Cell Burning of High Moisture Cellulose Refuse

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The phrase "cell burning" infers the efficient utilization of the heating value of the refuse as distinguished from straight incineration, wherein the disposal problem alone is eliminated. Hence, reference to waste fuel rather than refuse seems more appropriate.

The broad field of cellulose waste fuels which are utilized for steam generation may be divided into two general categories based on source; namely, wood and agricultural, both of which usually are the residue of a manufacturing process.

Each category in itself is extensive. The wood potential would include lumbering, plywood, pulp and paper, naval stores, tanning and fabricating. The agricultural potential would include bagasse, hulls, corncobs, coffee grounds, straw, seeds, etc.

Four of these waste fuels are of particular interest at the moment because of their as-fired high-moisture content (30 percent or more); namely, hog fuel from lumbering, bark from the pulp and paper industry, bagasse from sugar production and spent coffee grounds, a relatively new fuel from the manufacture of instant coffee.

Although these fuels are quite dissimilar in their physical characteristics and range of moisture contents, a comparison of their proximate and ultimate analysis indicates, as one would suspect, that they do not differ greatly from each other, all having a derivation in the vegetable family.

MOISTURE CONTENT

Freshly cut timber may vary in moisture content from a low of 30 percent up to 50 percent, depending upon species, time of year, and whether it is heartwood or sapwood.

In the manufacture of lumber, the waste material consists of slabs, edgings, trimmings, bark, sawdust and shavings. For the purpose of facilitating the combustion process, conveying, storing, and feeding, the larger materials are reduced in size in a hog, hence the term "hog fuel".

This term, although extensively used, is quite ambiguous, both as to the sizing of the material as well as its consist. Many mills today chip the larger materials which are sold as pulpwood to paper mills or to chipboard manufacturers. In some instances the bark is sold for horticultural purposes. This practice results in a hog fuel consisting materially of sawdust and shavings.

Water transport of logs and/or millpond storage, together with water lubrication of saws, all contribute to the natural moisture content of the hog fuel. Hence an upper limit for as-fired moisture is a function of mill practice.

Bark, as received from the barking drum, may run 80 percent moisture or more. Good pressing will reduce this figure to 50 to 55 percent. Bark is fed directly to the furnace from the press and also may be hogged after pressing.

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TABLE 1. ULTIMATE ANALYSIS RANGE FOR VARIOUS FUELS & MEAN PROXIMATE ANALYSIS IN PERCENT BY WEIGHT, DRY BASIS

					Hi-Heat Value
Bagasse –	C	– 43.2 to 49.0			
	H	– 5.9 to 6.6	Vol.	– 83.8	
	O_2	– 35.3 to 47.9	Fixed C	– 12.7	8,350
	Ash	– 2.9 to 11.3	Ash	– 3.5	
Diffusion Process Excepted					
Bark –	C	– 51.0 to 56.2			
	H	– 5.1 to 5.9	Vol.	– 72.6	
	O_2	– 36.7 to 42.6	Fixed C	– 25.4	8,750
	Ash	– .5 to 3.8	Ash	– 2.0	
Coffee Grounds –					
	C	– 58.10			
	H	– 7.67	Vol.	– 85.23	
	N	– 2.58	Fixed C	– 14.66	10,800
	O_2	– 31.33	Ash	– .11	
	S	– .22			
Wood –	C	– 48.8 to 55			
	H	– 5.6 to 7	Vol.	– 81.5	
	O_2	– 38.1 to 45	Fixed C	– 17.5	8,400 – 9,870
	Ash	– .15 to 2.2	Ash	– 1.0	

Pitch Pine is excepted, as its Btu content is much higher – 10,600 to 11,320 Btu per pound.

Bagasse, the fibrous residue from the milling of sugar cane, will have a moisture range of 40 percent to 55 percent varying with the speed and efficiency of the milling operation. Bagasse from the diffusion process will vary in moisture content in the same manner where conventional mills are used for de-watering.

Spent coffee grounds will contain 75 percent moisture to the press, which reduces this figure to 55 - 60 percent.

COMBUSTION PROCESS

Since these waste fuels are not common fuels, a review of the combustion process may be of interest.

The burning of waste fuels, which are high in both moisture and volatile content, is accomplished in three overlapping stages which must be taken into consideration in the design of a suitable furnace.

The first stage is one of heat absorption in which the moisture in the fuel is evaporated, during which time the fuel temperature does not exceed 212°F.

The second stage, also one of heat absorption and later heat generation, occurs in the distilling off of the volatile matter. After the evaporation of the moisture is completed and with the continued addition of heat, the temperature of the fuel rises. At approximately 1100°F. in the presence of air, the volatile matter burns generating heat.

