FUEL BRIQUETTES FROM SOUTHERN PINE SAWDUST

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ABSTRACT

The object of this investigation was to find a method for the profitable disposal of the large amounts of wood wastes from the saw mills of our Southern States.

As a result of this investigation, a process has been developed for the manufacture of a high grade fuel briquette involving the following steps:

1. The wood waste in the form of sawdust, is preheated to destroy the elasticity of the wood. This preheating also eliminates moisture and considerable combined oxygen and hydrogen from the wood with the result that the weight is decreased about one-third and the heating value per pound almost doubled.

2. The preheated sawdust is then moistened and briquetted hot without addition of a binder. The resulting briquettes are firm and strong enough to stand rough handling and they resist weathering to an extent which should permit shipment and storage if protected from rainfall.

3. The optimum conditions of carrying out the various steps in the process have been determined and a study made of costs of plant and operation for a 20 ton per day plant.

INTRODUCTION

In the production of lumber from the Southern pine the waste is high, probably less than half of the weight of the tree being converted into lumber. Much of this waste is in the form of sawdust and shavings. These are more than sufficient for producing the steam needed by the mills and consequently sawdust burners are in constant operation. In some localities huge piles of sawdust accumulate and at times are a fire menace to the community.

Although a variety of processes have been proposed for the ultilization of sawdust and shavings few have made any appreciable headway on account of the mechanical difficulties involved in the handling of a bulky material of low heat conductivity and the poor financial return due to the low price and uncertain market existing for the chief products recovered from wood waste.

With the increasing costs of fuels and the growing interest in conservation of natural resources, it seemed desirable to make a further effort to obtain a marketable product from this waste material.

BIBLIOGRAPHICAL REVIEW

The methods for the utilization of sawdust may be conveniently classified as follows:

Briquetting of Raw Sawdust Without Binder.

The process employed by the Pacific Coal & Wood Company[2] consists of briquetting the wood waste at a light pressure in a special brick press. The briquettes are bound with baling wire to hold them together

At the chemical works of Carl Feuerlein[3] near Stutgart, the residue from which pharmaceuticals have been extracted is briquetted in an Exter press. The briquettes are a mixture of quebracho, logwood, and fustic with some chestnut and oak.

The Arnold process[4] controlled by Ganz & Company of Ratibor, Upper Silesia, is of some interest. Sawdust is cascaded over steam heated pipes and then over a steam heated plate. The dried sawdust is then briquetted in the Arnold press, a modification of the Exter press. This process has been developed on a commercial scale.

A method[5] recently introduced into Germany known as the "Berner Process" consists in the formation of a "rope" of briquettes. These are made on a light pressure press.

It does not appear however that any of these processes would be feasible for the waste material we are considering.

The Briquetting of Raw Sawdust With A Binder:

While it is true that sawdust has been briquetted with a great variety of binders still, as far as is known, none of these processes have attained any particular importance in this country. Typical processes are as follows: J. Armstrong[6] briquettes a mixture of coal, peat and sawdust with tar. Bunn[7] employs dehydrated mineral tar, resins and petroleum pitch for coal, sawdust or other fuels. Hughes and Loveli[8] employ pitch or other hydrocarbons or a carbohydrate as molasses, together with soot for the briquetting of coal, peat, sawdust, etc. Fallet[9] used clay for the agglutination of fine carbon or sawdust.

Briquetting of Charcoal:

The two methods for the conversion of comminuted wood into charcoal and by-products are as follows: (1) Distillation of the finely divided wood with subsequent briquetting of the fine charcoal. (2) Briquetting the wood waste and distilling the briquettes.

The Seaman process[10] is typical of the first class. The finely divided wood is distilled in a revolving retort provided with special charging and discharging devices. It is said that the distillation is completed within three minutes. The resulting charcoal is then briquetted with wood tar.

Processes typical of the second class include the unsuccessful attempts of Bergmann, Heidenstamm and others[11] to produce a strong, compact, coherent, charcoal by distillation of sawdust briquettes, the Heidenstamm process[12] of distillation of sawdust briquettes under mechanical pressure, the Hawley process[13] where the sawdust is briquetted at very high pressure (30,000 pounds per square inch) and subsequently distilled at 300 pounds per square inch, and the process employed by the Kingsport Wood Reduction Company[14] at Kingsport, Tennessee. In this process the sawdust is briquetted in a Duryea press at high pressure, and distilled under pressure by a method similar to the Heidenstamm process.

Special Process for the Destructive Distillation of Sawdust and Shavings:

The mechanical difficulties involved in the distillation of sawdust and shavings are very great. Consequently many processes have been proposed to avoid these difficulties as far as possible. In the Stafford process[15] the heat liberated by the exothermic reactions involved in the decomposition of the wood, serves to initiate a fresh charge, the process being continuous.

Blair[16] divides the retort into a series of trays. The sawdust passes from the top of the retort to the bottom, being pushed from each tray by scrappers.

In the Sautelle[17] process the distillation products from the lower part of the charge pass through the upper part.

Halliday[18] carries out the carbonization of sawdust by means of a screw conveyer in a closed and heated retort.

In the Bower[19] retort an endless belt working inside the retort is employed.

Felzat[20] showers the fine sawdust into the retort.

According to Klar[21] sawdust has been used for fuel gas in a special form of gas producer.

Bueschlein[22] distills the fine wood in a special type of rotary kiln. Use is made of the exothermic heat liberated by the decomposition of the dry sawdust for the predrying and preheating of the wood to the temperature of decomposition.

A recently developed method of Mason[23] consists in subjecting the waste wood (chips) to steam at high pressure and then suddenly removing the pressure. The fibre obtained by exploding the chips by sudden release of the pressure is beaten roughly and made into a wall board somewhat similar to Beaver board.

Disadvantages of the Present Processes for Wood Waste Utilization:

Evidence of the fact that the various methods for waste wood utilization are inefficient and are not renumerative is seen in the fact that the sawdust and shavings accumulate in large quantities. According to Beuschlein[22] it has been estimated that the annual waste which is burned in open or closed burners is 500,000,000 cubic feet.

The difficulties encountered in the large scale operation of the various methods for the utilization of waste wood are many. Briquettes made at a moderate or high pressure without a binder are of low heating value, and due to the elasticity of the wood they swell rapidly and disintegrate. It was found that briquettes made from raw sawdust at 7,000 pounds pressure per square inch were excellent when first made but they fell to pieces within six days. Briquettes of this type also disintegrate at once when exposed to water. Briquettes made at low pressure without a binder not only have a low heating value but also have little coherence, it being necessary to bind them together with baling wire. This of course insures additional expense and difficulty in disposing of the wire after the combustion of the briquettes. Briquettes made with a binder are expensive, often burn with much smoke, and at least in certain cases, swell and disintegrate in a way similar to the briquettes made without a binder.

Methods for the production of charcoal by the distillation of sawdust briquettes under mechanical pressure are not promising due to the competition of cheap synthetic methonol and the consequent decline in price of wood alcohol, which in the past has been one of the most important by-products, as well as to the uncertain market and low price of charcoal in this country. Due to the fact that special facilities are necessary for the briquetting and the application of the pressure during distillation, the cost of the charcoal made by processes of this kind would probably be considerably above that of charcoal made in the usual way by carbonizing of cord wood. A method of this kind might possibly be operated on a commercial scale at profit in localities where there was a specific demand for absorbent charcoal although the production of charcoal of this type has added disadvantage of requiring a very high pressure[13] for the briquetting of the sawdust.

