Chem. Engg
Thesis course

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THE UTILIZATION OF SPENT BLACK ASH FROM THE SODA RECOVERY SYSTEM OF THE PENOBSCOT CHEMICAL FIBRE COMPANY

June 3, 1922.

Fred Chase Koch

A Thesis

submitted as partial fulfillment of the requirements for the degree of Bachelor of Science in the School of Chemical Engineering Practice of the Massachusetts Institute of Technology.

The Bangor Station Bangor, Maine

The author wishes to express his sincere appreciation and thanks for the valuable assistance and advice given him by Professor R.T. Haslam, Director W.P. Ryan, Mr. A.L. Pitman, Mr. W.B. Larchar, Mr. H.H. Hanson, and others.

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SUMMARY

II tons of spent ash available per day.

Heating value of spent black ash (I% moisture)	= I4,000 B.T.U./#
Carbon in spent ash	= 96.2 %
Moisture content of ash as it comes from leaching tanks	= 600 %
Moisture content after drying in a centrifuge	= 233 %

The dried spent ash (I-2 % moisture) burns well either as a powdered fuel or on the grate, the two principal requirements being a good draught and sufficient combustion space.

The centrifugally dried ash will not support combustion alone. When mixed with I part of coal it burns with difficulty, with 5 parts it burns easily, and with I4 parts apparently as easily as the coal itself.

Briquets suitable for burning cannot be made economically with black liquor, the organic humus precipitated from black liquor, or concentrated sulfite liquor.

Recovery of Ash for Fuel in the Boiler Room

	Single Centrifuge	Dryer and Centrifuge
Initial Outlay	$ 6,500	$ I6,900
Value of ash recovered per year	I6,380	2I,000
Cost of recovery per year	3,750	7,770
Yearly profit	I2,630	I3,230

The centrifuge system has the advantage that it is simple, could be easily installed, and the initial outlay is small. The damp product would be easy to handle but would have to be mixed with at least five times its weight of coal in order to support combustion freely. This plan would use the furnace for the dryer and supply the heat from the coal.

With the centrifuge and rotary dryer the drying is done outside of the furnace by waste heat, and the product will support combustion alone. This system offers the larger profit in the long run although the initial cost is high. However it is a fairly complicated system, would be difficult to install , and the dried ash would be hard to handle.

INTRODUCTION

The Penobscot Chemical Fibre Company located at Great Works, Maine, has large quantities of "black liquor" coming from the soda process of manufacturing wood pulp. The wood in the form of chips is cooked in digesters with strong caustic by blowing in steam. After the cook is completed the contents of the digester are the wood pulp, mixtures of the compounds of the ligneous matter in the wood with caustic, the excess caustic, and water. All these with the exception of the pulp are in the form of a heavy dark liquor known as "black liquor", which is further diluted by washing the pulp.

The Origin of Black Liquor

The liquor is concentrated in evaporators to about 40 degrees Baume in which condition it goes to the incinerating furnaces, which are rotary cylindrical kilns fired by flue gas from adjacent coal burning furnaces. The flue gas concentrates the liquor as it rolls down the furnace until it is able to support its own combustion when it takes fire and burns to small particles of ash, consisting of 65-80% Na_2CO_3 and the rest carbon with small amounts of mineral salts from the wood.

Treatment of Black Liquor to Get Black Ash

These incandescent particles known as "black ash" fall into a conveyor and are dumped into leaching tanks where they are washed countercurrently to remove the sodium salts. The soda ash recovered by the wash water is causticized preparatory to using it again.

Removal of Soda from Black Ash

The residue in the leaching tanks is "spent ash" consisting of about 95% carbon, small amounts of soda ash and other mineral salts. Under the present system this "spent ash", of which there is about ten to thirteen tons per day, is washed into the sewer as a waste. The large amount thrown away per day, the high percentage of carbon in the ash, its finely divided and light porous condition open up several avenues for investigations of the commercial utilization of this waste. If used as a fuel with a ton of ash replacing a ton of coal, and at the coal price of $7.00 per ton, the value of the waste would be $70.00 per day or, conservatively, over $21,000 per year. Considering all the soda pulp mills in the country this loss must be enormous.

The Nature of the Spent Ash; Its Probable Value

Granting that it seems a queer idea of economy to try to save the carbon resulting from the burning of valuable organic compounds in the black liquor, we must consider that it will take many years to perfect and apply a system to recover these products and in the meantime the spent ash waste is going on continually.

Recovering Organic Compounds from Black Liquor

EXPERIMENTAL WORK

The spent ash as we find it is in the rectangular leeching tanks (six tanks 9' x 8' x 7') ready to be washed into the sewer through outlet pipes in the bottoms. Obviously the first problem is to get the ash out and into a convenient place as cheaply as possible. Shovelling by hand is not to be considered , and a screw conveyor would be clumsy in a tank with a false bottom.

The Spent Ash as We Find It

The answer is that the ash must be washed out as is the practice at present. Despite the fact that some of the ash is very finely divided , it can be caught on a screen efficiently due to the larger particles forming a filtering layer and holding the smaller ones back. The water will run through a filter of this sort with great rapidity.

Removing the Ash

The rate of filtration of water through an ordinary Buchner funnel was observed. The funnel was then packed with a layer of ash 2" thick and the rate watched. No appreciable difference could be detected.

Rate of Filtering the Ash

A suitable means of catching the ash is shown in Fig.A. The ash is washed on the screen, allowed to drain sufficiently, and the relatively dry ash taken out by means of the screw conveyor. This system has the advantage that only one screen is needed since one tank is dumped every four hours.

The Screen

The spent ash when handled in this manner will weigh around 70 tons per day of which about 59 tons is water. Due to its very porous structure the ash carries an enormous quantity of water. This water must be removed before the ash can be utilized in any way.

Necessity for Drying

The ash when spread out sufficiently was found to be dried by the air to I-2% moisture under the best conditions. However when allowed to drain in the tanks the ash will still hold at least 400 % moisture.* It is evident that neither of these methods is commercially applicable.

Drying the Ash by Air

A liberal sample of the ash was centrifuged for five minutes at 750 R.P.M., turned, and centrifuged for five minutes more. After this treatment it still contained 233 % moisture. It is doubtful whether the moisture content could be reduced materially further than this by using a centrifuge having a greater speed. G.H.Elmore[I] admits that his continuous centrifuge operating at 3000 R.P.M. will reduce the water to only 70% (wet basis). Sutermeister[2] states that 65% (wet basis) is the best result obtainable by this means.

Drying the Ash in a Centrifuge

The only means left to dry the ash to a usable state is the application of heat. In order to investigate the rate of drying a small brick oven was built. Flue gas from the boiler house stack of the Eastern

Experimental Drying

Manufacturing Company was drawn through the stack by means of a blower. The wet ash was placed on a tray of fine screen wire to insure the flue f gas having good contact with it. See Fig. B.

When the first run was made the gas flow was fixed and samples of the ash taken at regular intervals from the beginning. The rate of drying was found to be according to Curve (I). The ash is so porous that the moisture diffuses through it with great rapidity. This makes part of the drying dependent on the ability of the gas to evaporate the water from the surface of the particles. This stage in the drying is represented by the straight line AB , Curve (I).

