

Nov. 11, 1941.

J. E. GREENAWALT

2,261,995

METHOD OF BURNING BLACK LIQUOR

Filed July 8, 1938

3 Sheets-Sheet 1

Fig. 1

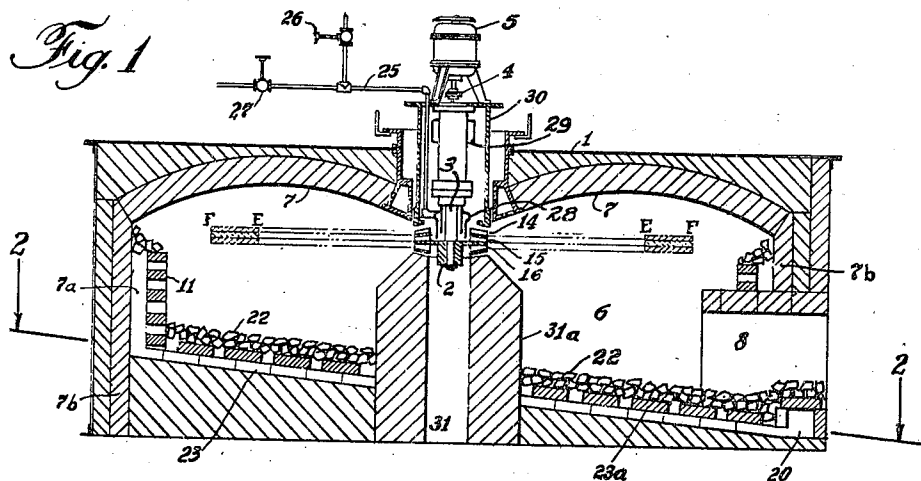


Fig. 2

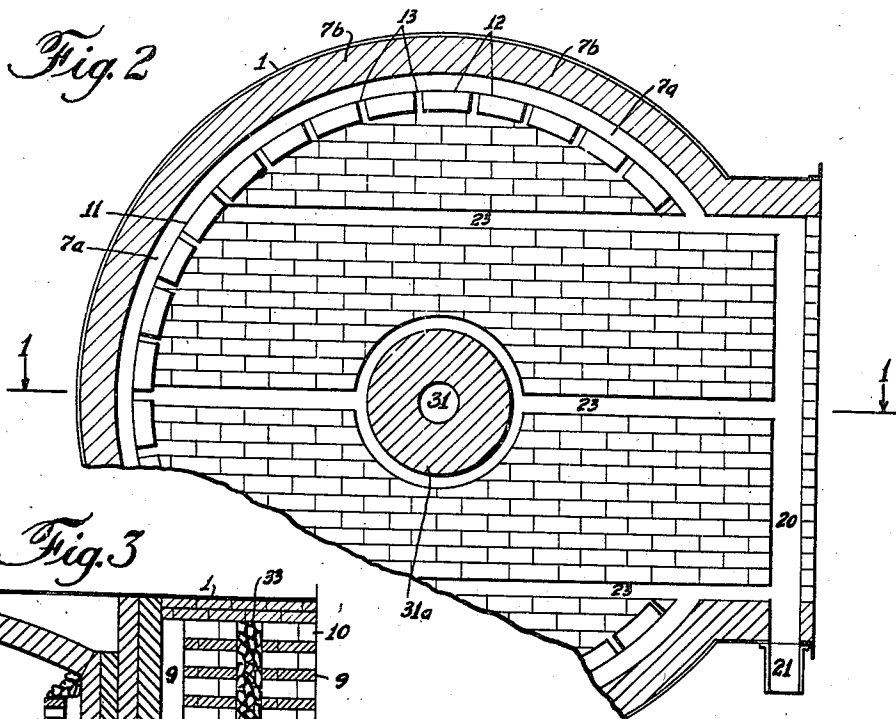
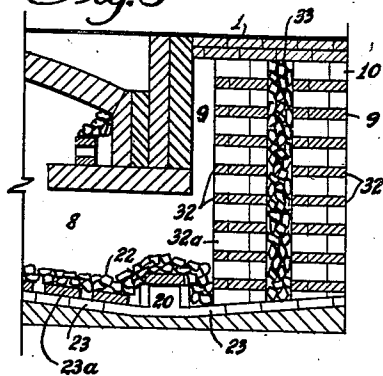


Fig. 3



INVENTOR

John E. Greenawalt.

Nov. 11, 1941.