TABLE 2.

BAGASSE			WOOD & BARK		
Percent Moisture	Gross Btu lb. as Fired	Net Btu lb. Available For Steam Production	Percent Moisture	Gross Btu lb. as Fired	Net Btu lb. Available For Steam Production
40	5010	3572	15	7440	5767
41	4927	3494	20	7000	5325
42	4843	3412	25	6563	4915
43	4760	3329	30	6125	4505
44	4676	3249	35	5688	4093
45	4593	3169	40	5250	3682
46	4509	3087	46	4725	3190
47	4426	3007	48	4550	3025
48	4342	2928	50	4375	2860
49	4259	2851	52	4200	2696
50	4175	2767	54	4025	2532
51	4092	2689	56	3850	2466
52	4008	2607	58	3675	2203
53	3925	2528	60	3500	2038
54	3841	2450	62	3325	1874
			64	3150	1710
			66	2975	1545
			68	2800	1381

The above tables, which are based on: 8350 Btu per pound for Bagasse and 8750 Btu per pound for Wood and Bark, on a dry basis; 50% excess air, a stack temperature of 500° F.; illustrate the effect of moisture on fuel value in reference to steam production.

The rate at which the evaporation of moisture and the distillation of volatiles occur, is dependent upon the rate at which heat is supplied and upon the sizing of the fuel. Reasonably small particle size provides greater surface exposure and decreases the amount of material through which heat must be transmitted by conduction.

The third stage occurs when the residual carbon reaches ignition temperature and in the presence of air burns. Here again, it will be readily seen, the fuel particle sizing has a definite bearing on the burning rate.

As the volatile content of these fuels is in the range of 72 - 85 percent of the entire combustible, it is readily apparent that most of the combustion, which would include much of the fixed carbon, occurs above the fuel bed, and consequently, the bulk of the combustion air should be supplied in this area.

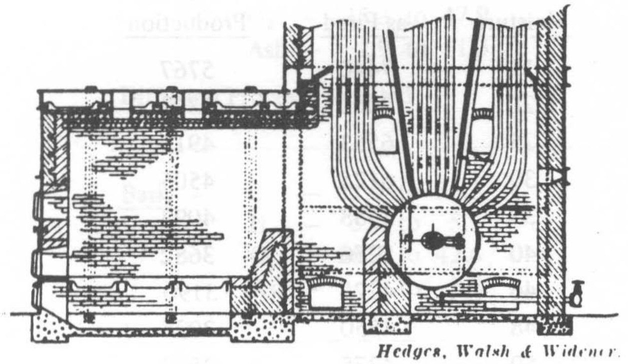
To maintain an environment suitable for rapid evaporation of moisture and distillation of volatiles, it also becomes apparent the use of refractory arches and walls is of considerable importance in providing the maximum amount of reflected heat to the fuel and shading it from black or heat-absorbing surfaces.

FURNACE DESIGN

A review of the history of the development of bagasse furnaces would also probably be of interest, as in this field which has been given much study, one will see a definite progression in furnace design in cell burning.

Prior to 1885, all bagasse was transported from the mill back to the cane field and sun dried, then returned to the mill for burning. This involved procedure was necessitated by the mill's complete dependence on bagasse as a fuel source, with the inability to burn it green.

In 1886, the first furnace for burning green bagasse was patented by Samuel Fiske, as illustrated below:



Hedges, Walsh & Widener.

FLAT GRATE BAGASSE FURNACE

This furnace consisted of an oven fitted with horizontal grate bars, on which the bagasse was burned, and was frequently connected to several existing boilers by means of flues. On new installations with but two boilers, the furnace was set under the front end of the boiler.

The bagasse is fed through the feed chutes in the oven roof, forming two conical piles on the flat grates with refractories installed in all available areas to provide the maximum amount of radiant and reflected heat for drying and gasification of volatiles.

The ash in combination with the residual juice in the bagasse forms a plastic clinker which is very difficult to handle on flat grates and maintain reasonable grate life. The use of preheated air further aggravates this problem, and hence is limited to 250°F.

