures ranging from 130°F at the start of the cycle to about 180°F at the end. In a conventional plant, air is heated by direct contact with natural gas in a burner, and all the combustion gases pass through the kiln.

Figure 3 is a schematic diagram of a geothermally heated malt kiln. In the basic process, brine is flashed to a temperature that corresponds to the point in the drying cycle, and the vapor is condensed in a shell and tube air heater. Otherwise, the kilning process is identical to that of a conventional plant. For instance, at the start of the cycle, flashed vapor is provided at 140°F to heat the air to 130°F, while at the end of the cycle, flashed vapor at 190°F heats the air to 180°F.

A typically sized (4 million bushel per year) barley plant requires, on the average, about 48 million Btu per hour for the kiln during its operating cycle. For the basic process described above, geothermal brine requirements will vary over the cycle, depending on the flash temperature required at each point in the cycle. The primary factor, though, governing brine flow rates is the brine temperature. These factors are summarized in Table 3 for various brine temperatures. Energy costs for amortization of capital equipment and for brine treatment are also given on Table 1.

An optional process involving vapor recompression permits the utilization of lower temperature geothermal brines, or the more efficient utilization of higher temperature brines. This option is indicated by the cross-hatched box on Figure 3. During the early stages of a cycle, geothermal brine is flashed, successively, to 140°F, 150°F, and 160°F, as in the normal cycle. For the high temperature phases of operation, the flash temperature is then maintained constant at 110°F, and the vapors are compressed so as to condense at 170°F for the fourth phase, and then at 180 and 190°F for the fifth and sixth phases. By this means, the cost of using 220°F brine, for example, can be reduced from $2.52 to $1.26/MM Btu for direct well and brine costs. In compensation, costs for compressor amortization and operation will add a weighted average cost of about $1.00/MM Btu. Thus, the total cost of using 220°F brine becomes $2.26/MM Btu. This is 90% of the cost for using geothermal brine in the base process (i.e., without a compressor). Additional optimization studies with the vapor compression option, or the use of a more complex heat pump system, could be expected to further lower these costs.



