SURVEY OF FORMOSAN SUGAR REFINERY PRACTICE WITH REGARD TO THE POSSIBILITY OF PRODUCING BY-PRODUCT POWER TO SELL TO UTILITY

by

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INTRODUCTION

The sugar industry is the largest and most important industry in Formosa. It yields about 60 per cent of the total foreign currency of all exported Formosan goods, and about one-sixth of the population depend directly or indirectly on it for a living (1). It has a considerable influence on the economic structure of Formosa. The Taiwan Sugar Corporation produced about 880,000 tons of sugar during the year 1953 (1).

The purpose of this research was to obtain pertinent data and make a preliminary evaluation of the by-product power generating resources of a typical Formosan sugar factory and the most advantageous means for exploiting these resources in the national interest.

GENERAL DESCRIPTION OF TAIWAN SUGAR CORPORATION

Before the end of the World War II, the Formosan sugar industry consisted of Nitto Kogyo Sugar Mfg. Co., Ltd., Taiwan Sugar Mfg. Co., Ltd., Meiji Sugar Mfg. Co., Ltd., and Ensuiko Sugar Mfg. Co., Ltd. These four sugar companies altogether owned forty-two modern factories. The attack of the allied air force during the Pacific War inflicted heavy damages on thirty-six of them, and only eight factories escaped from the bombardments.

Upon taking over the management from the Japanese, the Chinese government immediately set up a supervisory committee whose function was to keep the sugar industry in continuous operation and to prepare for reorganizing the industry. On May 1, 1946, the Taiwan Sugar Corporation was formed. The four former Japanese companies were merged into the Corporation as its four district branches and the sugar factories were rehabilitated and reduced to 36 in number. The total capitalization was then three billion Taiwan Dollars, and was divided between the National Resources Commission and the Provincial government of Formosa at a ratio of six to four.

In August 1948, the Corporation was ordered to place its shares on the open market as a parallel policy to the government stabilization program. At the same time, the local shareholders of the former Japanese sugar companies also became shareholders of this Corporation. The necessary reorganization was carried out in September 1948. As a result of the currency reform introduced by the Provincial government in June, 1949, the total capitalization was revalued at 600 million New Taiwan Dollars.

In July 1950, the four district branches were superseded by the five district branches of Pingtung, Tsungyeh, Hsinying, Huwei, and Taichung as agencies to supervise the operation of the sugar factories in their respective districts. In the meantime, the Tangtze factory and the Wuji factory were merged into the Taichung district factory, and the factories at Hsinchu, Miaoli, Chusan, and Henchung were closed in July 1951. There are now thirty sugar factories in operation.

In January 1951, a new unit of the company named the Agricultural Engineering office was formed. This replaced the former unit of AMOMO (Agricultural Machinery Operation and Management Office).

To supply compost manure for cane fertilization, a plan for a Farm Animal Breeding Station was put forth by the company in July 1952, and the preparatory work was started in the former Hsinchu factory.

A recent creation is the Taiwan Molasses Corporation which is to be jointly owned and operated by the Taiwan Sugar Corporation and the Japanese merchants so as to insure a market for the Taiwan Sugar Corporation.

The sugar factories and other organizations of Taiwan Sugar Corporation (TSC), Formosa, are listed in Table 1 (2), and the distribution of the Taiwan Sugar Corporation sugar factories and other organization is shown in Fig. 1 (2).

A BRIEF SUMMARY OF THE TAIWAN SUGAR MANUFACTURING PROCESS

Defecation Process

The cane is cut by hand or machine and is brought to the mill where it is cut into small pieces in a mechanical cutter and then shredded (Figs. 2 and 3). It is then passed through several sets of rolls, at a pressure of from 300 to 600 tons, which squeeze the juice from the cane. Louisiana mills pioneered in the use of turbine drives (Schmertz, 3). Some of the Formosan sugar mills pioneered in the use of electric motor drives for the mills to replace reciprocating steam-engine drives (4). However, most of the mills still use steam-engine drives.

The mixed juice is heated, strained, and then heated again.

Table 1. Taiwan Sugar Corporation sugar factories and other organizations.

廠號 No.	區別 District	單位名稱 Name	負責人 Manager	地址 Location	成立時期 Established Year	壓榨能力 Daily Grinding Capacity (M.T.)	製糖方法 Process	附屬工場 By-product Plants	自營農場面積 Mill's Farm (Ha.)	鐵道里程 Kilometerage (Railway & Push-car)
		董事會 Board of Directors	李崇實 T. Z. Lee	台北市 Taipei	民國35年 (1946)					
		公司本部 Head Office	楊繼曾 C. T. Yang	台北市 Taipei	民國35年 (1946)					
		糖業試驗所 Sugar Exp. Institute	盧守耕 S. K. Lu	台南市 Tainan	民前10年 (1902)					
		糖業試驗所屏東分所 Sugar Exp. Inst. Pingtung Branch	王世中 S.C. Wang	屏東市 Pingtung	民國35年 (1946)					
		農業工程處 Agr. Engineering Off.	江鴻 H. Jiang	台南市 Tainan	民國40年 (1951)					
		高雄儲運所 Koahsiung Warehousing and Transp. Service Station	陳學聖 S. S. Chen	高雄市 Kaohsiung	民國36年 (1947)					
35	東台區 Tungtai District	花蓮糖廠 Hualien Sugar Factoy	吳鍾靈 C. E. Wu	花蓮 Hualien	民國11年 (1922)	1,000	炭酸法 Ord. Carb.	酒精工場 Alcohol	1,266.00	153-903-37
32		台東糖廠 Taitung Sugar Factory	王書亭 S.D.Wang	台東 Taitung	民國5年 (1916)	850	石灰法 Def.	酒精工場 Alcohol	150.75	34-177-34
10	台中區 Taichung District	台中總廠 Taichung District Sugar Factory	林和甲 H. C. Lin	台中市 Taichung	民國1年 (1912)	3,900	石灰法 Def.	酒精工場、酵母工場 Alcohol, Yeast	1,322.87	226-739-09
8		彰化糖廠 Changhua Sugar Factory	黃安靜 Y. T. Huang	彰化 Changhua	民前1年 (1911)	1,500	石灰法 Def.		73.59	128-897-99
12		月眉糖廠 Yuehmei Sugar Factory	陳嘉樹 G. S. Chen	台中 Taichung	民國3年 (1914)	800	石灰法 Def.		1,017.70	89-804-71
22		埔里糖廠 Puli Sugar Factory	傅益永 I. Y. Fuo	南投 Nantow	民國1年 (1912)	750	石灰法 Def.		696.17	98-197-54
30		南投糖廠 Nantow Sugar Factory	馬翼漢 E. H. Ma	南投 Nantow	民國1年 (1912)	1,500	炭酸法 Ord. Carb.	酒精工場 Alcohol	114.13	180-544-54
31		溪湖糖廠 Chihu Sugar Factory	簡實 S. Chien	彰化 Changhua	民國10年 (1921)	3,000	石灰法 Def.	酒精工場 Alcohol	1,314.40	133-862-00
36		溪州糖廠 Chichow Sugar Factory	金貞觀 C. K. Ching	彰化 Changhua	民前3年 (1909)	2,700	炭酸法 Ord. Carb.		1,143.50	131-656-60
1	虎尾區 Huwei District	虎尾總廠 Huwei District Sugar Factory	朱有宣 Y. H. Chu	雲林 Yingling	一廠民前3年 二廠民國1年 (1st Mill 1909 2nd Mill 1912)	4,900	一廠石灰法 二廠炭酸法 1st Mill Def. 2nd Mill Ord. Carb.	酒精工場、酵母工場 Alcohol, Yeast	918.61	242-211-38
2		龍岩糖廠 Lungyen Sugar Factory	馬鏞 F. Ma	雲林 Yingling	民國25年 (1936)	1,600	石灰法 Def.	酒精工場 Alcohol	1,197.51	108-645-81
3		北港糖廠 Peikang Sugar Factory	陳梓慶 Y. C. Chen	雲林 Yingling	民國1年 (1912)	3,800	石灰法 Def.		1,378.02	157-682-14
5		大林糖廠 Talin Sugar Factory	程達雲 T. Y. Chen	嘉義 Chiayi	民國2年 (1913)	1,600	石灰法 Def.		964.74	116-209-18
6		斗六糖廠 Tawliu Sugar Factory	鍾天助 T. C. Chung	雲林 Yingling	民國1年 (1912)	850	炭酸法 Ord. Carb.		1,483.65	96-670-68
33	新營區 Hsingyin District	新營總廠 Hsingyin District Sugar Factory	陸寶愈 P. Y. Lu	台南 Tainan	一廠民前1年 二廠民國26年 (1st Mill 1911 2nd Mill 1927)	3,200	中間汁炭酸法 Mid. J. Carb.	酒精工場、酵母工場 Alcohol, Yeast	531.60	161-844-76
27		烏樹林糖廠 Wushuling Sugar Factory	林岩泉 Y. C. Lin	台南 Tainan	民國1年 (1912)	1,600	炭酸法 Ord. Carb.		914.21	107-944-71
28		南靖糖廠 Nantsing Sugar Factory	周厚樞 H. S. Chow	嘉義 Chiayi	民國3年 (1914)	3,200	炭酸法 Ord. Carb.	酒精工場、酵母工場 Alcohol, Yeast	2,051.80	125-647-91
29		蒜頭糖廠 Suantow Sugar Factory	陳宗仁 C. Y. Chen	嘉義 Chiayi	民國1年 (1912)	3,200	石灰法 Def.	酒精工場、酵母工場 Alcohol, Yeast	2,454.35	142-537-41
34		岸內糖廠 Annei Sugar Factory	陳遲 C. Chen	台南 Tainan	一廠民前6年 二廠民國1年 (1st Mill 1906 2nd Mill 1912)	2,100	中間汁炭酸法 Mid. J. Carb.		850.36	92-540-55
25	總爺區 Tsungyeh District	總爺總廠 Tsungyeh District Sugar Factory	吳卓 C. Wu	台南 Tainan	民前1年 (1911)	1,500	炭酸法 Ord. Carb.	酒精工場 Alcohol	238.52	67-951-49
4		玉井糖廠 Yutsing Sugar Factory	杜士俊 C. C. Tow	台南 Tainan	民國2年 (1913)	900	石灰法 Def.		145.77	121-280-97
19		車路墘糖廠 Cheluchien Sugar Factory	陳其誠 C. P. Chen	台南 Tainan	民前1年 (1911)	1,500	中間汁炭酸法 Mid. J. Carb.		2,119.45	97-783-52
20		三崁店糖廠 Sankantien Sugar Factory	楊守珍 S. C. Yung	台南 Tainan	民前3年 (1909)	1,200	中間汁炭酸法 Mid. J. Carb.		1,599.32	87-801-14
21		灣裡糖廠 Wanli Sugar Factory	楊一番 Y. S. Yung	台南 Tainan	一廠民前6年 二廠民國18年 (1st Mill 1906 2nd Mill 1929)	2,200	石灰法 Def.	蔗板工場 Bagasse Board	1,824.18	79-781-66
26		蕭壠糖廠 Shiaolung Sugar Factory	譚勝平 L. P. Tan	台南 Tainan	民前3年 (1909)	1,500	石灰法 Def.		486.04	72-789-92
18	屏東區 Pingtung District	屏東總廠 Pingtung District Sugar Factory	張孝熙 C. H. Chang	屏東 Pingtung	民國3年 (1914)	3,600	炭酸法 Ord. Carb.	酒精工場 Alcohol	3,994.40	222-242-27
15		橋仔頭糖廠 Chiaotzetow Sugar Factory	羅宗實 C. S. Lo	高雄 Kaohsiung	一廠民前10年 二廠民國4年 (1st Mill 1902 2nd Mill 1915)	2,000	石灰法 Def.	酒精工場、酵母工場 Alcohol, Yeast	3,571.43	81-619-30
16		小港糖廠 Shiaokang Sugar Factory	柴太平 T. P. Chai	高雄 Kaohsiung	民國3年 (1914)	1,500	炭酸法 Ord. Carb.	硬蔗板工場 Hard Bagasse Board	2,597.57	88-703-78
17		東港糖廠 Tungkang Sugar Factory	周天翔 T. S. Chow	屏東 Pingtung	民國12年 (1923)	1,200	石灰法 Def.		2,639.14	76-201-47
23		旗尾糖廠 Chiwei Sugar Factory	麥致祥 T. C. Mar	高雄 Kaohsiung	民前1年 (1911)	1,500	炭酸法 Ord. Carb.		1,900.86	111-780-44
		合計 Total				60,650			41,060.58	☆3,636-159-67

☆ 原新竹糖廠鐵道未包括在內
Excluding the railway kilometrage of former Hsinchu Sugar Factory.

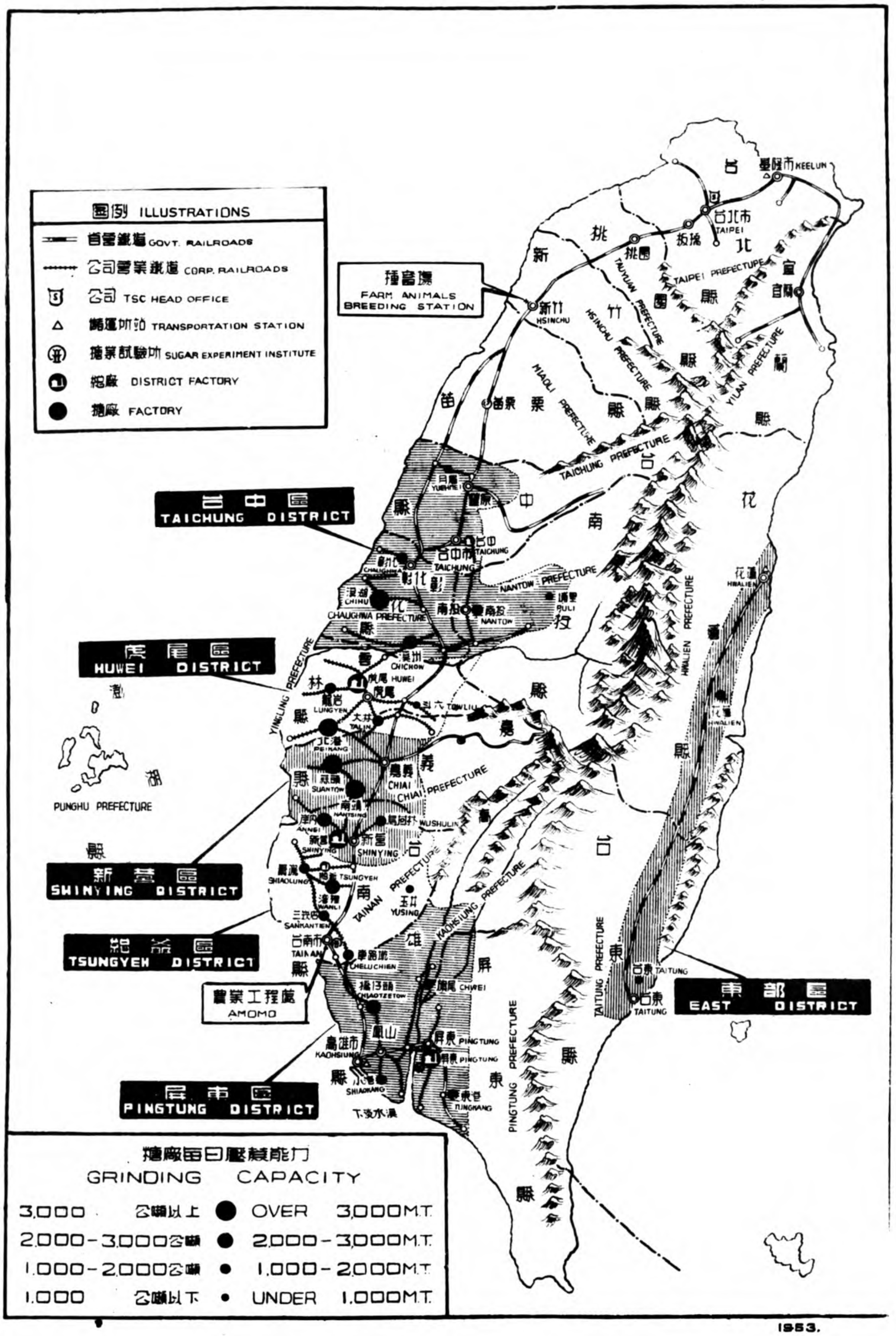


Fig. 1 Distribution of Taiwan Sugar Corporation sugar factories and other organizations

The defecation or clarification of the juice is accomplished by means of lime and heat. The acidity of the juice is neutralized by milk of lime and its temperature is raised to the boiling point. It is then passed through the subsider to separate the clarified juice from the mud, and thus impurities are removed. The mud is passed through the Oliver-filter and the resulting filtrate or press-juice is then sent back to the mixed juice receiver. The precipitates retained in the press, called filter-press cake, are discarded or used for fertilizing the cane fields. The clarified juice is passed through multiple-effect evaporators where it is concentrated. Following this procedure, the juice is sent to vacuum pans where sucrose or sugar is crystallized out. The mixture of crystallized sugar and syrup is centrifuged to get A sugar and first molasses. The first molasses is returned to a second vacuum pan and it is processed the same as before to get B sugar and second molasses. The mixture of A and B sugar is packed into bags (B White Crystal, or Raw Sugar) for shipment to refining plants. Second molasses is introduced into a third vacuum pan to get C sugar and final molasses. C sugar is mixed with syrup and is returned to the first and second vacuum pans. Final molasses is used to manufacture alcohol, yeast, and other chemicals. Bagasse, which flows from the fourth mill, is used as fuel for firing the boilers. It can also be used as raw material for celotex-type bagasse-board, structural-type bagasse-board, and paper pulp (4).