J. E. GREENAWALT

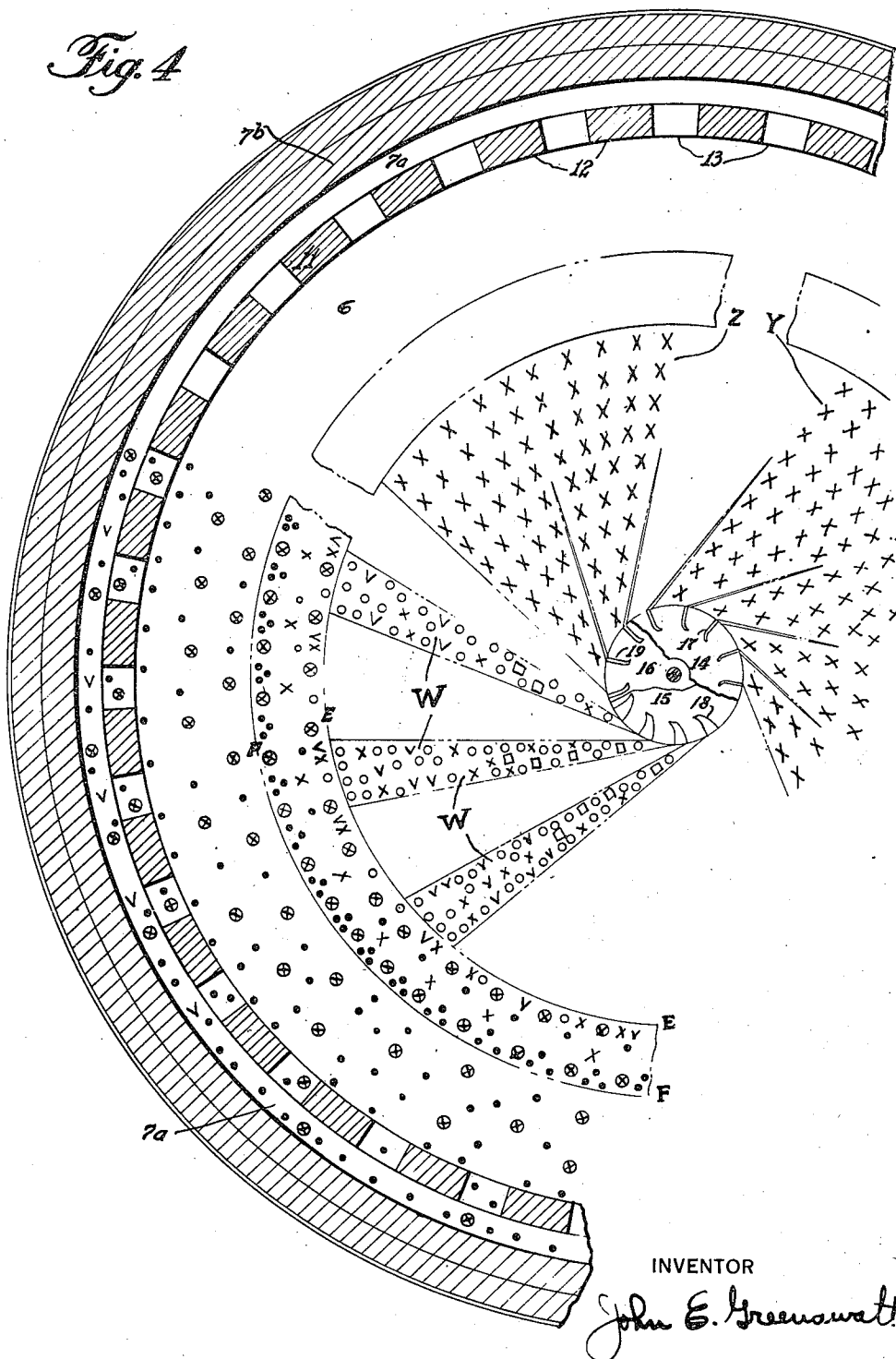
2,261,995

METHOD OF BURNING BLACK LIQUOR

Filed July 8, 1938

3 Sheets-Sheet 2

Fig. 4



INVENTOR

John E. Greenawalt

Nov. 11, 1941.

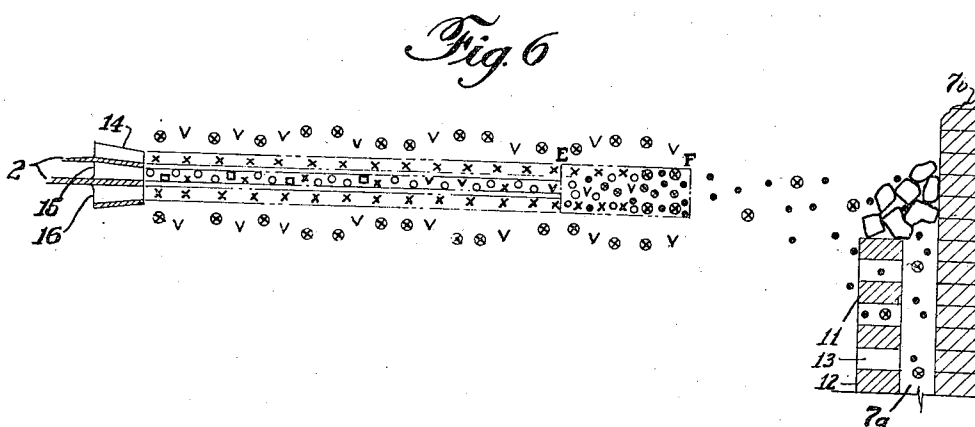
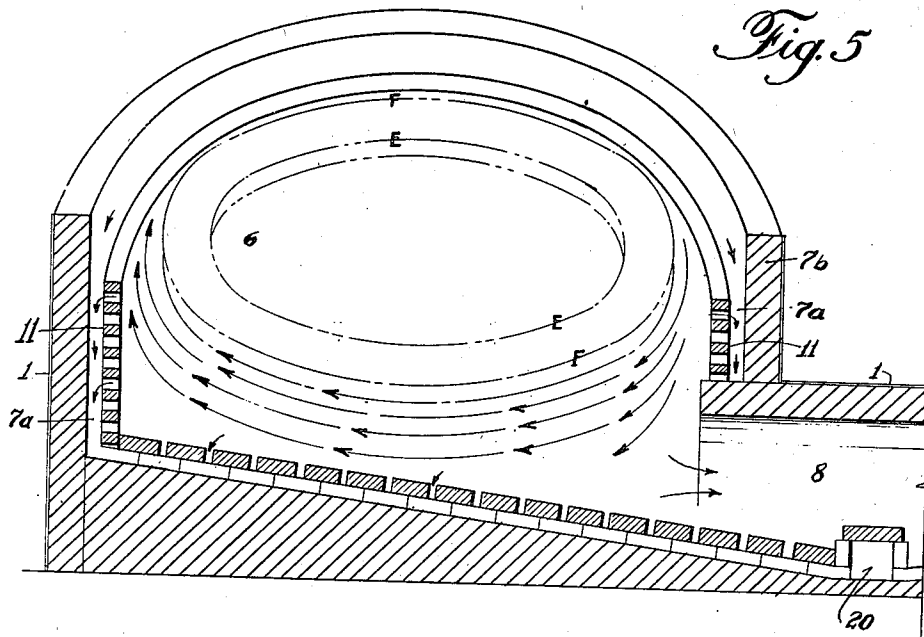
J. E. GREENAWALT

2,261,995

METHOD OF BURNING BLACK LIQUOR

Filed July 8, 1938

3 Sheets-Sheet 3



INVENTOR

John E. Greenawalt

UNITED STATES PATENT OFFICE

2,261,995

METHOD OF BURNING BLACK LIQUOR

John E. Greenawalt, Bronxville, N. Y.

Application July 8, 1938, Serial No. 218,144

6 Claims. (Cl. 23-48)

This invention relates to the method of recovering incombustible material in a molten state by burning in a furnace the combustible portion of a fuel such as consists of combustible and incombustible materials.

The invention will be described with reference to its application to the burning of waste black liquor, a by-product obtained in the manufacture of paper pulp, for the recovery of the incombustible soda compounds in molten state therefrom; but this invention is applicable to other products consisting of combustible and incombustible materials, especially when the recovery of valuable incombustible materials is of importance.

For instance, this invention is applicable to the burning of powdered coal and recovering therefrom the incombustible ash in a molten condition and thereby eliminating the objectionable "fly ash" which is discharged into the atmosphere by most of the present methods of combustion of such fuel.

Another adaptation of the invention would be in the smelting of ores, especially the ores containing a certain percentage of sulphides in which the combustion of the sulphur and the oxidation of the metals produce sufficient heat to convert the incombustible portion of the charge to a molten condition, whereby the volatilization loss of valuable metals is reduced to a minimum.

