

[54] **BENEFICIATION OF COALS**

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[56] **References Cited**

UNITED STATES PATENTS

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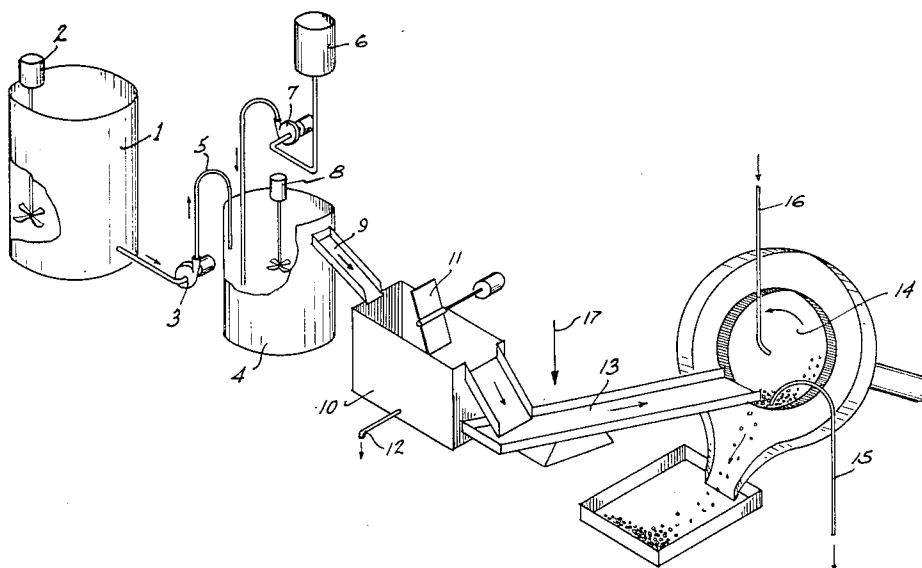
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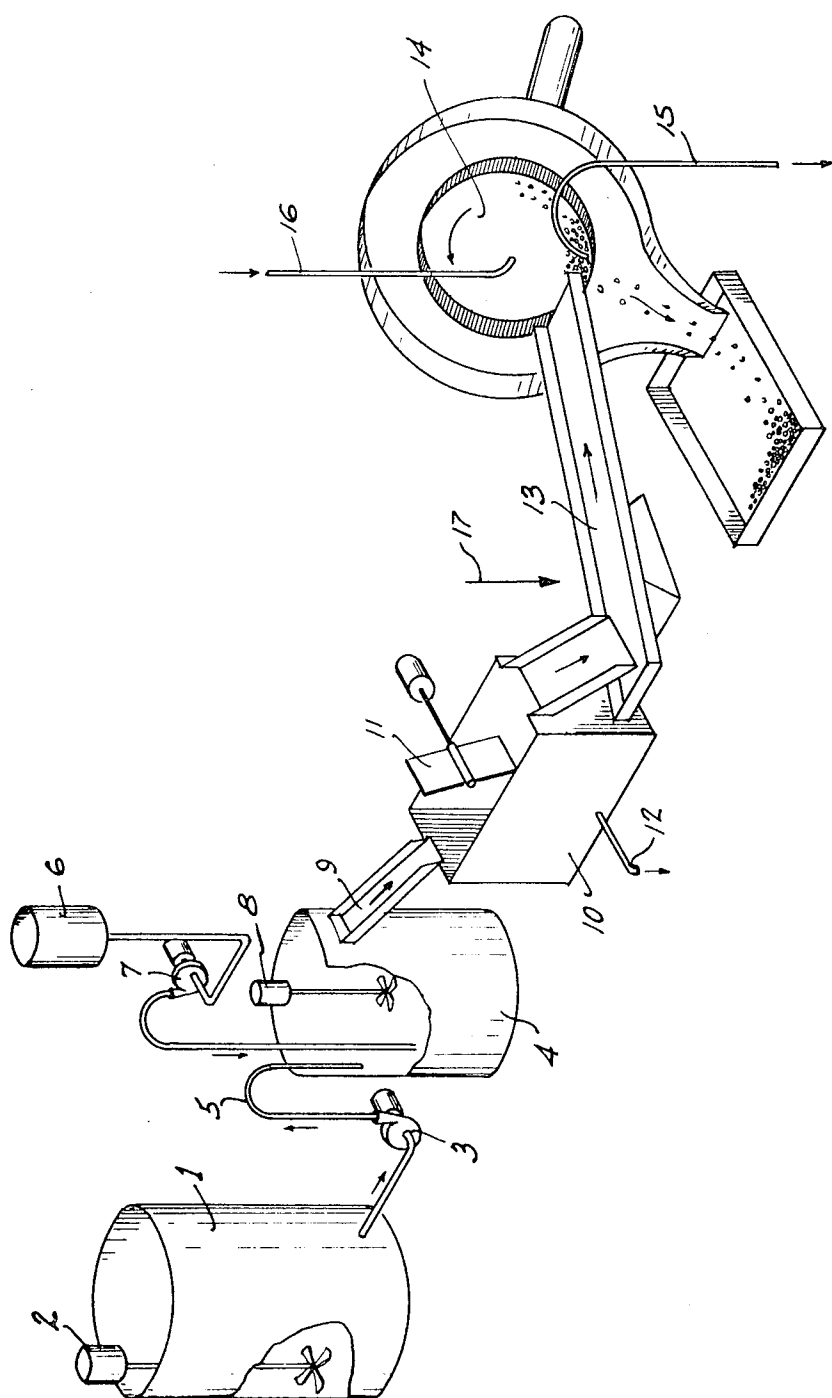
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[57] **ABSTRACT**