The disadvantages of the various processes for the distillation of raw sawdust are many. Sawdust and shavings derived from soft wood are much poorer in terpines than the parent wood[21] and are consequently unsuited for the production of turpentine. Further, the powdery nature of the resulting charcoal is a serious disadvantage[21] in view of the fact that the consumption of fine charcoal is relatively small. It is true of course, that the fine charcoal may be briquetted with a binder such as wood tar as in the Seaman process[10], but due to the quantity (thirty per cent) of wood tar required, the briquettes when burned produce a large quantity of acid smoke. The decline in the price of wood alcohol is another unpromising item in processes of this kind.

It is evident that in spite of the fact that many methods have been proposed by which the mechanical difficulties incident to the carbonization of a material as bulky and of as low heat conductivity as sawdust, can be largely overcome, nevertheless these methods are of little commercial value.

The recently developed process[23] (Mason process) for the production of fiber board somewhat similar to Beaver board shows some promise but is of limited application due to the fact that the method can not be applied to the finely divided forms of wood waste such as sawdust and shavings, which are produced in the greatest quantity.

A NEW WOOD BRIQUETTE

It has been seen that few of the processes for the utilization of waste wood show much promise of commercial success. In view of the facts that the carbonization of loose sawdust did not appear to be promising and that there were also serious objections to the various methods of briquetting the charcoal and of distilling the briquetted sawdust, it was thought advisable to study the briquetting of raw sawdust as the field which offered the greatest opportunity.

Briquettes made by compressing raw sawdust at a moderate pressure (6500 pounds per square inch), it was found possess considerable strength when first made but on aging disintegrate rapidly. They also have little resistance to the action of water, submergence for a few minutes, causing complete disintegration. Furthermore, briquettes made with a moderate quantity (three to six per cent) of pitch binder are little better than those made without a binder.

The unsatisfactory behavior of the briquettes mentioned above, suggested the desirability of studying the qualities of briquettes made from saw dust in which the elasticity of the wood had been removed by preheating.

Briquettes made from sawdust which has been treated in this way showed an unexpected resistence to water and to aging and it became apparent that it was possible to produce a briquette of a desirable type without a binder. The record of this investigation is presented below.

EXPERIMENTAL WORK

Preliminary experiments indicated that to remove the elasticity of the wood to the desired degree, it was necessary to preheat the sawdust to 275°C. This temperature is above the range easily obtained by steam and it is obvious that on account of the poor heat conductivity of the sawdust, some method of stirring would have to be used. It was decided therefore to use a rotary retort in the experimental work and to heat it with gas. To avoid ignition of the readily combustible material it was necessary to use external heating.

Consequently a retort, which would hold a convenient quantity of sawdust, was made from an iron pipe twelve inches long and three inches in diameter. The pipe was fitted with caps in one of which were provided two openings, one at the center for a delivery tube leading to the neck of a condenser and the other near the center for a calibrated thermometer. The retort was supported on small chains, or rings. Since it was found that one or two revolutions of the retort per minute were sufficient, and the time of preheating was only forty minutes, the retorts was rotated by hand, a large pipe wrench being employed for the purpose. The retort was heated by several wing top burners.

The remainder of the apparatus was quite simple. The delivery tube of the retort led to a water cooled glass condenser which was connected by an adapter to a flask for collection of the distillate.

The briquetting of the preheated sawdust was carried out in a steel mold six inches long which was provided with a piston seven inches long and one

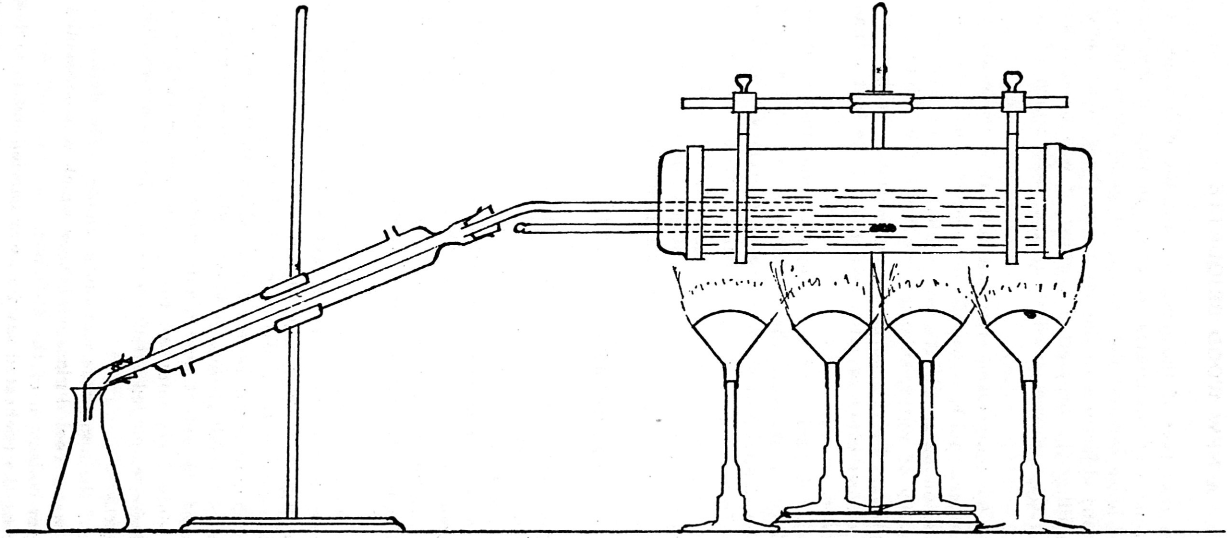

FIG. 1 - EXPERIMENTAL RETORT
SCALE - $\frac{3}{16}$" = 1"

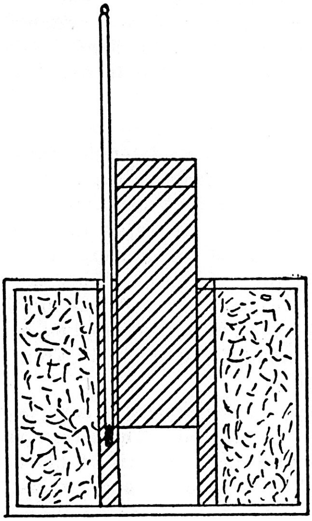

FIG. 2
BRIQUETTING MOLD
SCALE - 3/16" = 1"

and three quarters inches in diameter. A piston of this diameter was adopted after taking into consideration the capacity of the press available for the briquetting and the required briquetting pressure. The mold was also provided with a thermometer well five inches deep. The mold was heated to the desired temperature in a sand bath. The pressure was applied by means of a Richle compound lever press.

Materials and General Procedure.

As mentioned in a following section, briquettes made from sawdust were entirely satisfactory while those made from shavings were of inferior quality. Consequently attention was focused upon sawdust as the material best suited for briquetting purposes, it being assumed that the shavings and waste wood could be used to advantage as fuel in the heating of the sawdust. Analysis of a typical sawdust used is given in Table 1.

TABLE I.

Analysis of Sawdust

Moisture, per cent by weight	Rosin* per cent by weight	Ash, per cent by weight	Size per cent held	Ultimate Analysis per cent by weight (Dry Basis)	
12.33	6.59	0.70	15 by 10 mesh	Carbon	48.9
			54 by 20 mesh	Hydrogen	4.27
			87 by 40 mesh	Nitrogen, Oxygen, etc.	46.83

* Rosin determined by extraction with Ether.