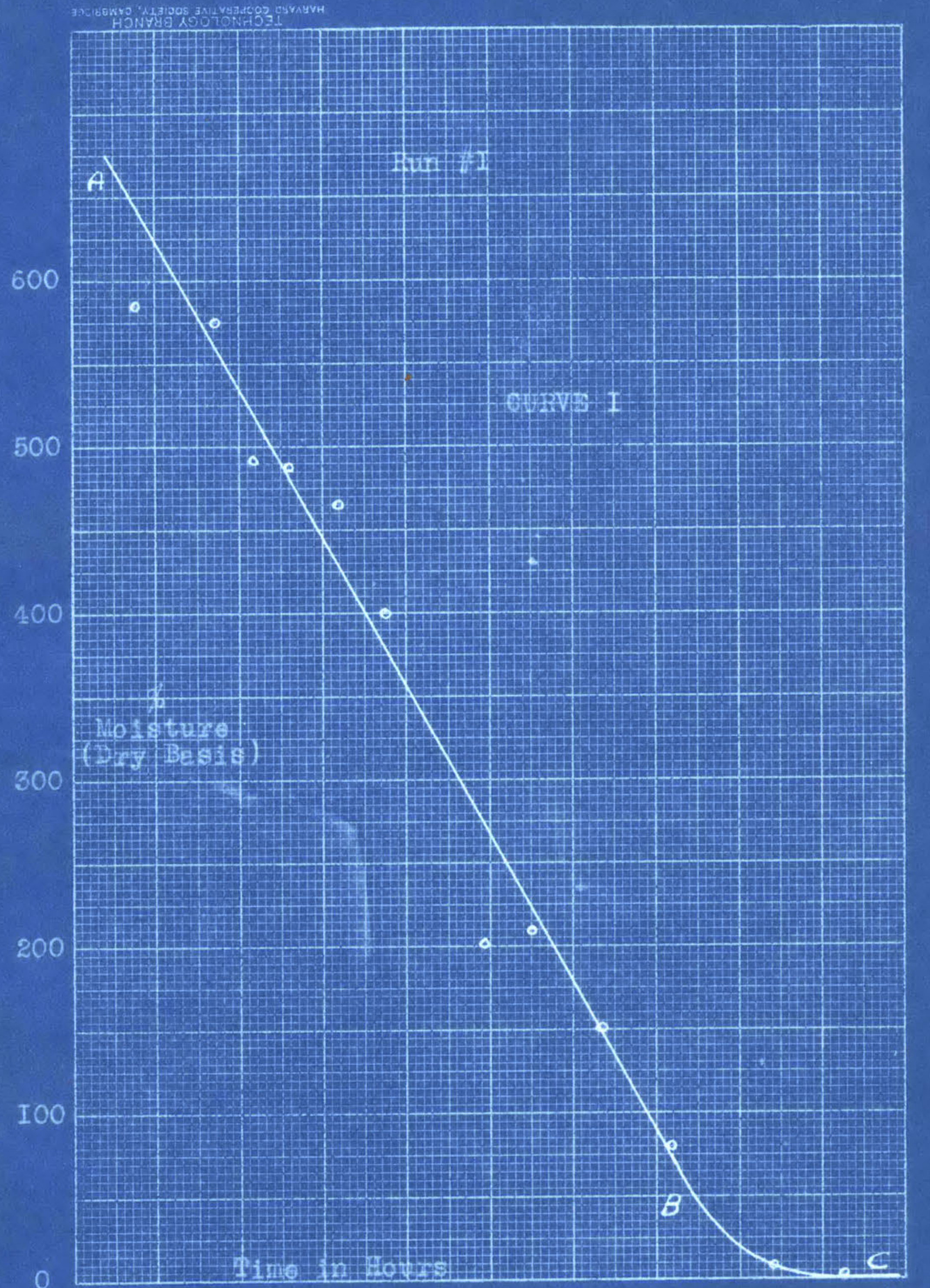
Surface Evaporation

The phenomenon of surface evaporation is ordinarily represented by the equation:

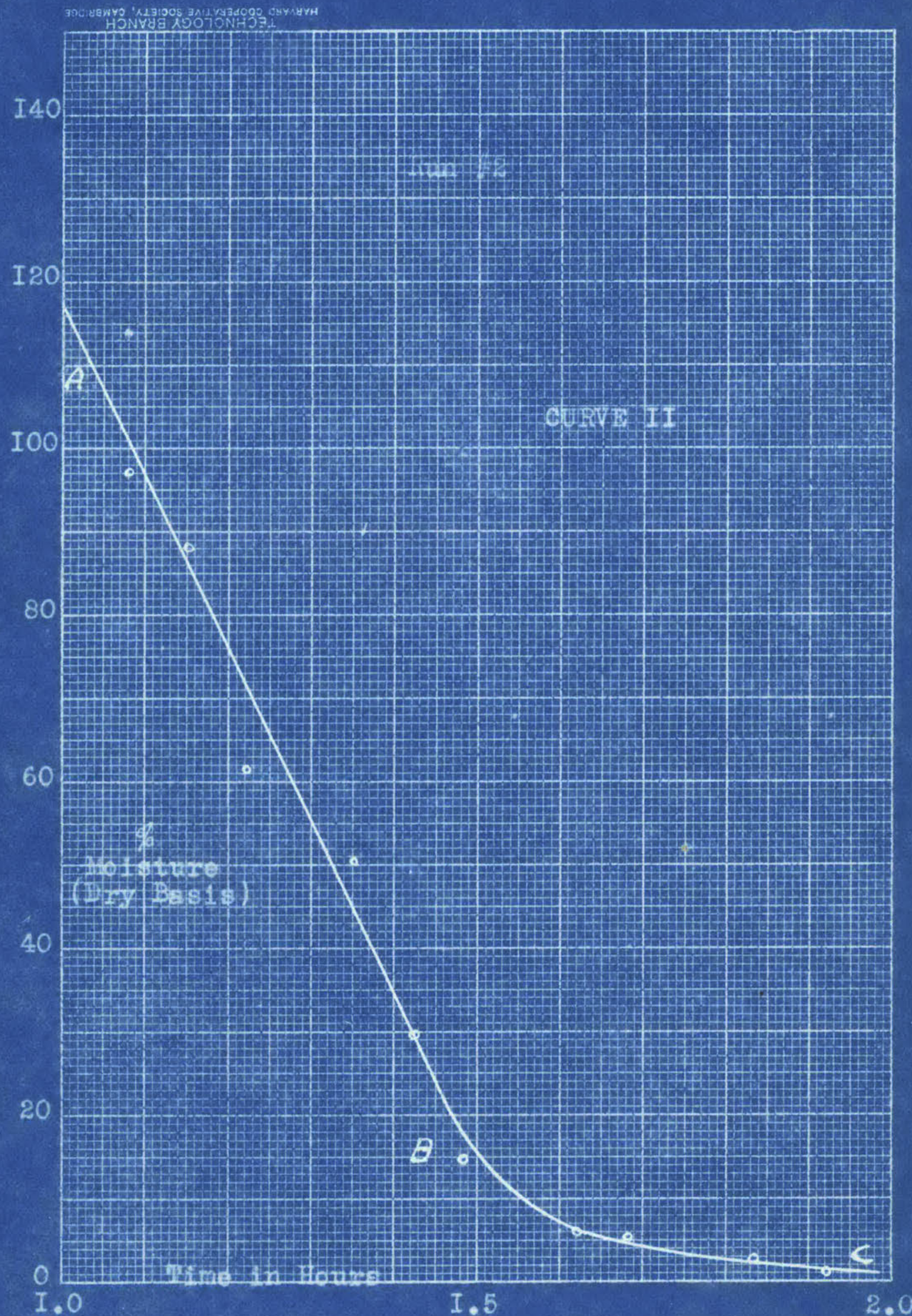
$$\log W_o/W = K\,\theta$$

where $K = b\, f(V) \Delta P/L$

W_o = Initial water content of stock
W = Final water content of stock
b = A constant
L = A constant depending on the size of the particles
$f(V)$ = Function of the gas velocity past the material
ΔP = Difference in vapor pressure of the water on the surface of the particles and of the water in the gas
θ = Time of drying



RATE OF DRYING OF SPENT ASH



RATE OF DRYING OF SPENT ASH

It would seem that AB should not be a straight line due to the ΔP changing in value as the drying progresses. This is accounted for by the fact that there is such an excess of water on the particles that the evaporation only lowers the remaining moisture to the wet bulb temperature, and keeps it there until the critical point is reached. As the humidity of the gas remains constant and the temperature of the water on the gas does not change, P can not change, the vapor pressure being dependent on the temperature. The gas velocity is not altered, therefore K becomes a true constant and the line AB , Curve(I) , must necessarily be straight.