A process for producing a balled coal product from coal fines involves mixing a bridging liquid with coal fines and agitating the formed mixture in an aqueous medium to cause agglomeration of the coal particles. The coal particle agglomerates are then at least partially de-watered and fed to a balling device, together with a balling nuclei of coarse coal particles and binding oil to form a balled product in which each ball comprises at least one balling nucleus in association with coal particles derived from the agglomerates. The balled coal product is moved from the balling device when formed.

10 Claims, 1 Drawing Figure





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BENEFICIATION OF COALS

The present invention relates to the production of a balled coal product from coal fines and also relates to the upgrading or beneficiation of coals.

The coal industry has become increasingly more mechanized over the past few years and this trend has resulted in the production of increasing quantities and proportions of coal fines, i.e. fine mesh coals having particle sizes in the range of -100 mesh (Tyler screen). Such fine mesh coals are difficult to clean and recover and the disposal and utilization of such fine mesh coals constitutes a pressing problem. This is not only because the loss of production represented by discarded fine mesh coals is of economic significance but also because the enforcement of air and water pollution legislation means that the fines cannot be disposed of as previously.

The failure to recover coal in the -100 mesh fraction may account for a loss in overall yield equivalent to a significant amount of the raw coal. In view of rising recovery costs the potential value of such coal is constantly increasing. Not only this but the removal of fines from the effluent leaving a coal washing plant would permit good water clarification and significantly reduce the pollution problems attendant upon coal recovery.

Most coal cleaning methods depend upon a density difference between the coal and its impurity in order to effect a separation. Such gravity concentration methods, however, are not practical for particles finer than about 100 mesh and cleaning methods which depend upon differences in the surface chemistry of the coal and of the impurities are used for such finer sizes. Currently the most important technique for the cleaning and recovery of fine mesh coals is froth flotation. In this hydrophobic coal particles attach themselves to air bubbles passed through a suspension of the particles in water and the hydrophilic impurity particles remain in suspension. The froth, which contains the desired coal particles, is subsequently dewatered, for example by vacuum filtration. The flotation process becomes less effective where extremely fine sizes of coal exist (for example of less than 200 mesh) or if there is a considerable clay impurity content in the coal. Extremely fine sizes of coal may be removed from suspension only if quite large quantities of oil, for example from 5 to 50 percent of the solid feed, are agitated with the suspension of coal in water. Two such bulk oil processes have previously been described. The first is the Trent process, which is described in Coal Age, 22 (23), 911 (1922), in which powdered coal, water and about 30 percent oil are beaten together to form an amalgam of cleaned coal, the oil passing into or being absorbed by the coal and the ash remaining in the water. By varying the degree and duration of agitation and the quality and quantity of the oil, the amalgam can be made either to float or to sink and can be removed mechanically from the water and ash. In the Convertol process, which is described in U.S. Pat. No. 2,769,537, oil is mixed with a slurry of coal in water under vigorous agitation and the product is discharged directly to a high speed screen centrifuge. These bulk oil processes produce fine flocculated concentrate but an important aspect is the dewatering and disposal of the material. Thus, for example, one disadvantage of the Convertol process is a loss of coal due to a gradual increase in the size of the centrifuge screen perforations which is caused by wear after comparatively small throughputs. The frequency with which it is necessary to change the screen and its relatively high cost are important factors in the economics of the Convertol process.