The course of a run was usually as follows:—The retort was filled about three-quarters full of sawdust. This required about three hundred grams. The burners were then turned on and the retort was rotated at the rate of one to two revolutions per minute. Readings of temperature were ordinarily taken every five minutes. When near the end temperature of 275°C. the temperature was taken every minute.

The distillate at 100°C. consisted chiefly of water. At about 170°C. the decomposition of the sawdust began, pyroligneous acid in considerable quantities making its appearance. At 275°C. or close to this point, the temperature suddenly increased while tar made its appearance. This point marked the completion of the run.

The time required for the preheating was about forty minutes. The preheated sawdust was allowed to cool and transferred to a suitable container where it was collected until a large quantity was on hand. The collected material was medium chocolate brown in color, the loss in weight on preheating amounting to thirty-five percent.

The preheated sawdust was thoroughly mixed to insure an uniform product. The mold was then heated to the desired temperature in a sand bath, while the piston was heated to the same temperature in a drying oven. The charge consisting usually of forty grams of preheated sawdust was moistened with a carefully determined quantity of water, thoroughly stirred and also heated in the drying oven to the same temperature as the mold and piston. After allowing sufficient time for the charge to become uniformly heated, it was quickly transferred to the mold where it was lightly tamped, the piston placed in the mold and the pressure quickly applied by means of the press. The briquettes were then immediately removed from the mold. They weighed about forty grams each.

It will be noted that in the above process the preheated sawdust is allowed to cool and then reheated before it is briquetted. The advantages of this procedure on a small scale are that a preheated sawdust of uniform composition can be more easily secured, and there is less danger of insufficient or uneven heating of the charge. An additional advantage in allowing the preheated sawdust to cool is the elimination of the mechanical difficulties involved in the handling of the hot retort.

On a large scale it would probably be desirable to briquette the preheated sawdust while it was still in the heated condition. A number of runs were carried out in this way. The preheated sawdust was allowed to cool down nearly to the desired temperature, (100°C.), the required quantity of water was added with stirring, and the material transferred to the hot mold where it was briquetted in the usual way. Results secured in this way were entirely satisfactory.

Temperature of Preheating.

As previously mentioned, briquettes made from raw sawdust are excellent when first made but soon swell or crumble. The object of the preheating is to remove the elasticity of the wood, or to so reduce it, that briquettes can be produced which do not seriously deteriorate on aging for a reasonable period. Further advantages of the preheating are the increased resistance of the briquettes to water, an increase in the heating value and a reduction in the quantity of smoke. The latter is due to the vaporization of part of the rosin of the wood during the preheating.

The best temperature for the preheating was the object of considerable investigation. It is evident that as the temperature of the preheating increases and the elasticity of the wood is removed to a greater degree there should be a corresponding increase in the aging and weathering qualities and in the heating value of the briquettes and a decline in the quantity of smoke. In other words the quality of the briquettes should steadily increase as the temperature of the preheating increases. This being the case, the temperature of the preheating should be as high as possible. The upper limit to the temperature of preheating is the point where the natural binder of the wood has been destroyed to such an extent that the briquettes are weak and fragile. At this point the sawdust loses its wood like characteristics and takes on the qualities of charcoal. Preheating above this point was undesirable since a binder would then be required in briquetting and the briquettes could not be made economically.

The proper temperature for the preheating was determined by examination of briquettes made from sawdust preheated to 170°, 200°, 225°, 250°, 275°, and 300°C. These temperatures were selected for the following reasons: Preliminary experiments indicated that there was little effect on the elasticity of the wood below 170°C., the point where the decomposition of the wood starts. Above this point the elasticity slowly declines, its removal being complete at about 300°C. Therefore, 170°C. was taken as the point where the decomposition of the wood begins and the decrease in the elasticity becomes evident. Further experiments indicated 275° as the temperature at which exothermic decomposition of the wood begins. This point may be considered as marking the conversion of wood into charcoal. The temperature of 200°, 225° and 250° divide the range between 170° and 275° into four approximately equal parts and were therefore chosen as intermediate points. The results of these tests are given in Table II.

TABLE II.

Comparison of Briquettes Made From Sawdust Preheated to Various Temperatures

	Briquetting Pressure (lbs. per sq. inch)	Drop Test of Briquettes when made	Drop Test* of Bri quettes after aging for six weeks	Results of submergence in water for two hours
Raw Sawdust	6500			Goes to pulp
Sawdust Pre heated to 170°C.	6500	96	39	Goes to pulp
Sawdust Preheated to 200°C.	6500	96	61	Swells to 3 times original length
Sawdust Preheated to 225°C.	6500	95	70	Swells to 2.5 times original length
Sawdust Preheated to 250°C.	6500	86	75	Swells to 1.4 times original length
Sawdust Preheated to 275°C.	6500	85-90	81	Swells slightly no crumbling
Sawdust Preheated to 300°C.	6500	25	20	Little change

Examination of Table II discloses the fact that the strength of the briquettes is inferior above 275°C. Briquettes made from sawdust preheated to 275°C. are slightly weaker when first formed than those made from sawdust preheated to lower temperatures. On the other hand, these briquettes, as will be shown later are sufficiently strong for all practical purposes. They also possess the maximum resistance to aging and weathering agencies for

* The values under the Drop Test in Table II refer to the percent by weight held by a one inch screen when the briquettes are allowed to fall five times on a cement floor from a height of six feet.

temperatures not exceeding 275°C. Consequently 275°C. was selected as the best temperature for the preheating. This temperature is also a natural stopping place since the exorthermic decomposition of the wood which is the cause of uneven heating and over heating of the sawdust, begins at about this temperature. It will be shown later that the selection of this temperature leads to the production of briquettes wih a heating value nearly double that of raw wood.

Sawdust preheated to 275°C. is dark brown in color. The loss in weight on preheating is thirty-five percent (wet basis). Typical analyses of the raw sawdust and of the preheated product on a dry basis are given below.

	Raw Sawdust	Preheated Sawdust
Carbon	48.9 per cent	52.03 per cent
Hydrogen	4.27 per cent	5.23 per cent
Oxygen, Nitrogen, etc.	46.83 per cent	42.74 per cent

Distillate Recovered from the Preheated Sawdust.

This distillate is of little value. It consists chiefly of water with small quantities of alcohol, acetone, and acids of the acetic acid series. The latter which are present in the greatest quantity, were determined by the method of Grotlisch[24]. The total acids present amount to 4.6 per cent of the distillate or 1.60 per cent (wet basis) of the sawdust preheated. With the present method of refining, it is doubtful if the recovery of these acids would be profitable. The distillate contains little if any tarry material or other toxic bodies. Consequently its disposal would not present a problem.

Size of Preheated Wood Best Suited for Briquetting.

The waste wood available at a mill, exclusive of cord wood, consists mainly of sawdust and shavings. A large part of the shavings is generally used as fuel for boiler purposes. Hence it appears that the problem with which we are concerned is essentially one of the utilization of sawdust. This is particularly true in view of the recently developed process[23] for the production of artificial wood board from the coarser forms of wood waste.

However, in order to determine experimentally the relative value of sawdust and shavings for briquetting purposes, sawdust and shavings of as near the same composition as possible (both were made from the same lumber) were each preheated and briquetted in the usual way. The briquettes from each were then tested by the method developed in a later section (page 17.) The results are given in Table III.

TABLE III.