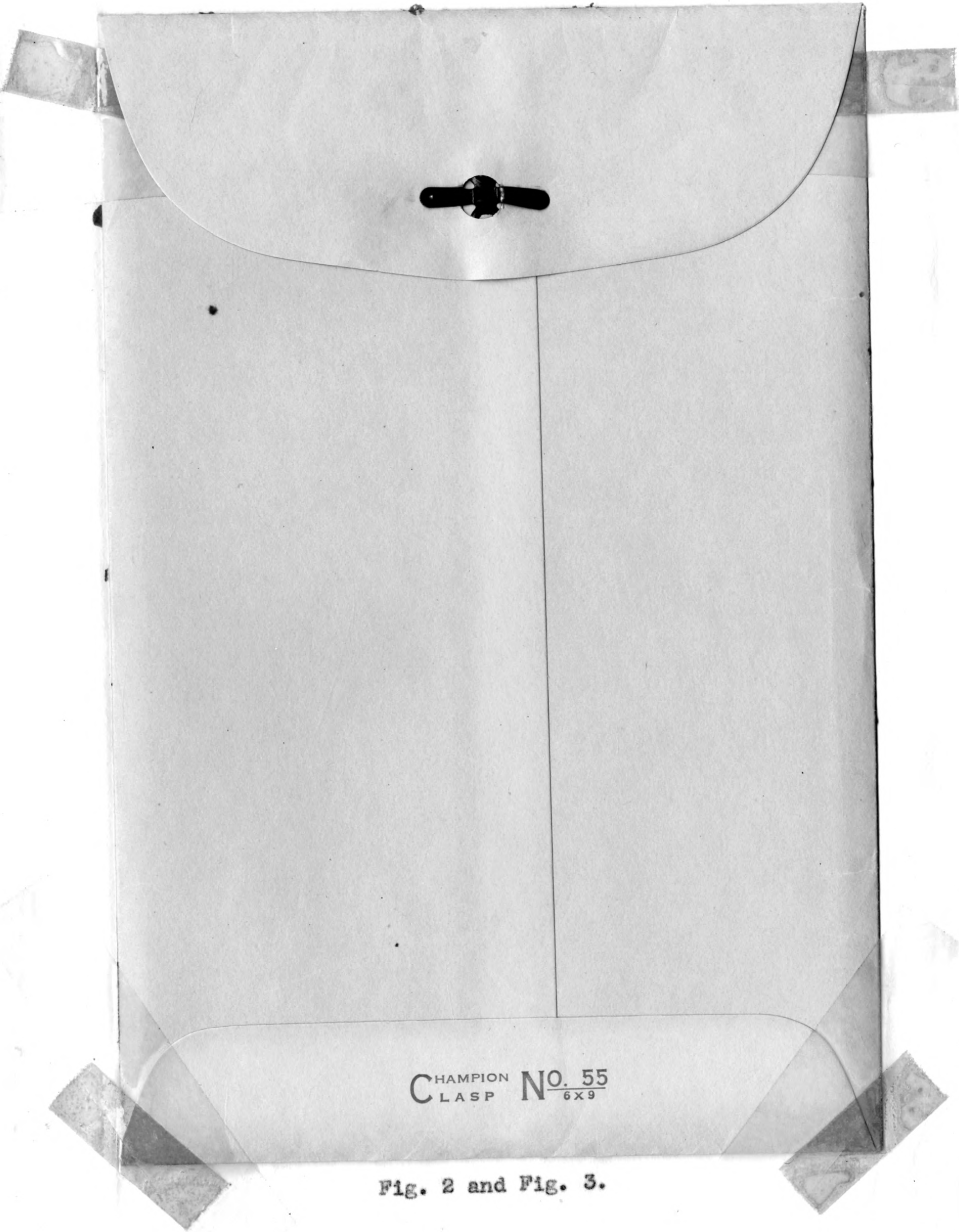


Fig. 2 and Fig. 3.

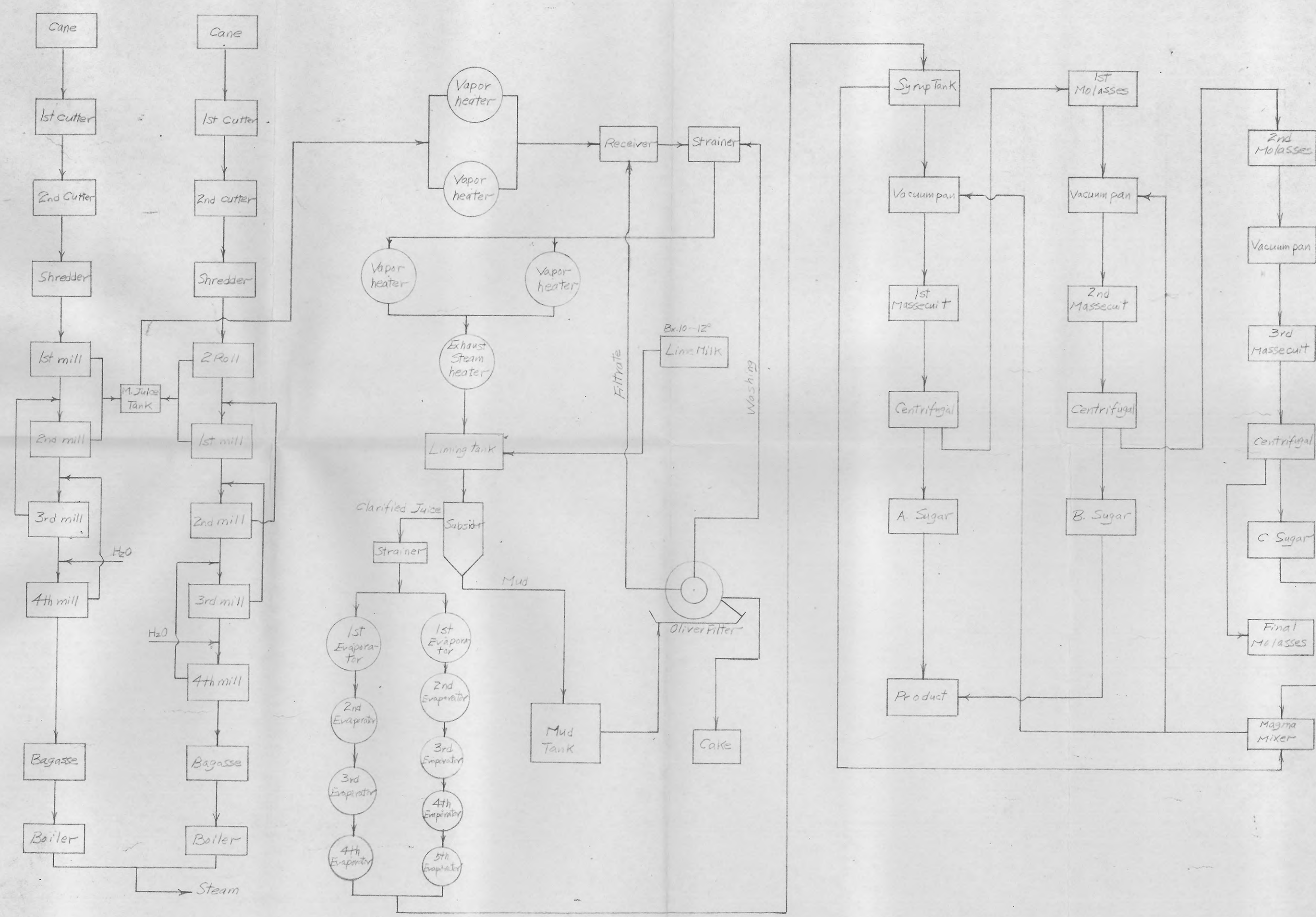


Fig. 2 Flow sheet with defecation process in Taiwan sugar factory, Formosa

Oct. 20, 1954 Lun-jy Wei

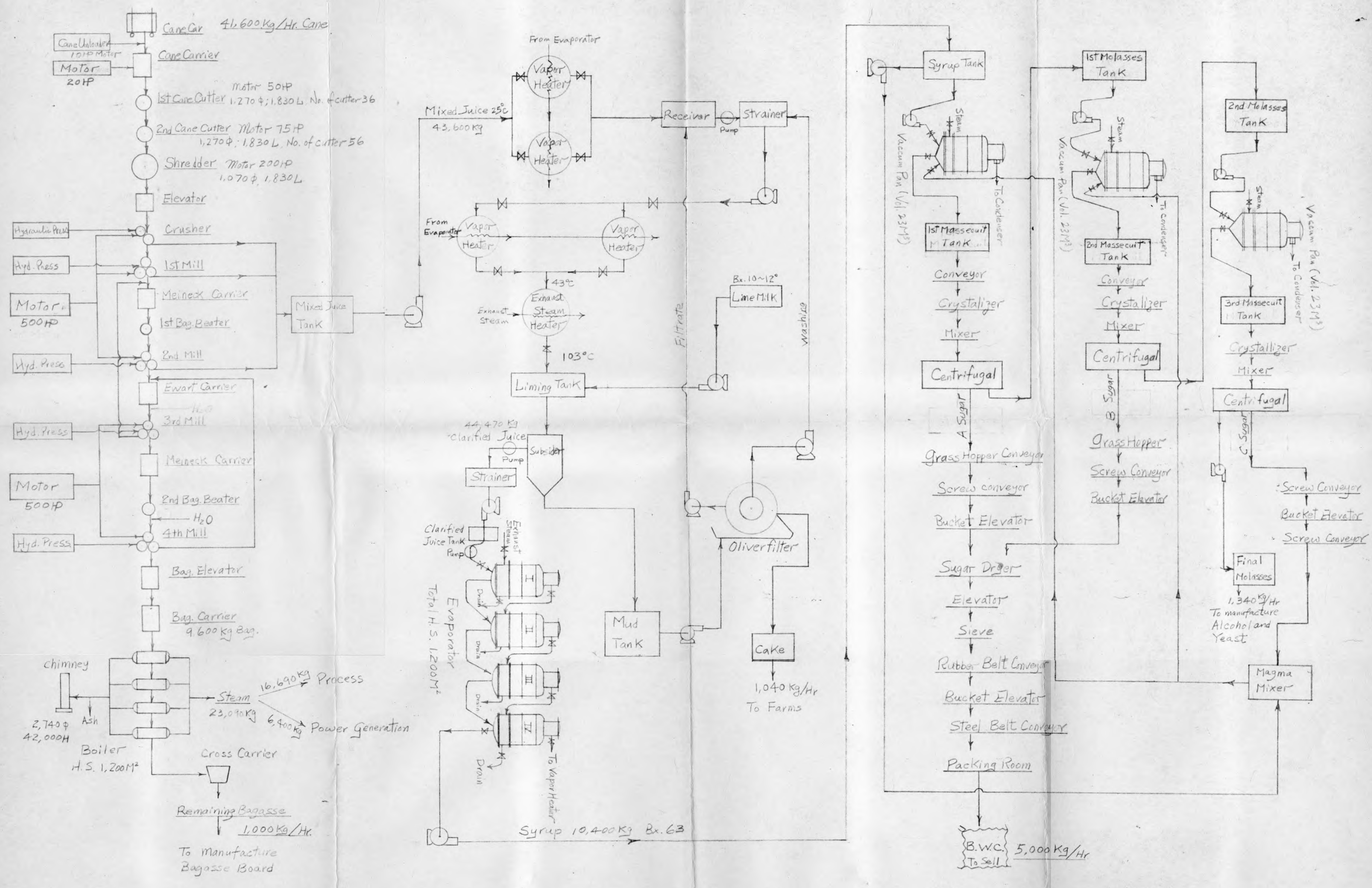


Fig. 3 Flow sheet in defecation process with grinding capacity of 1,000 metric tons of cane per day

Principle of Defecation Process

Defecation or subsiding is the process in which the impurities (colloids) in the juice are precipitated by liming, and allowed to settle out under the force of gravity. It will be obvious that such a process is feasible only when there is a definite difference in specific weight of the materials to be separated. After defecation is complete, there will remain three zones:

1. The scum, floating on top of the juice.
2. The clear juice itself.
3. The mud beneath the clear juice zone (Tromp, 5).

The reaction which takes place upon adding the lime to the juice is as follows:

$$C_{12}H_{22}O_{11} + C_a(OH)_2 \longrightarrow C_{12}H_{22}O_{11} \cdot C_aO + H_2O$$

Sugar   Lime   Calcium Monosaccharate (Soluble at room temperature)

$$C_{12}H_{22}O_{11} + 2C_a(OH)_2 \longrightarrow C_{12}H_{22}O_{11} \cdot 2C_aO + 2H_2O$$

Calcium Disaccharate

$$C_{12}H_{22}O_{11} + 3C_a(OH)_2 \longrightarrow C_{12}H_{22}O_{11} \cdot 3C_aO + 3H_2O$$

Calcium Trisaccharate
(Insoluble after heating)

$\downarrow$

Precipitate

Principle of Double Carbonation Process

The double carbonation process consists of the following steps:

First carbonation: This produces a precipitate of C_aCO_3 which absorbs the impurities of the juice.

Second carbonation: This reduces the amount of lime in the juice, accelerates the reaction and produces a second precipitate of C_aCO_3 preparatory to filtration. Sulphitation of the filtrated juice from the second carbonation is practiced in order to remove the lime still remaining in the filtrated juice and also to bleach the juice.

Except for these two steps, the carbonation process of sugar refining is nearly the same as the defecation process.

From 7 to 10 per cent by volume of milk of lime of 35.7 degrees Brix (weight per cent of total solid in the solution) is added to the juice which has been warmed to about 133 degrees F (45 degrees C). The first carbonation is then conducted precisely, using a DuPont test paper to keep the pH of the juice between 10.5 to 11.0 for good filtrability. The juice is next warmed to a temperature of nearly 130 degrees F (55 degrees C) and is then filter-pressed. The second carbonation proceeds continuously, that is, the first carbonated juice is then carbonated continuously to a pH of about 8.0. The juice is finally heated to 158 degrees F (70 degrees C) preparatory to filtration. Before discharging from the tank, the juice should be gassed by SO_2 for a few seconds to prevent deleterious action occluded in the precipitates (6).

Adding lime and CO_2 gas results in the carbonation reaction according to the equation:

$$Ca(OH)_2 + CO_2 \longrightarrow CaCO_3 + H_2O$$

Lime $\quad$ CO_2 gas $\quad$ Precipitate ↓

The flow sheet of a carbonation process factory is shown in Fig. 4.

CALCULATIONS ON STEAM CONSUMPTION AND ITS HEAT BALANCE IN A SUGAR FACTORY

Introduction

To study the performance of a sugar factory, it is necessary to determine the steam consumption of the various components of the plant. Steam consumption means the amount of steam used for the various processes. As the first step, the necessary amount of steam for each part of a factory is calculated. From the results of the calculation, the necessary amount of steam for a whole factory is determined. Generally speaking, the average steam consumption in sugar factories is nearly 55 to 70 per cent of the weight of cane (4). Steam consumption is expressed as the necessary amount of steam in lb/hr or kg/hr.

