ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

PROGRESS REPORT II

PROCESSING OF SUGAR BEETS

By

L. E. BROWNELL
Supervisor

S. A. ZIEMINSKI
Research Associate

TEH LEE
Research Assistant

Project 2047

U. S. DEPARTMENT OF AGRICULTURE
CONTRACT NO. A-1s-33464

December, 1952

TABLE OF CONTENTS

	Page
List of Tables	iii
List of Figures	iv
Abstract	v
Part I - Experimental Technique	1
A. Preparation of Cossettes	1
B. Reference Juice	3
C. Reproducibility of the Method	4
Part II - The Explosion Equipment and Its Operation	6
Part III - Experiments	12
A. Series I	12
B. Series II	19
C. Series III	21
D. Conclusions	25
E. Future Experiments	25
Bibliography	26

LIST OF TABLES

No.		Page
I	Reproducibility of the Digestion Method	5
II	Reproducibility of the Centrifuge Method	6
III	Increase of the Temperature of Cossettes Before the Start of the Experiment	10
IV	Explosion Experiments at 0, 5, 20 and 60 psig Steam Pressure	13
V	Steam Treatment of Cossettes at 0 and 60 psig Pressure	20
VI	Steam Treatment of Cossettes at Atmospheric Pressure Followed by a Sudden (1 sec or less) Increase of Pressure to 60 and 55 psig	24

LIST OF FIGURES

No.		Page
1	Manually Operated Slicer	2
2	Digestion Vessel	4
3	The Explosion Equipment	7
4	The Explosion Equipment	8
5	Steel and Glass Linings	9
6	Centrifuge Tube, Cylinder and Filtering Medium	11
7	Change of Purity of Juice at Different Steaming Pressures and Different Times of Steam Treatment	14
8	Change of Invert Sugar Content at Different Steaming Pressures and Different Times of Steam Treatment	16
9-19	Photographs of Exploded Cossettes	17-18
20	Explosion Equipment with Arrangement for Sudden Increase of Stream Pressure	23

ABSTRACT

This report describes the work performed since the preparation of Progress Report I. A series of experiments has been performed to determine the influence of variables such as temperature, steam pressure, and time of steam treatment on the destruction of the cell wall and on the apparent purity and invert sugar content of the resulting juice. It was reasoned that the most favorable range of operating conditions should be determined before making a comprehensive study regarding the yield and the processing quality of the resulting juices.

The report is divided into three sections. The first section covers the experimental technique used and the reproducibility of its results. The second section describes the explosion equipment and its operation. In the third section the experimental data are presented in detail, followed by a discussion and the conclusions.

PROGRESS REPORT II

PROCESSING OF SUGAR BEETS

PART I - EXPERIMENTAL TECHNIQUE

A. Preparation of Cossettes

The beets used in these experiments were cut into V-shaped cossettes with an ordinary beet-slicer knife with vertical splitters, 46 division in 165 mm. Great care was taken to obtain cossettes free from pulp and slabs, clean-cut, and of as uniform a shape as possible. For this purpose a manually operated slicer was designed (Fig. 1) in which the beet was kept firmly in place during the slicing operation, thus avoiding the formation of pulp or fines. The slicer consisted of two main parts: The slicing board and the slide cage. The knife was mounted in a slot cut out of the middle of the board and held in place by two adjustable screws.* This arrangement permitted simple setting of the knife for different requirements. The recess between the edge of the slot and the upper surface of the knife was filled in with Wood's metal to provide the smooth upper surface so important in beet slicers. The slide cage which carried the beet was provided on both sides with metal guides running in the siderails of the board. In this way the cage and the beet it contained could be moved easily along the board and against the knife. The crown and the tail of the beet were cut off flat to give the beet a tight fit inside the cage, the longitudinal axis of the beet being parallel to that of the slicing board. To avoid any side movements of the beet during slicing, the beet was kept in place with a board pressed against it by three powerful springs. The necessary force to press the beet against the surface of the slicing board was applied by means of a screw running through the swing arm of the cage and a wooden block put on the top of the beet. The cossettes were collected in enamelled

*The figure does not show the edge of the knife but only the Wood's metal filling and its irregular contours.

Fig. 1. Manually Operated Slicer

bowl placed below the slicing board. The knife was kept clean during operation by a stream of compressed air. The capacity of the slicer is 4 to 6 pounds in 30 minutes, depending on the quality of the beet.

To avoid errors in the preparation of an average sample, it was important to have cossettes of approximately uniform length. To provide such a sample, each beet was cut lengthwise into two parts and deep parallel incisions were made in the flat surface perpendicular to the long axis of the beet. Each half of the beet was then sliced separately. The incisions were usually made at a distance of 2 inches apart; this was therefore the length of the majority of the cossettes obtained. This method permitted quick and thorough mixing of cossettes and decreased the error of preparation of small average samples. The preparation of an average sample of cossettes of different lengths is difficult and may result in an error, as the difference in sugar content between the short and long cossettes may vary, according to some authors, from 0.1 to 1.8 per cent.[1]

From each batch of well mixed cossettes thus prepared, a part was taken for sugar determination and for the preparation of the reference juices and the rest was used for explosion tests.

B. Reference Juice

Obviously the most suitable reference juice with which the quality of the "explosion juice" may be compared is the diffusion juice prepared by a standard, reproducible method from the same material. Small laboratory diffusion batteries, when operated under standard conditions, have proved to give reliable, reproducible results. This method is being considered for the future work in this laboratory in order to compare the processing qualities of the juices. The standard of comparison used in this preliminary stage of the research was the juice obtained by hot-water digestion of cossettes, under time and temperature conditions similar to those used in the usual diffusion process. The juice prepared by this method is more suitable for purposes of comparison than expressed juice, since the purity of the latter changes with the fineness of the pulp and with the applied pressure.[1,2,3]

For the preparation of the hot digestion juice, a 1000-ml pyrex beaker, with an inner diameter of about 100 mm was used. The stirrer, which was located inside the beaker (see Fig. 2), consisted of two parallel, perforated stainless-steel discs. The lower disc, which was welded to the bottom of the stirrer rod, was provided with a transverse performated baffle. The upper disc had a hole drilled in the center and could be moved freely on the stirrer rod.

When preparing the digestion juice, the upper disc first was removed and 200 g of cossettes were uniformly distributed on both sides of

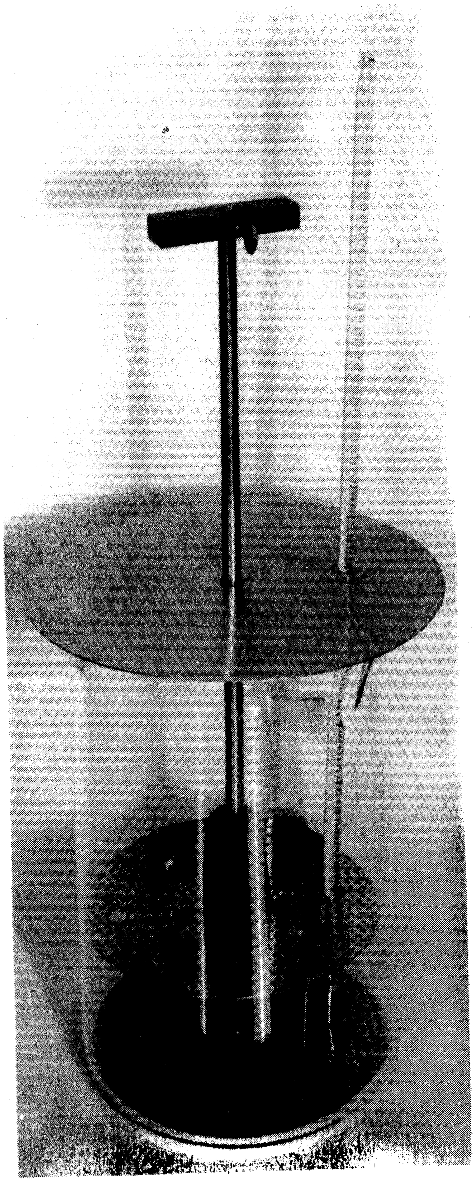

Fig. 2. Digestion Vessel

the baffle; then the upper disc was slid onto the rod and pressed against the cossettes until a distance of about 2 inches remained between the discs. This space of 2 inches corresponded to a volume of approximately 400 ml in the beaker. The upper disc was kept in place by a rubber stopper inserted on the rod. Then 300 g of boiling distilled water was added slowly, the beaker being kept tilted to facilitate the removal of air trapped between the cossettes. When all the water had been added, the liquid stood about 10 mm high above the upper disc. After addition of the water, the beaker was covered with a stainless-steel plate and put into a water bath previously adjusted to 85°C. The digestion was carried out for 50 minutes and the contents were mixed every 5 minutes by turning, lifting, and then lowering the stirrer. However, at all times the upper disc was kept submerged to avoid foaming. The juice reached the temperature of 75°C after approximately 12 to 15 minutes and was kept between 75° and 80°C during the rest of digestion. After 50 minutes of digestion the stirrer and the cossettes were withdrawn from the beaker, and the juice transferred to a thick-walled Erlenmeyer flask and cooled in ice water to a temperature of approximately 15°C. The cold juice was then deaerated under vacuum in the same flask and the deaerated juice analyzed.