It is an object of the present invention to provide a process for the recovery of fine mesh coals which makes possible good overall coal utilization and recovery. The process also makes possible the production of substantially coal free effluents and may be modified to provide upgraded or beneficiated coals of desired grades in a form which can readily be handled.

In accordance with the present invention, there is provided a process for producing balled coal from coal fines in which at least 75 percent of the particles pass through a 100 mesh Tyler sieve, (i.e. 150 microns), comprising:

- a. adding a bridging liquid capable of wetting the coal fines to an aqueous slurry of the coal fines,

- b. agitating the resultant mixture to form agglomerates of said coal fines,
- c. at least partially dewatering the agglomerates,
- d. transferring said agglomerates to a balling device into which is introduced a binding oil and balling nuclei coal particles of 0.5-10 mm average diameter,
- e. balling the balling nuclei and agglomerates in said balling device to form an enlarged balled coal comprising balls in which at least one balling nucleus is associated with a plurality of agglomerates, and
- f. removing said enlarged balled coal from said balling device.

It is within the scope of the present invention to practice a process in which the material treated in the initial agglomeration step contains appreciable proportions of larger particles which could subsequently act as balling nuclei without the need to provide a separate feed or balling nuclei to the balling device.

The coal particles in the coal fines are hydrophobic (or oleophilic) and the bridging liquid which is added to the dispersion of the fines in an aqueous medium should be such as preferentially to wet only the hydrophobic coal particles to form a film over their external surfaces. When the mixture of bridging liquid and dispersion is vigorously agitated the wetted hydrophobic particles flocculate and compact into spherical agglomerates. The coal fines may also contain significant proportions, dependent upon the quality or grade of the coal fines, of hydrophilic (or oleophobic) impurity particles such as of ash. Since it is desirable in some cases to up-grade or beneficiate the coal fines by removing the ash or other impurity particles from the coal particles, the bridging liquid which is used in the preliminary agglomeration step of the process of the present invention preferably should be such as not to wet the surface of the hydrophilic particles. Thus the bridging liquid preferably should not contain any functional groups which are capable of attaching themselves to the surfaces of the hydrophilic impurity particles. If this is the case then hydrophilic particles remain suspended in the water and can effectively be separated from the coal particle agglomerates. Suitable bridging liquids for use in the process of the present invention are light hydrocarbon oils such as domestic heating oils, illuminating oils and solvent oils, for example fuel oil; kerosene and Varsol (tradename for a commercial oil manufactured by Imperial Oil Co. Canada). If the coal fines do not contain appreciable quantities of ash or other impurities and beneficiation or upgrading of the coal is not essential then the bridging liquid may be a heavier oil which not only wets the surface of the hydrophobic particles but also, upon prolonged agitation, wets the surfaces of hydrophilic particles with the result that both types of particle form agglomerates and may be separated from the aqueous phase.

The total amount of oil used in the mixing vessel and balling device should be sufficient to ensure a good overall recovery of the desired coal particles from the coal fines and suitable amounts are from 5 to 50 percent by weight based on the weight of the dry coal fines. Preferred amounts for the total amount of oil are from 5 to 30 percent by weight based on the weight of dry coal fines.

The character of the flocculated or aggregated product from the first stage is somewhat dependent upon the proportion of bridging liquid used. With low proportions a fine, light textured flocculated material is produced while higher proportions lead to coarser agglomerates which are essentially microspheres which may have diameters of up to 1 millimeter. The time taken for effective agglomeration is somewhat dependent upon the level of agitation and, in general, the higher is the speed of agitation then the shorter is the time required to complete agglomeration. During the agglomeration process the black slurry of coal changes to a mixture of distinct black coal agglomerates which are dispersed in a light colored slurry comprising the water and the suspended impurity particles. This inversion generally occurs in about half the time required for complete agglomeration.