The heat balance is the tabulation of the amount of heat absorption and heat liberation by material in the various processes. However, the sugar industry is different from most chemical industries. In the sugar industry, the sugar is extracted from the raw material (cane), but no chemical reaction and no absorption or liberation of heat of reaction takes place. In the

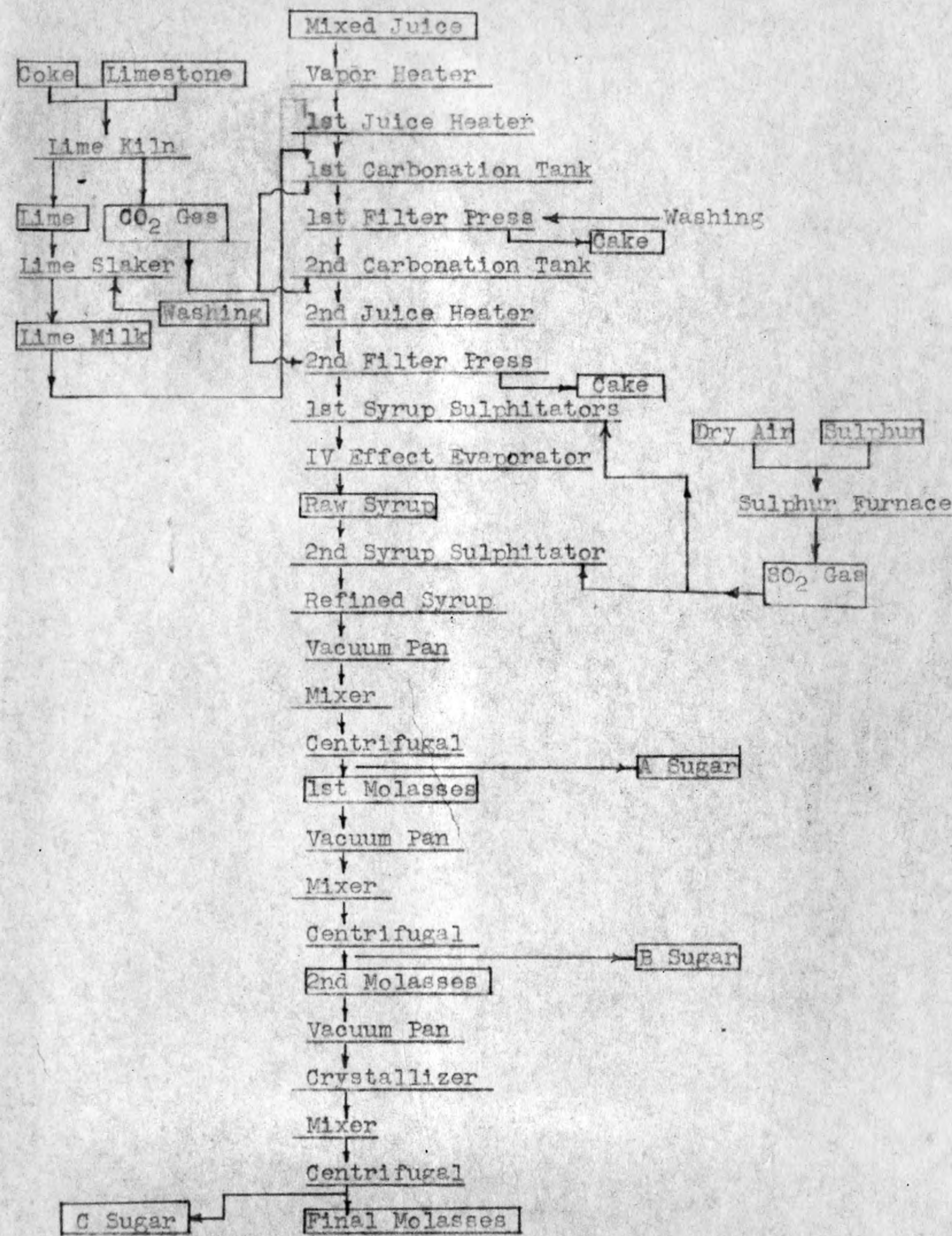


Fig. 4 Flow sheet of a carbonation process

heat balance of the sugar factory, the incoming heat is mainly supplied by the steam which heats the juice; and the outgoing heat is the heat loss from juice due to cooling and radiation. At the same time, heat converted into mechanical energy, for example, in turbines and pumps, is also considered. Therefore the heat balance in the sugar factory is the steam heat balance. Tromp (5) divided steam heat balance into three definite stages:

(a) The boiler heat balance.
(b) The heat balance of live steam consumers.
(c) The heat balance of exhaust steam consumers.

Exhaust steam coming from turbines and pumps is used for the heating and boiling of juices.

The steam consumption and heat balance have a close relation. From the heat balance, the steam consumption, the heat loss, and the efficiencies will be known. This information will be the guide to lowered steam consumption and to an improved heat economy in the factory.

In the sugar factory, if fuel is purchased, the fuel cost will comprise most of the process cost. The bagasse is available as fuel in the sugar factories. In the past it was satisfactory to burn the bagasse as fuel. However, at present, the bagasse is valuable as raw material for various kinds of chemical products, such as paper pulp and bagasse-board. Therefore, it is desirable to save a great amount of the bagasse by partly burning coal as an auxiliary fuel. Economy in the use of heat and steam is important in plant operation.

There are two methods for saving fuel:

(a) Heat recovery from stack gases by the installation of economizers, superheaters, and air preheaters.

(b) Reduction of steam consumption by (1) the use of more efficient components in the plant layout, such as multiple-effect evaporators, (2) more efficient operation of existing components such as the turbine-driven prime mover for the mills, and (3) utilization of the available heat of the vapor for evaporated juices.

The experimental data in the following calculations come from "A Handbook for the Taiwan Sugar Industry" (4) and the operation data of the Taiwan sugar factories.

General Assumptions

1. Grinding capacity: 1,000 tons of cane per day.
2. Grinding capacity per hour: $\frac{1,000 \times 1,000}{24} = 41,600$ kg/hr.
3. Cane fiber: 12.8 per cent of cane.
4. Cane fiber: 56.0 per cent of bagasse.
5. Ratio of bagasse to cane: $\frac{12.8}{56.0} = 22.9$ per cent.
6. Ratio of mixed juice (Bx. 15) to cane: 105 per cent.
7. Weight of mixed juice: 41,600 x 1.05 = 43,600 kg/hr.
8. Water added to dilute juice for clarification: In defecation process, 2 per cent of mixed juice; in carbonation process, 10 per cent of mixed juice.
9. Thin juice:

   Defecation process: 43,600 x 1.02 = 44,470 kg/hr.

   Carbonation process: 43,600 x 1.10 = 47,960 kg/hr.
10. Syrup (Bx. 63): $43,600 \times \frac{15}{63} = 10,400$ kg/hr.

Defecation Process

A. Steam consumption in each part.

1. Mill House

Assume:

(a) 1 - cane carrier; 2 - cane cutters; 1 - crusher with two rolls; 1 - shredder; 4 - mill with three rolls; 1 - bagasse carrier.

(b) Cane cutters, shredder, and bagasse carrier are driven by motors; cane carrier is driven by vertical steam engine.

Calculated Horsepower and Steam Requirements:

(a) Horsepower for crusher: 18 hp/ton of cane fiber/hr

Horsepower for single mill: 22 hp/ton of cane fiber/hr

Horsepower for crusher: 41.6 x 0.128 x 18 = 96 hp

Horsepower for mill: 41.6 x 0.128 x 22 x 4 = 470 hp

Total horsepower: 96 + 470 = 566 hp

Steam consumption of Corliss steam engine used to drive mill and crusher: 13 kg/hp-hr

Total steam consumption of Corliss engine:

566 x 13 = 7,350 kg/hr

Horsepower of vertical steam engine used to drive cane carrier: 15 hp

Steam consumption of vertical steam engine: 36 kg/hp-hr

Total steam consumption of vertical engine:

15 x 36 = 540 kg/hr

In summary, steam consumption in the mill house is:

For crusher and mills: 7,350 kg steam/hr

For cane carrier: 540 kg steam/hr

2. Clarification House

Assume single-batch liming system, continuous subsider to separate mud from clarified juice, and Oliver filter to filter out the mud. Except for juice heating and evaporating, no steam is consumed in the clarification house.

(1) Juice Heater (exhaust steam heater)

The mixed juice is heated from 25° C to 43° C in the vapor heaters by means of the vapor juice from the fourth evaporator.

To heat mixed juice from 43° C to 103° C requires:

43,600 x 0.90 x (103 - 43) = 2,350,000 kcal/hr

Assume:

Exhaust pressure of steam, 0.4 kg/cm^2 gage.

Temperature of condensed water, 85° C.

Steam consumption of juice heater: $\frac{2,350,000}{643 - 85}$ = 4,220 kg/hr

Enthalpy of steam = 643 k-cal/kg, and specific heat of juice = 0.9

(2) Evaporator

Assume four effect evaporators and exhaust steam at 0.4 kg/cm^2 gage (temperature 109° C, latent heat 534 k-cal/kg). Conditions in each effect evaporator are as shown in Table 2.

Table 2. Conditions in each evaporator.

	I	II	III	IV
Pressure or vac.	0.13 kg/cm^2 (gage)	180 mm (vacuum)	420 mm (vac.)	660 mm (vac.)
Absolute pres. kg/cm^2	1.13	0.79	0.46	0.13
Boiling point ° C	102	93	80	55
Latent heat k-cal/kg	538	543	551	565

Calculation of specific heat of the juice in each evaporator.

According to "Abraham Formula" (7),

$$C = \left(1 - \frac{\text{Brix}}{100}\right) + 0.3 \times \frac{\text{Brix}}{100} = 1 - 0.007 \times (\text{Brix})$$

where C = specific of the juice; Brix = Brix of the juice.

Evaporator	Brix	Specific heat
I	15	0.90
II	20	0.85
III	30	0.80
IV	40	0.75

Assume:

Temperature of inlet juice: 95° C

Steam consumption in evaporators: W kg/hr

Quantity of evaporated water in each effect evaporator:

X_1, X_2, X_3, and X_4.

Quantity of evaporated water = thin juice - syrup

= 44,470 - 10,470 = 34,070 kg/hr

$$534\ W = 44{,}470 \times 0.90\ (102 - 95) + 538\ X_1$$

$$538\ X_1 + (44{,}470 - X_1) \times 0.85\ (102 - 93) = 543\ X_2$$

$$543\ X_2 + (44{,}470 - X_1 - X_2) \times 0.80\ (93 - 80) = 551\ X_3$$

$$551\ X_3 + (44{,}470 - X_1 - X_2 - X_3) \times 0.75\ (80 - 55) = 564\ X_4$$

and $X_1 + X_2 + X_3 + X_4 = 34{,}070$

Simplified:

$$X_1 = 0.993\ W - 520$$
$$X_2 = 0.969\ W + 120$$
$$X_3 = 0.918\ W + 960$$
$$X_4 = 0.800\ W + 2{,}400$$
$$3.680\ W + 2{,}960 = 34{,}070$$

Therefore W = 8,450 kg/hr, and

X_1 = 7870 kg/hr, X_2 = 8,310 kg/hr, X_3 = 8,730 kg/hr,

X_4 = 9,160 kg/hr

3. Boiling and Crystallization House

(1) Boiling of sugar in vacuum pans

Assume a three-vacuum pan system which mixes A sugar and B sugar as commercial sugar, i.e., B White Crystal (BWC), and uses C sugar as seed sugar for A and B sugar when boiling. Before boiling, molasses is diluted to Bx. 65 (see Fig. 2 and Fig. 3). Conditions in each step of boiling are as shown in Table 3.

Table 3. Conditions in each boiling.

Steps of boiling	Sugar		Massecuite		Molasses	
	Water %	Purity %	Brix	Purity %	Brix	Purity %
1st step (produces B White Crystal)	0.1	99.3	92.0	86.1	82.0	66.1
2nd step (produces B White Crystal)	0.2	99.3	94.0	78.0	84.0	54.0
3rd step (produces seed sugar)	2.5	90.0	99.0	60.0	93.0	31.0

The weight of the massecuite will always be the sum of the sugar crystals plus the weight of the molasses.

Let Pur. sug. = purity of sugar
Pur. mas. = purity of massecuite
Pur. mol. = purity of molasses
X = per cent of sugar in crystal form present in massecuite

Prinsen Geerligs (Tromp, 5) long ago established the following formula:

$$100 \text{ Pur. mas.} = \text{Pur. sug.} \times X + \text{Pur. mol.} (100 - X)$$

and the formula can also be written:

$$X = \frac{\text{Pur. mas.} - \text{Pur. mol.}}{\text{Pur. sug.} - \text{Pur. mol.}} \times 100$$

Per cent of sugar in crystal form present in massecuite.

$$\text{1st step: } \frac{86.1 - 66.1}{99.3 - 66.1} \times 100 = 60\%$$

$$\text{2nd step: } \frac{78.0 - 54.0}{99.3 - 54.0} \times 100 = 53\%$$

$$\text{3rd step: } \frac{60.0 - 31.0}{90.0 - 31.0} \times 100 = 49.2\%$$

The amount of evaporated water in each step of boiling is as shown in Table 4.

Table 4. The amount of evaporated water in each boiling.

Subject	Solid	Brix	Contained water
1st step			
Syrup	5,220*	60.0	8,700
C sugar	750*	97.5	770
1st massecuite	5,970*	92.0	6,490
Evaporated water = (8,700 + 770) - 6,490 = 2,980 kg/hr			
2nd step			
Syrup	1,000*	60.0	1,670
1st molasses	1,140*	65.0	1,760
C sugar	470	97.5	480
2nd massecuite	2,610*	94.0	2,800
Evaporated water = (1,670 + 1,760 + 480) - 2,800 = 1,100 kg/hr			
3rd step			
1st molasses	1,240*	65.0	1,900
2nd molasses	1,220*	65.0	1,880
3rd massecuite	2,460*	99.0	2,500
Evaporated water = (1,900 + 1,880)- 2,500 = 1,280 kg/hr			

* Operation data of the Taiwan Sugar Corporation.

Steam consumption in vacuum pans for boiling is shown in Table 5.

Table 5. Steam consumption in vacuum pans.

Step	Evaporated water	Boiling factor (Ratio of steam to water)	Steam consumption
1st step	2,980	1.10*	3,280
2nd step	1,110	1.15*	1,280
3rd step	1,280	1.20*	1,540
Total	5,370 kg/hr		6,100 kg/hr

* Operation data of the Taiwan Sugar Corporation.

(2) Vacuum Pans

Each vacuum pan, after boiling and after massecuite flows out, is washed by live steam for 15 minutes, using 4 kg/cm^2 gage pressure live steam (diameter of a steam pipe $1\frac{1}{2}$ inches). To calculate steam consumption for washing, assume the massecuite of a vacuum pan is 15 KL, and specific weight of the massecuite at 60 degrees C, Bx. 85 is approximately 1.45, i.e., 1.45 kg/L. Therefore, each vacuum pan has 1.45 x 15,000 = 22,000 kg of massecuite. Total weight of massecuite = 5,970 + 2,610 + 2,460 = 11,040 kg/hr. Necessary number of vacuum pans for boiling per hour = $\frac{11,040}{22,000}$ = 0.50 set/hr. By the method given in "A Handbook for the Taiwan Sugar Industry" (4),

$$W = 199\ A_t \sqrt{\frac{P}{V}}$$

where W = steam consumption kg/sec
A_t = nozzle area, 0.00131 m^2 ($1\frac{1}{2}$" diameter pipe)
P = pressure of live steam, 5 kg/cm^2 absolute pressure
V = specific volume of steam, 0.38 cu m/kg at 5 kg/cm^2 absolute pressure

Therefore, $W = 199 \times 0.0013 \times \sqrt{\frac{5}{0.38}} = 0.95$ kg/sec

Therefore, steam consumption = 0.95 x 15 x 60 x 0.50 = 430 kg/hr

(3) Heating of Molasses

Live steam at 3.5 kg/cm^2 gage pressure is directly introduced into molasses tanks to heat molasses from 40 degrees C to 70 degrees C to reduce viscosity.

$$\text{1st molasses} = \frac{2,380}{0.82} = 2,900 \text{ kg/hr}$$

$$\text{2nd molasses} = \frac{1,220}{0.84} = 1,450 \text{ kg/hr}$$

$$\text{Exhaust molasses} = \frac{1,240}{0.93} = 1,340 \text{ kg/hr}$$

$$\text{Total molasses} = 5,690 \text{ kg/hr}$$

Assume: Specific heat of molasses: 0.58

Specific heat of liquid: 1.00

Steam at 3.5 kg/cm^2 gage pressure, temperature 147 degrees C, has a latent heat of 507 k-cal/kg. Therefore,

$$\text{steam consumption} = \frac{5,690 \times 0.58\ (70 - 40)}{507 + 1.0\ (147 - 70)} = 170 \text{ kg/hr}$$

(4) Centrifugals

Using 40-inch by 20-inch centrifugals each served by a steam pipe of 3/4-inch diameter, the steam consumption per second for washing is calculated as follows:

$$W = 199\ A_t \sqrt{\frac{P}{V}}$$

where A_t = 0.000345 m^2, P = 5 kg/hr, and V = 0.38 cu m/kg. Therefore, $W = 199 \times 0.000345 \times \sqrt{\frac{5}{0.38}}$ = 0.25 kg/sec, or 15 kg/min.

In the defecation factory, steam is introduced into A sugar and B sugar only two minutes. Steam consumption in centrifugals is as shown in Table 6.

Table 6. Steam consumption in centrifugals.

	Massecuite into each centrifugal, kg	No. of centrifugals per hour, sets	Time for introducing steam per each, minutes	Steam consumption, kg/hr
A sugar	305	22	2	660
B sugar	300	10	2	300
		Total steam consumption		= 960 kg/hr

(5) Drying of Sugar

Assume steam consumption for drying sugar is 0.5 per cent of sugar produced. Because commercial sugar consists of A sugar and B sugar, the weight of sugar is calculated as follows.

$$\text{Weight of sugar} = \frac{5,970 \times 0.60 + 2,610 \times 0.53}{0.993} = 5,000 \text{ kg/hr}$$

Steam consumption = 5,000 x 0.005 = 25 kg/hr

4. Vacuum Pumps

The necessary horsepower for vacuum pumps in defecation process sugar factory is nearly 25 hp. Assume rate of steam consumption is 21 kg/hp-hr.

