

CONVENTION

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APPLICATION FOR A STANDARD PATENT

/We Ryan Investments B.V

of c/o Cyprus Drive,
St. Mellons,
Cardiff,
UNITED KINGDOM.

627699

hereby apply for the grant of a standard patent for an invention
entitled:

METHOD AND APPARATUS FOR SEPARATING AND RECOVERING
PARTICULATE MATERIAL

which is described in the accompanying complete specification.

Details of basic application

Number of basic application: 87 26428

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DECLARATION FOR A PATENT APPLICATION

INSTRUCTIONS

(a) Insert "Convention" if applicable
(b) Insert FULL name(s) of applicant(s)

In support of the (a) convention application made by
(b) Ryan Investments B.V.
c/o Cyprus Drive
St. Mellons, Cardiff, Wales, Great Britain

(c) Insert "of addition" if applicable
(d) Insert TITLE of invention

(hereinafter called "applicant(s) for a patent (c) for an
invention entitled (d)
"Method and apparatus for separating and recovering
particulate material"

(e) Insert FULL name(s) AND address(es) of declarant(s) (See headnote*)

I/We (e) Mr Frank paul Jackson: General Manager of Ryan Investments B.V.,:
c/o Cyprus Drive, St. Mellons, Cardiff, Wales, Great Britain

do solemnly and sincerely declare as follows:

- 1. I am/We are the applicant(s).
(or, in the case of an application by a body corporate)
1. I am/We are authorized to make this declaration on behalf of the applicant(s).
2. I am/We are the actual inventor(s) of the invention.
(or, where the applicant(s) is/are not the actual inventor(s))
2. (f) Francois J. Callut
17, rue de la Ganterie
6428 Ham-Sur-Heure, Belgium

(f) Insert FULL name(s) AND address(es) of actual inventor(s)

is/are the actual inventor(s) of the invention and the facts upon which the applicant(s)
is/are entitled to make the application are as follows:

(g) Recite how applicant(s) derive(s) title from actual inventor(s) (See headnote**)

(g)

The applicant is the assignee of the invention from the said actual inventor.

(Note: Paragraphs 3 and 4 apply only to Convention applications)

- 3. The basic application(s) for patent or similar protection on which the application is based is/are identified by country, filing date, and basic applicant(s) as follows:
(h) British patent application No. 87 26428 filed 11th November 1987
Ryan Investments B.V.
4. The basic application(s) referred to in paragraph 3 hereof was/were the first application(s) made in a Convention country in respect of the invention the subject of the application.

(h) Insert country, filing date, and basic applicant(s) for the/or EACH basic application

(k) Insert PLACE of signing

Declared at (k) Surrey, England

(l) Insert DATE of signing

Dated (l) 12 January, 1989

(m) Signature(s) of declarant(s)

(m) Frank Paul Jackson,
General Manager

Note: No legalization or other witness required

To: The Commissioner of Patents

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(57) Claim

1. A method of separating and recovering particulate material by means of a plurality of cyclone separators each having an inlet, an overflow outlet and an underflow outlet, wherein said separators are connected in series in a flow direction from a first one to a last one of the separators by the overflow outlet of each separator other than the last being connected to the inlet of a next separator in the flow direction, and wherein the material entrained in a liquid medium is fed in the flow direction through the separators, each separator having a cyclone angle such that the cyclone angle of successive separators decreases in the direction of flow and the cyclone angle α_2 of a cyclone separator in the series being $\pm 5\%$ of the angle calculated according to the formula

$$\frac{\cot (90 - 2\alpha_1)}{\cot (90 - 2\alpha_2)} = \frac{\phi_1}{\phi_2}$$

where α_2 is the cyclone angle of a cyclone separator following a separator with cyclone angle α_1 , and ϕ_1 and ϕ_2 represent the geometric mean particle size of the cut of successive separators with these angles.

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12. An apparatus for separating and recovering particulate material which comprises a plurality of cyclone separators each having an inlet, an overflow outlet and an underflow outlet, wherein said separators are connected in series in a flow direction from a first one to a last one of the separators by means connecting the overflow outlet of each separator other than the last to the inlet of a next separator in the flow direction, means for supplying the particulate material entrained in a liquid to the inlet of the first separator, each cyclone in the series having a cyclone angle which is less than that of its predecessor in the series and conforming to the formula

$$\frac{\cot (90 - 2\alpha_1)}{\cot (90 - 2\alpha_2)} = \frac{\phi_1}{\phi_2}$$

where α_1 and α_2 are the cyclone angles of two successive cyclone separators, ϕ_1 and ϕ_2 are the geometric mean particle size of the cut of successive separator stages and α_2 is within $\pm 5\%$ of the calculated value.