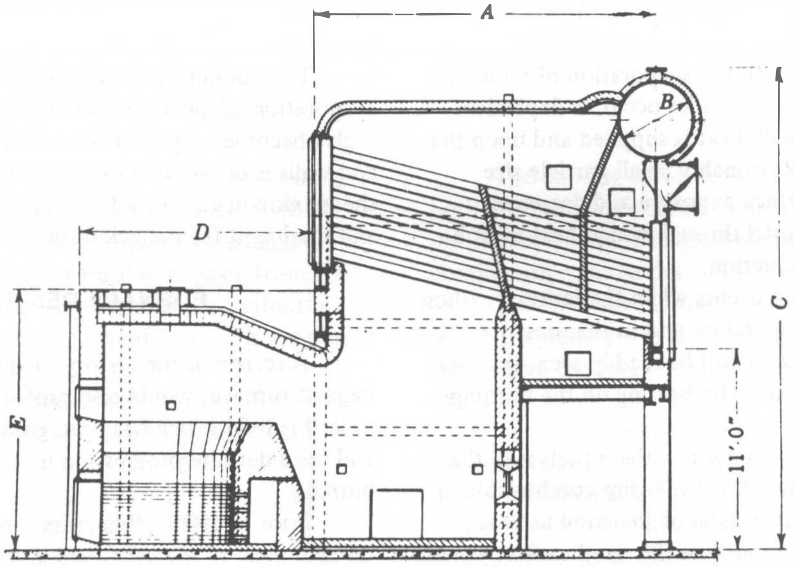
With a rectangular furnace and conical fuel piles, it is readily apparent that fuel distribution over the flat grates is a variable one, resulting in "blow holes" in the fuel bed, on the periphery of the pile, allowing forced draft air dilution to pour into the products of combustion.

Shortly after the advent of the Fiske furnace, Frederick Cook introduced his green bagasse furnace, as illustrated below:

This is a hearth burning furnace, wherein the problems in connection with the horizontal grate are eliminated. The hearth is broken up into two or more cells, horseshoe in shape, thus more closely surrounding the fuel cone with refractories. The cells are fed through the feed chutes in the oven roof as before.

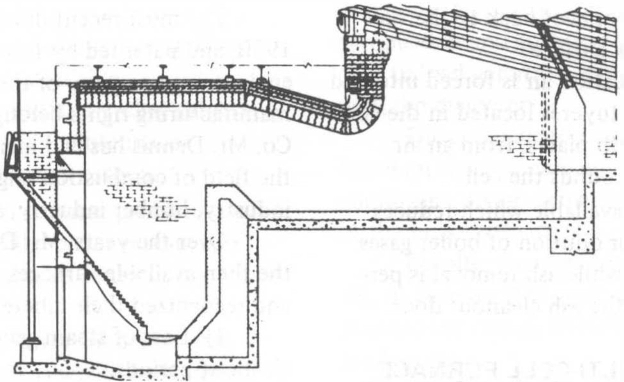
The combustion air is forced into and over the fuel cone through tuyeres located in the cell walls, from an air plenum which virtually surrounds the lower portion of the cell.

Another important detail illustrated is the dropping of the oven roof at the entrance to the boiler furnace. The use of refractory suspension permitted this change which promotes mixing of the gases as an aid to complete combustion, reflects heat



Combustion Engineering Co., Inc.

HEARTH BAGASSE FURNACE.



Hedges, Walsh & Widener.

STEP GRATE BAGASSE FURNACE.

back to the fuel cone, and further, shades the fuel cone from black or heat-absorbing boiler surface.

In the rear wall of the boiler furnace is indicated provision for auxiliary firing which is used to supplement bagasse firing and also to provide continued steam production while the mill is idle. Due to inadequate furnace volume, these burners frequently produce a severe slagging condition.

The third development was the use of the inclined step grate, frequently referred to as "step ladder", which it resembles.

These grates are long and narrow. The combustion air passes through the relatively large openings between steps in the grate in a horizontal direction. This grate adequately supports the fuel and eliminates the need for the small vertical air openings found in the horizontal grate which are readily plugged with clinker, resulting in its eventual destruction.

The possibility of "blow holes" occurring in the fuel bed is reduced, however, is always a potential source of combustion gas dilution.

The bagasse is fed onto the upper drying hearth, from which it tumbles onto the top step of the grate, and gradually works its way to the small flat grate at the bottom.

Here again you will note the dropping of the roof at the boiler entrance.

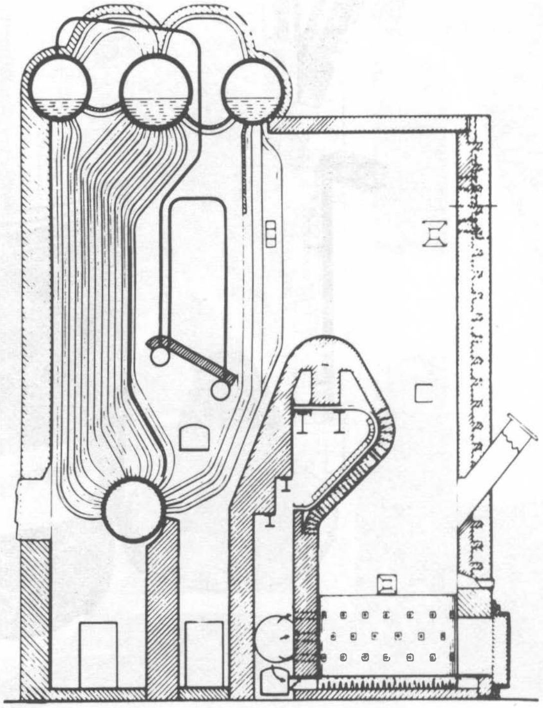
This type found favor in those countries in which the moisture content is on the lower edge of the range, for example, Hawaii and the Philippines.