C. Reproducibility of the Method

From a well mixed sample of cossettes prepared from California beets four digestion tests were carried out simultaneously and polarization, Brix (pycnometer), purity, and invert sugar content of the resulting juices determined. Table I gives the results of two different runs, each consisting of four digestion tests.

The mean error of each purity determination was calculated by the expression $\pm\sqrt{\Sigma\delta^2/n\text{-}1}$ where $\Sigma\delta^2$ is the sum of the squares of the deviations of the individual determinations from the mean and n is the number of determinations. The value of the mean error of each determination of purity was ±0.275 for Run I and ±0.33 for Run II.

TABLE I

REPRODUCIBILITY OF THE DIGESTION METHOD

Run Number		Test Number I	II	III	IV
I	Brix	5.88	5.86	5.91	5.90
	Polarization	4.73	4.70	4.78	4.76
	Purity	80.4	80.2	80.8	80.7
	Invert per cent of Juice	0.057	0.058	0.057	0.058
	$\frac{\text{mg of Invert}}{100 \cdot \text{Polarization}}$	1200	1240	1200	1220
II	Brix	6.02	5.91	5.96	6.01
	Polarization	4.78	4.67	4.70	4.72
	Purity	79.4	79.0	78.9	78.6
	Invert per cent of Juice	0.089	0.092	0.090	0.092
	$\frac{\text{mg of Invert}}{100 \cdot \text{Polarization}}$	1850	1970	1940	1950

In the actual explosion experiments two digestion tests were always made for each run carried out from the same lot of cossettes. The purity of the resulting juices was determined and the mean value of the purities taken as a reference. In this way, the experimental error was decreased still further. The results of the reproducibility test (Table I) as well as the results obtained later (Tables IV and V) in actual explosion tests show good reproducibility as far as the apparent purity and invert sugar content of the reference juice are concerned. Although in the actual experiments the purity and invert sugar content of the hot digestion juice was always taken as a reference, a number of experiments were carried out with juice obtained directly from the beet separating it from the beet pulp in a centrifuge. Table II shows the purities of centrifuge juices obtained from the two different samples of coessettes.* Two kinds of pulp were prepared from each sample: one, "coarse," obtained by passing the cossettes only once through the "Enterprise" chopper; and the other, "fine," prepared by passing the cossettes three times through the same chopper. Each of the resulting pulps was then spun in the centrifuge at 900 and 1800 rpm. The method and equipment used for separating the juice from the pulp was the

*California beets.

same as that used for separation of the juice from exploded cossettes, and is described in Part II of this report. It is seen from Table II that the different degrees of subdivisions used as well as the different forces applied have no noticeable influence on the purities of the resulting juices.

TABLE II

REPRODUCIBILITY OF THE CENTRIFUGE METHOD

Sample	1800 rpm			900 rpm		
	Bx	Pol	Purity	Bx	Pol	Purity
1						
Coarse	14.09	11.06	78.5	14.19	11.12	78.4
Fine	14.19	11.12	78.4	14.26	11.14	78.1
2						
Coarse	15.65	12.78	81.7	15.81	12.89	81.5
Fine	15.84	12.97	81.8	16.00	13.05	81.6

It was decided to determine for every series of explosion tests the concentration, purity, and invert sugar content of the beet juice obtained by this method. This will provide additional data for comparison purposes and will make it possible to determine the degree of dilution the juice undergoes during the process.

PART II - THE EXPLOSION EQUIPMENT AND ITS OPERATION

The explosion equipment, as shown in Figs. 3 and 4, was constructed in the Instrument Shop of the University of Michigan according to our design. It consists of two stainless-steel vessels connected by means of a 2-inch pipe and a quick-opening 2-inch valve (j). The upper vessel (A) has a 4-1/4-inch inside diameter and is provided with a removable stainless-steel cover. In this vessel the cossettes undergo steam treatment, after which they are exploded into the lower vessel (B). The volumes of the upper and lower vessels are 2.6 and 24 liters respectively.