Explanation of the Straight Part of Curve

However, after the moisture content has reached a certain critical point the diffusion begins to slow up very quickly. Surface evaporation becomes rapid as compared to diffusion, consequently the rate of drying becomes dependent on the rate of diffusion. This remains the case until the material is thoroughly dry. The section BC of the curve represents this diffusion stage.

The Diffusion Stage

The first run showed the critical point to be at 50% moisture, but the second run, undertaken for the purpose of getting this point more accurately gave 30% .

The Critical Point

It was suggested by Mr. Larchar, Superintendent of the Soda Division of the Penobscot Chemical Fibre Company, that the spent ash be centrifuged, mixed with coal and burned in the boiler plant which uses I50 tons of coal per day. G.H. Elmore[I] claims that his continuous centrifuge , which reduces the moisture content to 233 % , will deliver the ash in a condition ready to burn.

Suggestion on the Centrifugal -ly Dried Ash

With these statements in view an attempt was made to burn the centrifugally dried ash on a blacksmith's forge in order to secure varying draughts and to approximate as closely as possible the conditions found in a furnace. A thin bed of live coals was spread on the forge and several handfuls of ash distributed over them. No combustion was developed with a good draught, and a very poor one when the draught was strong enough to blow the fuel off the grate. This proves conclusively that the ash dried in this manner cannot be used alone in a furnace.

Burning of Centrifugally Dried Ash

When mixed with equal parts of finely divided coal used in the boiler plant of the Easterm Manufacturing Company, the ash burned much better,although not very freely except with a very high blast of air. It is very doubtful whether this mixture could be used successfully in a furnace.

Combustion of Ash with Coal

Using the ash dried in the centrifuge in this manner would mean a loss of 0.0I5I x I50 = 2.26 tons of ash per day, or 20% of the total amount saved. This is clearly too much of a loss to be neglected. Whether the ash should be dried by heat, by centrifuge, or both resolves itself into a question if the large dryer could be installed and operated at less than the centrifuge, and the small dryer and Centrifuge at less than $ I6.00 per day.

The Question of Method of Drying

There are also other factors which come into consideration other than the apparent monetary saving. The centrifugally dried ash is damp, easy to handle, and will not fly off as dust. However, it cannot be used alone in a furnace but must be handled along with a larger Quantity of coal. The heat dried ash while it will support combustion readily enough is finely divided, light, difficult to handle, and has a strong tendency to fly off as dust.

Other Considerations

It was planned originally to use the waste heat in the gases going up the stack from the incinerators to do the whole work of drying but calculations (See Appendix) show that there is insufficient heat in them to vaporize the 60 tons of water per day present in the ash.

Insufficient Heat in Incinerator Gases to do All the Drying

While there is a great excess of waste heat in the stack gas from the boiler room to do the whole work of drying, it is in a very inconvenient place due to cramped floor space and to its remoteness from the leaching tanks. There is also the added difficulty of altering the draught in the stack by cooling the gases materially, although this might be remedied by the blower. The length of such a dryer would be prohibitive. At best it would be a dangerous experiment to alter such a vital part of the plant as the boiler room.

Disadvantage of Using Boiler Stack Gas

Despite the comparatively large amount of moisture in the stack gases from the incinerators there is plenty of heat to dry the ash which has been through the centrifuge. This method also has the advantage that the dryer could be conveniently located next to the leaching tanks where the incinerator flue gas would be easily accessible.

Advantage of Using Incinerator Gas on Centrifuged Ash

In the ratio of one part of ash to five parts of coal the ash burned well even with a very low draught. A good fire could be maintained with this mixture. In the ratio of one to fourteen,as the ash would be used at the Penobscot Chemical Fibre Works, the mixture burned as freely as coal alone. A few calculations will throw considerable light on this matter.

The P.C.F. Company uses I50 tons of coal per day.

Assume:

Stack temperature -- 600° F

Heating value of coal -- I4,000 B.T.U./#

II tons of ash carrying 25.7 tons of water

Loss from Burning Ash Dried by Centrifuge

$$\frac{\overset{\text{tons Water/day}}{25.7} \;\Big|\; \overset{\text{\#/Water/day}}{2000} \;\Big|\; \overset{\text{BTU to heat to 600°F}}{\text{I000} + 600 \text{ X } .4} \;\Big|\; \text{I00}}{(\underset{\text{tons coal}}{\text{I39}} + \underset{\text{tons Ash}}{\text{II}}) \text{ X } \underset{\text{\#s in 1 ton}}{2000} \text{ X } \underset{\text{Heat Val. of coal and ash}}{\text{I4,000}}}$$

$$= \frac{3,\text{I}80,000}{2,\text{I}04,000} = \text{I.5I \% of heat in total fuel to vaporize and heat the water with the ash.}$$

0.0I5I I50 7 = $ I5.90 fuel loss per day

Comparison of the Three Drying Systems

Estimates

Assume:

The ash is to be burned in the boiler room.
The value of the ash is $7 per ton.
There are 300 working days per year.
The price of labor is $3 for 8 hours.
Fixed charges are 30% of the original cost.

Depreciation -------	10.0%
Interest -----------	6.0%
Superintendence ----	6.0%
Taxes --------------	2.0%
Insurance ----------	0.5%
Repairs, etc. ------	5.5%
	30.0%

Comparison of the Dryer Systems

Equipment Cost

	Single Centrifuge	Single Large Dryer	Dryer and Centrifuge
Drain Tank	$ 1,000	$ 500	$ 500
Centrifuge	3,000		3,000
Rotary Dryer		8,000	5,000
Blower		3,000	2,000
Storage Bin		400	400
Pump	200	200	200
Conveyors	1,000	2,000	1,800
Motor	500	750	1,000
Installation	800	4,000	3,000
	6,500	18,850	16,900

Yearly Costs

Single Centrifuge-			
Labor - 2 shifts - 300x2x3	=	$ I,800	
Fixed Charges - 6,500x0.3	=	I,950	
Loss in Value of Ash - IIx7x300x0.2	=	4,620	
		8,370	
Single Large Dryer-			
Labor - 3 shifts - 300x3x3	=	2,700	
Fixed Charges -I8,850x0.3	=	5,655	
		8,355	
Small Dryer and Centrifuge -			Annual Saving
Labor - 3 shifts- 300x3x3	=	2,700	
Fixed Charges - I6,900x0.3	=	5,070	
		7,770	

Value of Ash -	$	2I,000
Cost to Utilize Ash with Small Dryer and Centrifuge -		7,770
		I3,230
Yearly Saving	$	I3,320

As the estimates and a study of the various features of the different systems show the use of the centrifuge and small dryer is the best and most most economical plan. For the centrifuge an Elmore[I] continuous machine is reccommended to be used two shifts during the day, and by the night shift when the ash begins to accumulate. The 24" machine seems to be the best size.

The Centrifuge

A countercurrent, rotary dryer (50' x I2' dia.) which will use all the incinerator flue gas is the best dryer for the purpose. (For calculations in design see Appendix). A countercurrent dryer is preferred because the gases are not hot enough to injure the ash in any way, the drying is more efficient, and any of the light, dry particles being blown out by the gas are caught by the heavy wet particles at the other end. There should be lifting plates at the wet end tapering off toward the dry end where there are none. This will keep the wet ash continually in the air, but as it gets lighter and dryer it will not be thrown so high. The gas velocity (5'/sec.) is low enough so there is no danger of the ash being blown out.