The fourth development was made in 1936 by George Ward, an engineer of the Babcock & Wilcox Boiler Company.

This is a hearth burning furnace, which becomes a part of the boiler setting instead of a separate oven, as illustrated previously. This is accomplished by elevating the boiler and utilizes floor space much more efficiently.

The furnace consists of two or more cells, which are quite similar to the original Cook cells, with the addition of cast-iron hearth plates, on which the cell wall rests.

Bagasse is fed to the cells through the feed chutes located in the front wall. The rear wall of the furnace is sloped inward, through the use of refractory suspension, to promote gas mixing as an aid to



WARD SINGLE-PASS BAGASSE FURNACE.

complete combustion, reflect heat back to the fuel pile and shade it from black surface.

Here again the combustion air is forced into and over the fuel cone through tuyeres located in the cell walls and the cast-iron hearth plates, from an air plenum which virtually surrounds the cell.

A dumping hearth is available which reduces labor and eliminates cold air dilution of boiler gases and cooling of refractories while ash removal is performed manually, through the ash cleanout door.

DETRICK-DENNIS MULTI-CELL FURNACE

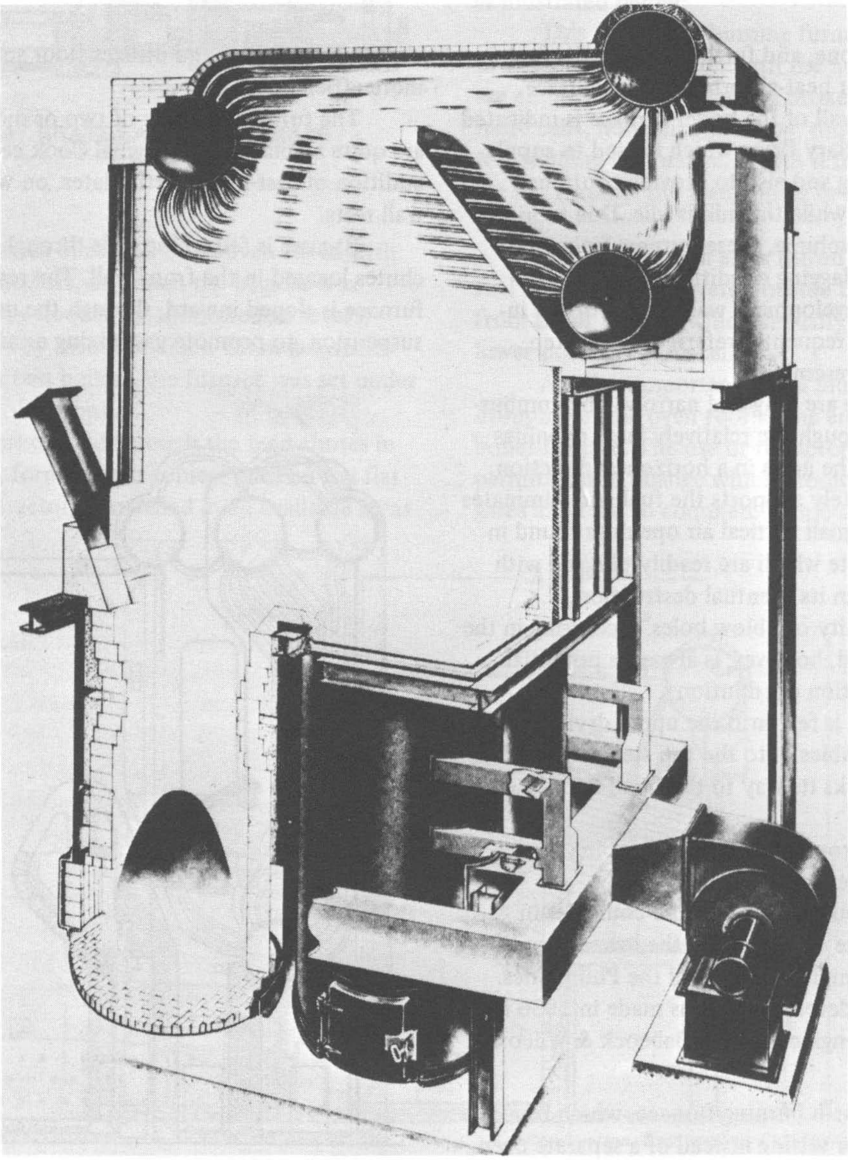
In the boiler furnace above the throat of the cell furnace, provision is made for auxiliary firing.