The mixing and agitation of the bridging liquid with the coal dispersion may be carried out in any suitable type of apparatus; for instance, a drum equipped with a bladed propeller type of mixer. An apparatus in which a zone of high shear is produced in the annular space between a solid conically shaped rotor rapidly rotating inside another cone has been found to bring about the desired agglomeration rapidly and also to serve as a blockage-resisting pump. In addition to the Premier Mill mixer which was used, a modified turbine, disc or cone impeller may also prove suitable. Recently a flotation cell without air additions has been employed with good results.

After they are formed the agglomerates may be separated, at least partially, from the aqueous phase by use of a screen or by use of such size separators as elutriators, cyclones, or spirals. Alternatively, the agglomerates may be removed in a float-sink tank where the coal agglomerates tend to float and may be skimmed off by a paddle. The unagglomerated impurities tend to sink and may be removed to waste in the underflow. To improve recovery of the coal component a suitably sized screen, for example of 100 mesh, may be located horizontally over the whole cross section of the float-sink tank just below the level of the skimming paddle.

In the next stage of the process of the invention the agglomerates are fed to a balling device, such as a rotating balling disc, together with balling nuclei, which comprise coarse coal particles having an average particle size diameter of from 0.5 to 10 millimeters (corresponding to 32 mesh to 10 millimeters, especially 1 to 5 millimeters (corresponding to 16 mesh to 3 mesh), and also with a binding oil capable of forming a balled product in which substantially each ball comprises at least one balling nucleus in association with coal particles derived from the agglomerates. The size of the final balled product may be controlled by controlling the relative rates of feed of coal agglomerates and balling nuclei to the balling device. Good control of the final balled product size to within the range of from 1/8 inch diameter to 1 inch diameter is possible.

If the balling nuclei are not fed to the balling device then while an increase in the size of the coal particle agglomerate is achieved the size of the balled product may increase apparently without limit and a very unsteady operation results. Furthermore, the balled product resulting merely from the balling of the coal particle agglomerates is of low strength and easily crumbles upon handling. The balled product produced in accordance with the process of the invention reduces dusting losses and makes possible the easy handling and classification of the product.

The balled product leaving the balling device has a moisture content of the order of from 5 to 15, more especially 8 to 12 percent, moisture. This product may be further dewatered in the centrifuges normally used on only coarse coal fractions or by mill thermal drying of what is essentially surface moisture alternatively, of course it may be allowed to dry merely by standing. Control of the grade of the balled coal product may be achieved by judiciously beneficiating the coal fines in the initial agglomeration step and by choosing coal nuclei with appropriate ash contents. High grade coal balls may be obtained by using a bridging liquid which preferentially wets the hydrophobic coal particles while leaving the hydrophilic impurity particles substantially unwetted and by using also low ash content coal nuclei in the balling device. Coal nuclei having comparatively high ash contents may be upgraded by combining them with coal particle agglomerates of low ash content, again by using a bridging liquid which preferentially wets only the hydrophobic coal particles in the initial agglomeration step. From this it can be seen that the process of the invention is capable of producing balled coal products having predictable ash contents and suitable for a variety of different and uses.

Preferably the balling nuclei are coal chips having an average particle size diameter of from 1 to 5 millimeters which size corresponds to 16 mesh to 3 mesh.

The binding oil which is fed to the balling device together with the coal particle agglomerates and balling nuclei preferably is a heavy hydrocarbon oil, such as Bunker C fuel oil and coal tar. The requirement here is that the binding oil produces a coherent and relatively high strength balled product in which the agglomerate particles are well bonded to the balling nuclei to produce a product which may be handled without disintegrating. The binding oils often develop their full strength only after the balls are dried at, for example 100° C. The total amounts of oil which may be used in the mixing vessel and balling disc are in the range of from 5 to 50 percent by weight based on the weight of the dry coal fines. Preferred amounts of oil range from 5 to 30 percent.

Suitable amounts of bridging oil used may be from 1 to 35 percent based on the weight of the dry coal fines with preferred amounts being between 1 to 20 percent. The bridging oil used in the mixing vessel would normally amount to 20 to 70 percent of the total oil given above and binding oil ranges used in the balling device may then be:

Operable amounts 1.5 to 40 percent

Preferred amounts 1.5 to 24 percent

The amount of binding oil used of course should be sufficient for good agglomerate strength i.e. between 30 to 80 percent of the total oil used.