In the manufacture of paper pulp, only about 50% of the wood entering the process is cellulose, the valuable ingredient available for pulp; the remainder consists approximately of 30% lignin, 16% carbohydrates, 3.3% rosin and fats; all of which are dissolved by chemical solution during the cooking process. The liquor resulting from the cooking process is known as waste "black liquor" and contains about 50% of the wood entering the process, that part of the wood having the highest fuel value. This "black liquor" is produced in large quantities in the alkaline processes and contains all the valuable soda compounds necessary for carrying out the processes. As it comes from the digesters, where the cooking process is carried out, it contains about 16.4% solid matter and 83.6% water, and will test 11° Bé. at 60° F. In order to utilize this liquor for the soda recovery processes it is subjected by evaporation to varying degrees of concentration before being submitted to the recovery process, that is, the process of recovering the valuable soda compounds. In some instances the concentration is conducted to the point where the liquor will contain 70% solids and 30% of

water. Obviously, the greater the degree of concentration, the greater is the percentage of solids in the liquor and the less the percentage of water, and therefore, the combustibility of the liquor is greatly increased as the concentration is increased. In practice, however, many obstacles are encountered with high concentration, due to the high temperature required to keep the mass liquid and the strong tendency to deposit carbon and carbon compounds upon the evaporating surfaces.

As far as known, two methods for burning the combustible constituents of the black liquor and recovering the valuable incombustible soda compounds are in use at the present time. In one, the liquor is fed into one end of a revolving cylinder having a fire box at the discharge end and in passing through this rotary furnace, the water is evaporated, the volatile hydrocarbons burned and the soda, mixed with a large percentage of carbon, called char, is discharged from the furnace and is known as "black ash." This "black ash" was treated in one of two ways. In the soda recovery process, this black ash is subjected to a leaching process whereby the soda is dissolved and the char discharged as a waste product. In the sulphate process, this black ash is discharged into a smelting furnace where the char is burned and the soda recovered in a molten condition. In the other of the aforesaid methods, the black liquor is sprayed into a combustion chamber and the water evaporated and some of the hydrocarbons burned and a large quantity of char is deposited on either the bottom of the furnace or on the side walls of the furnace from which it drops to the bottom of the furnace. However, in the case of either method, the resulting mixture of char and soda is then subjected to a distinct and separate step of smelting with an independent blast of air.

The improved method of my invention is the first instance where black liquor is treated in one single step for the recovery of the soda and the reclamation of the heat value of the fuel; that is so say, it is the first time black liquor has been burned successfully, and the soda recovered by initiating combustion of the combustible constituents and completely finishing it and producing molten soda in a single definite and continuous step. The relatively large percentage of water present in this black liquor, the large amount of incombustible material contained by it and its low calorific value has made the accomplishment of this impractical with the methods heretofore used.

The present invention includes:

1. A method of recovery in which the incombustible material leaves the zone of combustion in a molten state and flows into a quiescent zone where the molten incombustible material is gathered and collected.

2. A method of recovery in which the incombustible molten material is separated from its turbulent zone of combustion and directed to a non-turbulent zone where it is readily collected.

3. A method of recovery in which the molten incombustible material after it has been so collected, is protected from the turbulent flow of products of combustion and then discharged from a common discharge opening in the furnace.

4. A method of recovery in which other finely divided particles of molten incombustible material having been carried along by the hot products of combustion, are made to strike against stationary surfaces where the molten particles coalesce on these surfaces and flow by gravity to a common discharge from the furnace.

5. A method of recovery in which the finely divided particles of molten incombustible material are subjected to the action of a separation chamber where the products of combustion still carrying some of the molten particles are separated therefrom, and in which the remaining molten incombustible material is made to flow into quiescent channels to a common discharge nozzle.

6. A method of recovery of molten incombustible material in which, preferably, the combustion takes place in a combustion chamber under pressure above atmospheric whereby the products of combustion are caused to flow more uniformly through the furnace. This pressure also forces some of the hot products of combustion to accompany the molten incombustible material as it flows through the quiescent zone of the combustion chamber and separation chamber. These products of combustion keep the molten incombustible material heated so that it remains molten until it is recovered from the furnace.

To carry out these methods the following description aided by the examples shown in the drawings will describe the manner of carrying out the same, and the invention will be finally pointed out in the claims.

In the accompanying drawings are shown mostly diagrammatically such parts of the furnace with which the invention is more directly concerned. Actually the furnace consists of a combustion chamber, a separation chamber and the usual type of boiler. As the function of the boiler is to abstract the heat from the products of combustion and as almost any type of boiler can be adapted for use with this invention, the drawings show diagrammatically only the combustion chamber and separation chamber in which the burning of the combustible part of the products to be treated and the recovery of the molten incombustible part takes place.

Referring to the drawings:

Fig. 1 is a longitudinal cross section through the combustion chamber of a furnace along the line 1—1 of Fig. 2. It also shows the flue through which the products of combustion leave the combustion chamber.

Fig. 2 is a plan view of cross section 2—2 of Fig. 1 looking in the direction of the arrows, and shows the construction of the floor and the collecting troughs of the combustion chamber for

the guidance of the molten incombustible material.

Fig. 3 is a vertical cross section through the flue and separation chamber lying beyond the flue.

Fig. 4 is a diagrammatic representation of the method in which black liquor, for example, with primary and secondary air are propelled into the combustion chamber. It also shows diagrammatically the zone of combustion, and also the method in which the molten material under turbulence while the combustion action takes place is directed to a quiescent zone for collecting the molten material.

Fig. 5 is a diagrammatic representation of the zone of combustion within the combustion chamber and shows diagrammatically the whirling products of combustion accompanied by the molten particles as they leave the turbulent zone of combustion and enter the quiescent zone, some of the particles passing through the flue.

Fig. 6 is a diagrammatic representation to an enlarged scale of the method of propelling black liquor, for example, primary and secondary air into the combustion chamber, the method of burning the same and the method of collecting and recovering the incombustible molten particles thereof.

Similar parts bear the same numerals and designations in the various figures.

In the drawings, and more particularly Fig. 1, an outer airtight furnace wall 1 encloses the furnace. In the embodiment, three superimposed fans for centrifugally propelling the product to be treated, with primary and secondary air into the combustion chamber are shown at 2, the intermediate fan propelling the product to be treated mixed with primary air and the upper and lower fans propelling secondary air for the complete burning of the combustible part of the product to be treated.

The circular combustion chamber 6 is lined with refractory bricks 7. These are preferably chrome bricks and form the refractory material protecting the outer walls of the furnace. A short connecting flue 8 connects the combustion chamber 6 with the separation chamber 9 where one is desired to be used, such chamber 9 being shown in Fig. 3. The products of combustion leaving the combustion chamber 6 pass through the flue 8 into the separation chamber 9, where they flow through the reticulated walls 32 of open brick work and through a zone of broken chrome blocks 33 arranged between the reticulated walls 32. After flowing through this separation chamber the hot products of combustion flow out of the separation chamber at 10 and pass into a boiler of known construction.

The boiler is not shown in the drawings but can be of the ordinary type for producing steam, the exit end 10 of the separation chamber through which the hot products of combustion pass can be easily changed to correspond to the entrance opening of any particular kind of boiler. In this boiler, the heated products of combustion are used for producing steam, in a manner well known and forming no part of this invention.