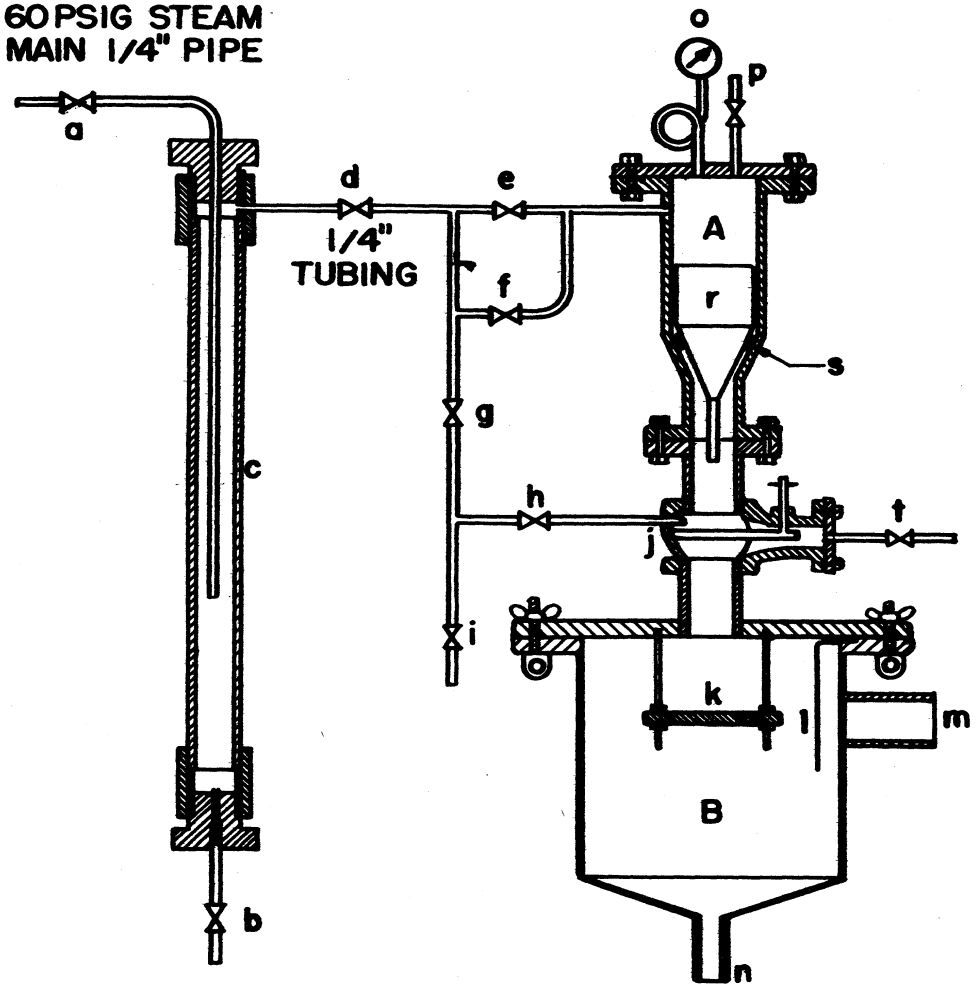

FIG. 3. EXPLOSION EQUIPMENT

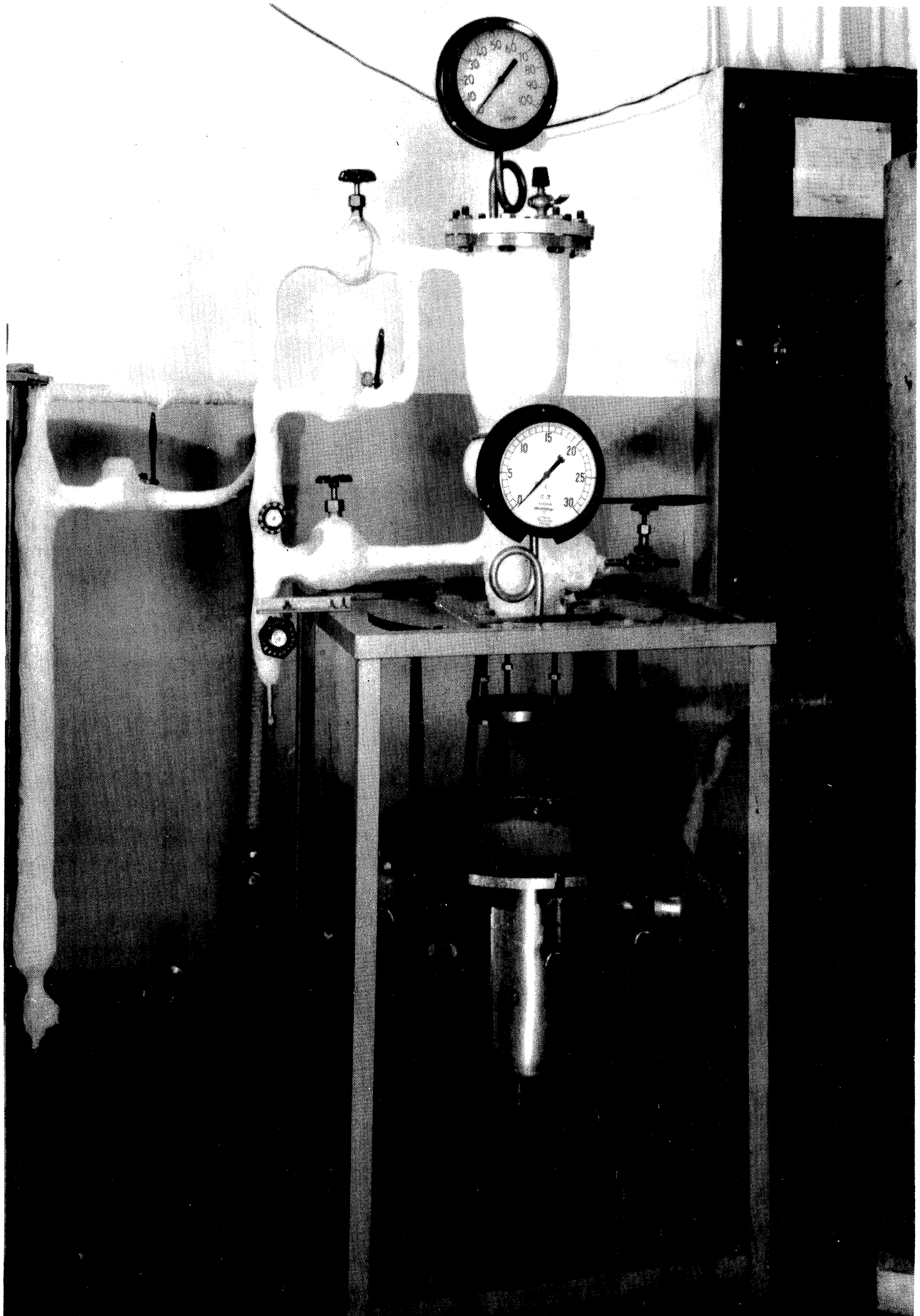

Fig. 4. The Explosion Equipment

Before each test the explosion vessel A was warmed up by filling it with 60 pounds of saturated steam in order to decrease the amount of condensate formed during the steaming of cossettes. The steam from the main was first dried in a condensate separator C, from which it was introduced into vessel A through valves d and e. The quick-opening valve j and valves f, g and h were kept closed during this stage of operation. As soon as the air present in the vessel had been removed the vent p was closed and the condensate drained through the valve h and through the cracked open valve i. To avoid excessive heat losses, the vessel A was insulated with 1 inch of asbestos cement and the upper part of the vessel tightly covered with 1/4-inch thick asbestos cloth. After 30 minutes of steaming at 60 pounds pressure, valves e and h were closed, the pressure released through vent p, and the cover removed.

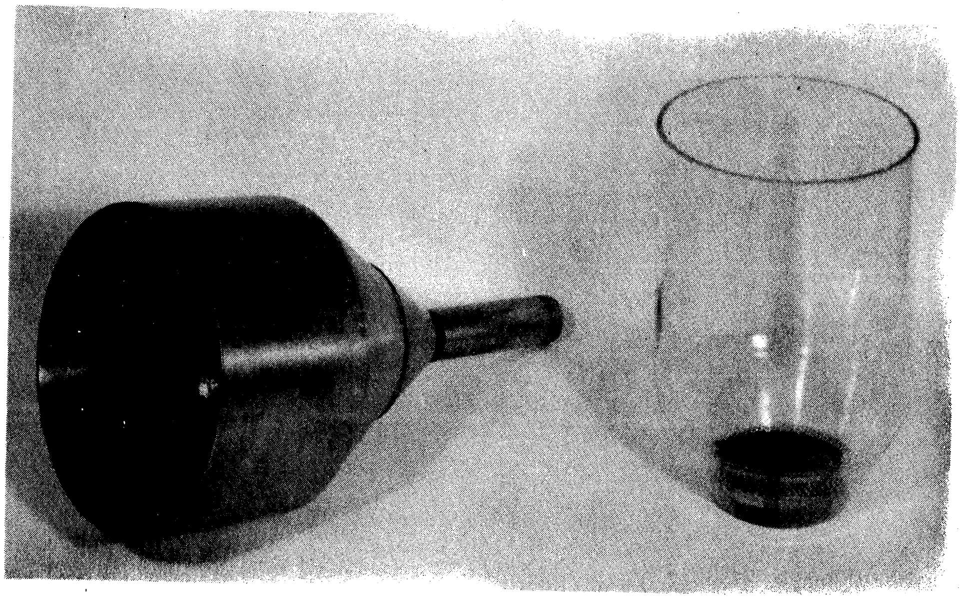

Fig. 5. Steel and Glass Linings

A stainless-steel lining shown on the left of Fig. 5 and containing 400 g of cossettes was then introduced into the vessel A and lightly pressed against the conical asbestos gasket s. This arrangement has several important advantages. It avoids the direct contact of cossettes with the hot wall of the preheated vessel, which usually has a higher temperature than the steam used for steaming the cossettes, and it decreases the uncontrolled warming of cossettes before the actual start of the experiment, that is, before the cover is fixed and steam introduced into the vessel. Table III shows the increase of the temperature of cossettes after 4 minutes and 20 seconds inside the warmed vessel. This small increase of temperature is insignificant as far as

TABLE III

INCREASE OF THE TEMPERATURE OF COSSETTES BEFORE THE START OF THE EXPERIMENT

Initial temperature of cossettes	Temperature of cossettes after 4 minutes and 20 seconds inside the warmed vessel		
	In middle of cossettes	At 1/4 of diameter from wall of lining	Close to wall of lining
16°C	19°C	23°C	35°C

the purpose of these experiments is concerned. In the actual explosion experiments, the time the cossettes stayed in the vessel before the start of the experiment (that is, before steam was introduced) varied from 1 minute and 45 seconds to 3 minutes rather than 4 minutes and 20 seconds and therefore a lesser temperature rise occurred. When using a glass lining, as shown on the right side of Fig. 5, the temperature increase was further reduced. The lining used in the following series of experiments had a conical bottom (angle of convergence, 50°). The tube welded to the bottom of the cone was 3 inches long and 5/8 inch in inner diameter. This shape of the lining had proved successful in helping the disintegration of cossettes during explosion.

As soon as the lining containing the cossettes had been placed in the vessel A and the cover fixed, steam was introduced and kept at the desired pressure by means of a regulating valve e. During the period of steaming, the valve p was left slightly open to provide the necessary venting. The condensate which formed was drained from the lowest part of the vessel by means of valves h and i, valve g being kept closed. The condensate thus recovered was later mixed with the exploded material. The continuous removal of condensate prevented flooding of the lower part of the explosion vessel. At the end of steaming period, valves e, h and p were closed and the pressure increased rapidly to 60 psig by opening the quick-opening valve f. As soon as this pressure had been reached, the quick-opening 2-inch valve j was opened and the cossettes blown out against the impact baffle k placed in the lower vessel B and the steam removed through the exhaust opening m. Immediately after explosion, the exploded material was transferred to a stainless-steel beaker mixed with the condensate and cooled down in an ice water mixture. After each experiment both the vessels were thoroughly rinsed with water and steamed. A 1/4-inch tube t connected to the body of the valve j permitted quick and easy rinsing of the inside of the valve. The cold semiliquid mash was well mixed and weighed into four stainless-steel cylinders, each containing a filtering medium consisting of two layers of cloth and two bronze screens resting on a support (see Fig. 6). The cylinders were then inserted into centrifuge tubes and the juice spun off at 1800 rpm (for 20 minutes). The resulting juice was collected in a thick-walled Erlenmeyer flask, deaerated under vacuum, polarization, Brix (by pycnometer) and