The Dryer

The heating value of a representative sample of the dried ash was determined with a bomb calorimeter. The result was higher than that of most coals : I4,000 B.T.U./# on a wet basis - I% moisture. The sample ran about 3.8% mineral salts, ash, etc. and 96.2% carbon.

Heating Value of the Ash

Since the ash when dry is rather hard to handle it was thought that this difficulty could be eliminated by the use of some cheap, combustible binding material to hold the particles together in the form of briquets.

Briquets

Since the ash was at a soda pulp mill the heavy, viscous 40° Bé black liquor seemed to be the material best suited. As it contains a large amount of valuable soda the ash resulting from the burning of the briquets could not be thrown away. If the briquets were burned in furnaces supplying the flue gas to the incinerators and the ash carried down with the black ash to be leached, it would be a closed cycle with no chance of soda being lost.

Black Liquor as a Binder

When CO_2 is passed through black liquor part of the organic humus material is precipitated in the form of a thick, brownish black tar which is soluble in water. It seemed feasible to use this material as a binding agent, using flue gas of course to precipitate it. In the event these two materials did not answer the purpose waste sulfite liquor from nearby sulfite pulp mills might be evaporated down to the right consistency so that it could be used.

Tar from Black Liquor; Evaporated Sulfite Liquor

All of the above liquors contain about one half the heating value of the original wood so an added fuel value should be given to the ash. As a last resort common binders such as coal tar soft pitch, asphaltum,etc. could be used.

Results from Briquets

Briquets were made in the laboratory from the dried ash (I-2 % moisture) and black liquor, the tar precipitated from black liquor, and concentrated sulfite liquor. The briquets from black liquor and the tar were very weak in structure, too weak, in fact, to be handled without drying. The minimum weight of black liquor which would hold one pound of ash together was 2.9 pounds. As the ash has practically no moisture and the black liquor is 6I.3 % water (38% - wet basis) this means that there would be I.I pounds of water to every pound of ash. The tar also carries a large percentage of water which explains why neither of these types of briquets would burn. The sulfite liquor briquets were much stronger but did not burn at all well. All of these types of briquets were very strong and burned well after they had been thoroughly dried.

Conclusions

It is obvious that briquetting with these liquors is not to be considered commercially because of the necessity of drying both the ash and the briquets. If spent ash is to be briquetted the binder must be coal tar soft pitch, asphaltum, or some similar material.

Experimental Furnace

In order to study the combustion of the dried ash a small brick experimental furnace was built with a device for blowing in the powdered ash.(Fig.C) The air was brought from a compressed air tank by means of a rubber hose. The injecting device for sucking the ash from the hopper is shown in the drawing.

Preliminary Run

At first considerable difficulty was experienced in getting the furnace to operate with either powdered ash or coal. The air pressure (30# gage in the reservoir) was not enough to burn either the ash or coal. When the pressure in the reservoir was gotten up to 60# the coal burned well , in fact, a sheet of flame could be made to shoot several feet out of the furnace. The air pressure fell down to 30# again, and an attempt was made to burn the ash. A large part of the ash was blown out of the furnace The particles which burned did not do so with a flame but merely became incandescent and burned slowly. With conditions as they were the best position for the feed pipe was pointing downward at an angle of 20° into a pile of incandescent ash.

Conclusions

The preliminary run showed two things: I) the furnace as used did not have enough combustion space; 2) a strong blast of air was necessary to burn the ash.

The next step was to make the combustion space about three times its former size by putting a large sheet iron pipe in the furnace. It was then planned to make a comparative run of ash and coal for a given length of time. The coal and the ash were weighed, and a gas sampling tube and thermometer were placed in the end of the flue. Enough information could be obtained from these data to make a good comparison between the ash and the coal as fuels.

Preparations

Unfortunately the only thermometer available (950° F) was not large enough to measure the gas temperature, so the quantitative value of the run was partly spoiled.

Comparative Burning of Coal and Ash

Ash

Weight of Ash--- 7#

Screen Analysis:

I5-20	mesh	I3.5%
20-60	mesh	36.5%
60-	mesh	50.0%

Moisture ----- I.2 %

Reservoir Air Pressure -- 70#

Average CO_2 in Flue Gas -- 9.6%

Flue Gas Temp. °F at ½ minute intervals

550
575
700
750
775
800
850
.
.
.
Off Scale

Coal

Weight of Coal ---7#

Screen Analysis:

I5-20	mesh	4I%
20-60	mesh	37%
60-	mesh	22%

Moisture ----- 3.0%

Reservoir Air Pressure -- 70#

Average CO_2 in Flue Gas -- 6.7%

Flue Gas Temp. °F at ½ minute intervals

555
570
580
590
600
6I5
625
635
650
660
675
700
725
770
800
.
.
.
Off Scale

Comparative Burning of Coal and Ash

Despite the fact that the ash was fed in at a slower rate than the coal due to its greater volume the gas temperature of the former rose much more rapidly than that of the latter. This may have been due to some extent to the difference in the size of the particles of the two.

Difference in Gas Temperature

The 9.6 % CO_2 in the ash stack gas is not bad combustion practice even for coal. The excess air represented by this analysis is approximately:

$$\frac{20.9 - 9.6}{9.6} \times 100 = \frac{11.3}{9.6} = 118 \%$$

Consideration must also be taken of the fact that on a small scale the fuel feed is unavoidably intermittent. On a larger scale with a better feeding device the % CO_2 would no doubt be higher. This proves that a large excess of air is not needed for the combustion of the ash.

Stack Gas Analyses

The combustion of the coal was not very good as is shown by the low percent of CO_2 (6.7) and the slowness with which the gases increased in temperature. This was caused by the poor feed of the coal which had a tendency to pile up and then go into the injector in large amounts.

Combustion of the Coal

On the other hand the combustion of the ash was excellent. This time the ash burned with a free flame which could be made to shoot from one end of the furnace to over a foot out of the other. (The furnace is 8'4" long and the cross section of the combustion space is 68 sq. inches.) In this run the best position of the fuel feed pipe was at the top of the furnace pointing slightly upward. The gases were very hot, the control was easy, and there was only a negligible quantity of fuel blown out of the furnace.

Combustion of the Ash

This proves that the ash will make an excellent fuel either as a powder or on the grate, only two things being necessary, namely, a strong draught and sufficient combustion space.

Conclusions

* All the moisture percentages in this thesis are expressed on the dry basis unless otherwise stated. By dry basis is meant the pounds of water divided by the pounds of stock times one hundred.

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SPENT ASH AS A DECOLORIZING AGENT FOR SUGAR SOLUTIONS

Upon examining the light, porous particles of spent ash or organic carbon, the first thought that occurs to one is that it should make an excellent decolorizing agent. However it is contaminated with I - 2% Na_2CO_3 , small amounts of NaCl and Na_2SO_4 which render it unfit without treatment for the sugar industry, the biggest user of decolorizers. It seems a comparatively simple matter to treat the ash with acid and then wash these salts out.

Survey of Conditions

The time available for this work was necessarily very limited so not enough data was obtained to make any definite statement. However the few results obtained are very interesting, and it is hoped will be an incentive to further work along this line.

Limited Time

A quantity of the ash was washed, dried, ground finely, treated with dilute HNO_3 , and washed again until it gave a neutral reaction with phenolthalein and methyl orange. It was then air dried to I-2% moisture.

Treatment of Ash

Standard color solutions were made up by carmelizing a quantity of sugar and diluting it with water. The colors ranged from that of pure water #0 to #I6, a dark opaque. Standard Grade A bone char was obtained from the Revere Sugar Refinery to serve as a basis of comparison. Equal volumes of the same carmel solution were treated with the same weight of ash, boiled for the same length of time and filtered, the time of filtering being observed. The solutions before and after treating were compared with the standard and the difference noted.