The most recent development was made in 1950, and patented by Edwin L. Dennis, of the engineering company of the same name, with sole manufacturing rights belonging to M. H. Detrick Co. Mr. Dennis has had many years of experience in the field of combustion engineering for the sugar industry, lumber industry, and in several other fields.

Over the years, Mr. Dennis had employed all of the then available furnaces for burning waste fuels and recognized their inherent disadvantages as:

1) Loss of steam generating capacity during ash cleanout periods.

Mechanical cane harvesting has materially increased the amount of dirt in the bagasse which increases the amount of material to be removed from



DETRICK-DENNIS MULTI-CELL FURNACE

the furnace.

2) Inadequate furnace volume for auxiliary firing when waste fuel is not available.

3) Use of refractory roofs or arches subject to high service conditions and maintenance.

4) Carry-over of unburned carbon.

Mr. Dennis's solution to these problems was accomplished by elevating the boiler setting and installing properly designed cells beneath, as illustrated.

This is a three-drum, low-head boiler with a standard boiler furnace such as would be supplied for continuous firing with any of the conventional fuels, gas, oil or coal.

Beneath the boiler furnace, four hearth burning cells are indicated which are fed through the walls of the boiler furnace, the bagasse being discharged into the restricted cell throat.

This type of cell is quite different from that illustrated previously. No longer is the cell a portion of an oven or furnace, but is a complete furnace in itself, circular throughout its height, of variable diameter, and from 9 to 12 feet in height.

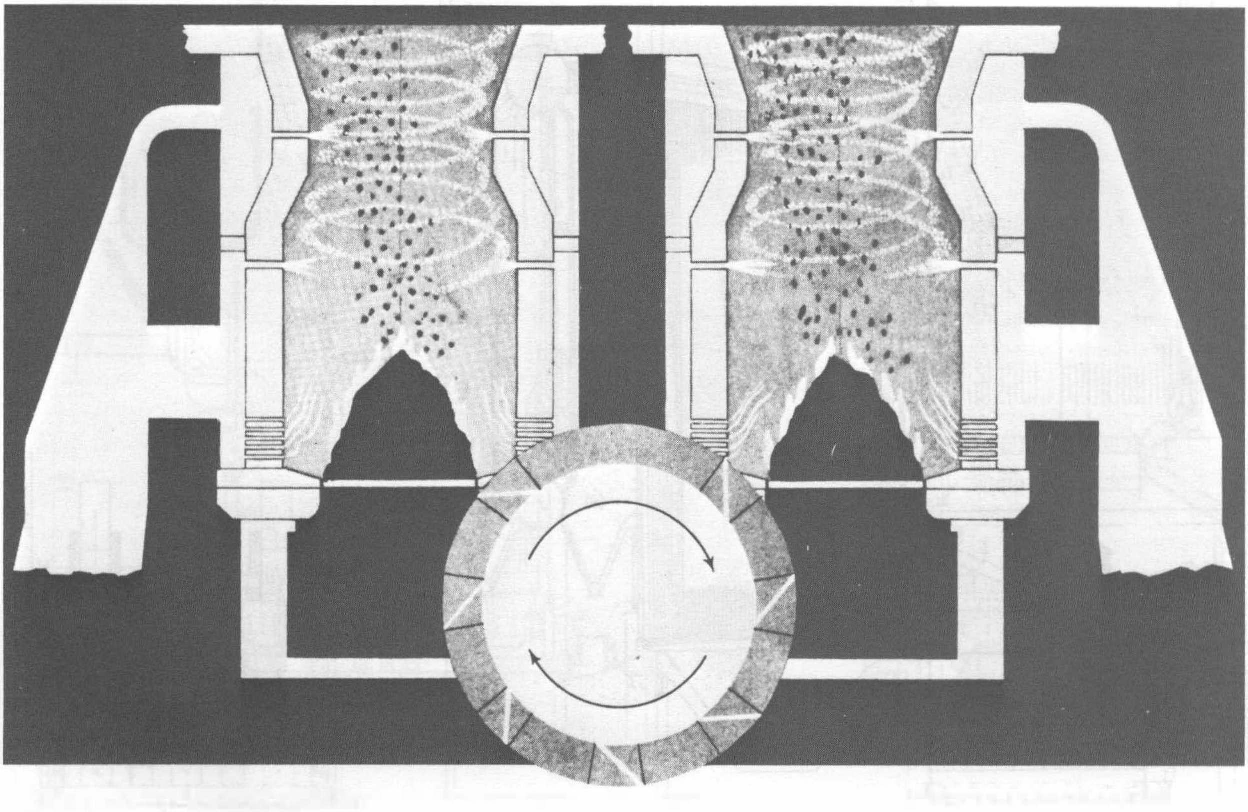
The positioning of the refractories in relationship to the fuel cone is of great importance in providing the heat source for the first two stages of combustion and governs the responsiveness of the cells to load variation, hence the cell height is variable with the diameter.