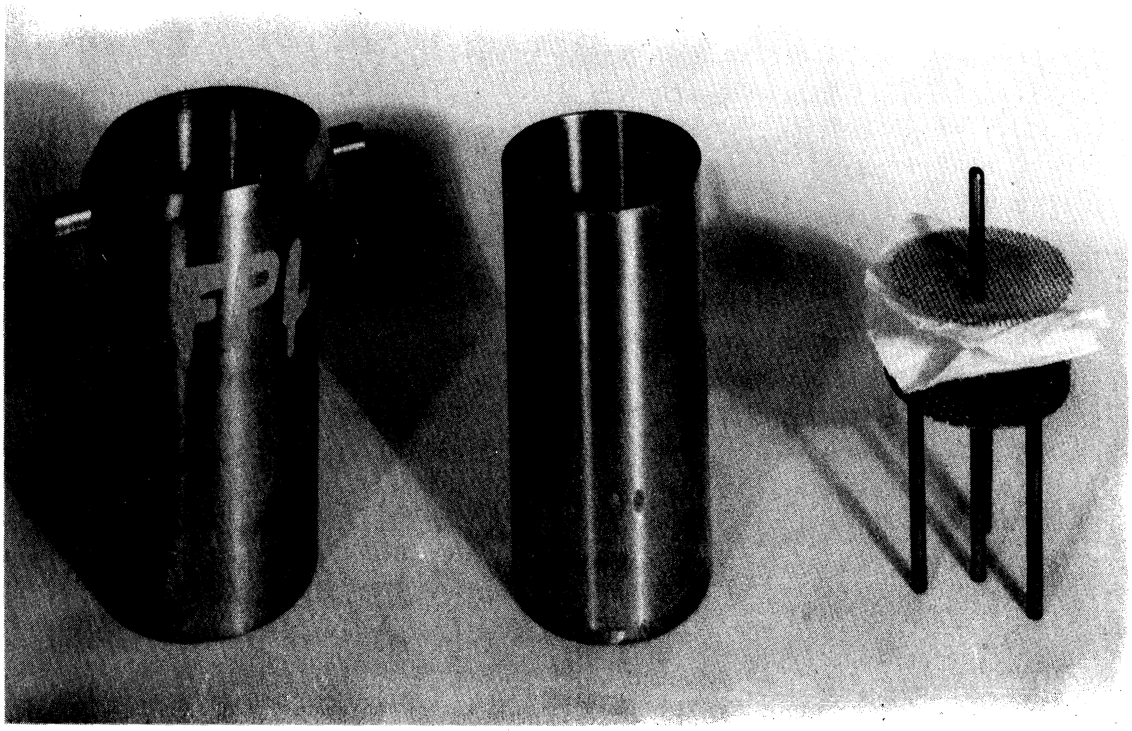

Fig. 6. Centrifuge Tube, Cylinder and Filtering Medium

invert sugar content by the Ofner method determined.* In each experiment the weight of the cake and its sugar content by hot digestion were also determined.

It is important to know what approximate sugar recovery from the cake can be expected if it is subjected to washing or repulping. For this purpose the cake was cold-digested for 1 minute at room temperature and the ratio of polarizations of solutions obtained by hot and cold digestion determined. Photographs of the mash in transmitted light were taken in most of the experiments to permit a better insight into the disintegration the material undergoes during explosion.

*See Progress Report I, Appendix.

PART III - EXPERIMENTS

A. Series I

In the experiments of Series I, the cossettes were first steam-treated at pressures of 0, 5, 20, and 60 psig during varying time intervals and then the pressure was quickly raised to 60 psig and the cossettes exploded from 60 psig into atmospheric pressure. About 25 pounds of beets harvested in the Michigan area were selected for these experiments. The beets were cleaned, washed, and then stored in a refrigerator at a temperature of -1° to +4°C. As it is important for purposes of comparison to have beet material of the same quality for each explosion test, the following sampling procedure was adopted. For each of the four runs corresponding to the four selected steaming pressures, one quarter of each beet was cut out along the long axis, sliced and the resulting cossettes mixed. From the sample prepared in this manner two or three explosion tests were made at the same pressure but for different durations of treatment.

The remainder of the sample was used for the preparation of two samples of the digestion juice and of the centrifuge juice. The exposed surfaces of the remaining sections, consisting of three-quarters of each beet, were then covered with a mixture of paraffin and beeswax to decrease evaporation and oxidation. The paraffin-coated sections were stored for 48 hours at -1° to +4°C until the next run of experiments. Then another quarter of each beet was cut out and the paraffin, together with a thin layer of the beet was sliced away. The subsequent slicing and sampling procedures were the same as previously described.

The results of this series of experiments are presented in Table IV and plotted Fig. 7 (Curves I, II, III, and IV). It is seen that the purities of the digestion and centrifuge juices (Columns 13 and 6) were constant in all runs except in Run III, where the purity was about 0.7 higher. This change in purity was probably due to the fact that during slicing of beets for Run III some of the beet tails had been broken off and discarded. Comparing the purities of the "explosion juice" (Column 18) with that of the digestion juice (Column 13) in Run I, it is seen that after 5 minutes of steaming at atmospheric pressure and then exploding at 60 psig there was a considerable drop of apparent purity, which, however, changed but little with the increase of the steaming time from 5 to 15 minutes. Similarly in Run II, where 5 psig steam was used, the purity dropped to 86.0 after 1 minutes of steaming but did not decrease appreciably when the time of steaming was increased to 5 minutes. The corresponding curves (I and II) in Fig. 7 are almost horizontal.

TABLE IV

Test Series I

EXPLOSION EXPERIMENTS AT 0, 5, 20 AND 60 psig STEAMING PRESSURE

Characteristics of Cossettes:

Length of cossettes = 18.7 meters per 100 g
Average cossettes length = 4.8 cm
% of cossettes of 4-6 cm length = 91%

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
			Centrifuge Juice			Digestion Juice									Explosion Juice					Cake			
						I			II				Invert Sugar					Invert Sugar					
Run No.	Pressure psig	Time of Treatment min	Bx	Pol	Purity	Bx	Pol	Purity	Bx	Pol	Purity	Mean Purity	% of Juice	mg/100 Bx	Bx	Pol	Purity	% of Juice	mg/100 Bx	% of Mash	Sugar % of Cake	R	Sugar in Juice to Sugar in Cake
		5													13.80	12.01	87.0			27.3	11.5	0.80	2.75
I	0	10	20.05	18.09	90.2	8.07	7.31	90.6	8.10	7.33	90.5	90.6	0.01	156	12.48	10.84	86.9			23.4	10.5	0.74	3.33
		15													10.56	9.09	86.1	0.02	185	16.6	9.0	0.66	5.07
II	5	1	19.92	17.90	89.9	7.99	7.19	90.0	8.01	7.25	90.5	90.3	0.01	137	15.01	12.90	86.0			29.8	12.1	0.81	2.35
		5													13.70	11.77	85.9	0.04	264	26.0	11.4	0.69	2.94
		1													15.21	13.16	86.5	0.06	406	24.3	12.2	0.81	2.71
III	20	5	20.59	18.67	90.7	8.27	7.54	91.2	8.25	7.52	91.2	91.2	0.01	142	13.32	11.40	85.6	0.08	625	18.5	10.7	0.82	4.69
		10													11.34	9.51	83.9	0.14	1190	13.9	9.0	0.77	6.56
		2													13.40	11.22	83.7	0.15	1088	16.5	10.6	0.89	5.42
IV	60	5	19.85	17.91	90.2	8.07	7.30	90.4	8.08	7.32	90.6	90.5	0.01	125	12.41	9.76	78.6	0.57	4608				
		10													10.58	6.95	65.7	1.40	13200				