First Attempts

Considerable difficulty was experienced getting the ash solution to filter clear. After several attempts this method was abandoned. The results seemed to show that the same weight of ash decolorized a sugar solution much better than the char. If this is true it is due no doubt to the more intimate contact of light porous ash with the solution than the heavy , comparatively non porous bone char.

Results Using Same Weight of Ash and Char

Two Buchner funnels (inside dimensions: 4I/8" diameter and I 5/8" deep) were filled with bone char and ash both over 20 mesh. Various carmel solutions were boiled and poured through the two filters. (the same volume of the same solution in each case) the time of filtering observed and the filtrates compared with the standard.

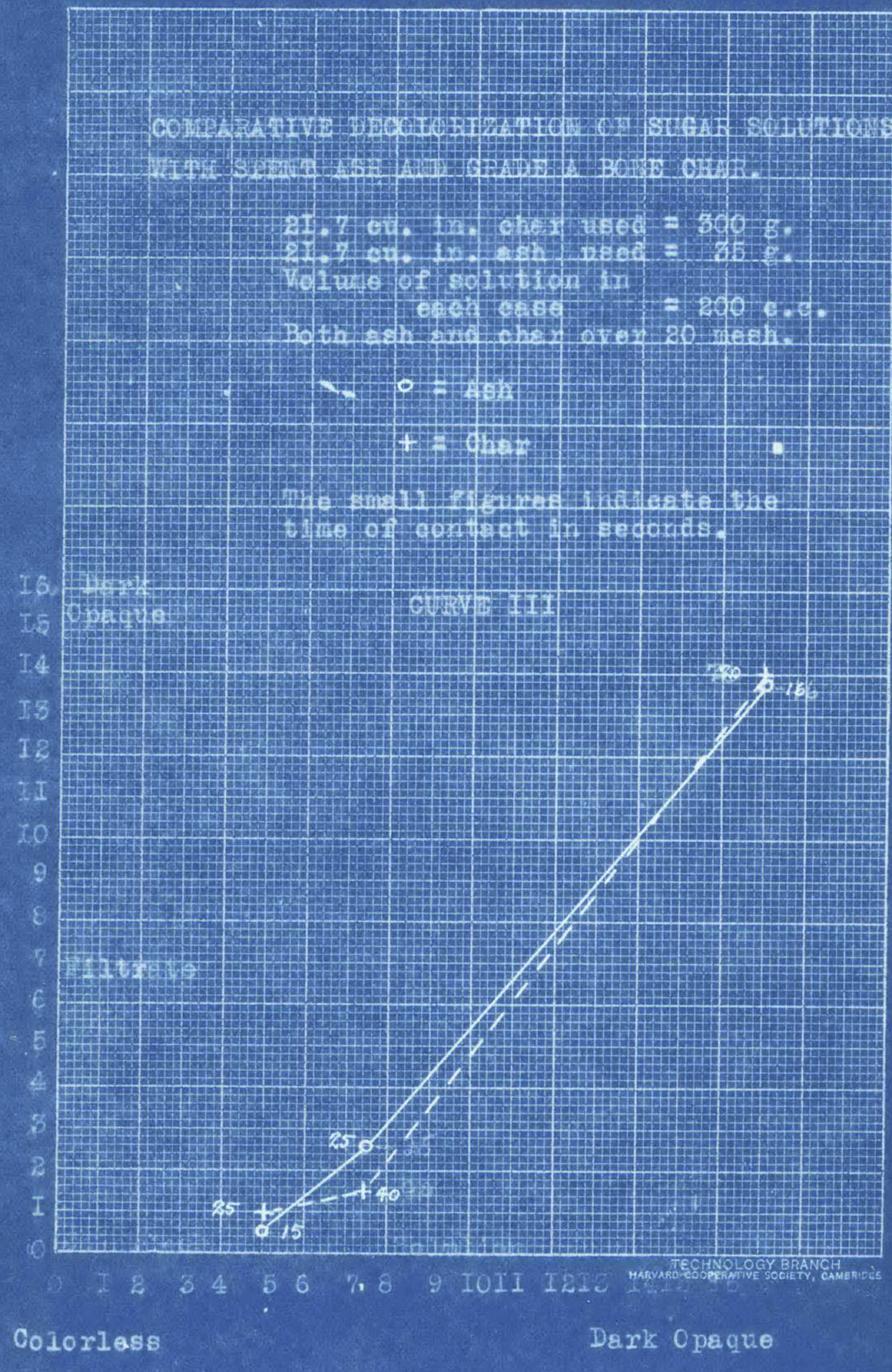
Same Volumes Used

It was difficult to measure the time accurately but it was taken from the second the solution was poured in until the solid stream issuing from the funnel was broken. As the time of contact is an important factor this inaccuracy may partly invalidate the comparisons.

Time of Contact

The results of the tests are shown on Curves

III and IV. In both cases there appears to be little difference at the start between the ash and the char. On second use the char appears the better and then falls back with the ash. Consideration should be taken that in every case the time of contact of the ash was less, and that 35g. of ash was used against 300g of char. This would seem to indicate that the ash is an excellent decolorizing agent. However, whether it can be revivified and used over and over again as the bone char is not known. If it can it seems that it should have a bright future in this field. Results



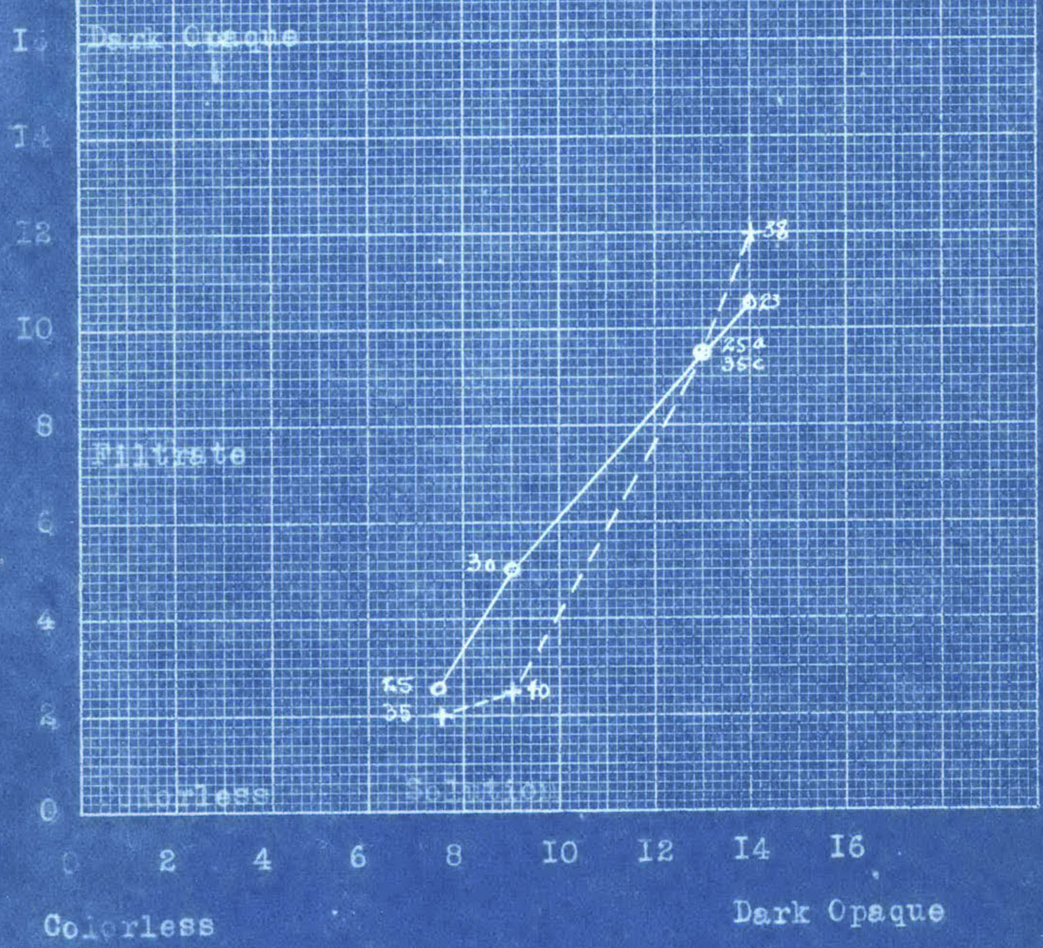
COMPARATIVE DECOLORIZATION OF SUGAR SOLUTIONS
WITH SPENT ASH AND GRADE A BONE CHAR.
21.7 cu. in. char used = 300 g.
21.7 cu. in. ash used = 35 g.
Volume of solution in each case = 200 c.c.
Both ash and char over 20 mesh.
o = Ash
+ = Char
The small figures indicate the time of contact in seconds.
CURVE III
Dark Opaque
Filtrate
Colorless
Dark Opaque
TECHNOLOGY BRANCH
HARVARD COOPERATIVE SOCIETY, CAMBRIDGE