The cell diameter and number of cells used is based on the moisture content of the fuel, steam conditions, steam demand, and physical dimensions of the boiler furnace.

Usually, four cells are used, and occasionally six, to develop 200 percent of the nominal boiler horsepower rating, wherever the waste fuel supply is adequate.

The lower portion of the cell refractory lining, opposite the fuel cone, is equipped with radial ports for injecting the primary combustion air. In addition, two sets of tangential tuyeres are provided. One set being situated directly above the radial ports and the other set in the throat of the cell.

From the second stage of combustion, it is evident that the burning of the volatiles, which may be as much as 80 percent of the combustible, occurs above the fuel bed, hence the lower set of tangential tuyeres provides the necessary turbulence required to obtain a thorough mixing of the volatiles and the air from the radial ports.



The lower set of tuyeres are fed from and controlled by the same gate which serves and controls the air supply to the radial primary air ports as the two air supplies implement each other in the combustion process.

The set of tuyeres in the cell throat are fed and controlled by a separate gate as they are provided for the dual purpose of additional turbulence and the separation and lifting of the fines in the fuel supply, which flash dry and burn in suspension in the boiler furnace above the cells.

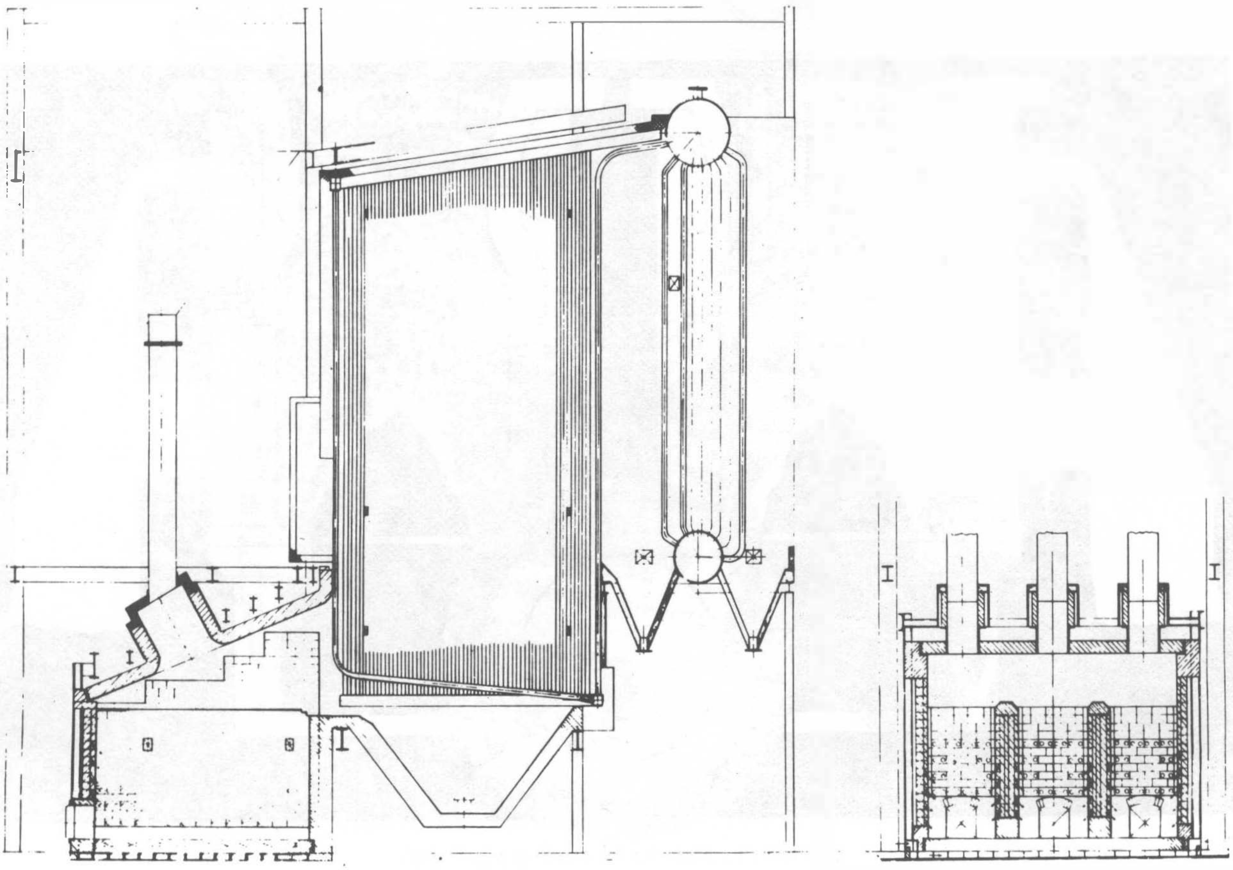
The elimination of the fines in the fuel cone removes their blinding effect, opening the matrix of the fuel pile to radiant heat, hot gases, and combustion air, with its beneficial effect on rapid response to load variations.