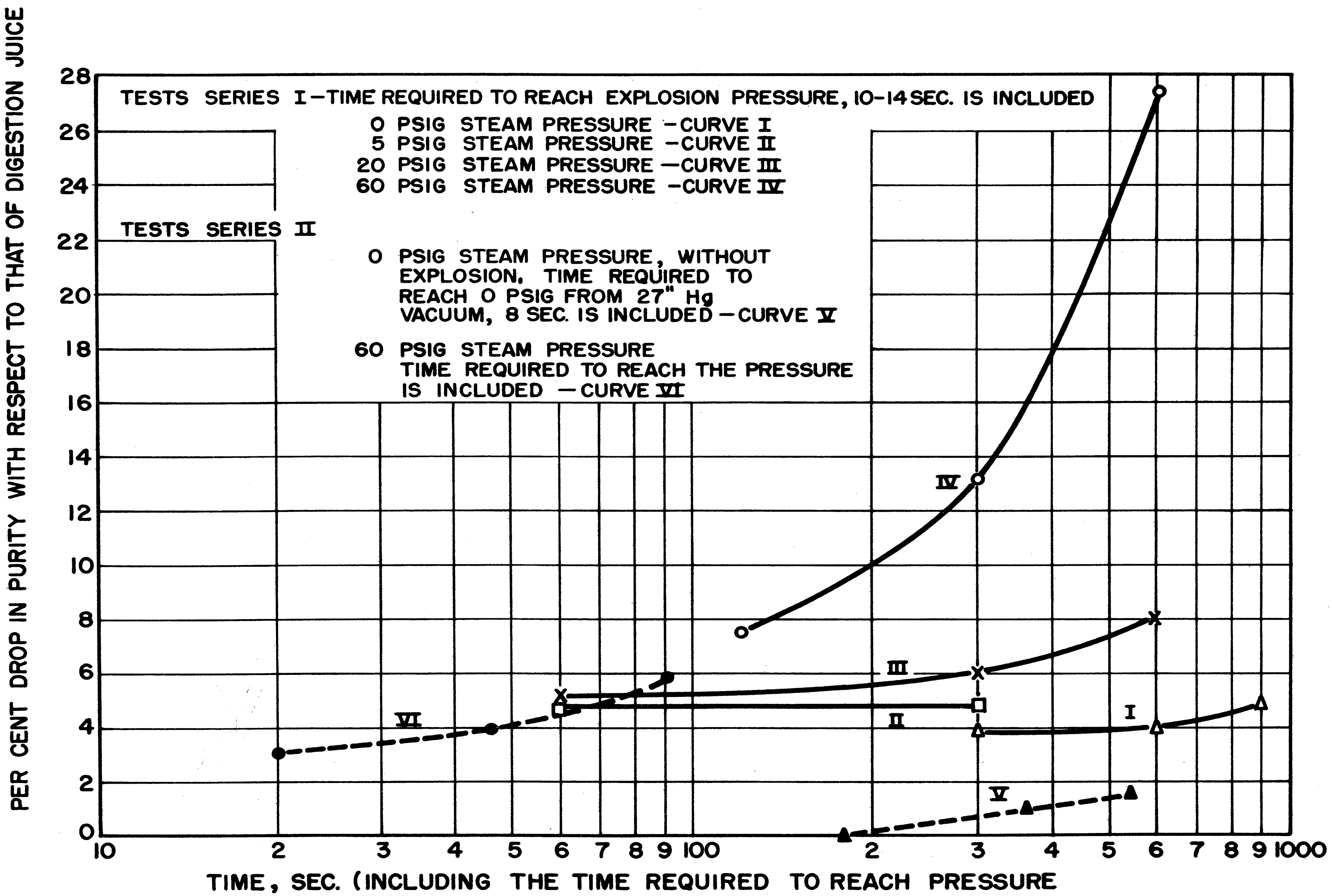

FIG. 7. CHANGE OF PURITY OF JUICE AT DIFFERENT STEAMING PRESSURES AND DIFFERENT TIMES OF STEAM TREATMENT.

The invert sugar content (Columns 20 and 15) of "explosion juices" in Runs I and II was comparatively small, although there was a definite increase after 5 minutes of steaming at 5 psig. In Run III, where the cossettes were steamed at 20 psig, the purity dropped after 1 minute of steaming to 86.5, which corresponds to a 4.7 decrease in purity as compared with that of the digestion juice. It is also seen that a longer action of 20 psig of steam causes a considerable inversion of sugar (Column 20) and a further drop of purity, which after 10 minutes reaches the value of 83.9 (see also curves III and I in Figs. 7 and 8 respectively). The results obtained for steaming at 60 psig (Run IV) (see Fig. 7, curve IV, and Fig. 8, curve II) show clearly the danger connected with the use of steam of this pressure even for only 2 minutes.

Column 21 (Table IV) gives the amount of cake obtained from the exploded cossettes after spinning for 20 minutes at 1800 rpm. It decreases in each run with increase of the steaming time. This is due in part to the dilution of the juice by the condensing steam and also to the better disintegration of cossettes preheated for a longer time. The favorable influence of the longer steaming time and higher pressures on the disintegration of cossettes can be seen clearly in Figs. 9-19.

The last column gives the ratio of the sugar in the juice to that in the cake. Here also, the increase of the ratio with the longer steaming time and higher pressures is due to the better disintegration of the structure of the beet as well as to the dilution caused by condensation of the steam.

Column 23 gives the ratio of polarizations of solutions obtained by cold and hot digestion of the cake. The high values of this ratio (from 0.69 to 0.89) indicate a possibility of recovery of sugar from the cake by comparatively simple methods as washing or repluping.

Although the results obtained in this series of experiments are strictly applicable to the equipment and the technique used, they give some important information of general value. In Runs I, II, and III the pressure was rapidly increased to 60 pounds at the end of the steaming period and the cossettes blown out of the pressure chamber. With the use of the quick-opening valve f (Fig. 3), the time necessary to reach this pressure varied from 10 to 14 seconds, depending on the pressure already existing in the chamber (steaming pressure). Even this comparatively short time of contact of higher-pressure steam with the cossettes might have been responsible for the drop of purity in Runs I and II. The slopes of curves I and II in Fig. 7 (Runs I and II) lead also to similar conclusions. Both the curves show a sharp drop in purity, which, however, changed but little with the increase of the steaming time. In addition to this, it was highly improbable that a 5-minute action of saturated steam at atmospheric pressure could have resulted in a decrease of purity of about 3.5.