MALT KILN SCHEMATIC

FIGURE III

FIGURE IV ; 1 OF 4
SUGAR BEET PROCESS DIFFUSION SECTION

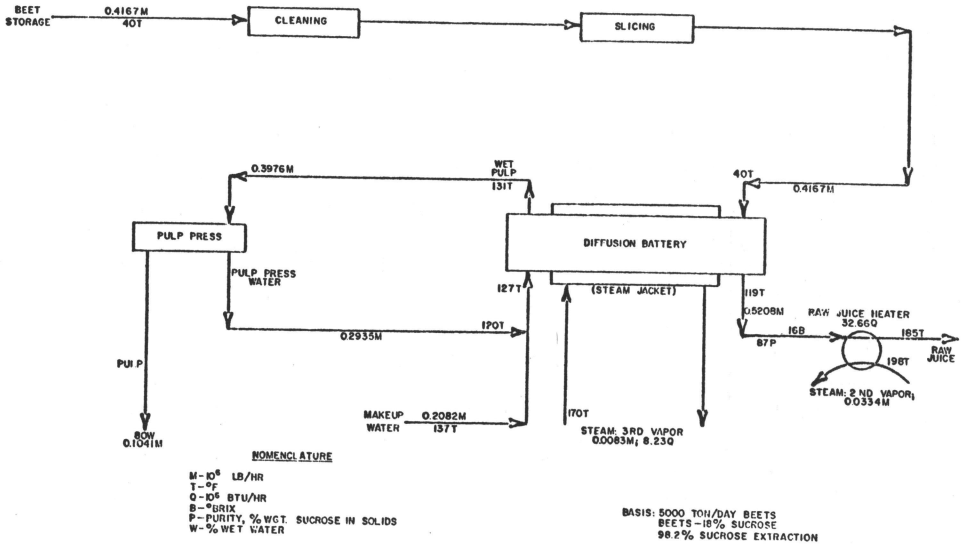


FIGURE IV ; 2 OF 4
SUGAR BEET PROCESS PURIFICATION SECTION

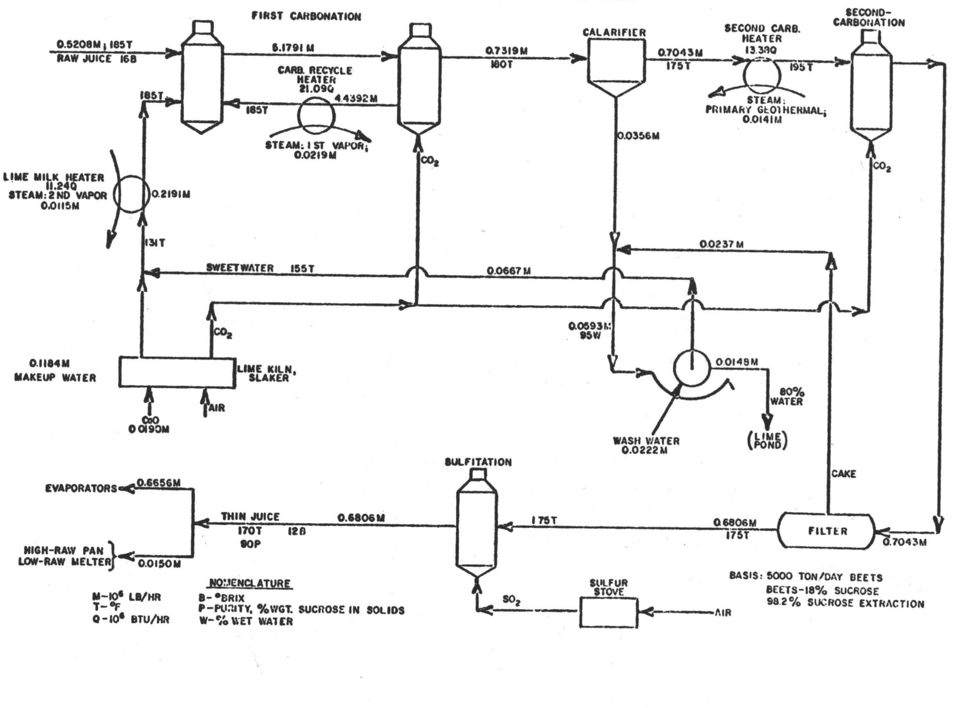


FIGURE IV;3 OF 4

SUGAR BEET PROCESS EVAPORATION SECTION

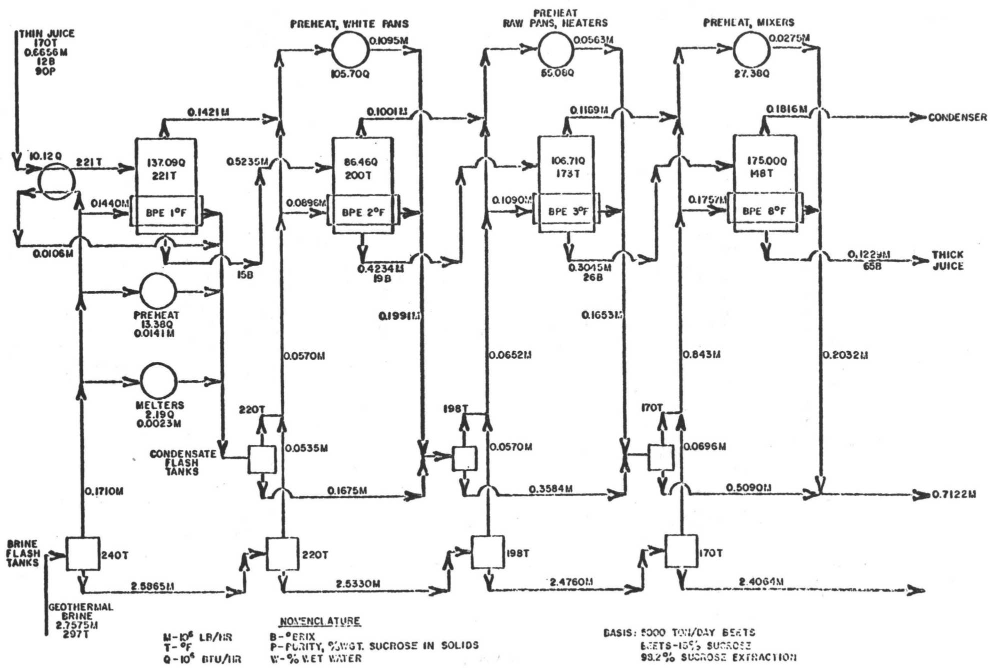


FIGURE IV; 4 OF 4

SUGAR BEET PROCESS CRYSTALLIZATION/SEPARATION