To rotate the fans 2, a vertical shaft 3 is provided and extends downwardly and upon it the fans are mounted, and this shaft also extends vertically upward to a coupling 4 for coupling the shaft 3 with a motor 5. The upper fan 14, the middle fan 15 and the lower fan 16 are superimposed, and the free zone of combustion

E—F is produced thereby as shown in Figs. 1 and 4.

In Fig. 4 the three fans are diagrammatically indicated and in broken away fashion. A part of the upper fan 14 shows part of the circumferentially disposed blades 17. A part of the middle fan 15 shows part of the circumferentially disposed blades 18, and a part of the lower fan 16 shows the circumferentially disposed blades 19. The blades 18 of the middle fan 15 are radially disposed at their exit ends and have a considerable thickness at exit. As this fan propels fuel and primary air into the combustion chamber the primary air containing atomized fuel will leave the fan in the form of jets of rectilinear cross section, the horizontal sides of which jets are very much longer than their vertical sides. The fans 14 and 16 propel secondary air. The atomized fuel of the middle fan 15 therefore presents a large surface to the adjacent secondary air propelled by fans 14 and 16. The blades 17 of the upper fan 14 and the blades 19 of the lower fan 16 are also radially disposed at their fan peripheries but are quite thin so that the secondary air propelled into the combustion chamber by these two fans enters the chamber as continuous flat ring-like layers of air, one layer immediately above and the other layer immediately below the jets.

The primary air admitted to the middle fan 15 and the secondary air admitted to the upper fan 14 flows from atmosphere through the opening 29 into the interior of casting 30 as shown in Fig. 1. The secondary air supplied to the lower fan 16 is admitted from atmosphere into the conduit 31 in the center post 31a of the combustion chamber 6. The opening through the center post is preferably constructed with means for water cooling as is also the cast steel parts of the castings exposed to high heat surrounding the driving shaft of the burner. The waste black liquor as it comes is admitted through regulating valve 26 into the pipe 25 leading it to the casting 28 where it is fed to the intake of the middle fan 15 of the burner through the cylindrical opening of casting 28 shown in Fig. 1. The valve 27 is a valve for admitting fuel oil for starting up the furnace when it is cold.

A cylindrical reticulated wall 11 made preferably of chrome blocks of open checker work construction is positioned inside of the vertical cylindrical refractory side wall 7b of the combustion chamber 6 with a clearance space 7a of about one inch between the checker wall 11 and the refractory side wall 7b of the combustion chamber. The chrome blocks 12 are placed so as to have spaces 13 between each of the chrome blocks thereby forming a wall 11 of open checker work construction.

The function of the space 7a between the cylindrical wall 7b and the checker wall 11 is for the protection of the molten incombustible material from the heat of the furnace and also from the turbulence of the gases within the combustion chamber. A very high percentage of the molten material recovered is collected at the point where, immediately after combustion, some of the products of combustion carrying atomized molten material is thrown against the wall 11, where the atomized molten material coalesces and wets the surface of wall 11. The molten material accompanied by a small amount of the hot gases passes through the openings between the bricks in the wall 11 and enters the relatively quiescent space 7a above referred to.

The floor of the combustion chamber is lined with refractory material, also preferably of chrome brick, and the floor slopes toward the molten material collecting conduit 20 positioned at the far end of the flue connecting the combustion chamber 6 with the separation chamber 9 as shown in Figs. 1, 2 and 3. In the floor of the combustion chamber are a number of troughs 23 covered partially with chrome bricks 23a, upon which a covering of broken chrome blocks 22 extending over the entire floor is arranged. The molten material that trickles through the broken chrome blocks 22 in the floor of the combustion chamber finds its way into the troughs 23. In these troughs 23, the molten material flowing in the space 7a between the vertical cylindrical reticulated wall 11 and the cylindrical refractory side wall 7b is collected and led to the conduit 20 as shown in Figs. 1 and 2. It will be noticed that the molten material in all these troughs 23 is protected from the direct action of the gases within the furnace. The broken chrome layer 22 in the bottom of the furnace also functions for the collection of the molten material and after it has trickled through the spaces between the broken chrome blocks, it is obvious that it also is protected from the direct heat of the furnace and the highly turbulent gases within the furnace, thus the troughs 23 also provide a quiescent space within the furnace, separated from the turbulency within the combustion chamber 6.

The separation chamber 9 forms an extension of the flue 8 and consists of four walls, a top, two side and bottom walls, with an open inlet and outlet. Transverse thereto are two rectangular vertical chrome brick walls 32 of checker work construction with a vertical partition of broken chrome blocks 33 between these two walls. The floor of the separation chamber is similar in construction to the floor of the combustion chamber. It slopes toward the molten material collecting conduit 20 and contains a number of troughs 23 leading into conduit 20 as shown in Fig. 3. The hot products of combustion containing some of the molten material in a more or less atomized state flow from the combustion chamber 6 through the open spaces 32a of the checker work construction of wall 32 of the separation chamber 9 where the atomized particles, still carried by the hot products of combustion, coalesce on the broken chrome blocks 33 and flow by gravity through the interstices between the blocks and into the troughs 23 in the floor of the separation chamber. In this separation chamber the last remaining molten particles are collected and the hot products of combustion leave the separation chamber 9 and enter the boiler substantially free from molten particles.

All the molten material collected in the conduit 20 from the combustion chamber and separation chamber of the furnace finally flows out of the furnace through the discharge nozzle 21 as shown in Fig. 2.

The method of operation when black liquor is to be treated is as follows:

When starting up the furnace from cold, the furnace is first heated by burning therein fuel oil. For this purpose valve 26 is closed and valve 27 admits fuel oil to the pipe 25. After the furnace has been heated up valve 27 is gradually closed and valve 26, admitting black liquor, is slowly opened. From practical operation it has been found that it will take about a three hour

period of heating up before the fuel oil valve 27 is entirely closed and the black liquor valve 26 is open to admit the proper quantity of black liquor so that the furnace could operate from then on with the black liquor as the only fuel supplied.

As the black liquor fuel enters the combustion chamber at a temperature of about 200° F. and as the relatively large amount of water in this fuel is immediately subjected to radiant heat from the zone of combustion, the water almost immediately flashes into super-heated steam so that by the time the fuel jets reach the zone of combustion E—F the black liquor fuel has been entirely dehydrated. Upon entering the zone of combustion, the combustible parts of the fuel are consumed and the incombustible parts are molten. As most of the molten particles have retained some of the velocity of motion given to them by the fans, they are carried beyond the zone of combustion in a general horizontal spiral direction and are sprayed against the reticulated wall 11. Against this wall the molten particles commingle and coalesce and flow down the wetted surface of the wall and together with some of the products of combustion they flow through the open checker brick work of this wall and into the quiescent space 7a between the cylindrical reticulated side wall 11 and the inner wall 7b of the furnace. The molten particles thus pass from a turbulent zone to a non-turbulent or quiescent zone and in this quiescent zone the molten particles are protected against the action of the turbulent products of combustion in the combustion chamber. The molten particles flow by gravity through the quiescent space 7a to the floor of the combustion chamber where they are collected in troughs 23 and flow to conduit 20 which leads to the discharge nozzle 21.