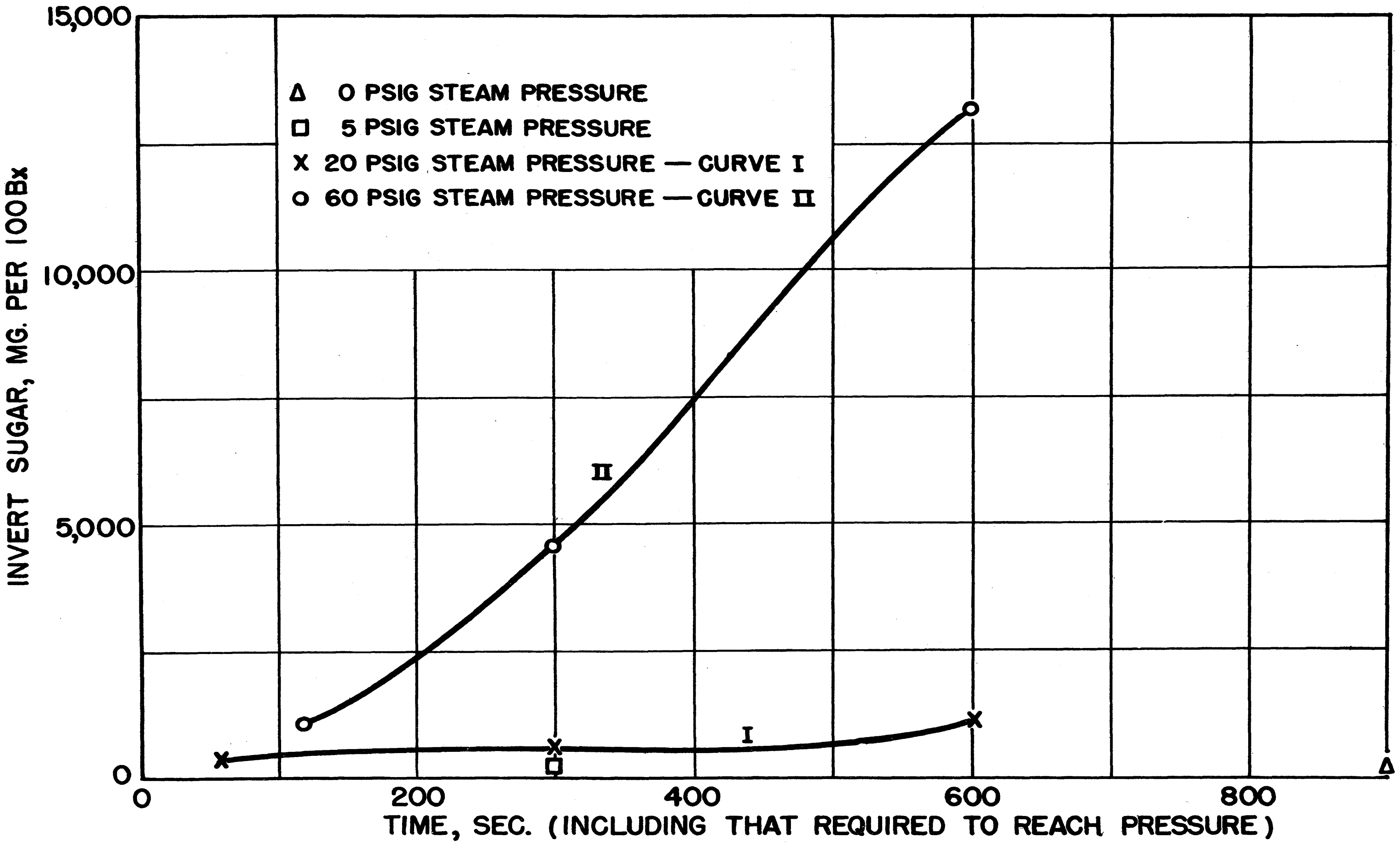

FIG. 8. CHANGE OF INVERT SUGAR CONTENT

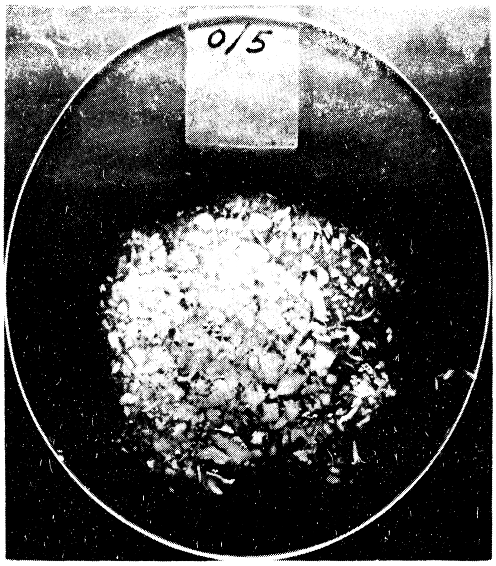

Fig. 9. 5 min steaming at 0 psig

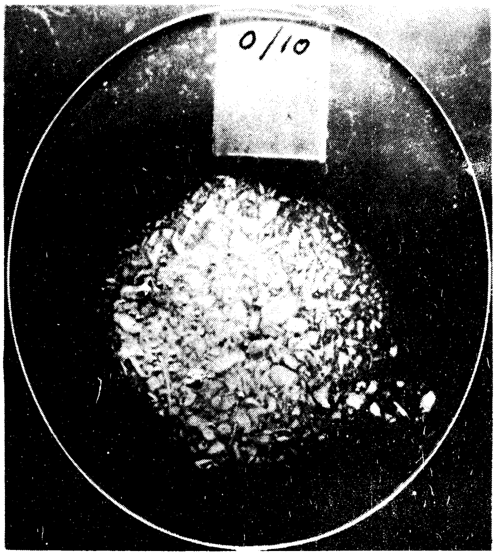

Fig. 10. 10 min steaming at 0 psig

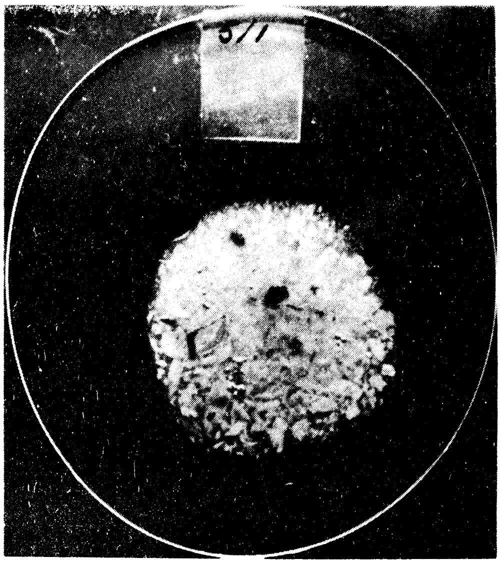

Fig. 12. 1 min steaming at 5 psig

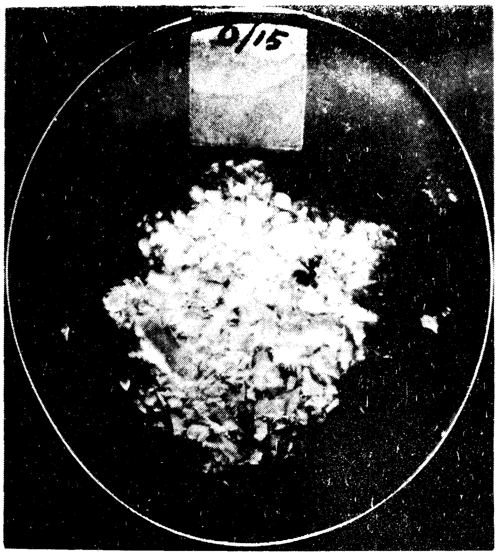

Fig. 11. 15 min steaming at 0 psig

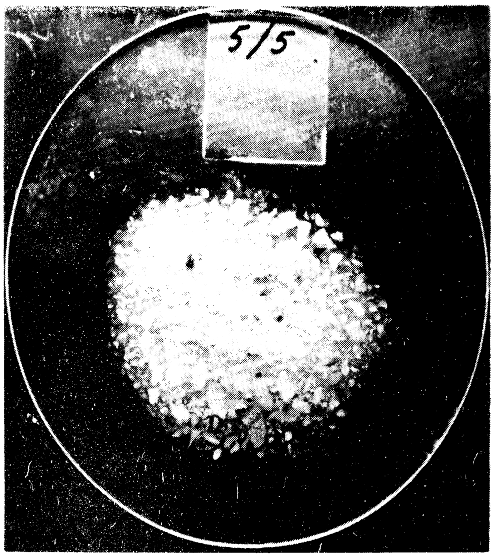

Fig. 13. 5 min steaming at 5 psig

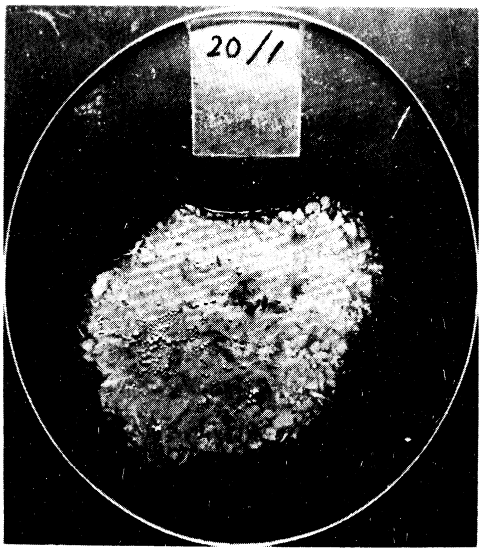

Fig. 14. 1 min steaming at 20 psig

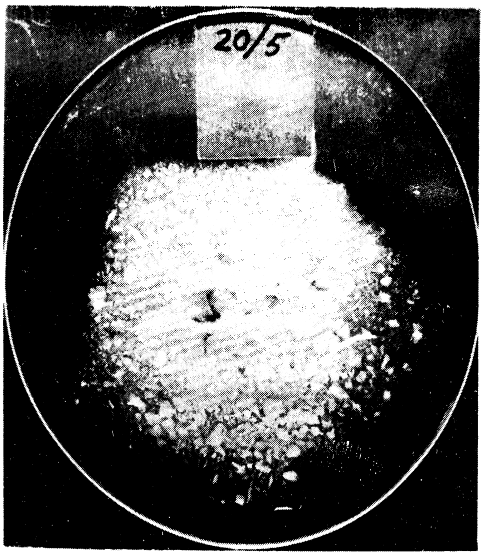

Fig. 15. 5 min steaming at 20 psig

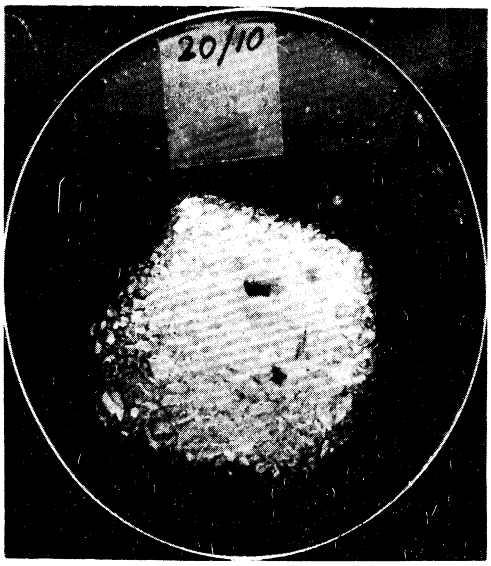

Fig. 16. 10 min steaming at 20 psig

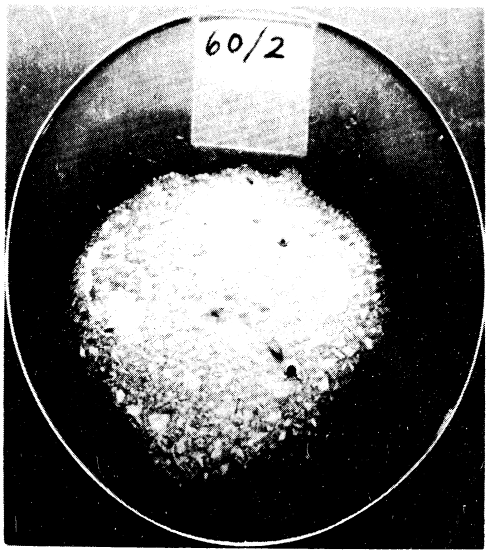

Fig. 17. 2 min steaming at 60 psig

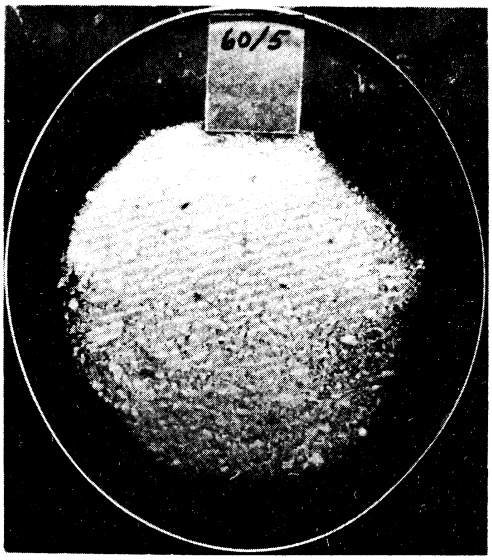

Fig. 18. 5 min steaming at 60 psig

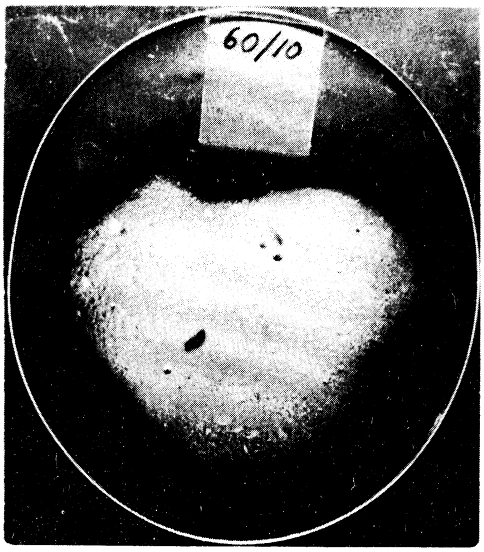

Fig. 19. 10 min steaming at 60 psig

It was decided, therefore, to investigate the action of 60 psig of steam on the purity of the resulting juice for time intervals shorter than 2 minutes, and to determine to what extent the steaming of cossettes at atmospheric pressure affects the purity of the juice. These problems are dealt with in the experiments of Series II.

B. Series II

The sampling method and the equipment used were the same as in Series I, but the experimental procedure was altered. In the experiment with steaming at atmospheric pressure, the cossettes were placed in a glass lining (see Fig. 5) provided with a screen bottom. The lining was then introduced into the previously warmed vessel A (Fig. 3), the cover fixed, and the vessel evacuated to avoid air venting during the steaming period. After evacuation, steam was introduced through the regulating valve e, and the pressure increased to atmospheric in approximately 8 seconds. After the required heating time valve e was closed, and the vessel A was connected to a vacuum tank (shown on the right of Fig. 4) and rapidly evacuated, thus decreasing the temperature of cossettes to about 40°C. By this means, it was possible to terminate the steaming period almost instantaneously. The cossettes removed from the lining were cooled in an ice water mixture and passed through an Enterprise food chopper and the juice was recovered from the resulting pulp with a centrifuge by the method described previously. In the experiments with 60 psig steam, the cossettes contained in the stainless-steel lining (see Fig. 5) were placed in vessel A, the cover fixed, and the vessel evacuated. Steam was introduced through the quick-opening valve f and the pressure increased to 60 psig in 19 to 20 seconds. This was the shortest time in which the pressure could be increased from 27 inches Hg vacuum to 60 psig in this explosion equipment. Therefore, in all experiments carried out with 60 psig steam this time is included in the total time of steaming; e.g., in the experiment at 60 psig and 19.5 seconds, the heating was discontinued as soon as the pressure reached 60 psig and in the experiment at 60 psig and 45 seconds the steam was allowed to act on the cossettes for 25 seconds after having reached 60 psig pressure.

After the cossettes had been steamed for the desired time, the 2-inch quick-opening valve T was opened and the cossettes blown out into the lower vessel B. To avoid prolonged action of high temperature on the cossettes, the outside surface of vessel B was cooled with cold wet rags. After explosion the mash was removed from the vessel and cooled down in ice water and the juice recovered in a centrifuge.

Each experiment of this series was duplicated. The results are presented in Table V and Fig. 7 (curves V and VI). It can be seen (Columns 13 and 18 and Fig. 7, curve V) that a 3-minute steaming of cossettes at

TABLE V

STEAM TREATMENT OF COSSETTES AT 0 AND 60 psig PRESSURE

Characteristics of cossettes: See Table IV

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Run No.	Pressure psig	Time sec	Centrifuge Juice			Digestion Juice I			Digestion Juice II			Mean Purity of Digestion Juice	Juice from Steam-Treated Cossettes				
			Bx	Pol	Purity	Bx	Pol	Purity	Bx	Pol	Purity		Duplicate	Bx	Pol	Purity	Mean Purity