As mentioned above the size of the balled coal product is dependent upon the relative rates of feed of the coal particle agglomerates and the balling nuclei to the balling device and the rate of feed of coal agglomerates to the balling device preferably is from 2 to 30 times the rate of feed of balling nuclei on a weight basis. Also for most stable operations the diameter of the binding nuclei should be equal to or greater than about one-fourth of the desired balled coal product diameter.

The invention will now be illustrated in more detail by reference to the following Examples, in which parts and percentages are by weight unless otherwise indicated.

EXAMPLE 1

The apparatus used in this Example was on a semi-pilot scale and is as shown in the accompanying drawing, which is a diagrammatic representation of the equipment. Experiments were performed with a 10 percent weight by volume coal slurry, this being a concentration typical of a coal wash plant effluent, and is described more fully hereinafter. The coal slurry was stored, under agitation, in a 45 gallon drum 1, provided with a stirrer 2. The coal slurry was pumped by means of pump 3 to a mixing vessel 4 through pipe 5. A bridging liquid, namely Varsol, was pumped to the mixing vessel 4 from holding tank 6 by means of pump 7 and the vessel 4 was equipped with a stirring device 8. The amount of Varsol introduced into the mixing vessel 4 was 28 percent based on the weight of dry coal fed to the vessel 4. The mixing vessel 4 was fabricated from stainless steel and was 9 inches in diameter by 8 1/2 inches in height with a capacity of 8.8 liters to an overflow spout 9. Coal slurry was normally pumped at 500 ml per minute into the vessel 4 leading to an average residence time in the vessel 4 of 17 to 18 minutes. The stirrer 8 was preferably a high intensity mixer in the form of a Premier mill consisting of a 1.6 inch diameter by 0.5 inch high cone rotating at 8,000 revolutions per minute within a housing to allow a 1/8 inch annulus through which the slurry was circulated by the action of the mixer from the top to the bottom of the vessel 4. Agglomerated coal particles dispersed in a slurry of clay impurities flowed from the vessel 4 by means of overflow spout 9 to a float-sink tank 10 where the coal particle agglomerates tended to float and were skimmed off by a paddle 11 while the unagglomerated ash-forming material sank and drained to waste through the underflow 12. To improve recovery of the coal component, a 100 mesh screen (not shown) was located horizontally over the whole cross-section of the float-sink tank 10 just below the level of the skimming paddle 11. A multitude of air bubbles may also be introduced at the bottom of the float-sink tank 10

to improve recovery of the coal component in some cases. The agglomerated coal fraction was conveyed together with coarser particles, or balling nuclei, by means of a vibrating feeder conveyor 13 to a balling disc 14; the balling nuclei being supplied to the feeder conveyor by suitable conventional supply means as generally indicated by arrow 17. The balling disc 14 was 16 inches in diameter by 3 inches deep and was rotated at an angle of approximately 45°. The disc 14 normally contained about 400 grams of balled coal product providing approximately 7 minutes residence time in the disc. A suction line 15 was provided at the foot of the rotating disc 14 to control the amount of water in the balling disc 14 since excess water was found to reduce friction between the disc and the load fed to the disc and resulted in a poor tumbling, cascading action in the disc 14. Binding oil was fed to the balling disc 14 through feed pipe 16. The process was run for at least 1 hour for a given set of operating conditions in order to ensure a steady state. It was found that mass balances for the equipment generally were within the range of from 5 to 10 percent of each other which indicated that a reasonably steady operation could be attained. It may be noted that the suction line 15 is not always necessary. For example, if a very dense binding oil is used in the balling disc, the balls would sink in the liquid and the desired cascading action could be obtained without a suction line.

The properties of the coal fines fed to the drum 1 were as indicated in Table 1 below:

TABLE 1

Properties of Coal Studied

	% by weight (dry basis)
Ash	21.1
Fe ₂ O ₃	7.8
Al ₂ O ₃	4.3
SiO ₂	7.7
Total Sulphur	6.1
Sulphate sulphur	2.4
Pyritic sulphur	2.3
Organic sulphur (by diff.)	1.4
Natural pH of 10% slurry approximately	2.0

WET SCREEN ANALYSIS

	Weight %	% Ash
+590μ	0.3	4.1
+297μ	1.5	9.3
+149μ	5.6	6.7
+74μ	11.5	7.8
+44μ	6.7	10.0
+31μ	11.3	10.3
+22μ	11.4	8.5
-22μ	51.9	29.9

This coal was supplied by the Avon Coal Company of St. John, New Brunswick and was the minus 1 millimeter fraction from the wash plant slurry which is normally recovered by flotation and filtration. It should be noted that approximately 80 percent of the ash forming material of this coal is contained in the minus 22 micron fraction.