Steam consumption = 25 x 21 = 530 kg/hr

5. Steam for Reciprocating Pumps

(1) Accumulator pump: 1.5 hp

(2) Mixed juice pump: 6.5 hp

(3) Mud pump: 1.7 hp

(4) Thin juice pump: 6.6 hp

(5) Syrup pump: 1.6 hp

(6) Molasses pump: 1.0 hp

(7) Condensate pump: 4.6 hp

Total horsepower of the seven kinds of pumps is 23.5 hp but for safety, use 25 hp. Assume the rate of steam consumption is 36 kg/hp-hr.

Steam consumption = 25 x 36 = 900 kg/hr

6. Power House

Assume necessary power per ton of cane is 7.5 kwhr per ton of cane in the defecation process sugar factory, and the rate of steam consumption for driving the generator is 20 kg/kwhr.

Power consumption = 41.6 x 7.5 = 312 kw; use 320 kw

Steam consumption = 320 x 20 = 6,400 kg/hr

B. Heat Balance of Steam

(1) Boiler Heat Balance

	%	Output k-cal/hr	Input k-cal/hr
8,620 kg/hr Bagasse, Heating value: 2,500 k-cal/kg			21,553,620
23,090 kg/hr Feed water, Temp 85° C			1,962,650
23,090 kg/hr Live steam, 8 kg/cm^2, 662 k-cal/kg	65	15,285,580	
Loss in combustion, radiation, stack, and others	35	8,230,690	
Total	100	23,516,270	23,516,270

(2) Heat Balance of Live Steam System

	Output k-cal/hr	Input k-cal/hr
23,090 kg/hr Live steam, 8 kg/cm^2, 662 k-cal/kg		15,285,580
Mill steam enging, heat converted to work, 566 hp	362,810	
Mill steam engine, condensation and other losses	544,220	
Cane carrier steam engine, heat converted to work, 15 hp	9,610	
Cane carrier steam engine, condensation and other losses	28,840	
Vacuum pump, heat converted to work, 25 hp	16,000	

	Output k-cal/hr	Input k-cal/hr
Vacuum pump, condensation and other losses	48,000	
Reciprocating steam pump, heat converted to work, 25 hp	16,000	
Reciprocating steam pump, condensation and other losses	48,000	
Power generating, heat converted to work, 320 kw	275,520	
Power generating, condensation and other loss	275,520	
13,658 kg/hr Exhaust steam 0.4 kg/cm^2, 643 k-cal/kg	8,782,120	
Vacuum pans, 430 kg/hr	284,660	
Heating of molasses, 170 kg/hr	112,540	
Centrifugals, 960 kg/hr	635,520	
Drying, 25 kg/hr	16,550	
Steam for boiling, 5,112 kg/hr	3,384,140	
Radiation and other loss, 673 kg/hr	445,530	
Total	15,285,580	15,285,580

(3) Heat Balance of Exhaust Steam System

	Output k-cal/hr	Input k-cal/hr
13,658 kg/hr Exhaust steam, 0.4 kg/cm^2, 643 k-cal/kg		8,782,120
Juice heating, 4,220 kg/hr	2,713,470	
Evaporating, 8,450 kg/hr	5,433,360	
Boiling, 988 kg/hr	635,290	
Total	8,782,120	8,782,120

C. Distribution of Steam Consumption

Based on calculation of steam consumption and heat balance of steam, necessary steam required in each part of the defecation process sugar factory is as shown in Table 7.

Table 7. Steam consumption in the defecation process.

Subjects	Steam consumption kg/hr	Steam consumption lb/hr	% of total steam consumption	lb steam per lb of cane in %
Mill steam engine	1,190	2,618	5.15	2.86
Cane carrier steam engine	40	88	0.17	0.10
Vacuum pumps	87	191	0.37	0.21
Reciprocating steam engine	75	165	0.33	0.18
Generator mover	670	1,474	2.90	1.61
Heating of molasses	170	374	0.74	0.41
Vacuum pans	430	946	1.86	1.03
Centrifugals	960	2,112	4.16	2.31
Drying	25	55	0.11	0.06
Heating	4,220	9,284	18.28	10.14
Evaporating	8,450	18,590	36.60	20.31
Boiling	6,100	13,420	26.42	14.66
Radiation and other loss	673	1,481	2.91	1.62
Total	23,090	50,798	100.00	55.50

In summary, steam and power requirements in the defecation process of a sugar factory with the grinding capacity of 1,000 tons per day are:

Steam consumption = 23,090 kg/hr, or 50,798 lb/hr

Power consumption = 320 kw

Carbonation Process

Using the same procedure of calculation as in the defecation process, the heat balance of a typical Formosan sugar factory with the carbonation process is determined.

The distribution of steam consumption is shown in Table 8.

Table 8. Steam consumption in the carbonation process.

Subjects	Steam consumption kg/hr	Steam consumption lb/hr	% of total steam consumption	lb steam per lb of cane in %
Mill steam engine	1,190	2,618	4.44	2.86
Cane carrier steam engine	40	88	0.15	0.10
CO_2 pump and vacuum pump	220	484	0.82	0.53
Reciprocating steam engine	100	220	0.37	0.24
Electric power	750	1,650	2.79	1.80
Filter press	540	1,188	2.01	1.30
Vacuum pan	565	1,243	2.11	1.36
Heating of molasses	215	473	0.80	0.52
Centrifugals	1,500	3,300	5.59	3.61
Drying	30	66	0.11	0.07
Juice heating	4,840	10,648	18.04	11.63
Evaporating	9,330	20,526	34.78	22.43
Boiling	6,760	14,872	25.20	16.25
Radiation and other loss	750	1,650	2.79	1.80
Total	26,830	59,026	100.00	64.50

In summary, steam and power requirements in the carbonation process of a sugar factory with the grinding capacity of 1,000 tons of cane per day are:

Steam consumption = 26,830 kg/hr, or 59,026 lb/hr

Power consumption = 360 kw

Comparison of steam consumption and power consumption between the defecation process and the carbonation process, each with a grinding capacity of 1,000 tons of cane per day, is shown in Table 9.

From Table 9, the steam consumption and power consumption in the carbonation process are higher by 16.2 per cent and 12.5 per cent respectively than in the defecation process. However, the carbonation process produces better sugar than the defeca-

Table 9. Comparison of steam consumption between the defecation and carbonation process.

Subjects	Defecation process	Carbonation process
Steam consumption	23,090 kg/hr or 50,798 lb/hr	26,830 kg/hr or 59,026 lb/hr
lb steam per lb cane in %	55.5%	64.5%
Bagasse consumption	8,620 kg/hr or 18,964 lb/hr	10,018 kg/hr or 22,040 lb/hr
lb bagasse per lb cane in %	20.72%	24.08%
Power consumption	320 kw	360 kw
Power per ton of cane	7.5 kwhr	8.5 kwhr

tion process. The carbonation process produces B White Crystal sugar (BWC) with pol. 99.5 and moisture less than 0.20 per cent, while the defecation process produces Superior White Crystal sugar (SWC) with pol. 98.5 and moisture less than 0.5 per cent.

CALCULATION OF HEAT BALANCE BASED ON AN EXAMPLE OF ACTUAL OPERATING DATA OF A FORMOSAN SUGAR FACTORY

The heat balance of the Huwei first factory of Huwei district sugar factory, Formosa, in 1953-1954 crop is shown in the following. The factory uses the defecation process. The heat balance is based on the actual operating data of the Huwei first factory.

This factory has two independent line assemblies of grinding mill equipment, designated A tandem and B tandem in Fig. 5, and a total grinding capacity of 3,200 tons of cane per day. The flow sheet for the defecation process is shown in Fig. 5. The actual operating data are given in the following.

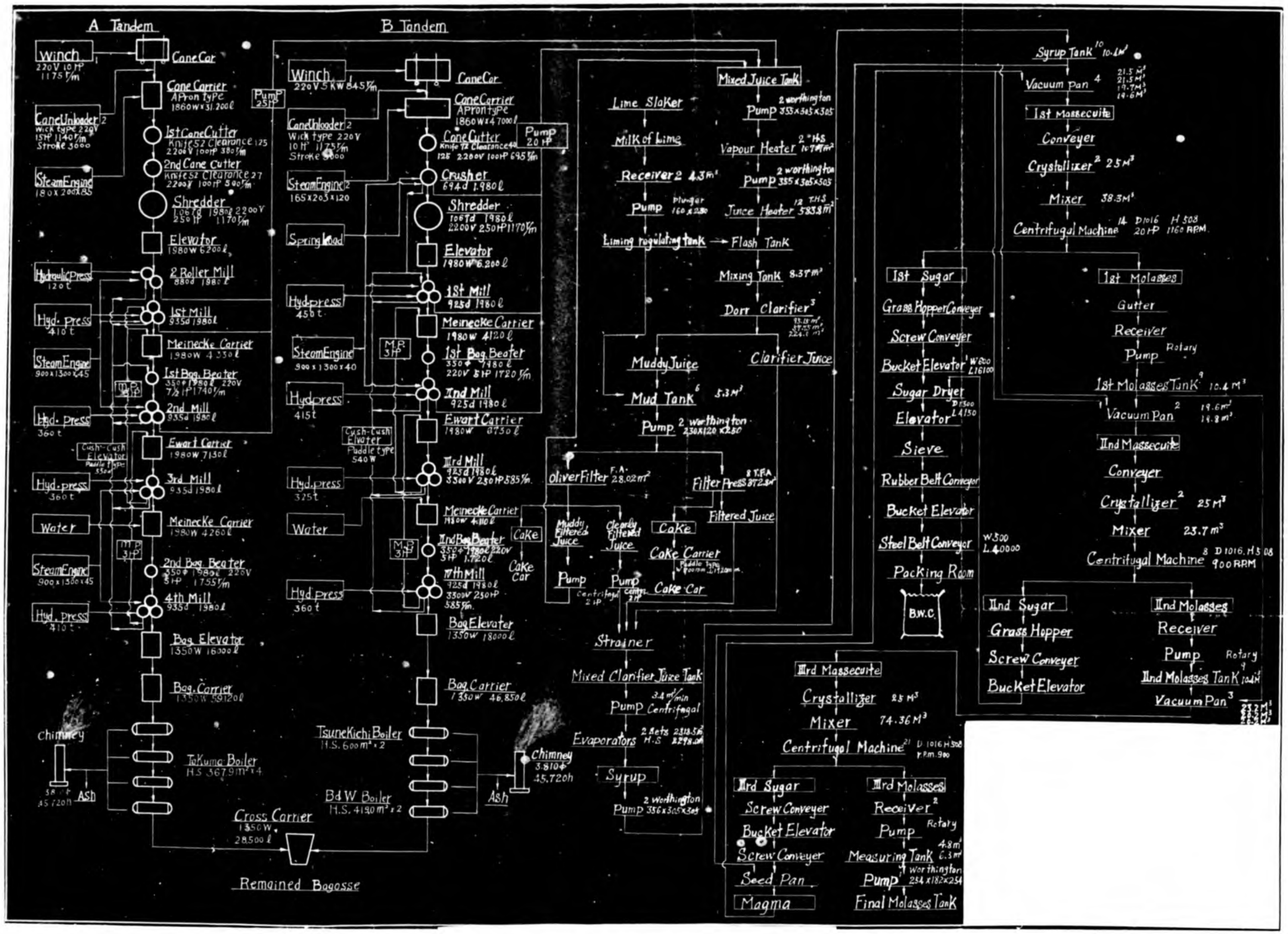


Fig. 5. Flow sheet of process for defecation in the Huwei First Factory of the Taiwan Sugar Corporation.

Actual Operating Data

1. Grinding quantity

   Through 1953-1954 crop = 323,396,970 kg/period

   Each day = 3,121,464 kg/day

   Polarization (sugar content) of cane = 13.17 per cent

   Cane fiber = 12.82 per cent

2. Bagasse

   Weight % cane = 22.59%; pol. of bagasse = 1.79% of bagasse

   Moisture = 40.92% of bagasse

3. Mixed juice = weight % cane = 102.03 per cent

4. Cake

   Weight % cane = 2.92%; pol. of cake = 2.17% of cake

5. Density and purity of juices

Juices	Brix	Pol. (%)	Purity (%)
Mixed juice	15.33	13.14	85.71
Clarified juice	15.02	13.17	87.68
Filtered juice	11.34	9.36	82.54
Mixed clarified juice	14.83	12.91	87.02
Raw sugar syrup	56.42	46.08	87.00

6. Temperature of juices

Vapor heater	Inlet	26.0°C = 78.8°F	Outlet	41.1°C = 106°F
First heater	"	38.0°C = 100°F	"	70.0°C = 158°F
Second heater	"	65.0°C = 149°F	"	100.0°C = 212°F
First evaporator	"	75.8°C = 168.4°F		

7. Conditions at each evaporator

Evaporator	Vacuum (inches)	Steam or vapor temp. (°F)	Latent heat (Btu/lb)
I	0.0	212.0	970.0
II	5.0	202.2	976.2
III	15.0	177.03	991.3
IV	20.0	161.49	1,001.4
Last juice	26.6	120.6	1,024.0

8. Conditions in each boiling[1]

Steps of boiling	Sugar Water %	Sugar Purity %	Massecuite Brix	Massecuite Purity %	Molasses Brix	Molasses Purity %
1st step	0.57	97.35	95.0	81.0	87.0	59.60
2nd step	5.0	81.0	99.6	62.0	85.0	29.50

Using the same procedure of calculation as in the previous calculation, the heat balance of heaters, evaporators, and vacuum pans was determined.

The heat balance of the boilers is shown in the following:

Fuel	Quantity for firing, kg/period	Heating value k-cal/kg	Heating value k-cal/grinding period
Bagasse	64,053,296	2,710[2]	173,584,432,160
Coal	--	4,500	--
Wood	25,000	2,500	62,500,000
Total	64,078,296		173,646,932,160

Heating value of bagasse fired per ton of cane =

173,646,932,160/323,396.97 = 537,256 k-cal/ton of cane

= 537,256 x 3.968[3] = 2,131,832 Btu/ton of cane

---

[1] This factory produces raw sugar with pol. 96.70 and moisture 0.57% in order to export for refining, and uses the two-vacuum-pan system.

[2] According to the empirical formula for the heating value of bagasse employed by the former Japanese Taiwan Sugar Mfg. Co. (8). Thus heating value of bagasse = 4,666 (1 - moisture of bagasse) = 4,666 (1 - 0.4092) = 2,710 k-cal/kg.

[3] 1 k-cal = 3.968 Btu.

Actual use of feed water measured by flowmeter

	Average number boilers in use	Steam evaporation ton/hr per boiler	Feed water flow rate ton/hr	Feed water flow rate ton/ton of can/hr
H-600 Tsunekichi Boiler	1.5	18	27	0.208
L-600 Takuma Boiler	3	9	27	0.208
B & W boiler	2	8	16	0.123
				0.539

H-600 boiler = 325 psig, 625°F, temp. of feed water = 95°C = 203°F

Temp. of furnace = 1325°F

Heat absorbed by the boiler =

0.208 x 2,200 x (1,325 - (203 - 32)) = 529,000 Btu/ton of cane

L-600 boiler = 120 psig, 341.25°F, temp. of feed water = 95°C = 203°F

Temp. of furnace = 1,190°F

Heat absorbed by the boiler =

0.208 x 2,200 x (1,190 - (203 - 32)) = 466,000 Btu/ton of cane

B & W boiler = 120 psig, 341.25°F, temp. of feed water = 95°C = 203°F

Temp. of furnace = 1,190°F

Heat absorbed by the boiler =

0.123 x 2,200 x (1,190 - (203 - 32)) = 276,000 Btu/ton of cane

Total heat absorbed by the boilers = 1,271,000 Btu/ton of cane

Boiler efficiency = 1,271,000/2,131,832 = 0.60 = 60%

The heating value of the steam for the turbo-generator was calculated as follows.

Steam at 300 psig, 625°F, enthalpy = 1,327.4 Btu/lb

Steam after isentropic expansion to 10 psig, 240°F, enthalpy = 1,141.4 Btu/lb

Assume over-all engine efficiency is 60 per cent.

Steam consumption = 3,413/0.60 x (1,327.4 - 1,141.4) = 30.6 lb/kwhr

Power consumption per ton of cane during 1953-1954 crop	= 9.21 kwhr
Power supply to second factory	= 3.54 kwhr
Power sold to Taiwan Electric Company	= 1.63 kwhr
Total	14.38 kwhr

Enthalpy of steam = 30.6 x 14.38 x 1,327.4 = 583,000 Btu/ton of cane

Equivalent heating value of power used

= 3,412 x 14.38 = 49,200 Btu/ton of cane

Enthalpy of exhaust steam

= 30.6 x 14.38 x 1,141.4 = 50,200 Btu/ton of cane

The distribution of the live steam and the exhaust steam is shown in Table 10 and Table 11, respectively.