Although the larger part of the molten incombustible particles is collected by being sprayed against the reticulated wall 11, some of the fine molten particles are carried by the turbulent products of combustion upon leaving the zone of combustion E—F in a downward spiral vortex motion. This motion of the products of combustion is quite effective in collecting some of the molten incombustible particles of the fuel that have lost their velocity of motion so that they do not carry over to wall 11, and uniting them into droplets having sufficient weight to be precipitated from the moving gases as rain and pass through the broken chrome blocks covering the floor of the combustion chamber and enter the collecting troughs 23 in the floor of this chamber, from which they also reach the discharge nozzle 21.

The products of combustion leave the combustion chamber through flue 8 and for the purpose of collecting a relatively small amount of very fine molten particles, which may still be carried by the products of combustion through flue 8, a separation chamber 9 is provided. In this chamber the broken chrome blocks forming the reticulated partition 33 cause separation of the molten material from the combustion gases. All this molten incombustible material (the soda compounds in the case of black liquor) ultimately find their way into the troughs 23 in the floors of the combustion chamber and separation chamber, from where they flow into the collecting conduit 20 and out of the furnace through the nozzle 21.

There are therefore three ways in which the molten incombustible material of the fuel is collected. The larger part of the molten incombustible

particles is sprayed against the reticulated wall 11 by having retained some of the initial velocity given to the fuel by the fuel burner fans; a smaller part of the molten particles which was not carried as far as the reticulated wall is carried by the turbulent products of combustion and is precipitated as rain to the bottom of the combustion chamber; and a still smaller part of the molten incombustible particles is collected in the separation chamber by the reticulated partition 33. In all of the three ways just referred to the free combustion zone ultimately strike a stationary wall of refractory material having interstices through which the molten particles pass and in doing so leave a turbulent zone and enter a quiescent zone accompanied by a small amount of products of combustion and where the molten particles are protected from the direct radiant heat of the combustion zone and are finally collected by gravity and flow into a common discharge from the combustion chamber.

It is seen that the improved method differs from the art hereinbefore referred to in that instead of having the fuel particles impinge against some stationary part of the furnace either before or during combustion, or instead of having the combustion take place at or in proximity to the burner itself, the combustion zone is entirely free from the furnace wall but the latter spaced at a predetermined distance from the combustion zone in order that all the combustible particles may be consumed in the free combustion zone but that the incombustible particles, which are molten in passing through the free combustion zone, will, due to the velocity originally imparted to the particles by the fan, be carried from a turbulent to a quiescent zone in which the particles coalesce and drop by gravity into collecting troughs that lead to a common discharge from the combustion chamber.

For further exemplification, referring to the diagrammatic representation in Fig. 4, it shows a cross section in part of the cylindrical combustion chamber in plan view. Segments of the flat ring-like combustion zone are shown between the inner boundary E and the outer boundary F of this zone. The secondary air propelled by fan 14 immediately above the fuel jets is shown in the form of a ring-like layer Y and the secondary air propelled by fan 16 immediately below the fuel jets is shown in the form of a ring-like layer Z. Only parts of these layers are shown, they are circumferentially continuous. Secondary and primary air is represented diagrammatically and symbolically by the symbol X, whereas the fuel jets consisting of combustible and incombustible fuel ○, water □ and primary air X are represented as leaving the middle fan 15 in the form of flat ribbon-like separated jets W. The water in these jets is quickly changed from a liquid to superheated steam, symbolically represented by V, by the radiant heat from the zone of combustion before it travels very far toward the zone of combustion so that the fuel jets when they reach the zone of combustion are practically entirely free of liquid water. In the zone of combustion the combustible part of the fuel is burned resulting in products of combustion, symbolically represented as ⊗, and in incombustible molten soda particles, symbolically represented by dots (•). The zone of combustion E—F also contains a small amount of unburned air (X) due to the excess amount of air in the secondary air over that which is theoretically required to burn

the fuel. Thus the zone of combustion is made up of X, ⊗, V, and dots (•), that is, unburned air, products of combustion, water vapor and incombustible material. Beyond the zone of combustion E—F are shown incombustible molten soda particles mixed with products of combustion, both of which still have sufficiently velocity to impinge against the reticulated wall 11 where the incombustible soda particles coalesce and find their way into the quiescent zone 7a between the reticulated wall 11 and the refractory wall 7b of the combustion chamber. In this quiescent zone the molten soda particles drop by gravity to the floor of the combustion chamber accompanied by a small amount of products of combustion and superheated steam.

A vertical cross section of Fig. 4 from the center of the combustion chamber outward is shown diagrammatically in Fig. 6 to an enlarged scale. The central jets propelled by fan 15 are accompanied by an upper and lower layer of secondary air propelled from fans 14 and 16 respectively. These two layers of secondary air moving at the same velocity and in similar directions to those of the jets of fuel and primary air form a protecting layer to keep the spent atmosphere of products of combustion existing in the combustion chamber from diluting the fuel jets. The radiant heat from the zone E—F evaporates the water shown by squares (□) in the fuel jet into superheated steam (V) before it has travelled very far toward the zone of combustion. In this zone of combustion the combustible part of the fuel is burned, producing products of combustion shown by the circle enclosing the cross (⊗) and the incombustible soda compounds in the fuel are molten shown by dots (•). Beyond the zone of combustion the molten incombustible soda particles (•) accompanied by some products of combustion (⊗) still have sufficient velocity to traverse the space between the zone of combustion and the reticulated wall 11 to impinge against this wall, where the molten incombustible soda particles coalesce and flow through the open spaces of wall 11 into the quiescent zone 7a between the reticulated wall 11 and side wall 7b of the combustion chamber.

In Fig. 5 the zone of combustion is diagrammatically indicated as lying between the inner boundary E and the outer boundary F. Lines with arrowheads (→) represent diagrammatically the turbulence within the combustion chamber produced by the products of combustion, molten incombustible soda particles, superheated steam and excess air as they leave the zone of combustion. Most of the molten soda in this whirling mass impinges against the reticulated wall 11 and flows into the quiescent zone 7a as explained before, but a part of this whirling mass does not impinge against the reticulated wall 11 but assists in the coalescing of some of the whirling molten incombustible soda particles so that they drop by gravity to the bottom of the combustion chamber where they trickle through the broken chrome blocks at the bottom of the chamber and enter the gathering troughs 23 in the floor of the chamber.

The heat value of black liquor depends upon the degree of concentration and various other factors. When evaporated to complete dryness, the resulting solid mass will contain an average of about 6500 B. t. u. per pound and the furnace temperatures attainable depend upon the degree to which the concentration is carried out. From actual furnace operation, I have obtained the

following results with liquor of the following concentration:

	°F.
37° Bé. at 60° F_____	2450
35° Bé. at 60° F_____	2200
33° Bé. at 60° F_____	2020
32° Bé. at 60° F_____	1910

The 37° liquor contained 60% solids and 40% water, while the 32° liquor contained 50% solids and 50% water and about 3250 B. t. u. per pound.