Comparison of Sawdust and Shaving Briquettes

	Size (Per cent Held)	Per cent Moisture	Per cent Rosin	Drop Test* when first made (per cent held)	Drop Test* after six weeks (per cent Held
Sawdust	10 x 10 mesh 51 x 20 mesh 81 x 40 mesh	12.33	6.59	93	81
Shavings	13.3 x 4 mesh 50 x 10 mesh 78 x 20 mesh	12.33	6.65	80	15

*The values recorded under the Drop Tests refer to the percent by weight held by a one inch screen when the briquettes are allowed to fall five times on a cement floor from a height of six feet.

The rapid disintegration of the shaving briquettes on standing largely eliminates their commercial possibilities since they could not be successfully shipped. In view of the fact that several other samples of shavings gave similar results, the shavings were eliminated from further consideration.

Moisture Content of the Preheated Sawdust Best Suited for Briquetting.

The preheated sawdust is perfectly dry. Such material, possibly due to friction between the particles, or to the presence of air does not briquette particularly well. Addition of water sufficient to produce perceptible dampness in the preheated sawdust leads to the development of a stronger and more compact briquette.

In the determination of the proper quantity of water, sufficient water was first added to produce perceptible dampness of the preheated sawdust. This required four per cent by weight. The quantity of water was then varied on both sides of this point. The briquettes were made in the usual way in the various runs that followed. Sufficient briquetting pressure (6500 pounds per square inch) was employed to give a high grade briquette. The results of these runs are summarized in Fig 3.

It will be seen that the addition of a small quantity of water appreciably increases the strength of the briquettes. The strength as determined by the Drop Test, increases directly as the water increases until the latter reaches four per cent. The preheated sawdust is perceptibly damp at this point. Further increase in the water has no apparent effect. As will be shown later, the presence of a large excess of water has a tendency to weaken the briquettes. In view of the fact that an appreciable improvement in the strength of the briquettes was noted up to four per cent, this quantity was employed in all further work.

Note: The quantity of water in Figure 3 refers not to the amount added, but to the amount retained after heating the sawdust to the briquetting temperature. This is about seventy-five per cent of the amount added.

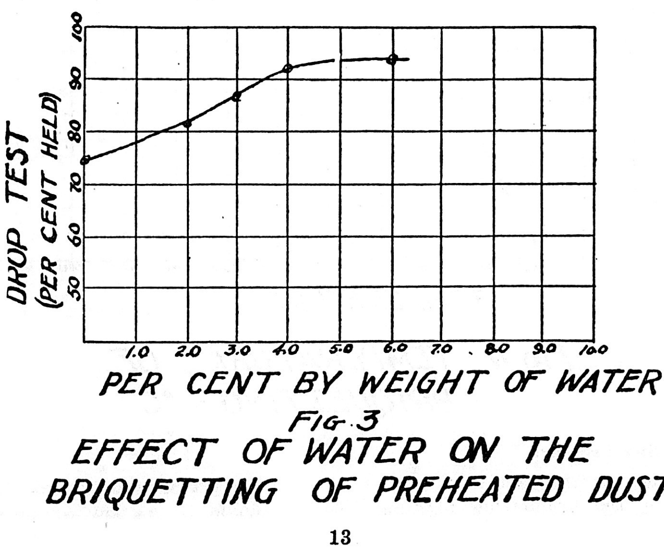

FIG. 3
EFFECT OF WATER ON THE BRIQUETTING OF PREHEATED DUST

Temperature of Briquetting.

Preliminary experiments on the briquetting of preheated sawdust at a moderate pressure (6500 pounds per square inch) were carried out at room temperature. The results proving to be unsatisfactory, hot briquetting was tried. The value of this procedure was indicated at once.

Before the best temperature for the briquetting could be definitely established, it was necessary to determine the proper pressure for the briquetting. As will be shown in the following section, a pressure of 6500 pounds per square inch was adopted. Consequently beginning with a temperature below the point where satisfactory briquettes could be produced, a series of briquettes, using in all cases a pressure of 6500 pounds per square inch, was made at different temperatures. The strength of the briquettes was measured by the Drop Test. The results secured in this way are given in Fig 4.

It will be noted that the briquettes made at 75°C. were rather weak. Below 75°C. they had very little strength or coherence. As the temperature is increased above 75°C. there is a very rapid increase in the strength of the briquettes. This reached a maximum at 100°C. Above 100°C. there was a very slight and gradual decline in the strength of the briquettes. This may be due to the partial or complete evaporation of the water previously added to the preheated sawdust.

Accordingly, 100°C. was taken as the best temperature for the briquetting. Not only are briquettes of the maximum strength produced at this temperature but there is the further advantage that a steam heated briquetting press can be most conveniently maintained at this temperature since steam at atmospheric pressure can be employed.

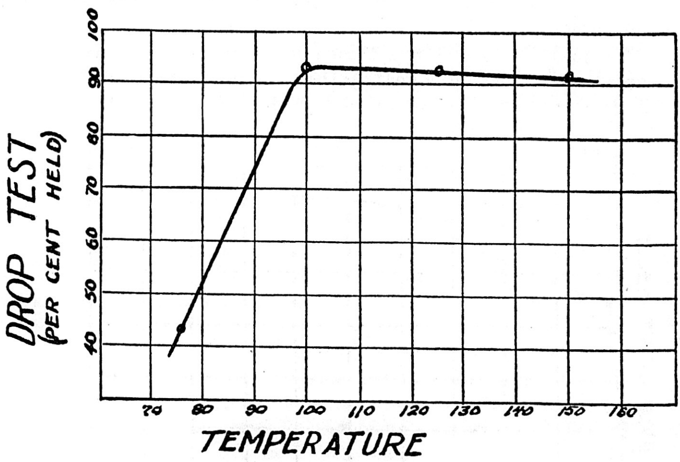

FIG 4 - TEMPERATURE OF BRIQUETTING - °C

Briquetting Pressure.

In view of the fact that briquetting at high pressure is comparatively expensive, the briquetting pressure selected should be as low as possible.

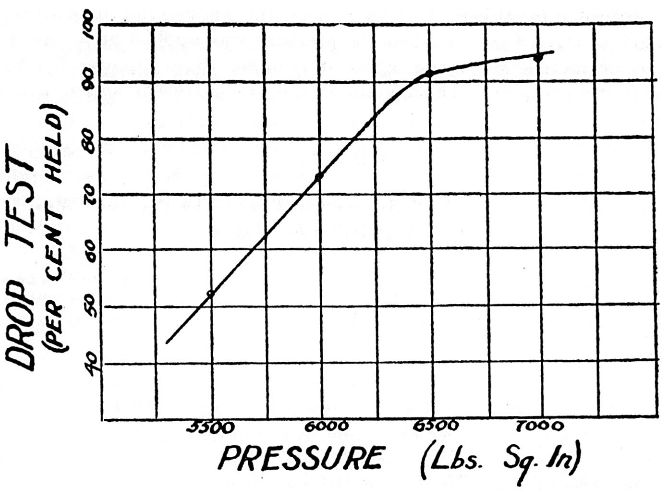

FIG 5 - PRESSURE OF BRIQUETTING

Since the piston and mold presses are specifically recommended for the briquetting of waste wood[25], is is particularly important that the briquetting pressure be within the range of presses of this type. Presses of this type exert a pressure up to 10,000 pounds per square inch[26].

In the determination of the best briquetting pressure, a series of briquettes was made of various pressures. The first pressure tried was below the pressure necessary to give an entirely satisfactory briquette. The pressure was then increased at regular intervals. In other respects the briquettes were made in the usual way. The quantity of water was four per cent (4.0) and the temperature of briquetting was 100°C. The strength of the briquettes was determined by the means of the Drop Test. The results of these runs are summarized in Fig. 5.