Various coal fractions were used as the balling nuclei and the properties of these various fractions are identified in Table 2 below.

TABLE 2

Properties of Coal Fractions used as Nuclei

Screen fraction (Tyler)	Average diameter from screen sizes (mm)	Mean volume diameter ^a (mm)	True density of coal (g./cm. ³)
-4+6	4.01	4.24	1.21
-6+9	2.68	2.16	1.26
-9+14	1.60	1.64	1.16

^a determined from the number of particles per gram and the average particle density.

It was found when using these coal fractions as balling nuclei that the pellet or balled coal product size was effectively stabilized. The product size was found to be effectively controlled by suitably adjusting the ratio L/N where L and N are the rates of feed of fine agglomerated coal and coarser coal nuclei, respectively.

During the continuous operation of the apparatus illustrated in the drawing it was found that combustible product recovery was in the range of from 83 to 91 percent, that the ash content of the balled coal product was in the region of 5 to 6 percent but was in the region of 60 to 70 percent for the underflow from the float-sink tank 10. Balled coal product having an average particle size of $\frac{1}{4}$ inch diameter held approximately 12 percent surface moisture leaving the balling disc 14 but when air dried overnight had a moisture content of less than one-half percent.

EXAMPLE 2

A number of batch tests were performed in a high speed blender (capacity 1,000 milliliters) to study the effect on the process of the type of oil and concentration and also the level of agitation and contact time in the mixer 4. The coal slurry was agitated for approximately 1 minute and an amount of oil was added as bridging liquid. Agitation was continued for a further 10 minutes and the mixture was then poured onto a 100 mesh screen to allow the water containing the ash component to drain through while retaining agglomerated coal. The agglomerated product was washed with 500 ml of water and dried. Extraction with heptane and redrying followed if heavy oils were used and then the product was finally analyzed.

The results summarized in Table 3 below indicate the effectiveness of various oils and blends in recovering the combustible content from slurries of fine coal and also illustrate the selective ability of oils to recover combustibles from the coal slurry while leaving the ash constituents in suspension.

TABLE 3

Effect of Various Oils on Beneficiation				
Batch experiments:		55 g. (dry) coal 300 ml. water 26 ml. oil Waring blender at 6000 rpm. for 10 min.		
Collecting Oil	Temp. (°C.)	% Ash of product	% Sulphur of product	% Recovery of combustibles
Fuel Oil	21°C.	7.2	3.6	97
Kerosene	21°C.	5.2	2.8	83
Kerosene	90°C.	5.5	2.9	-
Varsol	21°C.	5.0	2.7	91
50% Kerosene	21°C.	10.6	-	-
50% Bunker C crude	90°C.	14.0	4.6	92
Light coal tar	21°C.	19.0	-	90
Light coal tar	90°C.	15.7	-	90

It was found that heavy viscous oils were not readily dispersed in the coal slurry while the lighter oils tended to form weaker agglomerates. The oils mentioned in Table 3 above were generally acceptable from the point of view of good recovery of the combustible content of the coal slurry but it should be noted that the heavier, more complex oils, for example the Bunker C crude and coal tar, gave higher ash

contents in the product with but little rejection of ash material. Since an increase in temperature did not affect the performance of the oils appreciably, the difference was not considered to be attributable to the higher viscosity of the heavy oils. Rather it was concluded that the heavier oils contain functional groups which are able to wet the ash particles in such a way as to render them hydrophobic and to allow them to report with the oil phase during agglomeration.

As summarized in Table 4 below it was found that a wide range of oil concentrations could be used in order to produce good grades and provide high recoveries of coal when a light oil such as "Varsol" is used.