Table 10. Distribution of enthalpy of live steam.

Enthalpy consumption at	Enthalpies Btu/ton of cane	Per cent of total enthalpy consumption
Turbo-generator	583,000	39.6
Mill engine and pump	726,000	49.4
Boiling	105,157	7.2
Miscellaneous	56,843	3.8
Total	1,471,000	100.0

Table 11. Distribution of enthalpy of exhaust steam.

Enthalpy consumption at	Enthalpies Btu/ton of cane	Per cent of total enthalpy consumption
1st juice heater	127,000	12.3
2nd juice heater	191,564	18.5
Evaporator	483,000	46.8
Boiling	220,843	21.4
Heat loss	10,000	1.0
Total	1,032.407	100.0

Work of turbo-generator = 49,200 Btu/ton of cane

Work of mill engine and pump = 78,000 Btu/ton of cane

Therefore, heat loss from live steam is

$$1,471,000 - 49,200 - 78,000 - 1,032,407 = 311,400 \text{ Btu/ton of cane}$$

DESIGN OF A PLANT LAYOUT FOR THE DEFECATION PROCESS WITH GRINDING CAPACITY OF 1,000 METRIC TONS PER DAY

The plant was designed, based on the previous "Calculation of the Steam Consumption and its Heat Balance for the Defecation Process," (Fig. 6). The plant consists of three floors, e.g., first, second, and third floors. These drawings are self-explanatory and represent the very careful planning as to location and arrangement of all equipment.

THE SUGAR INDUSTRY AND ITS BY-PRODUCTS

The problem of the disposition and the utilization of waste materials is one of the major functions of the Sugar Experiment Station. The sugar industry, in common with most heavy industries,

Fig. 6, part 1 and part 2.

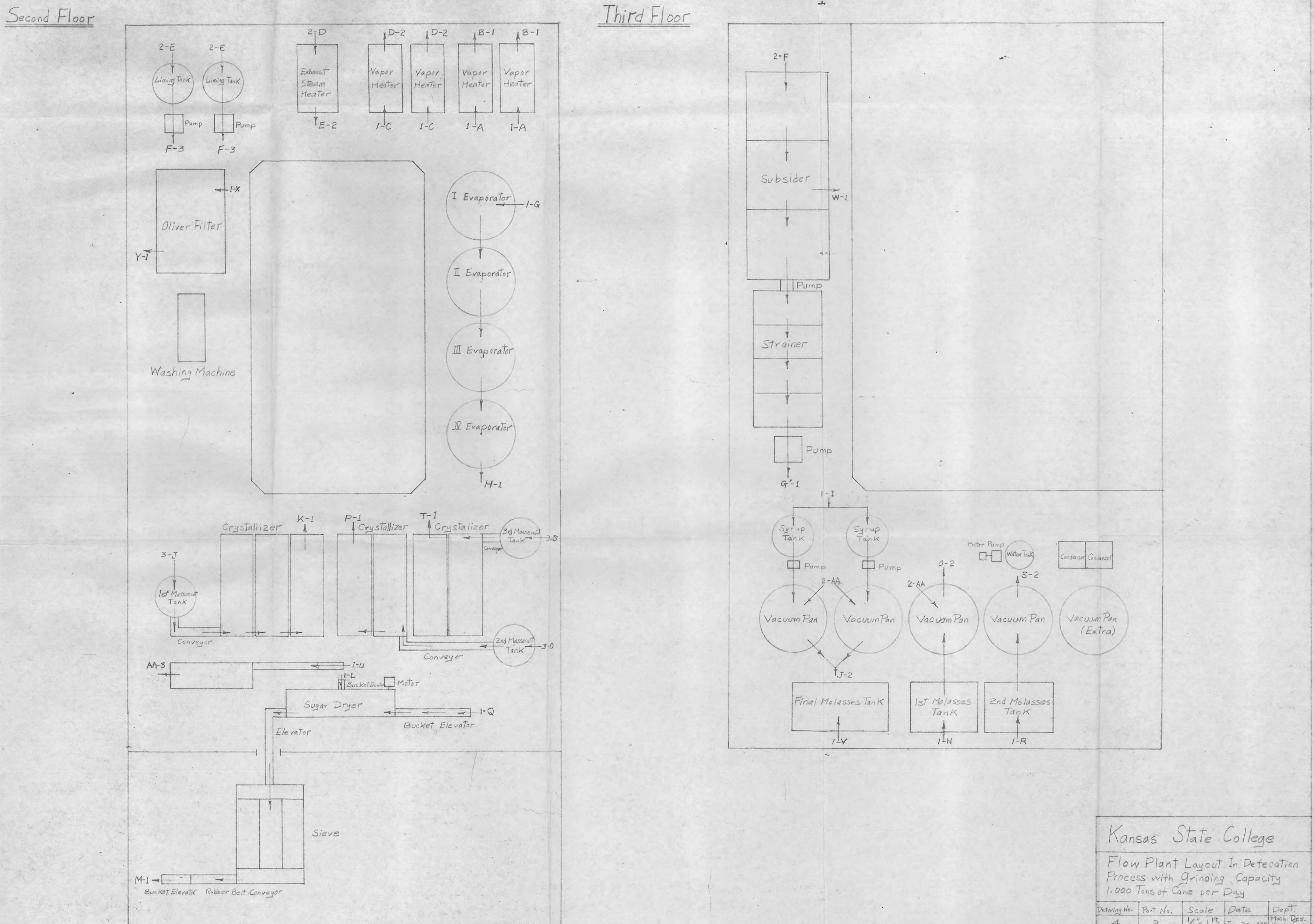


Fig. 6, Part 2 Plant layout in defecation process with grinding capacity of 1,000 metric tons of cane per day

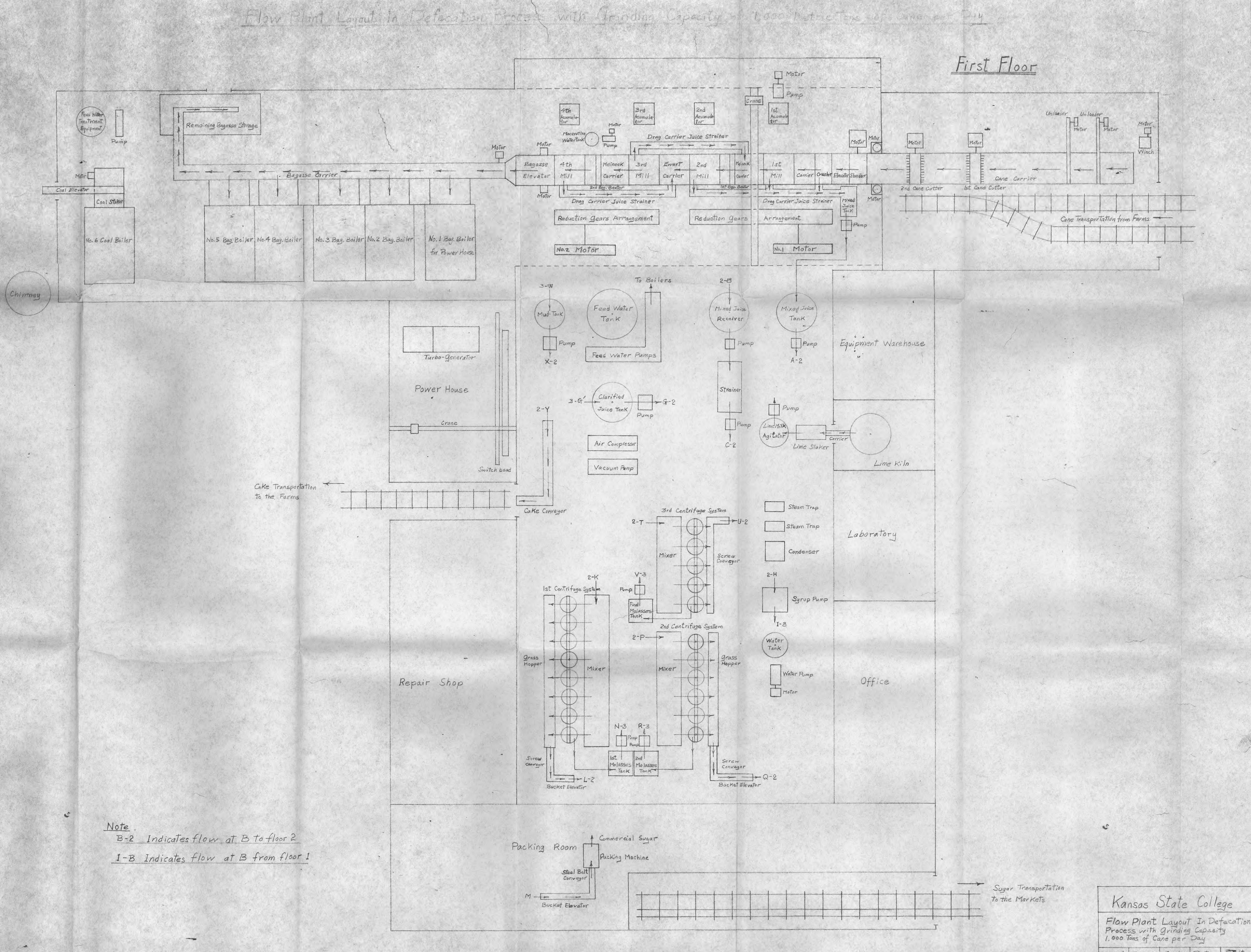


Fig. 6, Part 1 Plant layout in defecation process with grinding capacity of 1,000 metric tons of cane per day is beset with large volumes of effluents and waste materials. The disposition of these wastes presented no particular difficulty in the past. They were simply dumped on adjacent land or discharged directly into nearby streams. The slogan "by-products instead of waste products" is heard throughout the industry (Van Hook, 9). The discovery of by-products is an important part of the research program of the Sugar Experiment Station. Uses made of products that once were waste products are listed below.

1. Bagasse
    a. Fuel for firing the boilers
    b. Raw material for manufacturing paper pulp
    c. Raw material for manufacturing celotex-type bagasse-board and structural bagasse-board
2. Molasses
    a. Raw material for manufacturing alcohol and other chemicals
    b. Raw material for manufacturing yeast
    c. Raw material for manufacturing feed yeast for pigs and chickens
3. Cake
    a. Used as fertilizer for the farms.

The distribution of the products from cane is shown in Table 12 and Fig. 7. These data are derived from the previous calculations on the defecation process sugar factory.

Table 12. Distribution of products from cane, 41,600 kg of cane per hour

Product	Quantity (kg/hr)	Per cent cane
Sugar	5,000	12.0
Bagasse	9,600	23.0
Molasses	1,340	3.2
Cake	1,040	2.5
Impurities	620	1.5
Moisture	24,000	57.8
Total	41,600	100.0

STUDY OF A POWER PLANT FOR A SUGAR FACTORY WITH A GRINDING CAPACITY OF 2,000 TONS OF CANE PER DAY

Introduction

From Table 7 the following data were obtained for 1,000 tons per day grinding capacity, and the heat balance diagram is as shown in Fig. 8.

Subjects	Net steam consumption		Live steam supplied		Exhaust steam	
	kg/hr	lb/hr	kg/hr	lb/hr	kg/hr	lb/hr
Mill steam engine	1,190	2,618	7,350	16,170	6,160	13,552
Cane carrier steam engine	40	88	540	1,188	500	1,100
Vacuum pumps	87	191.4	530	1,166	443	974.6
Reciprocating steam pumps	75	165	900	1,980	825	1,815
Generator prime mover	670	1,474	6,400	14,080	5,730	12,606
Heating of molasses	170	374		Total	13,658	30,047.6
Vacuum pans	430	946				
Centrifugals	960	2,112				
Drying	25	55				
Heating	4,220	9,284				
Evaporating	8,450	18,590				
Boiling	6,100	13,420				
Radiation and other loss	673	1,480.6				
Total	23,090	50,798.0				

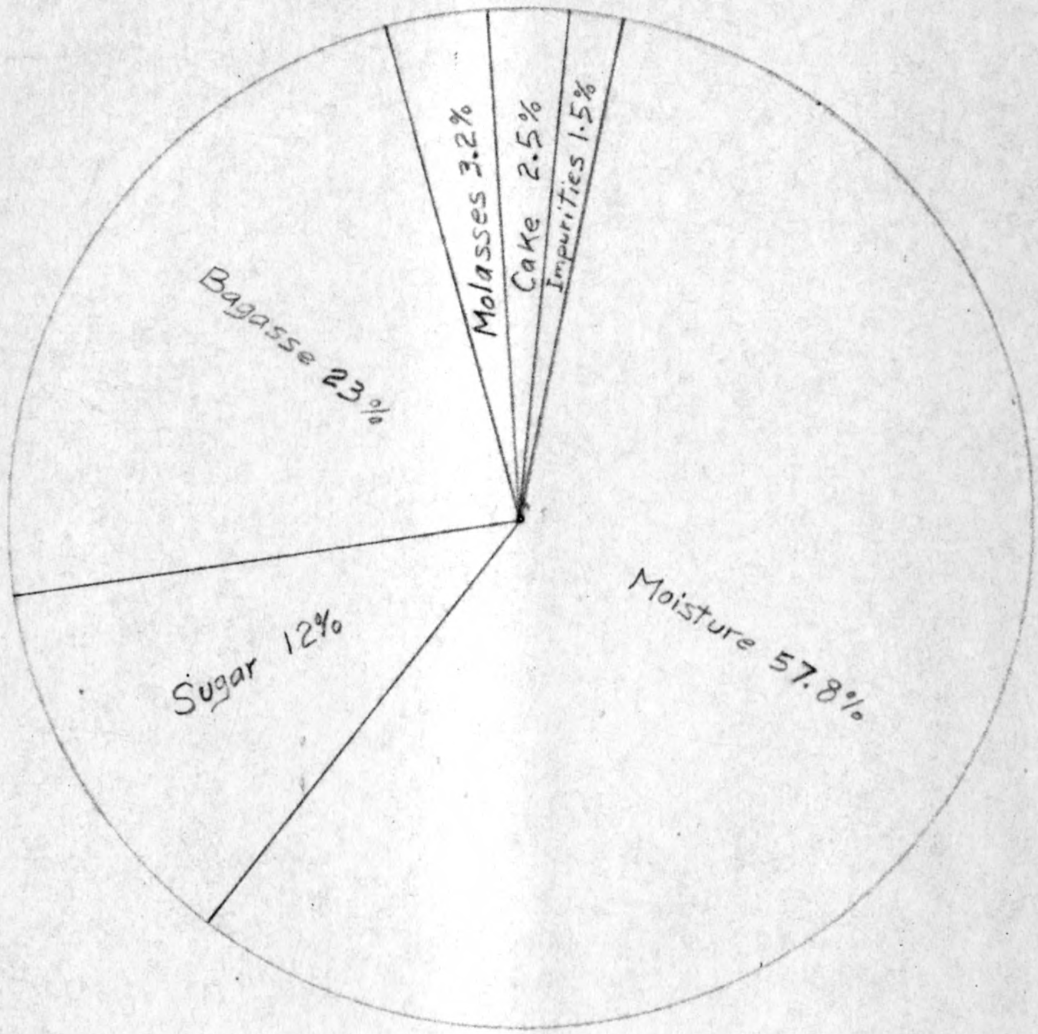
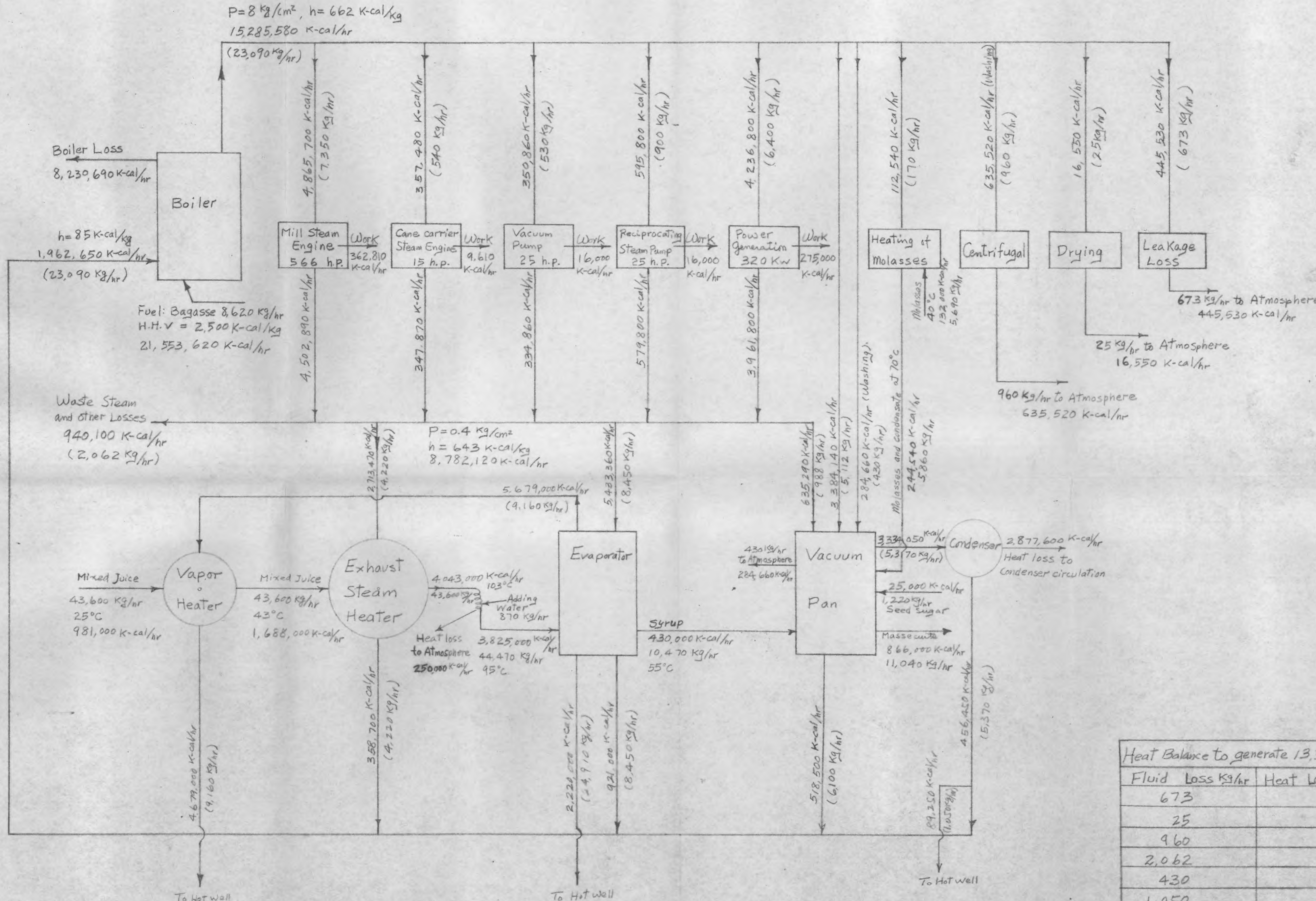


Fig. 7 Distribution of products from cane

Fig. 8.