It will be seen that briquettes made at 5500 pounds per square inch are rather weak. Below 5500 pounds the briquettes were fragile. As the pressure is increased beyond 5500 pounds, the strength of the briquettes increases rapidly. At 6500 pounds, the inclination of the curve changes, there being only a very slight increase beyond this point.

Since it would be desirable to make as strong a briquette as could be conveniently made without undue expenses, 6500 pounds is the pressure to be recommended. At this pressure, briquettes of high quality can be produced. This pressure is well below the maximum pressure of the piston and mold presses.

Rate of Application of the Pressure.

In order to secure the maximum output from a mechanical briquetting press, it is evident that the rate of application of the pressure should be as great as possible. With the testing machine available, it required one and one half minutes for the application of the pressure at the best speed that could be conveniently attained. Briquettes made at this speed were entirely satisfactory. In order to determine if there was any appreciable improvement in the strength of the briquettes when the pressure was applied at a slower rate, a series of briquettes was made where it required three minutes for the application of the pressure. The results at the two different speeds are given in Table IV.

TABLE IV.

Comparative Strength of Briquettes Where The Pressure Was Applied at Different Rates

Rate of Application of Pressure	Drop Test (per cent held by one inch screen)
*(1) One and one-half minutes	90
(2) Three minutes	92

While it is evident that the briquettes made at the slower speed are slightly stronger, still the slight increase in strength is not sufficient to counterbalance the increase in cost which is due to the decided reduction in capacity of the briquetting press at the slower rate. Consequently unless otherwise specified, the pressure was applied at the more rapid rate (one and one half minutes) in the production of all briquettes.

Duration of the Pressure.

The duration of the pressure has reference to the time the maximum pressure employed is maintained on the briquettes. It is desirable that this period be as short as possible since an increase in the duration of this period appreciably reduces the output of the press. This period is usually very short. In the briquetting of lignite by the Bureau of Mines[27] the maximum pressure in most cases was maintained for only thirty seconds.

Since a period of twenty seconds was successfully employed by the Bu-

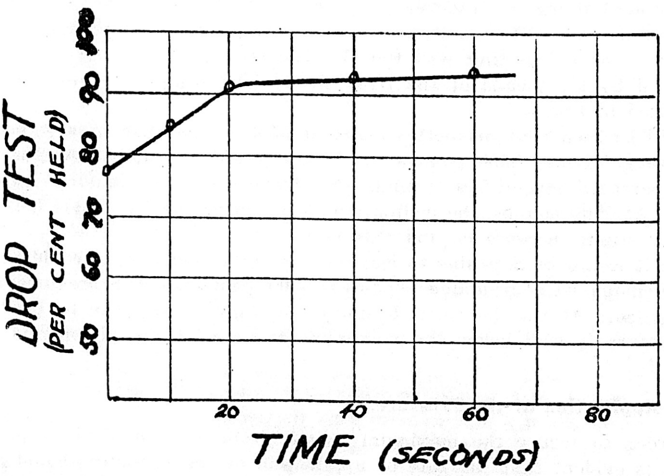

FIG 6 - DURATION OF PRESSURE

reau of Mines in some cases, this period was tried in the briquetting of sawdust. The results were entirely satisfactory. In order to determine if this was the best possible time interval, a series of briquettes was made in the usual way in which the time interval was varied on both sides of twenty seconds. The results of these runs are summarized in Fig. 6.

It will be seen that the duration of the pressure has some effect on the strength of the briquettes. Where the duration of the pressure is zero, the briquettes are only of moderate strength. The strength of the briquettes increases on increase of the time until twenty seconds is reached. Beyond twenty seconds the increase in strength is neglibible. The increase in strength at twenty seconds more than balances the slight reduction in output of the briquetting press at the slower rate. Consequently twenty seconds was adopted as the most favorable period.

Temperature of Removal of Briquettes from the Mold.

To insure any appreciable output on a large scale, it is necessary that the briquetting press be operated continuously. Consequently it is necessary that the briquettes be removed immediately from the mold without allowing the latter to cool. This idea was carried out in this work, the briquettes being removed while the temperature of the mold was 100°C. The results were very good. The briquettes slid evenly and smoothly from the mold and were of high quality.

In summing up the above results, it may be stated that the most favorable conditions for the briquetting of preheated wood waste have been shown to be: (1) Temperature of preheating 275°C; (2) size of waste for briquetting a typical sawdust of which the following is representative, 10 per cent held by 10 mesh screen, 54 per cent held by 20 mesh, and 87 per cent held by 40 mesh: (3) moisture content of preheated sawdust four per cent; (4) temperature of briquetting 100°C; briquetting pressure 6500 pounds per square inch; (5) rate of application of pressure not more than one and one half minutes; (6) duration of the maximum pressure twenty seconds; (7) temperature of removal of briquettes from mould 100°C.

METHODS AND RESULTS OF TESTING BRIQUETTES

The most important physical properties of the briquettes from a commercial standpoint, are their strength when first made, their resistance to aging and weathering agencies and to a somewhat lesser degree their crushing strength and specific gravity. The first and second tests mentioned are considered of special importance since they demonstrate the ability of the briquettes to endure handling, shipping and storage until they are consumed. The details and results of the various tests to which the briquettes were subjected are given below.

Drop Test.

The Drop Test employed by the Bureau of Mines[28] for the testing of lignite briquettes was slightly modified for this particular purpose. The details of this test as carried out are given below:

The briquettes were dropped on a cement floor from a vertical height of six feet. The pieces were collected and those that were held an one inch screen were dropped again. This procedure was repeated four times after which the weight of the pieces which would not pass through the screen was determined. It will be noted that the results of this test agree rather closely with those of the Tumbler Test given below, although no attempt was made to standardize the two tests, the first being a shatter test, while the latter was of the nature of an abrasion test.

Tumbler Test.

This test was also based on the one employed by the Bureau of Mines[28]. The details as carried out are as follows:

A tin can eight inches long and six inches in diameter was half filled with quartz pebbles approximately one inch in diameter. The briquettes were placed in same and the can rotated for two minutes at twenty-eight revolutions per minute. The can was then opened and the contents screened on a one inch screen. The weight of the pieces retained on the screen was recorded.

Aging Test.

Exposure of Briquettes to Climatic Conditions, The Briquettes Being Protected From Rainfall.

In view of the promising outlook for fuel briquettes employing sulfite liquor and other binders which are not impervious to water[29] it was not considered necessary that the briquettes be entirely unaffected by water. Under the circumstances, the most important test was considered to be one in which the briquettes were protected from rainfall but exposed to conditions similar to those to which they would be exposed in a dealer's coal or wood yard. The time of exposure should be sufficient to allow for the transportation of the briquettes and a reasonable period for their disposal. A period of six weeks would be considered sufficient for this although three months was preferable. Consequently the briquettes were placed in a rough shed where they were protected from the rain but exposed to the various climatic conditions. The shed was provided with a roof but had practically no sides nor ends. Some briquettes were removed and tested after six weeks, other briquettes were removed and tested after three months. The Drop Test and the Tumble Test were used.

Aging of Briquettes in the Laboratory:

In order to compare more carefully the effects of climatic conditions, a series of briquettes were exposed in the laboratory. During this period the temperature varied from 80°F. to 100°F.

Submergence of Briquettes in Water.

It has already been mentioned that resistance of the briquettes to water is not considered of vital importance. It was believed that a reasonable resistance of the briquettes to water could be demonstrated by submerging them in water for a period of two hours.

Crushing Strength.