TABLE 4

Effect of Oil Concentration on Beneficiation (see Table 3 for experimental conditions).			
Wt. % Varsol based on dry coal ^a	% Ash in product	% Sulphur in product	% Recovery of combust- ibles
20	6.9	3.8	90
26	6.7	3.3	90
31	5.6	3.1	89
37	5.0	2.7	91
43	5.2	2.8	89

^a26 ml. Varsol, i.e. 20.3 g. used with 55 g. dry coal gives 37%.

Further experiments indicated that whereas approximately 8 minutes were required to complete agglomeration at 6,000 rpm agitation speed, approximately 18 minutes were required at the lower speed of 3,000 rpm.

While for low values of L/N good agreement between theoretical calculations and experimental results could be found by assuming that each balled product contained only one coarse particle as a nucleus, i.e. by assuming that a thin layer of fine coal is laid down upon a single nucleus, a deviation of experimental results from theoretical calculations was observed for higher values of L/N . This deviation was considered to be due to the fact that more than one coarse coal particle was being incorporated into each balled coal product, thus increasing the effective nucleus size and leading to larger final product diameters. This explanation was confirmed by making an actual count on a large number of balls to determine the number of nuclei embedded within the product. It was found as a result that if the product diameter is less than about twice the coarse particle or nucleus diameter, only one nucleus is incorporated in each balled product. With larger ratios for product to nucleus diameter, however, many nuclei are incorporated in each ball, the number increasing with the ratio of the product diameter to the nucleus diameter. Apparently if the product size is considerably larger than the nucleus size, some of the coarse particles or nuclei are absorbed by existing balled products and do not initiate new balled products. Experimentally it was found that if the ratio of the product diameter to the nucleus diameter was greater than about 4, the product size tended to increase slowly. For the most stable operation the nucleus diameter should there-

fore be equal to or greater than about one-fourth of the desired product diameter. On this basis it was found that the experimental data could satisfactorily be represented by the equation:

$$D = P^{1/3} d_N \left(1 + \frac{L}{N} \frac{\rho_N}{\rho_L} \right)^{1/3}$$

where D represents the product diameter, P represents the number of nuclei in each balled product, d_N represents the diameter of the nucleus, L represents the rate of feeding agglomerated coal to the balling device in terms of mass per unit time, N represents the rate of feeding coarse particles to the balling device in terms of mass per unit time, ρ_L represents the bulk density of the coal particles in the agglomerates in grams per cc, and ρ_N represents the true density of the coarse coal particles used as nuclei in grams per cc.

We claim:

1. A process for producing balled coal from coal fines in which at least 75 percent of the particles pass through a 100 mesh Tyler sieve, comprising:
 - a. adding a bridging liquid capable of wetting the coal fines to an aqueous slurry of the coal fines,
 - b. agitating the resultant mixture to form agglomerates of said coal fines,
 - c. at least partially dewatering the agglomerates,
 - d. transferring said agglomerates to a balling device into which is introduced a binding oil and balling nuclei coal particles of 0.5–10 mm average diameter,
 - e. balling the balling nuclei and agglomerates in said balling device to form an enlarged balled coal comprising balls in which at least one balling nucleus is associated with a plurality of agglomerates, and
 - f. removing said enlarged balled coal from said balling device.
2. A process as claimed in claim 1 wherein the coal fines predominantly comprise particles not smaller than 200 mesh size.
3. A process as claimed in claim 1, wherein the coal fines comprise hydrophobic coal particles and hydrophilic ash particles and the bridging liquid is a hydrocarbon oil which preferentially wets the coal particles while leaving the ash particles substantially unwetted.
4. A process as claimed in claim 3 wherein the bridging liquid is selected from the group consisting of fuel oil and kerosene.
5. A process as claimed in claim 3 wherein the amount of bridging liquid is from 20 to 70 percent by weight of the total of binding oil and bridging liquid used.
6. A process as claimed in claim 1 wherein the balling nuclei are coal chips having an average diameter of from 1 to 5 millimeters.
7. A process as claimed in claim 23 wherein the binding oil is Bunker C fuel oil.
8. A process as claimed in claim 1 wherein the amount of binding oil is from 30 to 80 percent by weight of one-half total of binding oil and bridging liquid used.
9. A process as claimed in claim 1, wherein the balling device is provided with suction means for removing excess water from the balling device.
10. A process as claimed in claim 1, wherein the balled coal product leaving the balling device is dried to a moisture content of at most half percent by weight.

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