The problem, however, is not one of simple combustion, but is complicated by the soda recovery which is directly affected by the temperature of the furnace. The higher the temperature of the furnace, the greater is the loss of soda by volatilization, and also the destructive action of the molten soda on the refractory material of the furnace increases with the temperature of the furnace. Sodium carbonate melts at 1650° F., but for smooth and continuous operation, I prefer to control the furnace to maintain a temperature of about 2000° F. which can easily be obtained with liquor concentrated to 33° Bé. at 60° F. and when operating under these conditions, I have obtained a soda recovery of 93.6%.

I have found that the control of the furnace atmosphere is extremely important and with a method forming my invention, it can be maintained at any desired condition, within certain ranges. For example, the furnace was operated for long periods with a neutral atmosphere, that is, the analysis of the gases leaving the furnace showed neither free oxygen nor carbon monoxide. The furnace was also operated over a long period with a reducing atmosphere in which the carbon monoxide was maintained at from 2 to 3% and no oxygen, as shown by actual analysis of the gases leaving the furnace. This ability to maintain a definite reducing atmosphere is very important in the sulphate process for a high percentage of soda recovery; as in this process, the soda is recovered in the form of sodium sulphide instead of sodium carbonate recovered in the soda process and the maintenance of a slightly reducing atmosphere is decidedly advantageous.

I have also found that excellent results are obtained with the furnace when the furnace is operated under a pressure of preferably 9 or more inches of water above atmosphere. The benefits of maintaining the pressure in the furnace are manifested with as little as 2 inches of water pressure and become more pronounced as the pressure is increased. This pressure in the furnace is obtained by forcing the products of combustion through a checker wall of refractory brick and also a column of broken brick, preferably a refractory brick known as chrome brick. Also, the entire brick work of the furnace is encased in an airtight steel casing. By maintaining a pressure above atmosphere within the furnace, the gases pass through the furnace with great uniformity and the tendency of the gases to carry fine particles of soda with them is greatly minimized. A pressure above atmosphere within the furnace is also highly beneficial in keeping the soda trough through which the molten soda runs from the furnace at a temperature well above the temperature required to keep the soda in a molten condition. This is due to the fact that a small amount of highly heated products of combustion is forced through the trough or channel through which the molten soda flows.

I prefer to deliver the black liquor to the atomizing burner at a temperature not less than 150° F. and preferably from 200° to 212° F., as at the latter temperature the water in the finely atomized liquor as sprayed into the highly heated furnace flashes into steam almost instantly and thereby prepares the combustible material for practical instantaneous and complete combustion. The flashing of the water contained in these fine particles into steam with almost explosive effect still further intensifies the atomization of the fuel particles and thereby intensifies combustion. By observation I have found that practically all the water has been removed from the combustible particles by the time they are a very short distance away from the atomizing zone of the burner.

I have found that smooth and continuous operation of the method can be secured by maintaining a temperature in the furnace of about 2000° F. and that the black liquor need only be concentrated to about 33° Bé. at 60° F. In this condition the black liquor contains about 55% solid matter and 45% water.

When black liquor at a temperature of about 200° F. is pumped into the supply pipe 25, its quantity is regulated by valve 26. Pipe 25 admits the black liquor to casting 28 from which it flows in the form of a thin cylindrical ring-like stream into the inlet of the middle fan 15 of the fuel burner 2. Primary air is also admitted from the space within the casting 30 to the inlet of the middle fan. When this fan is rotated at high speed the primary air atomizes the black liquor fuel at the inlet to the middle fan and the mixture is propelled from the middle fan 15 in the form of a plurality of ribbon-like jets into the combustion chamber. At the same time secondary air from within the casting 30 is admitted to the inlet of the upper fan 14 and secondary air from the conduit 31 is admitted to the inlet of the lower fan 16. As the fan blades of the upper and lower fans are quite thin, the secondary air enters the combustion chamber in the form of flat ring-like layers of air, one layer immediately above and one layer immediately below the fuel and primary air jets. As all three fans have blades of the same diameter at their discharge and as the blades of all fans are radial at exit, the jets of primary air and fuel as well as the adjacent layers of secondary air are all propelled into the combustion chamber at approximately equal velocities and in similar directions. Let us assume that the diameters of all three fans are 18 inches and that the speed of the motor driving these fans is 3600 R. P. M. This gives the fans a peripheral velocity of 282.6 ft. per sec. Let us also assume that the relative radial velocity of the primary and secondary air at exit of the fans is 30 ft. per sec. Then the absolute velocity of the jets and air entering the combustion chamber will be $\sqrt{(282.6)^2 + (30)^2} = 284.2$ ft. per sec. This velocity is considerably greater than the velocity of flame propagation and assures that no burning of the fuel can take place at or near the fuel burner itself. It is only after the jets of fuel and primary air and the adjacent layers of secondary air have decreased in velocity to that of flame propagation, which is in this example approximately 80 ft. per sec., that burning of the fuel can take place. Calculation and observation places this flat ring-like zone of combustion at a diameter of about 9.5 feet for the example in question. In Figs. 1 and 4 there is designated a zone of combustion E—F

having an inner circular boundary approximately at E and an outer circular boundary approximately at F and in the example above quoted the mean diameter of this free zone of combustion would be approximately 9.5 feet. In order to have complete combustion in a free zone, that is away from the burner and the walls of the combustion chamber, the inner diameter of the cylindrical reticulated side wall 11 should be about 13.5 feet, that is, far enough away from the outer boundary of the combustion zone so that there cannot be any flame contact and near enough to this zone so that most of the finely divided particles of incombustible molten material present in the fuel have still sufficient velocity to impinge against this side wall 11.

As the fuel burner consists of fans rotating at high speed, a centrifugal pressure is established at the discharge end of these fans. The amount of this pressure can be obtained from the formula:

$$\frac{p}{d} = \frac{u_a^2 - v_a^2}{2g}$$

in which

p = pressure rise above inlet pressure in lb. per sq. ft.

d = density of air or fuel in lb. per cu. ft.

u_a = velocity at periphery of fan in ft. per sec.

v_a = relative velocity at exit of the fan in ft. per sec.