The direction of rotation of the tangential tuyeres in the cells is reversed in each of the four cells to again provide additional turbulence as the combustion gases leave the restricted throat of the cell and pass into the boiler furnace. This furnace then becomes an expansion chamber where the velocity is materially reduced and results in particles being held in suspension until combustion is complete.

With this multi-cell furnace, virtually twice as many cells are employed as with any of the other hearth-type furnaces, which has an inherent advantage both in connection with steam production and also the cell clean-out period, wherein, on a four-cell application, only 25 percent of the cells are inoperative at this time.

Usually, one forced draft fan is used to supply the four cells with a common air duct. The practice is to stagger the period at which each cell will be cleaned. The fuel supply having been discontinued to the cell being cleaned, in a short period the residual fuel pile is burned down, after which the air supply to the cell is also discontinued. Since the cells are served from a common duct, this automatically increases the air to the remaining cells and increases the firing rate, allowing maintenance of steam production at full rating.

A dumping hearth is also available for this type of cell, providing the same advantages as mentioned previously.



WOOD AND BARK

Over the years, there has been little change in the design of the Dutch ovens for burning hogged fuel and bark. One type of unit is very similar to the Cook design, with the exception of water-cooled grates being used. The other is the so-called tandem furnace design, which is usually quite long and narrow, having two or three feed openings used to supply each cell. This furnace also has water-cooled grates.

An interesting version of this furnace, which was developed by Mr. William Lundy, of the Kimberly-Clark Corporation, is illustrated on previous page.

Here we have a hearth burning unit consisting of three (3) cells, the common wall between cells, as well as the outer wall supplying overfire air.

SPENT COFFEE GROUNDS

The burning of spent coffee grounds, although relatively new to the field of waste fuel burning, is far from its infancy, as our records go back as fas as 1946.

Due to the physical characteristics of this fuel, this material has always been underfed, rather than overfed, as you have observed on the other types of cells.

The original installations were also of the Dutch-oven type and used pressurized overfire air.

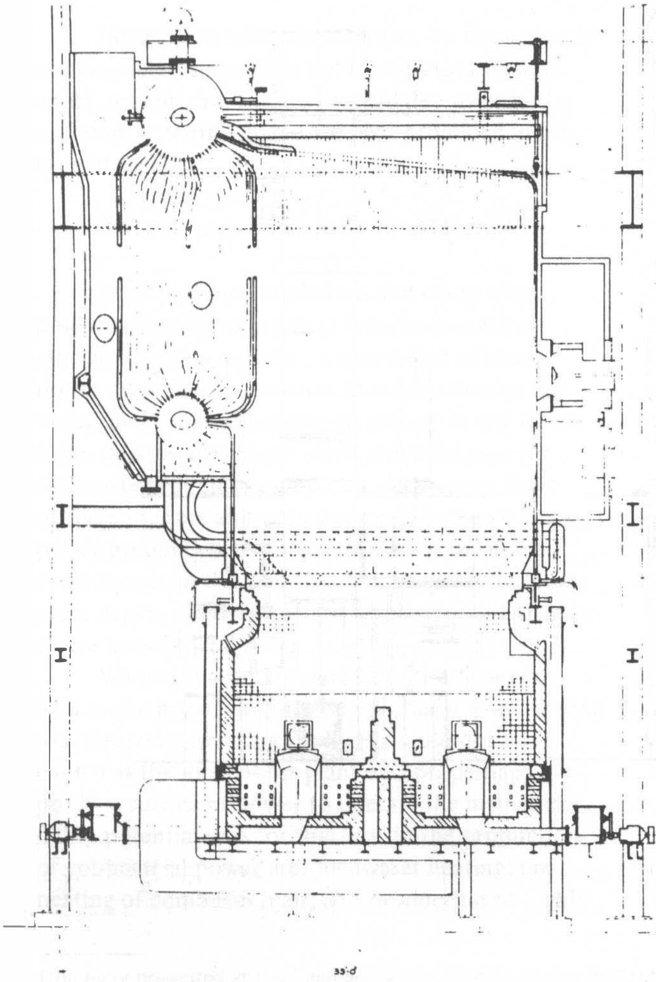
Below is an illustration of a recent installation which is probably the largest of its type in the world.