Heat Balance to generate 13,323,000 K-cal/hr Steam	
Fluid Loss Kg/hr	Heat Loss K-cal/hr
673	445,530
25	16,550
960	635,520
2,062	940,100
430	284,660
1,050	89,250
24,910	2,220,000
9,160	4,679,000
Condenser Circulation	2,877,600
Process Heat Loss	250,000
Work	680,000
Total	13,323,000

Fig. 8 Heat balance of defecation process sugar factory (1,000 tons of cane per day)

July 10, 1955

For 1,000 tons of cane per day, the steam consumption is calculated as 23,090 kg/hr and is very close to the actual operating value of 22,600 kg/hr for 1,000 tons of cane per day in the Huwei First Factory of the Taiwan Sugar Corporation. Therefore the data of Table 7 were used as the basis for calculations.

It is found that power plants for the sugar industry differ little from power plants for any other industry. There are three factors to be considered in sugar industry power plants.

1. The sugar industry offers a relatively new field for the application of the steam turbine drive; that is, in the sugar factory the steam turbine can be used not only as a direct prime mover for the sugar mills themselves but also for the shredders and cane knife sets. For the mill drives, the steam turbine compares favorably with any form of electric drive because of its lower cost, its better operating characteristics, and its fewer complications. The turbine can also effect a saving in maintenance cost for various reasons. One is the absence of oil in the exhaust steam, thereby saving in time needed for cleaning of the boiler, evaporator, and juice heater tubes. Another advantage worth mentioning is the fact that the turbines have an automatic forced free lubrication system, and therefore do not require the constant attention of an operator to oil cups and lubricators, as would be normally required in the case of reciprocating engine types of drive.

2. A sugar refinery, because of its requirement for low-pressure steam in refining processes, provides an opportunity for the generation of by-product power. This may be accomplished by delivering boiler steam to turbogenerators and extracting all or some of this steam at low pressure for use in the refinery.

3. A problem is often present due to the sugar contamination of condensate returns to boilers from the refinery. The presence of sugar in the boiler water causes priming and carry-over to the turbines. Aside from the physical deposits of sugar, an acid is formed in the boiler tubes which is highly corrosive. Therefore feedwater treatment is very important.

Steam Turbine Drive for Mills

Because the application of steam turbines to drive mills is new, there have been very little data published on this subject. Schmertz (3) had an opportunity to observe and study a number of installations in Louisiana and has developed the following data which will be of help to the owner or engineer who is contemplating the installation of turbines.

Table 13. Steam consumption for mill turbine.

Names of factories in Louisiana	Tons cane per 24 hrs	Width of mills inches	Hp/ton of fiber/hr/ mill average	Hp/ton of fiber/hr/ mill peak
Westfield-1st & 2nd mills	2,330	72	12	16
Westfield-3rd & 4th mills	2,330	72	13	17
Lula 4th mill	2,100	60	15	21
Greenwood-1st & 2nd mills	2,400	72	18	--
Evan Hall 4th mill	3,800	78	17	--
Evan Hall 5th mill	3,800	78	19	--

Note: For all four factories, fiber content average at 15 per cent, maceration 18-19 per cent, roll speed about 50 feet per minute, extracted sucrose 91 to 92 per cent.

After careful consideration of the above data, Schmertz concluded that turbine capacity should be selected on the basis of 24 horsepower per ton of fiber per hour per mill for the future maximum conditions.

Mechanical drive turbines are made in two types. One is the single-stage, as usually used for pump or cane knife drives, and the other is the multistage type which is usually used for mill drives. The steam consumption and the water rates of single-stage (25- to 28-inch wheels) and multistage (28-inch wheels) for 400-hp turbines operating at 3,600 rpm with 125 psig initial pressure, dry and saturated, and 10 psig exhaust pressure, as found by Schmertz, are shown in Table 14.

Table 14. Steam consumption for mechanical-drive turbine.

Type of turbine	Water rate lb steam per hp-hr		Total steam flow lb steam per hr	
	Full load	60% load	Full load	60% load
Single stage	40	50	16,000	12,000
Multistage	32	38	12,800	9,120

The steam consumption of the multistage turbine is about the same as that of Corliss engines, even at part load, while the steam consumption of the single-stage turbine is higher. Therefore the use of multistage turbines for mill drives is strongly recommended. Furthermore, the multistage turbine steam consumption is as good as that of the Corliss engine, even at an initial pressure as low as 85 or 95 psig.

Based on the foregoing:

Horsepower required for crusher = 18 hp/ton of cane fiber/hr

Horsepower required for mill = 24 hp/ton of cane fiber/hr

Horsepower for crusher = 2,000 x 0.128 x 18/24 = 192 hp

Horsepower for mill = 2,000 x 0.128 x 24 x 4 = 1026 hp

Total hp = 192 + 1,026 = 1,218 hp

Employing three sets of 400-horsepower mechanical drive multistage turbines with initial pressure 125 psig, exhaust pressure 10 psig, the average load = 400 x 3 x 0.6 = 720 hp. Therefore, total average steam consumption = 38 x 720 = 27,360 lb/hr.

By-product Power

Early in 1947, Farrar (10) mentioned that paper mills, pulp mills, sugar mills, and textile finishing plants are good examples of industries that use large amounts of steam in their cookers, digesters, and driers, as well as for space heating. It is usually found that by-product power can be generated at a cost lower than the purchase price of power from a utility.

Table 15 shows the distribution of the live steam and the exhaust steam for a grinding capacity of 2,000 tons of cane per day using the defecation process.

Table 15. Steam consumption.

Subject	Net steam consumption lb/hr at 125 psig	Live steam supplied lb/hr at 125 psig	Exhaust steam lb/hr at 10 psig
Mill steam engine, 1,200 hp	5,236	32,340	27,104
Cane carrier steam engine, 30 hp	176	2,376	2,200
Vacuum pump, 50 hp	382	2,332	1,950
Reciprocating steam pump, 50 hp	330	3,960	3,630
Generator prime mover, 320 kw	2,948	28,160	25,212
Heating of molasses	748	Total	60,095
Vacuum pan	1,892		
Centrifugal	4,224		
Drying	110		
Heating	18,568		
Evaporating	37,180		
Boiling	26,840		
Radiation and other loss	2,960		
Total	101,600		

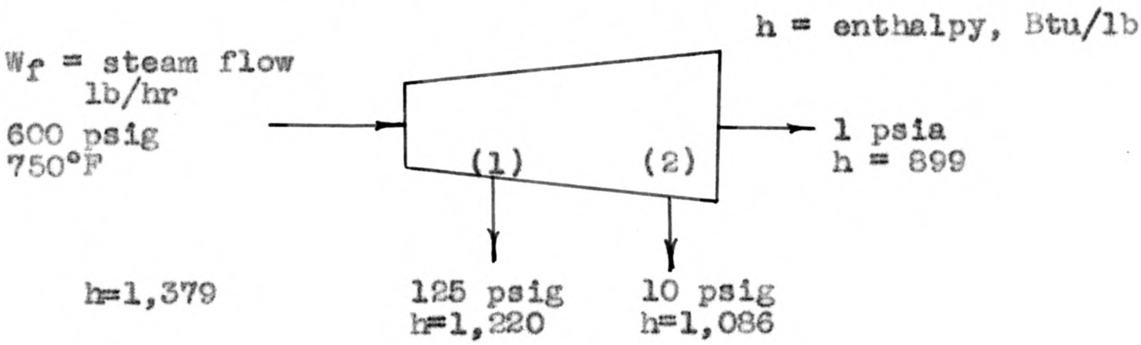
Use of exhaust steam at 10 psig is as follows:

Juice heating	18,568
Evaporating	37,180
Boiling	4,347
Total	60,095 lb/hr

From "Water Rates of Steam Turbines in Sizes from 500 kw to 7,500 kw," by Helander (11), the over-all engine efficiencies of 1,500-kw, 3,000-kw, and 6,000-kw turbines at 600 psig, 750 degrees F, and 1 psia exhaust pressure, and a 1,500-kw turbine at 300 psig, 625 degrees F, and 1 psia exhaust pressure, were found to be 66.8 per cent, 71.4 per cent, 75.1 per cent, and 69 per cent, respectively.

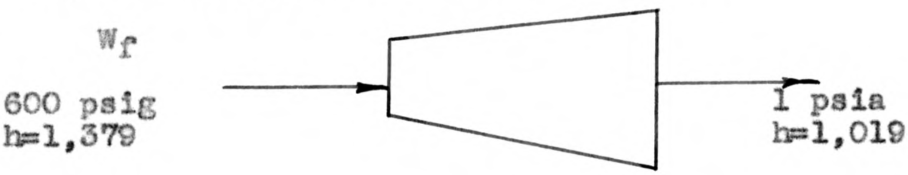
Using 600-psig, 750-degree F steam for a 1,500-kw, a 3,000-kw, and a 6,000-kw turbine, and 300-psig, 625-degree F steam for a 1,500-kw turbine, steam consumptions were calculated as follows.

For reversible adiabatic expansion, steam conditions at the turbine are shown in the following figure.



For the actual turbines, using the approximate over-all engine efficiencies given above, the following steam requirements were calculated.

(1) 3,000-kw straight condensing turbine:



$$h = 1,379 - 0.714(1,379 - 899)/(0.97 \times 0.98) = 1,019$$

$$\text{Throttle flow, } W_f = \frac{3,000 \times 3,413}{0.714(1379 - 899)} = \frac{3,000 \times 3,413}{1,379 - 1,036}$$

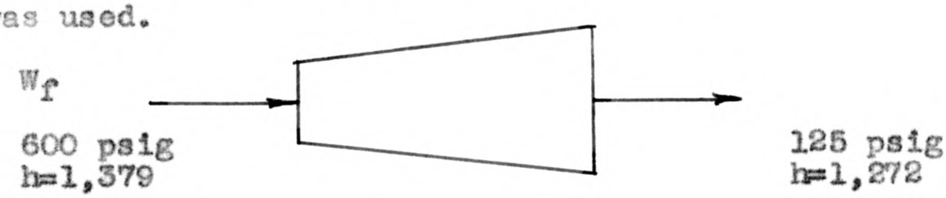
$$= 30,000 \text{ lb/hr}$$

(2) 1,500-kw noncondensing turbine

Assume generator efficiency is 97 per cent and turbine mechanical efficiency is 98 per cent. Then

$$\text{average internal efficiency} = \frac{66.8}{0.97 \times 0.98} = 70\%$$

For estimating performance of noncondensing turbine, 67 per cent was used.



$$h = 1,379 - 0.67(1,379 - 1,220) = 1,272$$

$$W_f(1,379 - 1,272) = \frac{1,500 \times 3,413}{0.97 \times 0.98} = 5,383,280$$

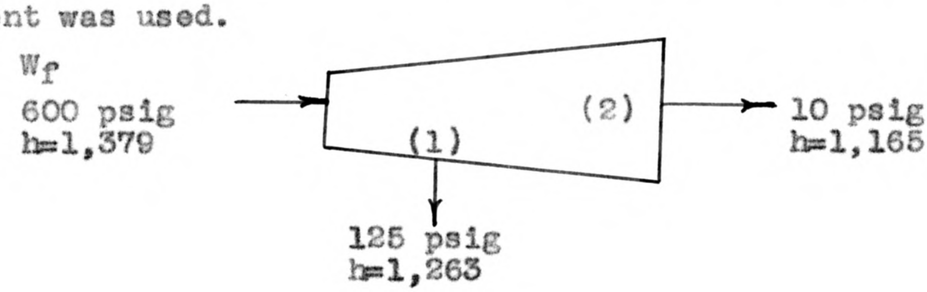
Therefore W_f = 50,300 lb/hr

(3) 3,000-kw noncondensing, single extraction turbine

27,360 pounds of steam per hour were to be extracted at 125 psig for the mill turbines.

$$\text{Average internal efficiency} = \frac{71.4}{0.97 \times 0.98} = 75\%$$

For estimating the performance of the extraction turbine, 73 per cent was used.



$$h_1 = 1,379 - 0.73(1,379 - 1,220) = 1,263$$

$$h_2 = 1,379 - 0.73(1,379 - 1,086) = 1,165$$

Work done, throttle to extraction point (1)

$$= W_f\ (1,379 - 1,263) = 116\ W_f$$

Work done, extraction point (1) to exhaust pres

$$= (W_f - 27,360) \times (1,263 - 1,165) \quad = \quad 98\ W_f - 2,681,280$$

Total work $= 214\ W_f - 2,681,280$

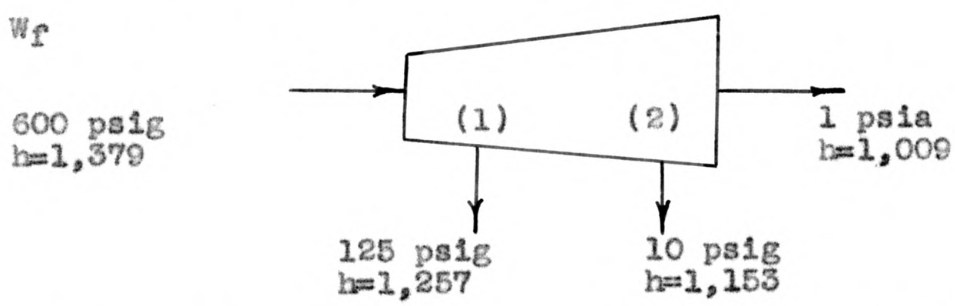
Total work $= 214\ W_f - 2,681,280 = (3,413 \times 3,000)/(0.97 \times 0.98)$

$$= 10,766,560$$

Therefore $W_f = 13,447,840/214 = 63,000$ lb/hr

(4) 6,000-kw double extraction condensing turbine

27,360 pounds of steam per hour are to be extracted at 125 psig for the mill turbines, and 24,955 pounds per hour are to be extracted at 10 psig for process.