In the absence of a more suitable testing machine, the crushing strength of the briquettes was determined by means of the large machine used for making them.

Results of Tests.

Using the methods just described a series of briquettes, made under the conditions previously given as most favorable, were tested. Due to the considerable number of briquettes employed in these tests, several days were required to make them. Hence the time of exposure to the different aging conditions varied slightly.

RESULTS OF TESTS ON BRIQUETTES

TABLE V.

Strength of Fresh Briquettes.

Bqt. No.	Drop Test Per cent held by one inch screen	Tumbler Test Per cent held by one inch screen	Crushing Strength Pressure applied on end of Bqt. (lbs. pressure per sq. in)	Pressure applied on lateral edge. lbs. pressure)
1	93	91.5	6100	100
2	92	94.0	7000	120
3	90	96.5	4300	115
4	88	93.0	5000	140
5	92	91.8	4700	120
6	91	93	5300	132
7	85	92		132
8	89			
9	90			
Averages	90	93.1	5400	121

TABLE VI.

Results of Drop Test on Aged Briquettes

(After aging, the Drop Test was applied in the usual way. Figures in Table refer to percent held a by one inch screen after five falls on a cement floor from a height of six feet.

Test Number	Exposed in Shed 6 weeks	3 months	Exposed in Laboratory 6 weeks	3 months
1	89.5	40.0	66	42
2	72.0	13.0	77	55
3	93.6	93.0	87	37
4	71.0	53.0	87	50
5	71.0	26.0	80	25
6	76.0		83	62
7	85.0		79	
Averages	79.7	46.0	79.8	45.1

TABLE VII.

Submergence of Briquettes in Water

Briquette Number	Period of Submergence (hours)	Conduct	Increase in weight (Per cent)	Strength after submergence (Drop Test Per cent held by one in. screen
1	2	Swells slightly	105	35 (one fall)
2	2	Little effect	83	37 (one fall)
3	2	Little effect	80	60 (one fall)
4	2	Swells slightly	91	40 (one fall)
5	2	Swells slightly	95	30 (one fall)
6	2	Swells	90	70 (one fall)
7	2	Little effect	96	60 (one fall)
Averages			91.4	47.4 (one fall)

Examination of Table V discloses the fact that the strength of the briquettes when first made is such that losses on handling and shipping should be negligible. As a matter of fact the testing of several samples of bituminous coal indicates that the strength of the briquettes is comparable by direct test to much of the bituminous coal, and is superior to most of the lignite briquettes made with a pitch binder by the Bureau of Mines[30]. The crushing strength even in the weakest direction should easily be sufficient to permit storage and combustion of the briquettes. The aging tests (Table VI) show that the briquettes when exposed to climatic conditions for a period sufficient to permit of their disposal (six weeks) decline in strength only to a limited degree and after aging are still of sufficient strength to permit handling and transportation. Even after three months the briquettes possess considerable strength and are not much weaker than fresh lignite briquettes made by the Bureau of Mines, (see page 27). It should be mentioned in this connection, that while not much importance is attached to the Tumbler Test, this test was nevertheless applied to a number of briquettes which had aged for three months. In these tests from eighty-seven to ninety-seven percent was retained by the one inch screen. It is evident from Table VII that the briquettes possess considerable resistance to water. On submergence in water for two hours, the briquettes do not crumble though they are weakened and they absorb considerable water. The briquettes rapidly regain their original weight when removed from the water. After being thoroughly wetted, the briquettes would require careful handling. Since resistance to water is not considered of vital importance, the conduct of the briquettes in this respect is considered satisfactory.

Specific Gravity of the Briquettes.

Due to the rapid absorption of water by the briquettes the specific gravity could not be determined by suspending the briquettes in water. The specific gravity determined by weighing the briquettes in air and determining the volume by direct measurement, was about 0.90. This was roughly verified by the fact that the briquettes just floated in water—not over one-tenth of the volume of the briquettes remained unsubmerged.

Heating Value of the Briquettes.

The heating value, determined in a Parr calorimeter, was 10,440 B.t.u. per pound. This is about double that of raw wood. This high heating value is explained by the fact that not only has all the original moisture been removed from the preheated sawdust but the latter has also been partly carbonized. The extent of this carbonization is estimated by the brown color of the preheated sawdust, the loss in weight on the wet basis being thirty-five percent. Charcoal, (in which the loss in weight on carbonizing is about sixty or seventy percent), has a heating value of 15,000 B.t.u. or more per pound. When the low amount of ash present and hence the minimum tendency for loss of combustible in the ashes is considered, the heating value of these briquettes compares favorably with that of other solid fuels.

Combustion of the Briquettes.

A number of briquettes was burned both singly and together in a stove and on a grate. They burned readily with a bright yellow flame and little smoke. During the combustion they showed little inclination to crumble although they swelled slightly and a number of cracks developed which permitted complete combustion with little stoking. The ash content of seven-tenths of one per cent is far lower than that of most other solid fuels.

PROBABLE LARGE SCALE APPARATUS AND COST ESTIMATES

For the preheating of material with as low heat conductivity as sawdust, very efficient stirring is necessary. The most practical way of securing this result seems to be by means of a rotary kiln. Becuse it is necessary to heat the retort to only 275°C. a fire brick lining of the retort is unnecessary. Since the sawdust can not be heated directly, indirect heating must be employed. The indirect-direct Erbo type rotary dryer made by the Allis-Chalmers Manufacturing Company used for indirect heating, appears to be exactly what is needed for this purpose. The shell of this dryer is enclosed in a brick housing nearest the feed end of the dryer. The flames are kept from immediate contact with the shell by means of an arch over the grates. The hot products of combustion then pass into the brick housing and heat the shell externally. At the opposite end of the housing there is located a stack through which the products escape. When desired, the products of combustion are drawn through the interior of the dryer by way of a flue or "vapor pipe," but do not come into direct contact with the material being heated. In this way the heat of the flue gases is utilized with a corresponding increase in efficiency. These dryers are slightly inclined to the horizontal and are unlined. The diameter is from three to nine feet while the length is from twenty to one hundred feet.

In order to make the operation of the preheater continuous, it is proposed to feed the sawdust from the storage hopper to the preheater by means of a screw conveyer. The hot distillation products from the preheater might be passed through the hollow shaft of the screw to the condenser. The preheater might be discharged by means of another screw conveyer into a storage bin. From this the preheated sawdust could be discharged automatically by a revolving shaft into a screw conveyer which would carry it to a steam heated mixer where the required amount of water would be added. The material could then be dropped by gravity into the feed box of the briquetting press. A piston and mold press of the type recommended for the briquetting of wood[25] can be secured from Wm. Johnson and Sons, Leeds, England. The briquettes may be dropped from the press on a pair of scales and then transported by a conveyer to the railroad car. A flow sheet of the proposed plant is shown in Fig. 7.

Cost of Manufacture of the Briquettes.

Since no binder is required in the proposed process, the greatest items will probably be interest and plant depreciation costs. These are closely related to plant output. Consequently before any reasonable estimate can be made of the cost of manufacture, it is necessary to form an estimate of the quantity of waste material available at the various mills. The results of the investigation carried out along this line are given below:

The U. S. Forrest Products Laboratory, Madison, Wisconsin, states that the manufacture of 150,000 board feet of lumber involves the production of about 212,000 pounds of sawdust and 105,000 pounds of shavings. This data is believed to be correct but is not guaranteed by this laboratory. The amount available after boiler requirements is not known. If all the shavings and half the sawdust are used for boiler purposes there remains 106,000 pounds of sawdust. Many of the large mills handle at least 150,000 board feet per day.