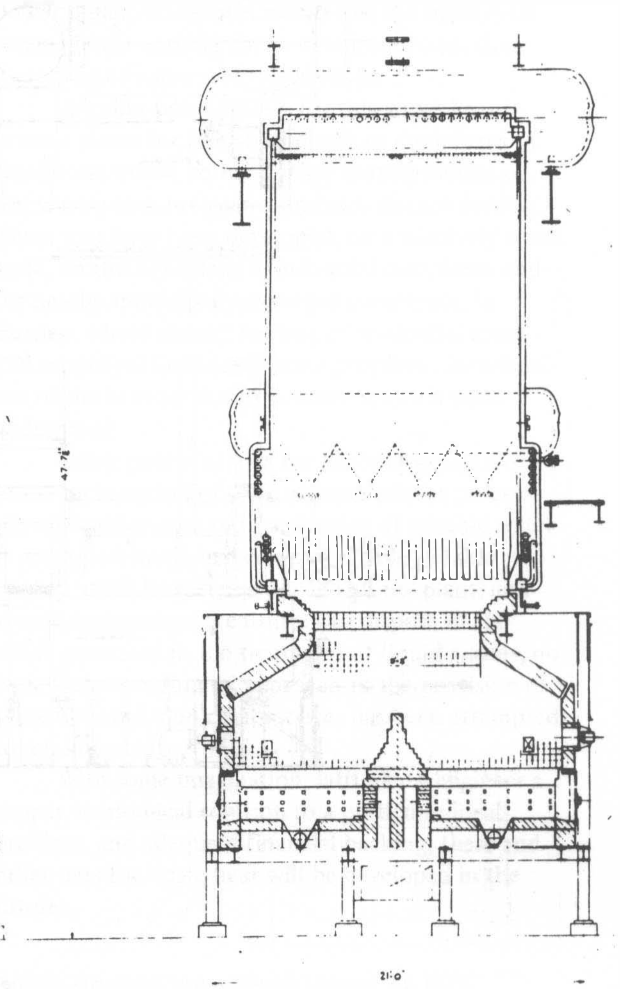
This furnace, as you will observe, consists of four (4) cells placed directly beneath the steam generator and designed to burn 25,000 lbs. of 60 percent moisture grounds per hour using 550°F preheated air, with the object of producing 53,000 lbs. of steam per hour.

Each of the four (4) cells is equipped with a stoker, warm-up burner and an independent air supply to provide a maximum of control at all times.

CONCLUSION

In conclusion, the burning of high-moisture cellulose fuels will always involve problems, which



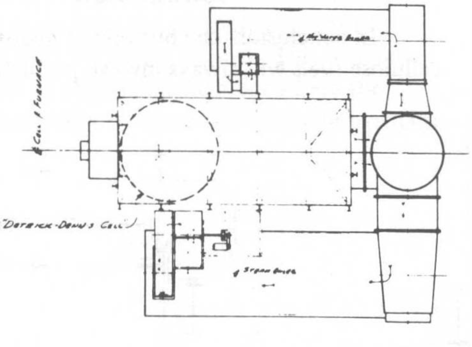


is inherent with the many variables encountered with these materials; however, constant study and experience has produced equipment which allows their efficient use in steam production. Experience has shown that when burning bagasse, a constant CO_2 of 14 percent may be maintained under normal operating conditions and readings as high as 16 percent have been obtained where particular care and attention were used.

Because refuse disposal is an acute problem today, it would not be proper to close without pointing out that cell burning is not necessarily confined to high-moisture fuels. With fuels low in moisture, cell burning is still efficient because only the first stage of the combustion process (evaporation of moisture) is affected.

Illustrated below is a good example of a relatively small unit that efficiently combines refuse disposal with profit producing steam generation. This installation is fully equipped with automatic controls and is designed to burn kiln-dried wood waste from a furniture factory at the rate of 2000#/hr., producing 11,000 lbs. of process steam per hour, and 4200 lbs. of steam per hour for a heating load, with the flexibility of straight incineration, when and if required.

Disposal of refuse has always been a burden and it is becoming more of a problem as land fill sites disappear. In the above case, refuse disposal is handled at a profit. By evaluating the savings in trucking, dumping fees, and fuel oil, indications are that this complete installation should amortize itself in approximately three years.



~ PLAN VIEW UNDER ROOF ~