Average internal efficiency = 0.751/(0.98 x 0.97) = 79%

For estimating performance of extraction turbine, 77 per cent was used.

$$h_1 = 1,379 - 0.77\ (1,379 - 1,220) = 1,257$$

$$h_2 = 1,379 - 0.77\ (1,379 - 1,086) = 1,153$$

$$h_3 = 1,379 - 0.77\ (1,379 - 899) = 1,009$$

Work done, throttle to extraction point (1)

$$= W_f(1,379 - 1,257) = 122\ W_f$$

Work done, extraction point (1) to extraction point (2)

$$= (W_f - 27,360) \times (1,257 - 1,153) = 104\ W_f - 2,845,440$$

Work done, extraction point (2) to extraction point (1)

$$= (W_f - 27,360 - 24,955) \times (1,153 - 1,009) = 144\ W_f - 7,533,360$$

$$\text{Total work} = 370\ W_f - 10,378,800$$

$$\text{Total work} = 370\ W_f - 10,378,800 = (6,000 \times 3,413)/(0.97 \times 0.98)$$

$$= 21,553,100 \text{ Btu/hr}$$

Therefore, throttle flow $= W_f = 31,911,900/370 = 86,200$ lb/hr

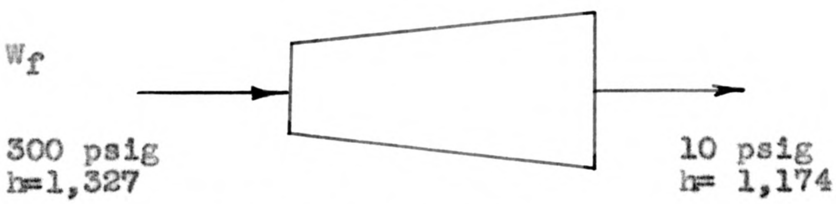
$$\text{Without extraction, } W_f = \frac{6,000 \times 3,413}{0.751 \times (1,379 - 899)} = 57,000 \text{ lb/hr}$$

(5) 1,500-kw noncondensing turbine

Initial pressure 300 psig, initial temperature 625° F, exhaust pressure 10 psig. For reversible adiabatic expansion, enthalpy at 10 psig is 1,105 Btu/lb.

Average internal efficiency = 69/(0.97 x 0.98) = 71%

For estimating performance of noncondensing turbine 68 per cent was used.



$$h = 1,327 - 0.68(1,327 - 1,105) = 1,174$$

$$\text{Work} = W_f(1,327 - 1,174) = (1,500 \times 3,413)/(0.97 \times 0.98)$$

$$= 5,383,280 \text{ Btu/hr}$$

Throttle flow $= W_f = 35,000$ lb/hr

The calculation of the size of the condenser required is shown in the following. To determine the over-all coefficient of heat transfer for a surface condenser, it was assumed that the tubes would be 1-inch, 18-gauge Admiralty metal, the steam-side coefficient would be 2,000 Btu per hour per degree temperature difference, the scale coefficients would be 2,000 Btu per hour degree on each side, and the water-side coefficient would be 1,800 Btu per hour degree. Standard dimensions of a 1-inch condenser tube are a wall thickness of 0.049 inch and an inside diameter of 0.902 inch, the mean tube diameter is 0.951 inch, and thermal conductivity k is 63.

McAdams (12) gives the following equation to determine the over-all coefficient of heat transfer.

$$\frac{1}{U} = \frac{dA}{h' dA} + \frac{X_w \, dA}{k_w \, dA_w} + \frac{dA}{h_d \, dA''} + \frac{dA}{h'' dA''}$$

where U = over-all coefficient of heat transfer

k_w = thermal conductivity for tube wall

X_w = thickness of tube wall

A = area of heat transfer surface; A'' on colder side; A' on warmer side

h = individual coefficient between fluid and surface

h' is based on A' and t'; h'' is based on A'' and t''; h_d is for scale

The area ratios in the above equation can be replaced by diameter ratios. On a basis of 1 square foot of outer surface, one obtains U = 446 Btu/(hr)(sq ft of outside surface)(deg F).

The saturated temperature in a condenser at 1 psia is 101.74° F. Temperature of cooling water was assumed to be: inlet, 70° F; outlet, 80° F.

Let Δtm = mean temperature difference

$$\Delta tm = (101.74 - 70) - (101.74 - 80) / \ln \frac{31.74}{21.74} = 27°$$

Q is $m(\Delta h)$, which for 3,000 kw is 30,000 x (1,019 - 69.7) = 28,980,000 Btu/hr. Then, using these values for the 3,000-kw straight condensing turbine, the equation $A = Q/(U \Delta tm)$ gives an area of 2,420 square feet of heat transfer surface of condenser. As a margin of safety, a value of 2,600 square feet was used.

For the 6,000-kw double extraction condensing turbine, Q is 57,000 x (1,009 - 69.7) = 53,523,000 Btu/hr, giving an area of 4,500 square feet of heat transfer surface for the condenser. As a margin of safety, a value of 5,000 square feet was used.

Possible Arrangements

Existing plant (Fig. 9, Existing plant).

Requirement of refinery:

125 psig steam, saturated	101,600 lb/hr
10 psig steam	60,100 lb/hr
Power for refinery from plant turbine	640 kw

Total fuel consumption, 172,428,000 Btu/hr (at 65% boiler efficiency)

No excess by-product power generation

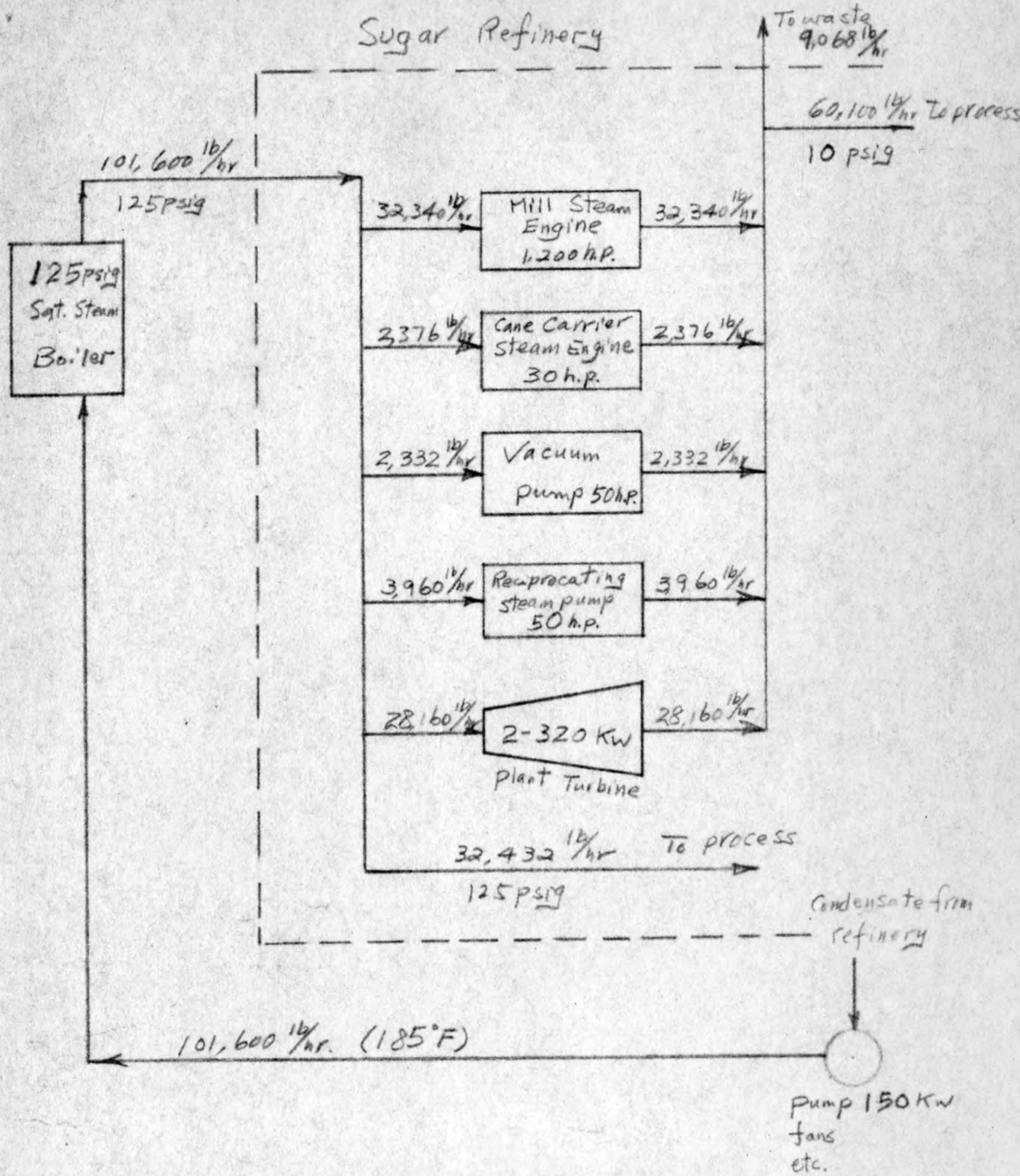


Fig. 9 Existing plant

Case I

Suppose that two 1,500-kw, 600-psig, 750-degree F topping turbines, plus boilers are used, turbines to exhaust 101,600 lb/hr of 125 psig steam to refinery. These turbines are used to produce by-product power. Power requirement of the refinery is still to be met by the existing two 320-kw plant turbines (Fig. 10).

Requirement of refinery:

600 psig, 750°F steam	101,600 lb/hr for noncondensing turbine during refinery operation
125 psig, steam exhausted from noncondensing turbine	101,600 lb/hr
10 psig, steam	60,100 lb/hr
Power for refinery from plant turbine	640 kw
Fuel consumption	164,000,000 Btu/hr for refinery and noncondensing turbine (at 75% boiler efficiency)
Power for high-pressure boiler-feed pump, fans, etc.	150 kw
By-product power to be sold	2,880 kw
Cost of high-pressure boiler, not installed	$437,500
Cost of turbine-generator (noncondensing), not installed	$180,000

Case II

Suppose that mill turbines and motor drives are to be used to replace steam engine drives.

To produce by-product power, suppose that one 3,000-kw noncondensing turbine, exhaust pressure 10 psig, with extraction

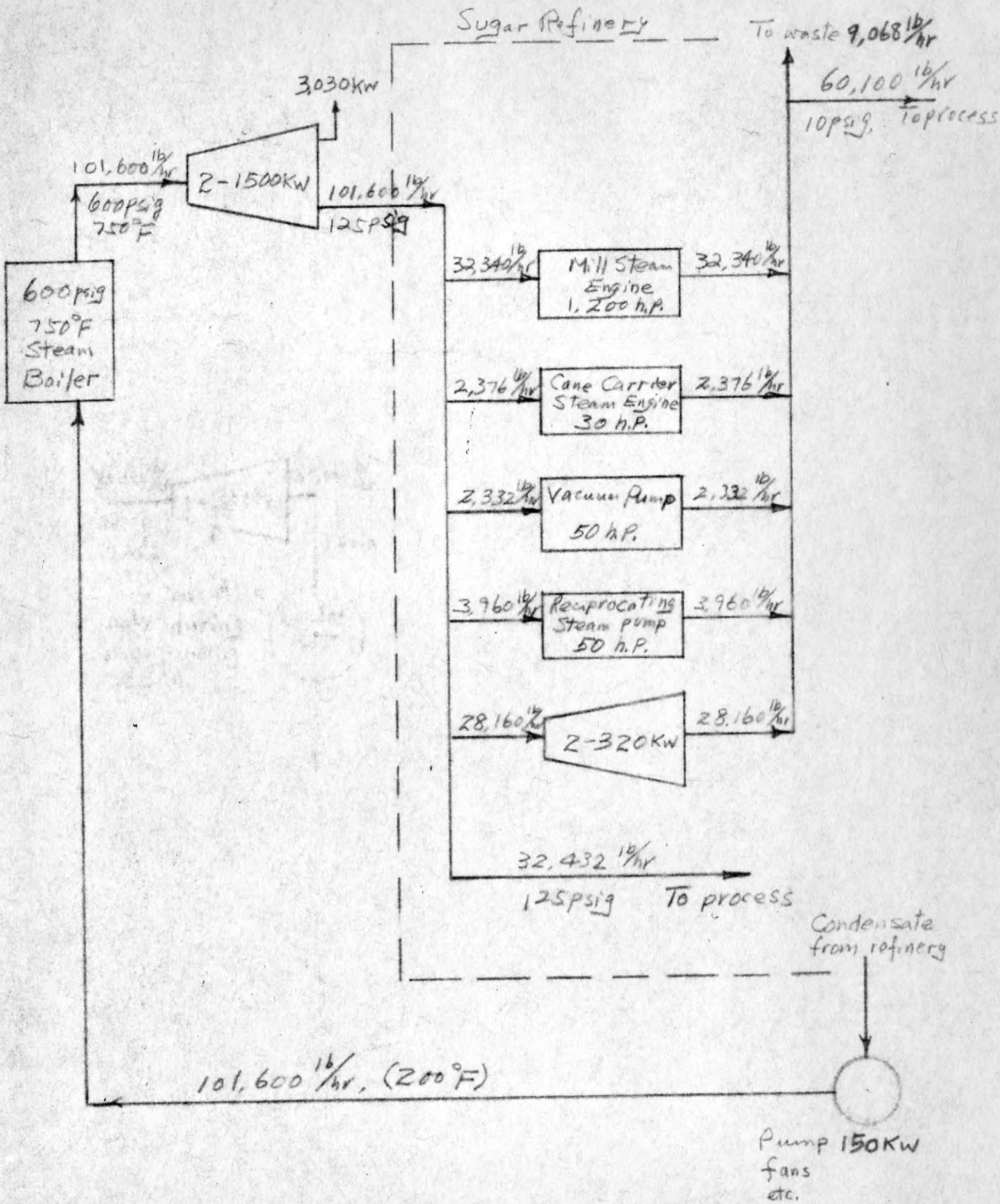

Sugar Refinery
To waste 9,068 lb/hr
60,100 lb/hr
10psig
To process
3,030Kw
101,600 lb/hr
600psig
750°F
2-1500KW
101,600 lb/hr
125Psig
600psig
750°F
Steam
Boiler
32,340 lb/hr
Mill Steam Engine 1,200 h.p.
32,340 lb/hr
2,376 lb/hr
Cane Carrier Steam Engine 30 h.P.
2,376 lb/hr
2,332 lb/hr
Vacuum Pump 50 h.P.
2,332 lb/hr
3,960 lb/hr
Reciprocating Steam pump 50 h.P.
3,960 lb/hr
28,160 lb/hr
2-320Kw
28,160 lb/hr
32,432 lb/hr
125psig
To process
Condensate from refinery
101,600 lb/hr, (200°F)
Pump 150Kw
fans
etc.

Fig. 10 Case I

at 125 psig is to be used to supply 27,360 lb/hr of steam to run mill turbines which are to exhaust to process at 10 psig.

Assume that new 125 psig, saturated steam boilers are to be used for supplying 32,432 lb/hr steam to process (Fig. 11).

Requirement of refinery:

600 psig, 750°F, steam	63,000 lb/hr for noncondensing turbine during refinery operation
125 psig, steam extracted from noncondensing turbine	27,360 lb/hr for mill turbine
10 psig, steam exhausted from noncondensing turbine	34,640 lb/hr to process
10 psig, steam exhausted from mill turbines	27,360 lb/hr to process
125 psig, saturated steam from 125 psig boilers	32,432 lb/hr
Power to refinery	738 kw
Fuel consumption of high-pressure boilers	101,400,000 Btu/hr (at 75% boiler efficiency)
Fuel consumption of low-pressure boilers	44,240,000 Btu/hr (at 75% boiler efficiency)
Total fuel consumption	145,670,000 Btu/hr for grinding season
Power for high-pressure-boiler-feed pump, fans, etc.	100 kw
Power for low-pressure-boiler-feed pump, fans, etc.	15 kw
By-product power to be sold	2,147 kw during grinding season
Cost of 600 psig boilers generating 63,000 lb/hr, not installed	$300,000
Cost of turbine-generator (noncondensing), not installed	$185,000

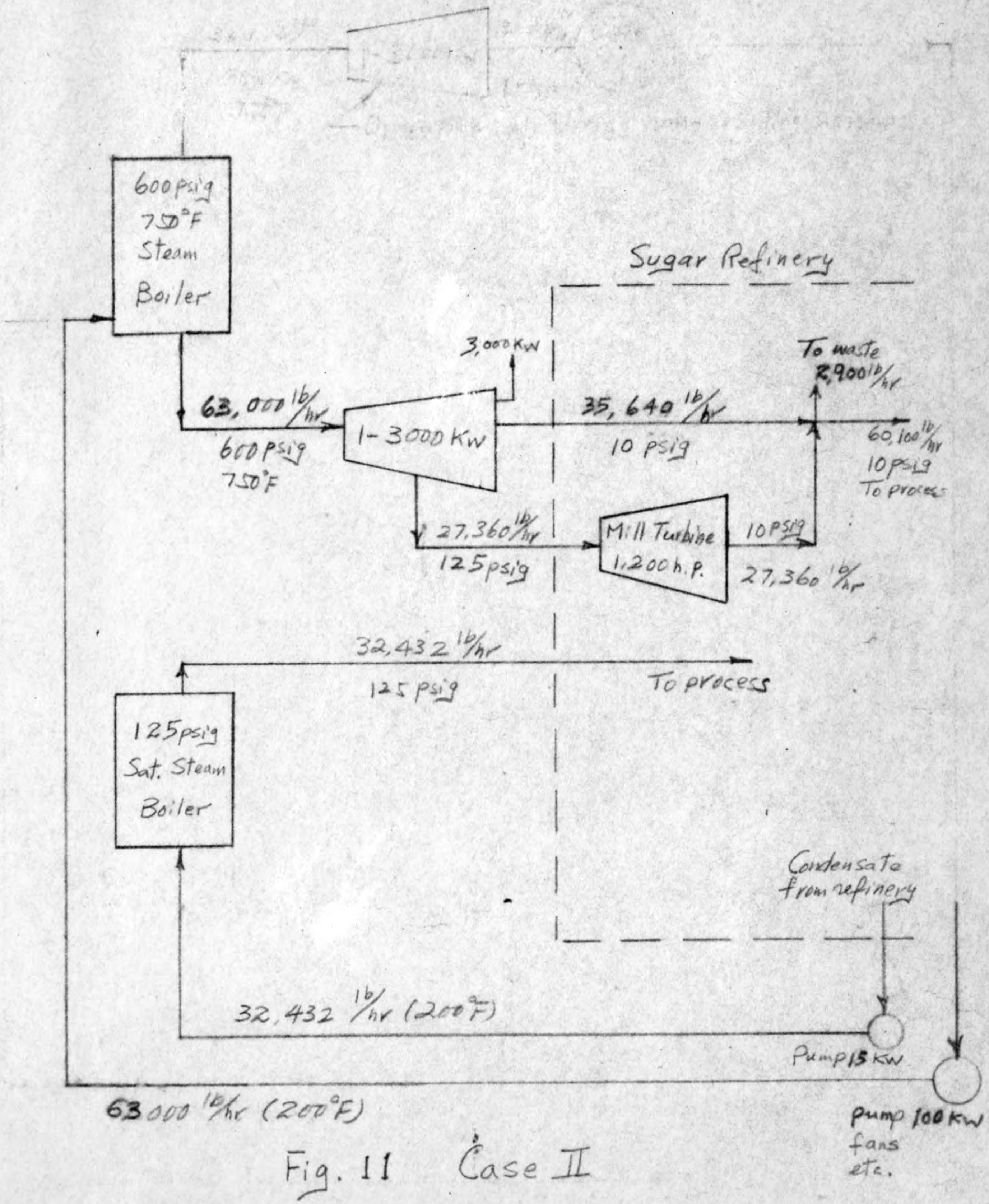


Fig. 11 Case II

Cost of 125 psig boilers generating 32,432 lb/hr, not installed	$90,000

Case III

Suppose that electric motor drives are to be used to replace all steam engine drives in the refinery.