Taking the example previously chosen of 18 inch diameter fuel burner fans operating at a speed of 3600 R. P. M. and assuming that the density of the air supplied to these fans is d equals 0.077 lb. per cu. ft. and that v_a equals 30 ft. per sec.; the pressure rise

$$p = \frac{[(282.6)^2 - 30^2] \times 0.077}{2 \times 32.2} = 94.4 \text{ lb. per sq. ft.}$$

or

$$\frac{94.4}{144} = 0.66 \text{ lb. per sq. in.}$$

or

$$0.66 \times 27.7 = 18.3 \text{ in. water.}$$

If the pressure of the fuel and air at inlet of the fans of the burner is atmospheric, then a pressure of 18.3 in. of water above atmosphere is created at the exit ends of the fans due to the centrifugal action of the fans. However, this pressure can only be maintained if the exit area from the separation chamber is made quite small, but pressures from 2 to 9 inches of water can easily be obtained with reasonable exit areas from the separation chamber. Naturally, the larger the exit area, the lower will be the pressure maintained.

Introducing the fuel into the combustion chamber in the form of whirling flat ribbon-like jets has a decided advantage over the old method of introducing fuel into the combustion chamber in the form of a solid jet of circular cross section. Let us assume that the fan for introducing the fuel has 16 blades and hence projects 16 flat ribbon-like jets simultaneously into the combustion chamber. Let us also assume that the cross section of each of these jets is in the form of a rectangle 1.75 inches in width and $\frac{1}{4}$ inch in depth. The cross section of these 16 jets will be $16 \times 1.75 \times 0.25 = 7$ sq. in. These 16 jets are in immediate contact with a layer of secondary air both above and below the surface of these jets, that is, $16 \times 1.75 \times 2 = 56$ in. as the perimeter of

the cross section of the jets in contact with the supply of secondary air. If these jets instead of being 16 in number and rectangular in cross section, were combined into one solid jet of circular cross section the jet would be 3 in. in diameter and have a perimeter of 9.4 in. In other words, the 16 jets have approximately 6 times as great an exposed surface than has the equivalent 3 in. single jet. This means that the 16 jets when they reach velocities equal to that of flame propagation are burned very much faster and in a smaller zone of combustion than that of the single jet of 3 inches diameter when it reaches a velocity equal to that of flame propagation. This results in a combustion zone having a higher temperature for the same amount of fuel consumed because actual observations have shown the 16 jets need not be supplied with as much secondary air as must be supplied to a single 3 inch jet in order to have complete combustion of the fuel.

If the fuel jets contain a large percentage of water, as is the case when waste black liquor is used as fuel, this water can be more readily and quickly changed into superheated steam by the radiant heat from the zone of combustion because the 16 flat jets have 6 times as much exposed surface as has the single 3 inch jet, although both have the same quantity of fuel projected into the combustion chamber.

It has also been found advantageous to keep as near a constant furnace temperature of 2000° F. as possible. A lower temperature approaches too closely the melting point of sodium carbonate, which is 1650° F. A higher temperature than 2000° F. would bring about a loss of soda by volatilization. Should the temperature of combustion go above 2000° F. for any reason, a small addition of secondary air would quickly re-establish the desired temperature in the furnace. Increasing the amount of secondary air can be accomplished among other ways by introducing air to the fuel burner fans under a small inlet pressure, thereby increasing the flow of secondary air into the combustion chamber.

It has been found advantageous to have a pressure above atmosphere existing in the combustion chamber and separation chamber. Allowing the products of combustion to flow through the furnace under the influence of an ordinary draft does not insure the products of combustion flowing uniformly through the separation chamber, that is, the products of combustion would find their path of least resistance. However, if the combustion chamber is under a pressure above atmosphere, the products of combustion would be forced to go through all the openings provided in the separation chamber. Creating a pressure in the combustion chamber above atmosphere also forces a part of the hot products of combustion to accompany the molten soda compounds flowing in the various troughs and therefore insures the soda compounds being kept in a molten condition until they are free of the furnace.

The treatment of black liquor has been particularly described. The invention is also applicable to other purposes, as the burning of powdered coal and in the smelting of certain kinds of ores.

Although a separation chamber has been shown as being desirable in the case of utilizing waste black liquor as a fuel, this separation chamber may not be desirable to use when this invention is applied to other processes, or where

the last small part of incombustible material need not be recovered. The flue of the combustion chamber can be connected directly to a boiler of known construction and the separation chamber could then be entirely omitted.

The separation chamber when used acts as a curtained conduit to commingle the liquid particles suspended by flotation in the products of combustion and to collect the same.

The separation chamber is shown in Fig. 3 as having two curtains of refractory brick of checker work construction arranged with broken blocks of refractory material between them. It has been found that the separation chamber in some cases may contain more than one curtain or wall of checker work construction. Hence, the proper choice of the number of curtain walls necessary in the separation chamber depends upon the kind and the amount of incombustible molten material entering the separation chamber.

It will have been noted that the combustion zone of the burner is placed relatively near to the arched top wall of the furnace. It is distant from the vertical cylindrical wall 7b so as to enable all combustible particles to be efficiently and entirely consumed without impingement upon the walls of the combustion chamber. Nevertheless, the walls are sufficiently near to the combustion zone E—F to enable the incombustible particles as liquids, to remain in a molten state at the time they impinge upon the walls. The wall 11 acts as a baffle or barrier against the turbulent interior of the combustion chamber, and provides a quiescent or non-turbulent zone or space at the other side thereof. It also acts as a coalescing gatherer. Thereafter the troughs for the liquid are protected from intense heat yet kept sufficiently heated to maintain the fluidity of the liquid to its discharge nozzle 21. The liquid is collected by gravity action.

In carrying out this method of burning fuel composed of combustible and incombustible materials the structure shown in my copending application, Serial No. 192,680 filed February 26, 1938, to which reference is herewith made, may be used, although other structures may also be used.

While I have illustrated and described the preferred method for carrying my invention into effect, this is capable of variation and modification without departing from the spirit of the invention. I, therefore, do not wish to be limited to the precise method set forth, but desire to avail myself of such variations, modifications and anticipations as come within the scope of the appended claims.

I claim as new:

1. The method of recovering soda from black liquor which consists in horizontally projecting jets of the liquor and separate air jets from a central point substantially radially and circumferentially in respect thereto through a circular zone of radiant heat at a velocity sufficiently higher than that of flame propagation to obtain substantial dehydration of the liquor prior to the time when the velocity of the liquor jets decreases to that of flame propagation, igniting the combustible matter in the residue at the point at which the velocity equals that of flame propagation, burning in the presence of the adjacent air jets while still in free movement due to centrifugal force the combustible matter in a free zone of combustion forming a horizontally disposed circular band, to raise the temperature of the soda con-

tained in the residue above the melting point, and radiate heat back from said circular band along the path of the jets for dehydrating following portions of the jets passing through the circular zone of radiant heat and forward to maintain the soda in a molten state, permitting the molten soda to pass beyond the circular zone of combustion, arresting the molten soda and collecting the same under the force of gravity.