The Southern Pine Association, New Orleans, Louisiana, states that some time ago the Verdenburgh Sawmill Company, Verdenburgh, Alabama, was able to furnish four cars of sawdust and shavings per week.

Professor W. L. Beuschlem[22] is the authority for the statement that a mill producing 200,000 board feet of lumber per day, after firing its boilers, will have 60 units of waste. This waste consists of sawdust, shavings and coarser wood. A unit is 200 cubic feet. At 12 pounds per cubic foot, the approximate density found for sawdust this is equivalent to 144,000 pounds or 72 tons per day.

The Edward Hines Lumber Company, Lumberton, Mississippi, reports that from two closely adjacent mills with a combined capacity of 315,000 board feet of lumber per day, they can furnish three cars of waste of forty tons each per day. It is believed that a car load of sawdust or shavings would come nearer weighing 25 tons than 40 tons. On this basis 75 tons are available per day.

On the basis of the above figures it would seem that at many of the larger mills, at least 30 tons of sawdust or shavings per day should be available for briquetting purposes with 30 tons available for the preheating of the sawdust and for the generation of steam. The use of a ton of fuel (wood waste) for the treatment of a ton of raw sawdust is based on an estimate of the bureau of Mines[31] in connection with the briquetting of lignite, without a binder. In this estimate, 0.5 tons of lignite fuel is allowed for the treatment of each ton and one half of raw lignite. This estimate provides fuel for steam generating purposes including the heating of the dryer where the moisture content of the lignite is appreciably reduced before it is briquetted. This often necessitates the removal of 15 to 20 percent of water. It is doubtful if the fuel required in this process exceeds that required in the briquetting of lignite. Probably a small quantity of additional fuel will be required for the briquetting of the sawdust since the latter is preheated to 275°C. while the lignite is merely dried. A 50 percent increase appears to be ample in this case. If one ton of sawdust is considered equal in heating value to one-half ton of lignite, then one ton of sawdust will be requird for each ton and one half of sawdust treated. Then on the basis of a 50 percent increase for

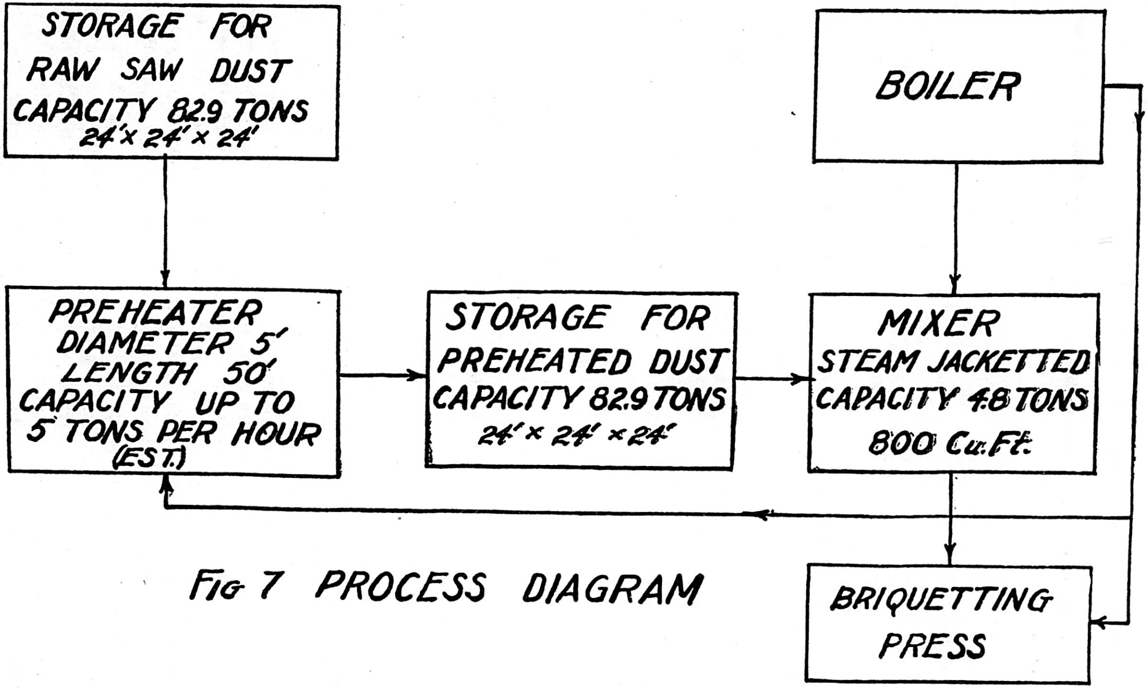

Fig 7 PROCESS DIAGRAM

preheating purposes, one and one-half tons of fuel (wood) will be required for the treatment of the same weight of raw sawdust.

In view of the fact that the loss in weight of the sawdust on preheating is about 35 percent, a plant preheating 30 tons per day would have a capacity of about 20 tons of briquettes per day.

Estimated Cost of a Plant With a Capacity of Twenty Tons Per Day of Ten Hours.

Although the process of briquetting preheated sawdust is not strictly comparable to the briquetting of lignite without a binder, it was believed that cost data available in the latter industry would be of interest in connection with this process. According to the Bureau of Mines[31] in 1913, the cost of a two press briquetting plant complete and housed in a building of steel and concrete walls, with a capacity of 100 tons per day of twenty-hours, should not exceed $100,000. The cost of the building is not given but $25,000 seems a reasonable estimate. In the briquetting of sawdust by the proposed method, due to the semi-permanent character of the installation, a cheap rough building or shed is all that would be required. On this basis, $75,000 represents, exclusive of housing, the cost of a lignite plant with a capacity of 100 tons per day of twenty hours, or 50 tons per day of ten hours. From this standpoint, a lignite plant with a capacity of 20 tons per day of ten hours would cost $30,000. In this connection, it should be mentioned that some allowance should be made for the fact that a 20 ton plant would cost somewhat more in proportion than a 50 ton plant. Some allowance should also be made for the increase in cost since 1913. One would therefore expect the total cost to be somewhat above $30,000.

Investigation of the present price of the probable machinery and equipment employed for the briquetting of sawdust, discloses the fact that the probable cost would be considerable less than the estimate given above for the briquetting of lignite. Wm. Johnson and Sons, Leeds, England, state that a "President" Toggle piston and mold press similar to that employed for the briquetting of lignite by the Bureau of Mines[27] and with an output up to eight tons per hour, can be had for 900 pounds f.o.b. Liverpool. This press is especially designed and supplied for special processes where very heavy pressure is required and is recommended for the briquetting of fuel without a binder. It makes best a cubical or rectangular briquette with rounded corners. The cross section as well as the thickness of the briquettes may be varied at will. Since the maximum depth of the mold is seven inches and the ratio of compression is nearly three to one, the maximum thickness of the briquettes will be slightly more than two inches. A convenient size will be four by four by two inches. It is estimated that briquettes of this size will weight about 1.2 pounds. Adding thirty percent duty[32] and making due allowance for freight, the cost of this press should not exceed $6500 delivered.