To produce by-product power, suppose that two 300-psig, 625°F, 1,500-kw noncondensing turbines are to be employed and that these are to deliver 63,000 lb/hr steam to process at 10 psig.

Assume that new 125-psig, saturated steam boilers are to be used to supply 32,432 lb/hr steam to process (Fig. 12).

Requirement of refinery:

300 psig, 625°F, steam	63,000 lb/hr for noncondensing turbines during refinery operation
125 psig, saturated steam	32,432 lb/hr from 125 psig boilers for process
10 psig, steam	60,100 lb/hr for process, exhaust from turbines
Power for refinery	1,633 kw
Fuel consumption	97,400,000 Btu/hr for high-pressure boiler (at 75% boiler efficiency)
Fuel consumption	44,240,000 Btu/hr for low-pressure boiler (at 75% boiler efficiency)
Total fuel consumption	141,640,000 Btu/hr
Power for high-pressure-boiler-feed pump, fans, etc.	80 kw
Power for low-pressure-boiler-feed pump, fans, etc.	15 kw

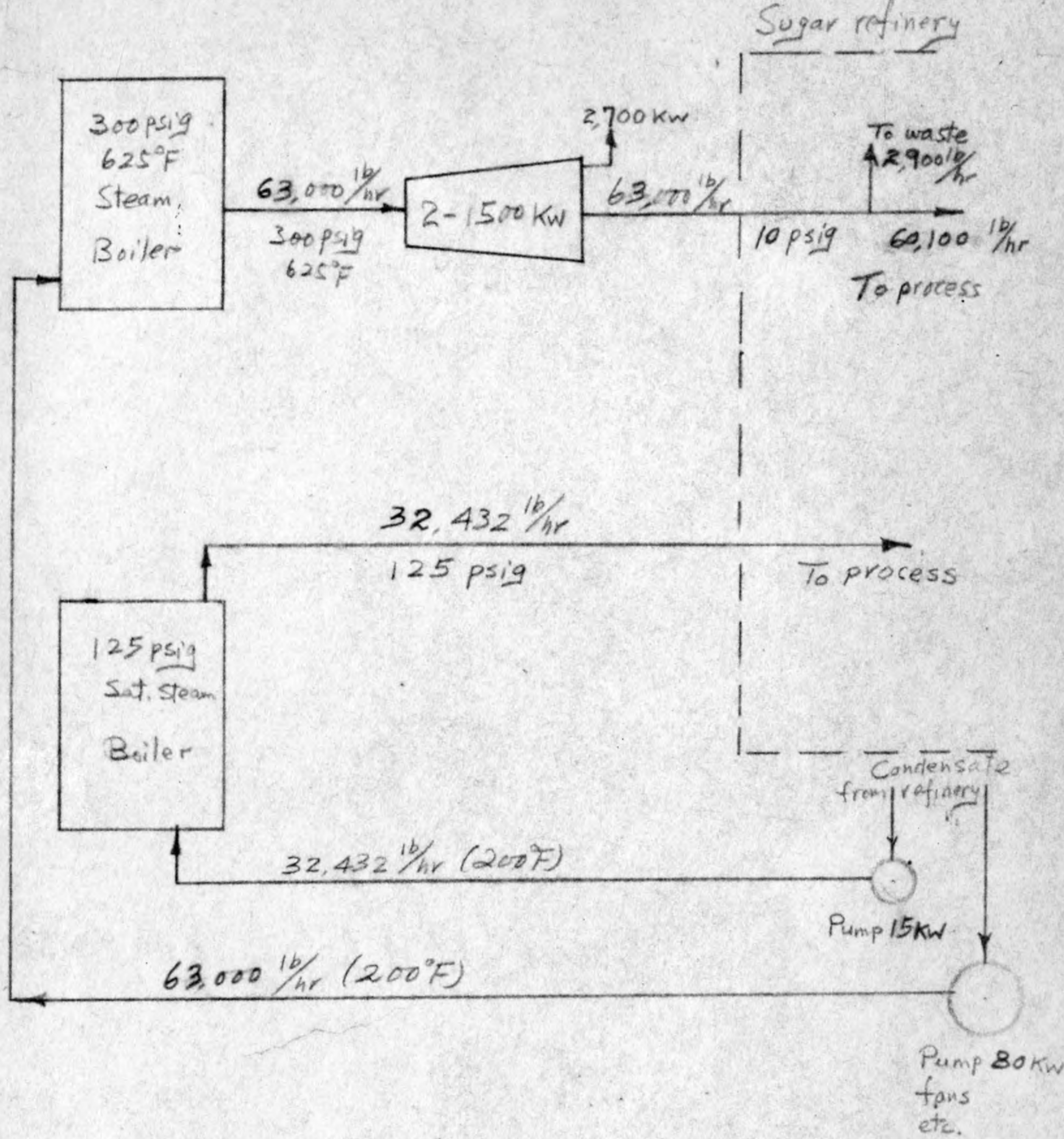


Fig. 12 Case III

Cost of 600 psig boilers generating 64,000 lb/hr, not installed	\$230,000
Cost of turbine (noncondensing), not installed	\$165,000
Cost of 125 psig boilers generating 32,432 lb/hr, not installed	\$90,000

Estimated Value of Power to Utility

Load factor	0.90	0.50
Fuel cost 13,500 Btu/kwhr at 20 cents/million Btu	0.27 cents	0.27 cents
Capital charges $\frac{175 \times 13 \times 100}{8760 \times 0.90 \text{ (load factor)}} =$	0.22 cents	0.44 cents
	0.49 cents	0.71 cents

Let sale value of power be 0.25 cents/kwhr if sold as dump power during the six-months period in which the refinery operates.

Let sale value of power to utility be 0.50 cents/kwhr if sold as firm power throughout the year at 0.90 load factor.

Let sale value of power to utility be 0.70 cents/kwhr if sold to aid utility solely during period of low availability of hydroelectric power.

Case I

Assume that existing 125 psig, steam boilers must be replaced, and that fuel consumption of a new 125 psig, base boiler generating 101,600 lb/hr is 149,300,000 Btu/hr (at 75% boiler efficiency.

Estimate of cost of 600 psig, boilers	\$437,500
Estimate of cost of turbine (non-densing)	\$180,000
Estimate of cost of 125 psig, boilers with capacity equivalent to that of 600 psig, boilers	\$280,000
Increment of investment over investment for 125 psig boilers	\$337,500

Assume by-product power is sold only during the six-months period in which the refinery operates, and the power-generating capacity of a utility is not enough to supply the demand for it.

Fuel charges against by-product power $164{,}000{,}000 - 149{,}300{,}000 = 14{,}700{,}000$ Btu/hr

$$\frac{14{,}700{,}000 \times 20 \times 8760 \times 0.5 \times 0.9}{1{,}000{,}000 \times 100} = \$11{,}600$$

Annual return from by-product power sold (sale value 0.7

$$\text{cents/kwhr}) = \frac{2{,}880 \times 0.70 \times 8760 \times 0.5 \times 0.9}{100} = \$79{,}400$$

Net annual return from increment of investment = \$67,800

Capitalized value of annual return = 67,800/0.15 = \$452,000

Capitalized value of return on investment - added cost of boilers and turbines (not installed) = \$114,500

Case II

Estimate of cost of 600 psig, boilers:	\$300,000
Estimate of cost of turbine (non-condensing)	\$185,000
Estimate of cost of supplementary 125 psig, boilers	\$ 90,000
Estimate of boiler cost using only 125 psig, boilers	\$280,000

Increment of investment over cost of 125 psig boilers	\$295,000

Fuel saved = 149,300,000 - 145,670,000 = 3,630,000 Btu/hr

$$\text{Value of fuel saved} = \frac{3{,}630{,}000 \times 20 \times 8760 \times 0.5 \times 0.9}{1{,}000{,}000 \times 100}$$

$$= \$2{,}900$$

Annual return from by-product power sold (sale value 0.7

$$\text{cents/kwhr}) = \frac{2{,}147 \times 0.70 \times 8760 \times 0.5 \times 0.9}{100} = \$59{,}400$$

Net annual return from increment of investment = \$62,300

Capitalized value of annual return = 62,300/0.15 = \$416,000

Capitalized value of return on investment - added cost of boilers and turbines (not installed) = \$121,000

Case III

Estimate of cost of 300 psig, boilers	\$230,000
Estimate of cost of turbine (non-densing)	\$165,000
Estimate of cost of 125 psig, boilers	\$ 90,000
Estimate of cost of base boilers	\$280,000
Increment of investment over cost of 125 psig boilers	\$205,000

Fuel saved = 149,300,000 - 141,640,000 = 7,660,000 Btu/hr

$$\text{Value of fuel saved} = \frac{7{,}660{,}000 \times 20 \times 8760 \times 0.5 \times 0.9}{1{,}000{,}000 \times 100}$$

$$= \$6{,}040$$

Annual return from by-product power sold (sale value 0.7

$$\text{cents/kwhr}) = \frac{972 \times 0.70 \times 8760 \times 0.5 \times 0.9}{100} = \$26{,}500$$

Net annual return from increment of investment = \$32,940

Capitalized value of annual return = 32,940/0.15 = \$220,000

Capitalized value of return on investment - added cost of boilers and turbines (not installed) = \$15,000

CONCLUSIONS

The demand for steam in the sugar refinery is heavy and the demand for power is light. Therefore there is an opportunity to produce by-product power and sell the excess amount of power to a utility. This may be accomplished by delivering high-pressure boiler steam to turbo-generators and extracting all or some of this steam at low pressure for use in the refinery. This was not attractive in the past in Formosa due to the small demand for electricity.

Due to the rapid increase of new industries and population in Formosa, the demand for power is increasing day by day. Most of the power plants of the Taiwan Electric Company are hydroelectric power plants. For three or four months of the year, the shortage of rain causes a shortage of power-generating capacity in the Taiwan Electric Company. During these months, and for an additional two or three months, a typical Formosan refinery is capable of delivering excess by-product power and supplying this power to the Taiwan Electric Company at a rate which might prove attractive.

The heat balance of a typical Formosan sugar refinery has been worked out and used as a basis for studying three cases wherein by-product power is to be generated for sale to the Taiwan Electric Company.

For preliminary studies to determine the feasibility of a Formosan sugar refinery selling by-product power to a utility, the sale value of power was assumed as follows: Dump power sale value, .25 cents/kwhr; firm year-round power sale value, .50 cents/kwhr; peak load power sale value, .70 cents/kwhr.

Case I represents one means of obtaining by-product power for six months annually during the grinding season from two 1,500-kw turbo-generators. In this case, assuming that power can be sold at .70 cents/kwhr, the estimated capitalized gain for generating by-product power during the grinding season is $114,500 in excess of the increment of investment in turbines and boilers alone, that is, not including installation and other associated costs, required for the generation of salable by-product power. This increment of investment is in excess of the cost of 125-psig boilers with capacity equivalent to that of the 600-psig boiler used for generating by-product power.

In Case II, the mill steam engines are replaced by mill turbines, the steam consumption of which has been assumed less than that of the mill steam engines. Also, steam drives are replaced by electric motor drives. To produce by-product power, one 3,000-kw extraction noncondensing turbine is installed for use during the grinding season. Assuming that power can be sold for 0.7 cents per kwhr, the capitalized gain for generating by-product power during the six-months grinding season is $121,000 in excess of the increment of investment in turbines and boilers alone, that is, not including installation and the associated costs required for generating salable by-product power.

In Case III, electric motor drives replaced all steam drives in the refinery. For producing by-product power, two 1,500-kw noncondensing turbines were assumed to be installed. Assuming that power can be sold for 0.7 cents per kwhr, the capitalized gain for generating by-product power during the six-months grinding season is $15,000 in excess of the increment of investment in turbines for boilers alone, that is, not including installation and the associated costs required for generating salable by-product power.

For sales values of power of .25 cents/kwhr and .50 cents/kwhr, the generation of by-product power for sale to a utility was found not to be economical. Further study is needed since the data presented on costs are preliminary estimates only and do not include all items of expense.

It was found economical to generate by-product power to sell to a utility only if one could assume that the utility, due to lack of water power, would need the additional capacity provided in the form of by-product power and would be willing to pay in the neighborhood of 7/10 cents per kwhr for the power purchased by it. The coincidence of the period of refinery operation with the period of low water for hydroelectric power favored the assumption that this requirement might be satisfied.

Case II provided more efficient refinery operation due to the use of mill turbines in the place of mill steam engines. It reduced leakage steam 4,980 lbs per hour. Insofar as the economic factors could be evaluated, this case gave the optimum cost condition. This case also provides the advantages of neatness and cleanliness obtainable with the electric motor drives and the mill turbine drives in the refinery.

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SURVEY OF FORMOSAN SUGAR REFINERY PRACTICE WITH REGARD TO THE POSSIBILITY OF PRODUCING BY-PRODUCT POWER TO SELL TO UTILITY

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ABSTRACT OF

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In the sugar refinery, if fuel is purchased, the fuel cost comprises most of the process cost. The bagasse is available as fuel in the sugar factories. In the past it was satisfactory to burn the bagasse as fuel. However, at present, the bagasse is valuable as raw material for various kinds of chemical products, such as paper pulp and bagasse-board. Therefore it is desirable to save a great amount of the bagasse, and thus the heat economy and minimum steam consumption must be considered as important considerations in plant operation.

The first step in analyzing the possibilities of improving the fuel economy of a plant is to develop what is known as a heat balance of the plant. This is simply an accounting of the disposition of the energy in the fuel burned, such that wastages may be detected and stopped.

The heat balance in the sugar refinery is the steam heat balance, and is divided into three definite parts for calculation purposes.

(a) The boiler heat balance.

(b) The heat balance of live steam consumers.

(c) The heat balance of exhaust steam consumers.

A heat balance of a typical Formosan sugar refinery has been worked out, and is presented in this thesis. The heat balance has been used as a basis for making preliminary predictions of the possibility of effecting economies in the utilization of fuel by the use of high-pressure boilers and modern steam turbines to produce electrical power as a by-product for sale to a utility.

Three different cases were studied. It was found that it may be economical to generate by-product power to sell to a utility only during the six-months grinding season.

Case II provided more efficient refinery operation due to the use of mill turbines in the place of steam engines. To produce by-product power, one 3,000-kw extraction noncondensing turbine was employed for use during the grinding season. Insofar as the economic factors could be evaluated, this case gave the optimum cost condition. This case also provided the advantages of neatness and cleanliness obtainable with the electric motor drives and the mill turbine drives in the refinery.

Due to the rapid increase of new industries and population in Formosa, the demand for power is increasing day by day, but the power generating capacity of the Taiwan Electric Company is not enough to supply the demand. Therefore there is a possibility of producing by-product power in the sugar refinery for sale to a utility.