2. The method of recovering incombustible material from a black liquor fuel consisting of combustible and incombustible materials by horizontally and centrifugally projecting from a central point substantially radially and circumferentially in respect thereto through a circular zone of radiant heat jets of atomized fuel of rectangular cross section, mixed with sufficient primary air to permit of igniting the fuel, at a velocity of movement sufficiently higher than that of flame propagation to obtain substantial dehydration and preheating of the fuel prior to the time when the velocity of movement of the jets decreases to that of flame propagation, and simultaneously centrifugally and horizontally projecting secondary air from said central point necessary for the complete combustion of the fuel in two layers one contiguously immediately above and the other contiguously immediately below said jets of fuel at a velocity of movement equal to and in a direction of movement parallel to those of the jets, igniting the combustible matter when the velocity of movement of the fuel jets equals that of flame propagation, burning the combustible matter of the fuel in the presence of the contiguous air jets in a free zone of combustion forming a horizontally disposed circular band to raise the temperature of the incombustible matter above its melting point and below its vaporization point, while still in free movement due to centrifugal force, and radiate heat back towards said central point along the path of the fuel jets for dehydrating and preheating following portions of the jets passing through the zone of radiant heat and forward to maintain the incombustible material in an atomized molten state, permitting the molten incombustible material to pass beyond the free zone of combustion of circular band formation, arresting the free movement of the molten incombustible material and collecting the larger portion of the same under the force of gravity in a relatively quiescent first zone, the remaining atomized molten incombustible material being carried with the products of combustion in a spiral vortex of movement impinging on each other and coalescing to form drops of molten matter, and collecting the said drops in a quiescent second zone, spaced from the first zone.

3. The method of recovering incombustible material from a black liquor fuel consisting of combustible and incombustible materials by horizontally and centrifugally projecting from a central point substantially radially and circumferentially in respect thereto into a combustion chamber maintained under pressure through a circular zone of radiant heat jets of atomized fuel having a rectilinear cross section of much greater width than depth, mixed with sufficient primary air to permit of igniting the fuel, at a velocity of movement sufficiently higher than that of flame propagation to obtain substantial dehydration and preheating of the fuel prior to the time when the velocity of movement of the jets decreases to that of flame propagation, and simultaneously

centrifugally and horizontally projecting under pressure from said central point secondary air necessary for the complete combustion of the fuel in two flat ring-like layers one contiguously immediately above and one contiguously immediately below said jets at a velocity of movement equal to and in a direction of movement parallel to those of the fuel jets, igniting the combustible matter when the velocity of movement of the fuel jets decreases to that of flame propagation, burning in the presence of said superposed and underposed secondary air the combustible matter of the fuel in a free zone of combustion forming a horizontally disposed circular band, to raise the temperature of the incombustible matter above its melting point and below its vaporization point, and radiate heat back towards said central point along the path of the fuel jets for dehydrating and preheating following portions of the fuel jets passing through the circular first zone of radiant heat and forward beyond the same to maintain the incombustible material in an atomized molten state, permitting the molten incombustible material to pass beyond said free first zone of combustion of circular band formation, arresting the free movement of the molten incombustible material and collecting the larger portion of the same under the force of gravity in a relatively quiescent second zone maintained at a lower pressure than that of the combustion chamber, the remaining atomized molten incombustible material being carried by the products of combustion in a spiral vortex of movement impinging against each other and coalescing to form drops of molten matter, collecting the said drops in a quiescent third zone maintained at a lower pressure than that of the combustion chamber, and causing the products of combustion and superheated steam vapor to flow through a flue into a boiler to utilize the available heat energy contained in the products of combustion.

4. The method of recovering incombustible material from a fuel consisting of combustible and incombustible materials by horizontally and centrifugally projecting into a combustion chamber maintained under pressure through a zone of radiant heat jets of atomized fuel having a rectilinear cross section of much greater width than depth, mixed with sufficient primary air to permit of igniting the fuel, at a velocity of movement sufficiently higher than that of flame propagation to obtain substantial dehydration and preheating of the fuel prior to the time when the velocity of movement of the jets decreases to that of flame propagation, and simultaneously centrifugally and horizontally projecting under pressure secondary air necessary for the complete combustion of the fuel in two flat ring-like layers one immediately above and one immediately below said jets at a velocity of movement equal to and in a direction of movement parallel to those of the jets, igniting the combustible matter when the velocity of movement of the jets decreases to that of flame propagation, burning the combustible matter of the fuel in a free zone of combustion to raise the temperature of the incombustible matter above its melting point and below its vaporization point, and radiate heat back along the path of the fuel jets for dehydrating and preheating following portions of the fuel jets passing through the zone of radiant heat and forward to maintain the incombustible material in an atomized molten state, permitting the molten incombustible material to pass beyond the free zone of combustion, inter-

rupting the free movement of the molten incombustible material and collecting the larger portion of the same under the force of gravity in a relatively quiescent zone maintained at a lower pressure than that of the combustion chamber, the remaining atomized molten incombustible material carried by the products of combustion in a spiral vortex of movement impinging against each other and coalescing to form drops of molten matter, collecting the said drops in a quiescent zone maintained at a lower pressure than that of the combustion chamber, causing the products of combustion and the superheated steam vapor to pass through a separation chamber having curtains of broken refractory brick for separating any remaining fine molten particles from the said products of combustion and superheated steam vapor and gathering the said molten particles by gravity in a space maintained at a lower pressure than that of the separation chamber, and causing the products of combustion and superheated steam vapor to flow through the separation chamber into a boiler for utilizing the available heat energy contained in the products of combustion and superheated steam vapor.

5. The method of recovering incombustible material from a black liquor fuel consisting of combustible and incombustible materials, which consists in spraying the fuel from a central point and at a velocity sufficiently greater than flame propagation to prevent its combustion and melting, burning the combustible part of the fuel in a free first zone when the velocity has decreased to that of flame propagation in a circular band zone horizontally disposed from said central point, free of any wall impingement, and at the same time supplying secondary air contiguously above and below said circular band zone and

melting at said circular band zone the incombustible material in the form of molten particles free of combustible material, said incombustible particles having a residual velocity sufficient to move them substantially horizontally outward from the predetermined circular band combustion zone and, without impinging upon any obstruction, to a quiescent second zone free from the turbulence attendant combustion, and arresting the molten particles so as to gather the same.

6. The method of recovering soda from black liquor which consists in horizontally projecting jets of black liquor of 55% of solid matter and about 45% of water, at the temperature of about 200° F., said black liquor having air intermingled therein, at such a velocity that flame propagation does not take place for a distance corresponding to a point where the velocity is such that flame propagation can take place, igniting said liquor when the velocity has been decreased to flame propagation and forming a zone of combustion in a circular band spaced from the source of the jets and spaced from a retaining wall, supplying said ignited liquor with additional air contiguous to the burning band of liquor, said air having a velocity at the band substantially equal to that of the liquor when it is burning in the combustion zone, allowing the velocity of the residue to move the molten soda in the same direction away from the combustion zone, arresting said soda while in motion by said retaining wall in the path of said soda, collecting said soda, and withdrawing the products of combustion below that level at which the liquor was introduced.

JOHN E. GREENAWALT.