COMPARATIVE DECOLORIZATION OF SUGAR SOLUTIONS

WITH SPENT ASH AND GRADE A BONE CHAR.

Another batch of ash and char;
Quantities the same as given on
Curve III.

CURVE IV.



APPENDIX

Quantity of Ash Available per Day

\# Na_2CO_3 recovered per day = 72,000

Na_2CO_3 in Black Ash = 74 %

\# Na_2CO_3/day   \# Black Ash/day

$$\frac{72{,}000}{0.74}\,\Big|\,\frac{0.26}{2000} = 12.6 \text{ tons}$$

Incinerator Stack Gases

Velocity = 30'/sec.   Temp. = 425°F

(These two facts were taken from a report on " The Chemical Losses and Efficiency of the P.C.F. Co. Soda Mill" of June 27, 1917 by Hanson and Wylde - Bangor Station.)

Assume:

4% moisture in the coal fired.

25,000 gal. of black liquor per day.

Analysis:
- 61.7% solids
- 13.6% Na_2C
- 24.7% water (wet basis)
- 39.4° Be.
- 0.8 specific heat
- 1.373 specific gravity

\# Na_2CO_3 / % Na_2C in B.L.   \# B.L./day   Gal BL/day

$$\frac{72{,}000}{.136}\,\Big|\,\frac{62}{106}\,\Big|\,\frac{7.5}{1.373 \times 62.4} = 27{,}000$$

formula for lignein is $C_{40}\ H_{42}\ O_{11}$

	Gal. B.L./day	# B.L./day	# H_2O/day in B.L.	
25,000	62.4xI.373	0.383		=
	7.5		24x60x60	

I.27 # water/sec. from black liquor in flue gas.

Total solids - Na_2O = 6I.7 - I3.6 = 48.I % lignein

Molecular Wt. Lignein - 700 = = 22 mols. water

	Gal B.L./day	# B.L./day	# lignein/day	# H_2O from lignein/day	
25,000	62.4xI.373	0.48I	I8x22		=
	7.5		700	24x60x60	

0.90 # water/sec. from lignein in flue gas.

6 tons of coal are used per day in the furnaces of the incinerators.

% H_2O in coal	# H_2O/day		
0.05	6	2000	= 0.00695 #water/sec from coal.
		24x3600	

Not all the water but shows the order of magnitude.

I.27 - 0.90 - 0.0I = 2.I8 # water/sec. in the f.g. at 425 - 2I2 = 2I3° superheat

Specific Volume of water at I4.7# pressure and 2I3° superheat = 36.0 cu. ft. / #.

2.I8 x 36 = 78.5 cu. ft. water vapor / sec.

The incinerator flue is 5' in diameter.

$30 \times \pi \times \frac{5^2}{4}$ = 590 cu. ft. of wet flue gas / sec.

590 - 78 = 5I2 cu. ft. of b.d. f.g. / sec.

Assume the dry flue gas I0% CO_2.

#Mols of S.G

$\frac{5I2 \;|\; 492}{359 \quad 885}$ = 0.793 mols f.g. (dry) /sec.

	CO_2	N_2	water vap
Heat in I mol. at 425°F	3680	2700	3280 B.T.U.
" " " " 2I2	I640	I220	I520
	2040	I480	I760

2040 x 0.793 x 0.I = I62
I480 x 0.793 x 0.9 = I055
I760 x 2.I7/I8 = 2I2
I429 B.T.U./ sec. above 2I2° in the f.g.

tons water with ash / day

water / min

$\frac{60 \;|\; 2000 \;|\; I122}{24x60}$ = 93,600 B.T.U./min. to vaporize all the water going with the wet ash.

I429 x 60 = 85,700 B.T.U./min. in the incinerator gas above 2I2°.

Design of a Dryer for Operation with Centrifuge

The centrifuge will redūce the moisture content to 233 %.

II x 2.33 = 25.6 tons of water to be removed per day of 24 hours.

Assume that all the drying is by surface evaporatīon

425° →	———————	320° →
200° ←	———————	← 60°

$\Delta t_1 = 240$

Tons H_2O/day in centrif ash; # H_2O/min

$$\frac{25.6 \mid 2000 \mid 1156}{24 \times 60} = 41{,}100 \text{ B.T.U./min. to heat to and vaporize at \# } 320^\circ F$$

Tons b.d. ash/day; # ash/day; BTU to heat 1°F

$$\frac{11 \mid 2000 \mid 0.2 \mid (200 - 60)}{24 \times 60} = 428 \text{ B.T.U. to heat the ash to } 200^\circ$$

	CO_2	N_2	Water Vap.
Heat in I mol at 425°	3680	2700	3280
Heat in I mol at 320°	2640	2000	2400
	I040	880	700

I040 x 0.793 x 0.I = 83
700 x o.793 x 0.9 = 500
880 x 2.I8/I8 = I07
690 B.T.U./sec. in gas above 320°.

690 x 60 = 4I,400 B.T.U./ min.

Data from Experimantal Dryer

Volume = I.36 cu. ft.
Time to dry from 233% to 3% moisture = 40 min.
Amount dryed = I# ash carrying 2.3 # moisture.
Gas velocity (by anemometer) = I6'/ sec.

Assume:

Average boiler flue gas temp. in the dryer = 450°F. Such a large volume of gas passed through in relation to the wt. of ash dried that the gas temp. could not vary much.

Average temp. of drying ash = I00°F
The ash went in the dryer at 60° and upon coming out could be held in the hand without discomfort. Therefore aver. t= 350°.

Coefficient of heat transfer in the actual dryer to be directly proportional tothe gas velocity. While this is not strictly true the assumption is on the conservative side.

The gas velocity in the dryer should be around 5' per second. If larger the lighter particles of ash will be blown out of the dryer.

$$Q/\theta = ha\ V \Delta t$$

where Q/θ = B.T.U. transferred per minute.
ha = Coefficient of heat transfer- (B.T.U./min./cubic foot/°F temp.diff.
Δt = Average temp. difference.
V = Volume of dryer in cubic feet.

$$\frac{2.3 \times 1000}{40} = ha \times 1.36 \times 350$$

$$ha = .121$$

.I2I x 5/I6 = 0.038 coeff. in actual dryer.

$$4I,000 = 0.038 \times V \times \Delta t_{1}(240)$$

$$V = 4500 \text{ cu. ft.}$$

Gas velocity in 5' diameter incinerator stack at the P.C.F. Works = 30'/sec.