I	0	180	19.69	17.64	89.6	7.95	7.16	90.1	7.96	7.16	90.0	90.0	1	18.99	17.05	89.8	90.0
		180	"	"	"	"	"	"	"	"	"	"	2	19.32	17.40	90.1	
		360	19.52	17.45	89.4	7.95	7.11	89.4	7.86	7.06	89.8	89.6	1	18.83	16.72	88.8	88.7
		360	"	"	"	"	"	"	"	"	"	"	2	18.33	16.24	88.6	
		540	"	"	"	"	"	"	"	"	"	"	1	-----	-----	----	88.2
		540	"	"	"	"	"	"	"	"	"	"	2	18.75	16.54	88.2	
II	60	19.5	19.69	17.64	89.6	7.95	7.16	90.1	7.96	7.16	90.0	90.0	1	14.17	12.38	87.4	87.3
		19.5	"	"	"	"	"	"	"	"	"	"	2	12.86	11.22	87.2	
		45	"	"	"	"	"	"	"	"	"	"	1	12.57	10.84	86.2	86.5
		45	"	"	"	"	"	"	"	"	"	"	2	13.74	11.91	86.7	
		90	19.52	17.45	89.4	7.95	7.11	89.4	7.86	7.06	89.8	89.6	1	13.23	11.19	84.6	84.4
		90	"	"	"	"	"	"	"	"	"	"	2	13.04	10.98	84.2	

atmospheric pressure had no influence on the purity of the juice, the purity of the explosion juice being equal to that of digestion juice. Steaming for 6 minutes at the same pressure resulted in a drop of purity of 0.9 (89.6 to 88.7) as compared with the purity of the digestion juice. A 9-minute steaming gave a purity drop of 1.4 (89.6 to 88.2). The results of Run II (Columns 6, 13, and 18 and Fig. 7, curve VI) show that the action of steam, the pressure of which increased from 27 inches Hg vacuum to 60 psig during the 19.5-second steaming period, resulted in a serious drop of purity, amounting to 2.7 (90.0 to 87.3). Steaming for a total of 45 seconds and 90 seconds is equivalent to extending the action of 60 psig steam for an additional 25 seconds and 70 seconds respectively, and resulted in purity drops of 3.5 and 5.2 respectively. The above results explain quite well the decrease of purity in Runs I and II of the first series of experiments, in which the cossettes were steamed at 0 and 5 psig and then exploded at 60 psig. The short time (10-14 seconds) at which the cossettes were in contact with steam of a pressure increasing to 60 psig was the chief cause for the decrease of purity of the juice. On the other hand, steaming of cossettes with steam of atmospheric pressure for a time of 3 minutes can be regarded as safe, as far as the apparent purity and invert sugar content of the juice are concerned.

The results obtained in the first as well as in the second series of experiments show clearly that the time necessary to reach an explosion pressure (60 psig) should be as short as possible, probably within a range of 1 to 3 seconds or even less.

C. Series III

Before the results of the last series of experiments are presented, some discussion is necessary. The main purpose of the steaming of cossettes at low pressure is to soften the structure of the beet. This is necessary for two reasons: first, it improves the disintegration of exploded cossettes, and second, the steam-treated cossettes give a better seal in the pressure chamber, thus improving the efficiency of explosion. On the other hand, the expansion of the high-pressure steam is needed to impart to the cossettes a velocity sufficient to cause their disintegration at the moment they strike the baffle. Apart from this purely mechanical action, the high-pressure steam increases the temperature of the cossettes, which results in a sudden evaporation of a part of juice at the moment the cossettes are blown out from the pressure chamber. It is believed that this sudden evaporation inflates the cells and thus helps the rupturing of cell walls. It is difficult to estimate the time necessary to heat the cossettes by saturated steam, but because of the great surface area of cossettes and the high coefficient of heat transfer of condensing steam, the rate of heat transfer should be very high. It seems, therefore, that the effect of reducing the time of contact of high-pressure steam with the cossettes should be small, as far as the heating of cossettes is concenred.

In this series of experiments (III), the cossettes were first prehated for 3 minutes with steam at atmospheric pressure then the pressure was increased to 60 psig in a time less than 1 second. In order to secure this quick rise of pressure the upper vessel A was connected through a 1-inch quick-opening valve z (Fig. 20) with a steam tank C kept at 60 psig pressure.