On the basis of the work carried out by Beuschlein[22], on the large scale distillation of sawdust in a rotary retort, the standard Erbo type rotary dryer five feet in diameter and fifty feet long made by the Allis-Chalmers Manufacturing Company, would be of sufficient capacity for the preheating. This presupposes that the same rate of heating is employed as in the work of Beuschlein[22] and that the time required to heat to 275°C. is two fifths that of a complete distillation. The price secured on this dryer exclusive of the brick work is $5,900. No reliable data could bd secured as to the cost of the brick work but is believed to be moderate. If $2,100 is allowed for the brick work the total cost would then be $8,000. From a financial standpoint the power plant is next in importance. Briquetting presses of the type employed in this work require about ten horse power (see Wm. Johnson and Sons, Leeds, England) while the rotary dryer according to Allis-Chalmers Company will require ten horse power. Allowing two horse power for each conveyer (according to the Jeffrey's Manufacturing Company this is sufficient), five horse power for the mixer, and seven and one-half horse power for a blower (Chattanooga Blow Pipe Company) a total of forty and one-half horse power will be required. Consequently sixty horse power should be ample to take care of all emergencies. The question of employing steam or electrical power is an item of some importance. Steam was selected for the following reasons. (1) A steam boiler is necessary to furnish steam for the briquetting press and mixer even if electrical drive is employed. This of course necessitates the employment of a fireman. The same fireman could be employed for the generation of steam power, there thus being no additional expense due to labor. (2) Sufficient waste wood such as shavings and chips which are not suitable for briquetting purposes, are available not only for the preheater but also for the generation of steam power. This waste wood can be had very cheaply there probably being no charge whatever. (3) Investigation of the probable cost of hydro electric power in this vicinity discloses the fact that in small plants using not over hundred horse power per day, the cost would be about three cents per kilowatt-hour. On this basis, assuming that the load factor is 75 per cent, the cost of the power is about $10.08 per day or 51 cents per ton of briquettes. This is nearly half the estimated cost of manufacture. A suitable 60 horse power high speed engine can be secured from Schofields Sons Company, Macon, Georgia, for about $1,200. A 60 horse power high pressure boiler can be secured from the same company for about $1,300. Since sufficient data was not available, no estimate has been made for the steam employed for heating in the jacketed mixer or briquetting press, but exhaust steam from the engine should be sufficient for these.

According to the Jeffrey Manufacturing Company, Columbus, Ohio, conveyers for the proposed process will cost about $410. This includes three screw conveyers twenty-five feet long with a capacity (for coal) several times that required in the proposed process, and a belt conveyer twenty-five feet long. The latter has a capacity (36 tons of coal per hour), much in excess of that required by the proposed process, but is the smallest conveyor of this type made by this company. According to the Chattanooga Blow Pipe and Roofing Company, a 36 inch American Blower Company slow speed fan connected to a 15 inch pipe, all of which they recommended for this purpose, would cost about $450. This is for conveying sawdust to the storage hopper. Several attempts to secure a price on a suitable jacketed mixer have been unsuccessful. It is not believed that this will exceed $1000. After allowing $4000 for the construction of the storage hoppers and for the construction of a rough shed over the plant, the cost of the plant amounts to $22,860. It is thus confidently believed that the cost of the completed plant should not exceed $25,000.

It will be remembered that the estimated cost based on a lignite briquetting plant is upward of $30,000. The somewhat lower estimate given above can be explained by the fact that much expensive equipment required in connection with the briquetting of lignite such as crushing rolls, sorting sieves and coal elevators are unnecessary in this process.

Cost of Manufacture of Briquettes.

This estimate is based on the following assumptions:

Capacity of plant 20 tons of briquettes per day of ten hours.
Cost of plant $25,000.
Operation of plant 300 days per year.

	Cost per Day	Cost per Ton of Briquettes
(1) Interest and depreciation (Interest 7% on $25,000) (Depreciation 10% on $25,000)	$14.17	$0.709
(2) Labor 1 pressman at $4 per day 1 man for preheating and mixing at $4 per day 2 firemen at $2.50 per day 1 scale man and loader at $2.50 per day.	15.50	0.775
(3) Raw sawdust (a) for briquetting purposes 30 tons) (b) for heating and power 30 tons)	No charge	No charge
*(4) Oil, waste and light	1.40	0.07
*(5) Repairs, maintenance	1.74	0.087
Total	$32.81	$1.64

In this estimate as already mentioned, no charge is made for the sawdust. Marketing costs are also not included.

The low briquetting cost is not without a precedent according to the Bureau of Mines[32] the cost of briquetting of **lignite** without a binder, exclusive of the **cost** of the lignite in 1913, was 88c per ton. On the basis of a 75 percent increase in cost since that date, the cost would be $1.54 per ton which is closely comparable to the estimated cost of the sawdust briquettes.

Commercial Possibilities of the Process.

As previously mentioned, briquettes made from sawdust by other processes have many disadvantages including: rapid distintegration on aging which leads to serious difficulties in transportation and disposal, lack of resistance to water, low heating value due to the presence of moisture or to inorganic constituents added to increase resistance to aging, high cost if made at high pressure without binder, and smokiness due to the presence of rosin or organic binders. In the briquettes made by the proposed method these disadvantages have been almost wholly overcome.

As shown by Table VIII fuel briquettes made from pine saw dust by the proposed method, compare very favorably with the lignite and sub-bituminous coal briquettes made by the Bureau of Mines[30].

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*Based on estimate of Bureau of Mines for briquetting of lignite the figures used representing a seventy-five percent increase over this estimate.

TABLE VIII.

Comparison of New Sawdust Briquettes with Lignite and Sub-bituminous Coal Briquettes.

	Strength (Drop Test) Percent held	Ash per cent	Heating Value (wet basis)	Cost per ton in 1918	Cost per Ton in 1929
Sawdust Briquettes	85-90	0.70	10,440 B.T.U.		$1.64
Lignite Briquettes (Pitch Binder)	50-90	9.65 to 23.51	6,000 to 15,000 B.T.U.	$2.80 to $4.34 depending on location	$4.90 to $7.59 assuming a 75 per cent increase since 1913

The resistance of the new sawdust briquettes to water is probably somewhat less than that of the lignite briquettes, but this is not believed to be vital if they are protected from rainfall and stored in a reasonably dry place. In most other respects the advantages are on the side of the briquettes made by the new process. Since the lignite briquetting industry is expanding in this country there should be a ready market for a superior kind of briquette.

In view of the foregoing, the possibilities of fuel briquettes made by the proposed process should be clear. Due to the shortage of wood and to high labor and transportation costs, the price of cord wood for domestic and commercial purposes in various centers have reached a high figure. The new process should have a promising future in furnishing briquettes from sawdust as a substitute for cord wood and as a fuel for other purposes. The briquettes have a heating value well over 10,000 B.t.u. per pound which is from fifty to ninety percent above the heating value of air dried wood. Though made at a moderate pressure they are strong and retain their strength sufficiently on aging to permit transportation and handling. They also have considerable resistance to the action of water. Due to the preheating in the manufacture which party decomposes and destroys the rosins of the wood, the new briquettes produce somewhat less smoke than those made by other processes or than the wood itself. The cost of manufacture is low. At anywhere near the figure, $8.47 per ton which is reported[33] to be the average price received by the manufacturers of lignite and coal briquettes in 1924, the fuel briquettes prepared from Southern pine sawdust by the proposed process ought to yield a good profit.

SUMMARY

A process for the manufacture of a high grade sawdust briquette from waste wood has been outlined and studied in detail. The effect of variations in the process has been studied and the optimum conditions for the process determined.

The probable large scale installation has been outlined and the cost of the manufacture of the briquettes estimated.

The results of the exprimental work indicate that by the proposed process a high grade fuel briquette can be produced from Southern pine saw dust at a moderate cost. These briquettes have been shown to have many qualit which should make them desirable as a low ash, free burning fuel for domestic purposes and as a substitute for cord wood.

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