Diameter of cylindrical dryer for 5'/sec. gas velocity.

= 30 x $5^2/5$ = I2' Cross section = II3 sq.ft.

4500/II3 = 40'

Applying a 25% safety factor on volume:

40 x I.25 = 50' length of dryer.

Safety factor on heat $= \frac{85,700 - 4I,I00}{4I,I00} = I09\%$

Excerpt from a letter from the American Process Co. 68 Williams Street, New York City:

> "To handle say I000 pounds per hour of spent black ash residue (porous vegetable carbon) carrying say 80% initial moisture and drying same to approximately5% final moisture would require one of our Special VI-C Dryers, which we could furnish for $4725,f.o.b. cars, Philadelphia, Pa.,consisting of cylinder with rolled steel tires, running mechanism,sheet steel feed chamberwith gas flues, feed chute and angle iron supports, also one steel plate exhaust fan with water cooled bearings......
>
> We are offering an outfit of ample capacity the cylinder being 50' long.
>
> .....We have handled this material in our direct heat dryers and know just what it is. ...."

Calculations on Equipment Sizes

Pump-

Assume three times the volume of one tank to wash it out.

Simple rotary pump.

$9 \times 8 \times 7 \times 3 \times \frac{7.5}{60} = 189$ Gal./ min.

The capacity of the pump will be 200 G.P.M.

It will empty a tank in one hour. Cost $ 150

Drain Tank-

This tank should have three times the capacity of one of the leaching tanks to provide for the centriguge being idle one shift.

Volume $3 \times 9 \times 8 \times 7 = 504 \times 3 = 1512$ cu. ft.

Dimensions: 12'wide by 15' long; 8' deep on side, 10' in the middle.

Equipped with an 8" screw conveyor.

Bottom made of perforated steel plate, punched with 3/16" holes.

Centrifuge-

Elmore Continuous; 24"; 800 cu. ft./hr. capacity

35 Horsepower required.

Storage Bin for Dryer Feed-

Capacity - one leaching tank @ = 500 cu. ft.

Equipped with screw conveyor.

Blower-

600 cu. ft. / sec. = 36,000 C.F.P.M.
Power required = 5 H.P. (From the estimates In catalog I6 of the Ruggles Coles Engineering Company of New York City)

Operation of the Broposed Recovery System

After the black ash has been thoroughly leached the leaching tank is filled with water, the proper valves opened, and the slurry pumped on to the drain table. With the size pump reccommended this operation will take under an hour. While the ash is draining the screw conveyor takes it to the continuous centrifuge which reduces the moisture content to 233%.

Upon leaving the centrifuge the ash is thrown into a dryer storage bin by the bucket elevator. The drain ta table holds three tankfuls of ash orI8 hours production so as to provide for any shut downs of the centrifuge. The dryer storage holds one tank or enough to keep the dryer going for 4 hours. The wet ash is fed into the dryer by a screw conveyor. It comes out with 2-3% moisture and falls on the belt conveyor which takes it at once to the boiler room where it is piled ready for burning. See Fig. D.

Standard Color Solutions

0 (colorless) to I6 (dark opaque)
Ratios below are c.c. original carmel solution to c.c. water.

#I- .00625:I0	#5- .04:I0	#9- .20:I0	#I3- .60:I0
2- .0I25 :I0	6- .05:I0	I0- .30:I0	I4- .75:I0
3- .02 :I0	7- .075:I0	II- .40:I0	I5-I.0 :I0
4- .025 :I0	8- .I0:I0	I2- .50:I0	I6-2.0 :I0

Runs

I0 g. Black Ash in 200c.c. of #I3-I4 solution
I0 g. Bone Char " " " " "

solutions boiled for I5.5 min. each; filtered.
Ash filtrate ------------- # II
Char filtrate ------------- I3

35 g. Ash in Buchner funnel 4 I/8" dia. x I 5/8" deep.
300 g. Char " " " " " "
Both ash and char over 20 mesh.
200 c.c. solution boiled and poured through the funnel.

Solution #7-8
Ash filt. 2-3 35 sec.
Char filt. 2 35 sec.

Solution #I3
Ash filt. 9-I0 25 sec.
Char filt.9-I0 30 sec.

Solution 9
Ash filt. 5 30 sec.
Char filt. 2-3 40 sec.

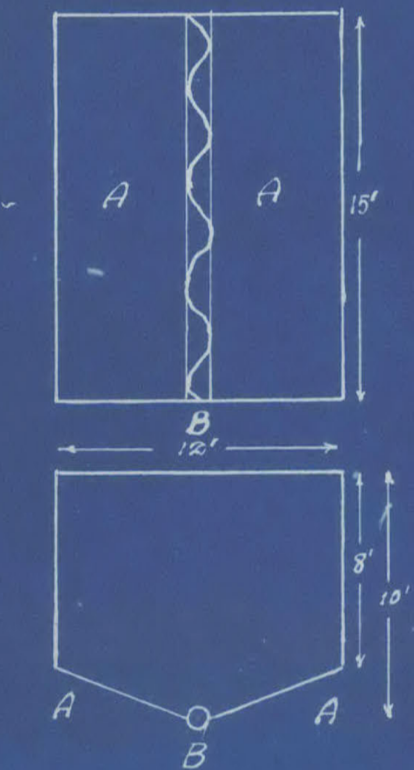
Solution I4
Ash filt I0-II 23 sec.
Char filt I2 38 sec.

New batch same quantities as above.

Solution # 5
Ash filt. 0-I I5 sec.
Char filt. I 25 sec.

Solution # 7-8
Ash filt. 2-3 25 sec.
Char filt. I-2 40 sec.

Solution over I6
Ash filtrate I3-I4 I6 sec.
Char filtrate I4 20 sec.



DRAIN TANK

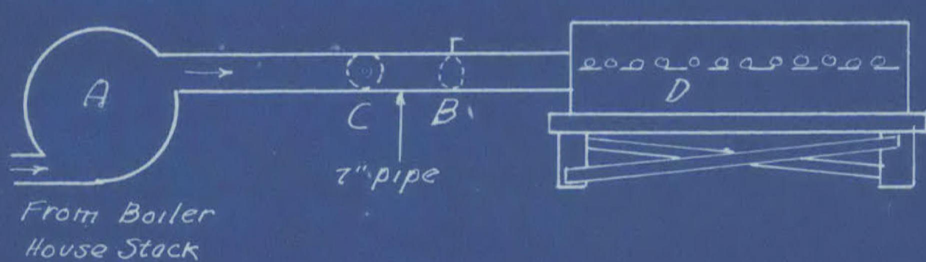
Capacity 1620 cu. ft.