The beets used in this series of experiments were from the same lot as those used in previous experiments. In the two runs of experiments carried out in this series, the cossettes contained in the stainless-steel lining (Fig. 5) were placed in the pressure vessel A and steamed at atmospheric pressure for 3 minutes. During this operation the 2-inch quick-opening valve was left open and the condensate, together with excess steam, passed to the lower vessel B. This steaming procedure was analogous in the two runs except that in Run I a 2-inch screen (9-mesh) disc was placed inside the conical part of the lining to act as a support for the cossettes. When the cossettes had been steamed for 3 minutes, the valve z was opened and the pressure increased in a time less than 1 second. In Run I, where the screen was used, the time necessary to force the cossettes through the screen openings at 60 psig pressure difference was 5 seconds; thus the time of contact of 60 psig steam with the cossettes increased. On the other hand, in Run II (where no screen was used) the pressure rose to 55 psig and the cossettes were blown out into the vessel B. The total time from the moment the quick-opening valve z was opened to the end of explosion was estimated to be no more than 1 second. After each of the explosion tests the mash was quickly removed from the lower vessel B and cooled down in ice water and the juice recovered by the usual method in a centrifuge. Each experiment of this series was duplicated. The results are presented in Table VI.

It can be seen from Table VI (Columns 6, 13, and 18) that in the case of Run I, when 5 seconds were required to push the cossettes through the screen, the purity drop was 1.8 as compared with the purity of digestion juice (90.2 to 88.4) and 1.4 as compared with that of the centrifuge juice (89.8 to 88.4). Here again it is apparent that even the comparatively short time lowers the quality of the juice a significant amount. On the other hand in Run II (without the screen support) the approximate time the cossettes were in contact with 55 psig steam was less than 1 second. The purity drop was small, amounting to 0.3 as compared with that of centrifuge juice (89.8 to 89.5) and 0.7 as compared with that of the digestion juice (90.2 to 89.5). It is believed, however, that this small drop of purity is partly the result of the fact that it took about 3 minutes to open the lower vessel and to transfer the mash to the ice-cooled beaker. During this time the mash was in contact with the hot walls of the vessel B

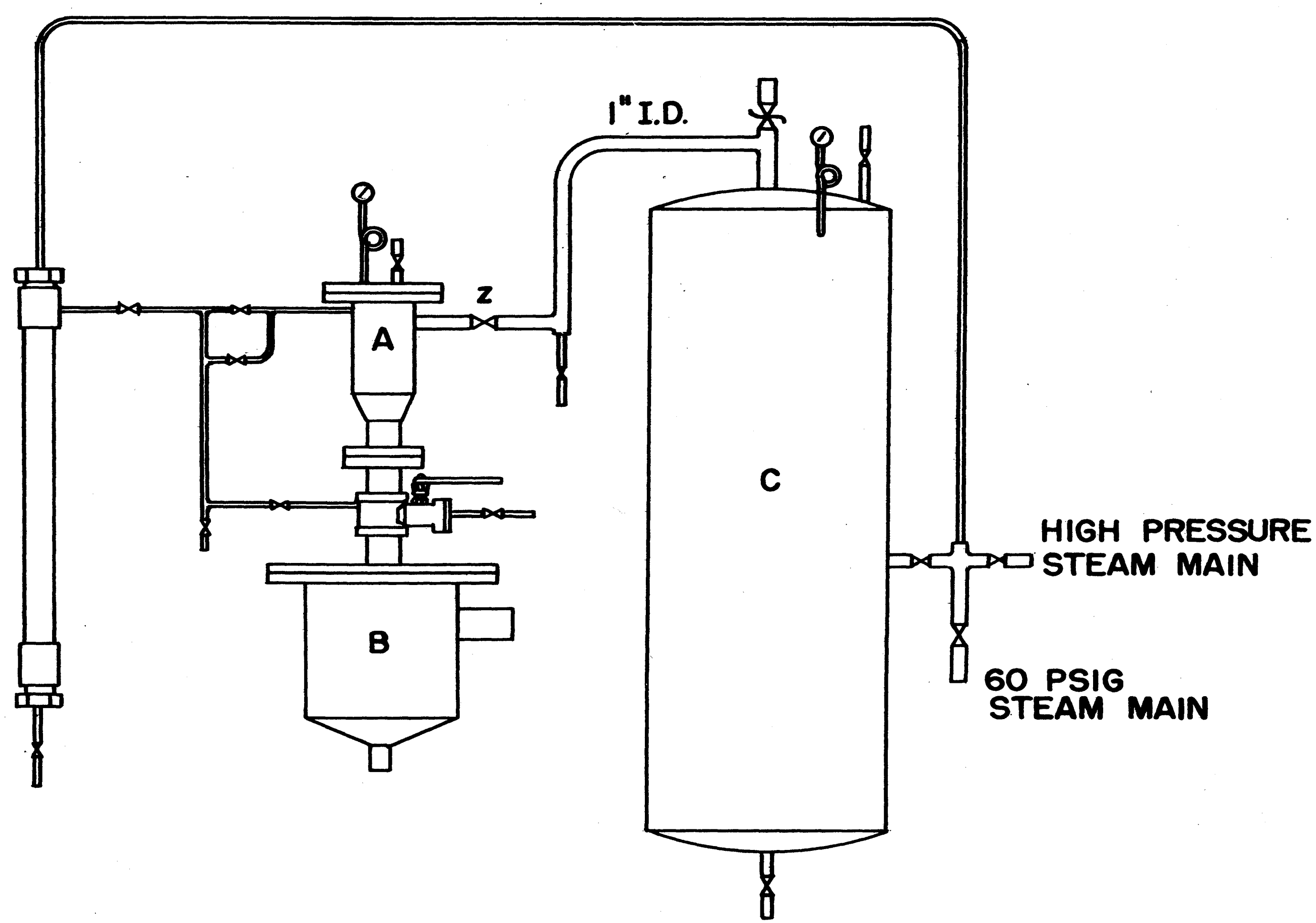

FIG. 20. EXPLOSION EQUIPMENT WITH ARRANGEMENT FOR SUDDEN INCREASE OF STEAM PRESSURE.

TABLE VI

STEAM TREATMENT OF COSSETTES AT ATMOSPHERIC PRESSURE FOLLOWED BY A SUDDEN (1 sec or less) INCREASE OF PRESSURE TO 60 AND 55 psig

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Run No.	Pressure psig	Time at High Pressure sec	Centrifuge Juice			Digestion Juice I			Digestion Juice II			Mean Purity of Digestion Juice	Juice from Steam-Treated Cossettes				
			Pol	Bx	Purity	Pol	Bx	Purity	Pol	Bx	Purity		Duplicate	Pol	Bx	Purity	Mean Purity
I	60	5	17.59	19.59	89.8	7.15	7.90	90.5	7.18	7.99	89.9	90.2	1	9.20	10.42	88.3	88.4
	60	5	"	"	"	"	"	"	"	"	"	"	2	9.33	10.55	88.4	
II	55	1 or less	"	"	"	"	"	"	"	"	"	"	1	12.13	13.54	89.6	89.5
	55	1 or less	"	"	"	"	"	"	"	"	"	"	2	12.64	14.14	89.4	

previously heated by the excess steam and hot condensate from the steaming period. It can be seen from Table V (Run 1, Columns 18 and 13) that extending the time of heating beyond 3 minutes will tend to lower the purity.

D. Conclusions

The results of the last series (Run II) show that it is possible by controlling the duration of steaming to obtain good-quality juices as far as apparent purity is concerned. In this series of experiments invert sugar was not determined. Under the more severe conditions of Run I, series I, the inversion was shown to be negligible for short periods of steaming.

Although the juice was easily recovered from the mash of Run II, series III, by the usual spinning procedure the disintegration of cossettes was not complete and needs further improvement.

E. Future Experiments

In the experiments which will be carried out during the next three to four weeks air-steam mixtures at pressures up to 120 psig will be used instead of 60 psig saturated steam. This will make possible to use greater pressure drops so as to improve disintegration, and at the same time avoid the harmful action of higher temperature. Different systems of nozzles and baffles also will be investigated with the object of increasing the impact velocity of the cossettes and to provide more complete disintegration upon impact. The dilution of the juice experienced in series I-III was caused in part by heating the cossettes to the temperature corresponding to 60 psig saturated steam and in part by heat losses due to convection and radiation. Obviously a certain dilution due to heating of cossettes by saturated steam cannot be avoided, although it is greatly decreased by flashing of the preheated cossettes after explosion. However, the major source of dilution in these experiments was the condensation on the inside walls of a vessel A. A method of draining of this condensate will be used in the next experiments.

As the sugar season in the Michigan area wil be finished in the next few weeks, the experiments planned in Progress Report I, Section V, paragraph c, will have to be altered. Instead of factory diffusion juice, a juice obtained in a laboratory diffusion battery will be used in these experiments.

BIBLIOGRAPHY

1. Sazavsky, V., and Šandera, K., Cukrovarnicka Analytika, Spolek československeho prumyslu cukrovarnickeho, Prague, 1930, with supplement 1937.

2. Claassen, H., Die Zuckerfabrikation mit besonderer Berücksichtigung des Betriebes, Schallehn and Wollbrück, Magdeburg, Germany, 1944.

3. Browne, C. A., and Zerban, F. W., Physical and Chemical Methods of Sugar Analysis, John Wiley and Sons, Inc., New York, 1941.