A - Punched Plate $\frac{3}{16}$" holes

B - Screw Conveyor

Scale $\frac{1}{8}$" = 1'

Fig. A



EXPERIMENTAL DRYER

A - Blower Connected to Stack

B - Damper

C - By Pass

D - Screen to Support Ash

Fig. B

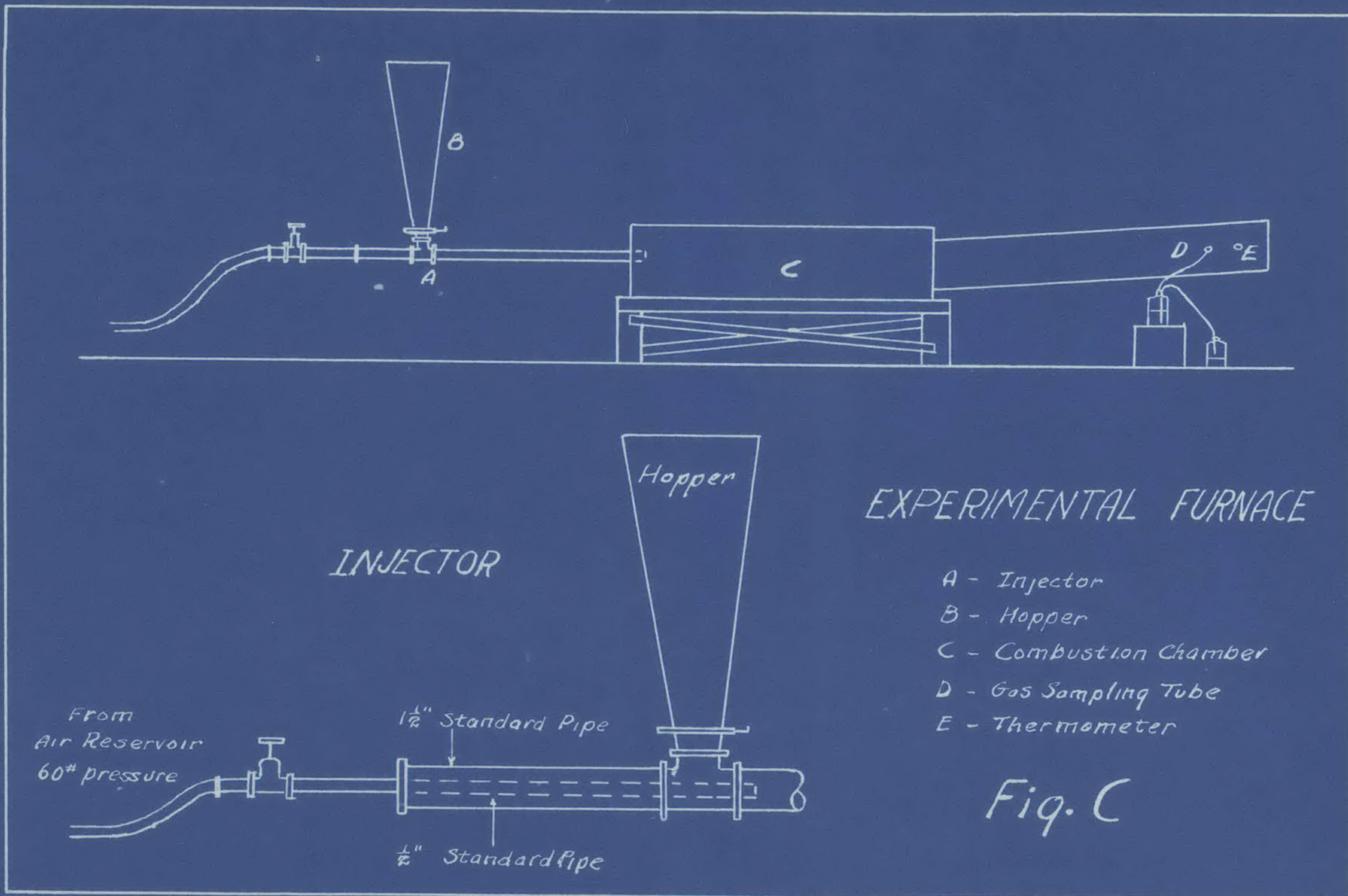
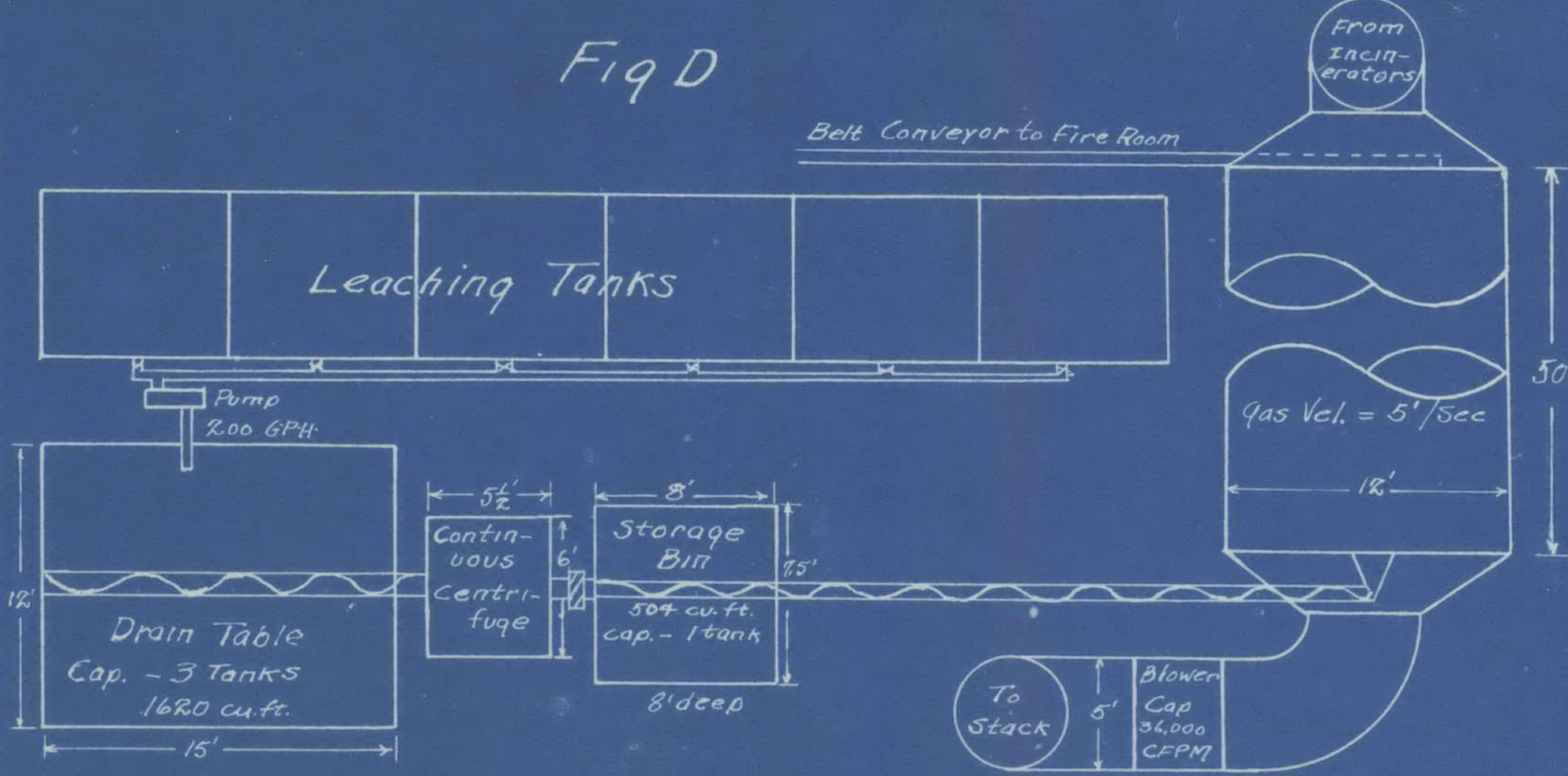

B
A
C
D
°E
Hopper
EXPERIMENTAL FURNACE
INJECTOR
A - Injector
B - Hopper
C - Combustion Chamber
D - Gas Sampling Tube
E - Thermometer
From
Air Reservoir
60# pressure
1½" Standard Pipe
½" Standard Pipe

Fig. C

Fig D



APPROXIMATE LAYOUT FOR SPENT ASH RECOVERY SYSTEM

Legend -
- ∿∿ - Screw Conveyor
- ▨ - Bucket Elevator
- ⊠ - Valve

Table of Approximate Costs

Drain Table -	$ 500	Dryer -	$ 5,000	Conveyors	$ 1,800
Pump -	200	Blower -	2,000	Motor	1,000
Centrifuge -	3,000	Stor. Bin -	400	Installation	3,800