Method and Apparatus for Separating
and Recovering Particulate Material

5 This invention relates to improvements in the method of
and apparatus for separating and recovering particulate
material.

10 There are many applications where the separation and
recovery of particulate material from bulk waste material
and untreated run of the mine material (R.O.M.) would be
economically and ecologically desirable. An example of
this is the mounds, tips or slag heaps erected and being
15 erected by the mining industry and composed of what was or
is considered to be waste material produced in the winning
of a mineral from the mine. Such tips, slag heaps or
ponds contain quite large proportions of the mineral
concerned but in a form which, at the time the reject
20 reserve was being created, it was not considered viable to
recover. Generally speaking, the mineral in the slag
heaps and ponds is of particulate form and of such a small
size that it was not thought possible to recover it
economically.

25 The present invention provides a method of and apparatus
for recovering and separating particulate material of the
small sizes in question so that not only can the minerals
concerned be recovered but the slag heaps and ponds can be
demolished and re-distributed in the process to remove an
unsightly presence from the landscape.

30 Of particular, but not exclusive, concern is the recovery
of coal from slag heaps and ponds. The amount of coal
present in such a reserve varies from area to area, but we
have found that 20 to 100% of the coal present is of a
35 particle size which is 1 mm or less. Coal of this size
has not hitherto been believed to be recoverable
commercially. We have now found that the major part of
this coal, e.g., 70 to 100% by weight can be recovered
using cyclone separators.

It is known to use cyclone separators for separating and recovering granular or particulate material. Such separators comprise an upper cylindrical portion having a coaxial tube (vortex finder) therein and a frusto-conical portion extending away from the cylindrical portion to the smaller diameter outlet or underflow. Material to be separated is mixed in a liquid medium to form a slurry and is introduced substantially tangentially into the cylindrical portion so that it spirals about the tube moving towards the underflow. After passing the inner end of the tube a proportion of the medium changes direction and flows upwardly through the tube to exit at the overflow, taking with it the particles of lesser density and size, the remainder exiting through the underflow.

The maximum density of the mineral to be recovered is generally known. In the case of coal the density is in the range of 1.5 to 2.5 and, more usually, about 1.8 to 2.0. It has hitherto been considered not possible or practical to recover by mechanical means only coal in this density range and having a particle size of 1 mm or less. Our research has shown that conventional cyclone separators operated in a conventional way do not separate coal particles of 1 mm or less in the density range of 1.8 to 2.0 from the waste material in which they are to be found. Our investigations have further revealed that the "cut" or characteristic of a cyclone separator can be modified by changing or selecting the cyclone angle. For present purposes, the cyclone angle is considered to be the angle a generatrix of the frusto conical part subtends to the axis in a common plane. By reducing this angle one can reduce the size of the particles which exit at the overflow having a given density or density range. If one assumes the cyclone angle to be α and the geometric mean of the particle sizes exiting at the overflow to be ϕ , then the expression

$$K_1 + K_2 \cdot \cot (90 - 2\alpha) = \emptyset \quad \text{---- } \underline{1}$$

appears to hold true in the density range for coal. As K_1 is very small (close to 0), $\underline{1}$ can be written

$$\cot (90 - 2\alpha) = K\emptyset \quad \text{---- } \underline{2}.$$

Thus, if one were looking to cut or separate coal particles in the range of 250 to 500 μ , then

$$\emptyset = \sqrt{250 \times 500\mu} \approx 350\mu.$$

According to the present invention there is provided a method of separating and recovering particulate material by means of a plurality of cyclone separators each having an inlet, an overflow outlet and an underflow outlet, wherein said separators are connected in series in a flow direction from a first one to a last one of the separators by the overflow outlet of each separator other than the last being connected to the inlet of a next separator in the flow direction, and wherein the material entrained in a liquid medium is fed in the flow direction through the separators, each separator having a cyclone angle such that the cyclone angle of successive separators decreases in the direction of flow and the cyclone angle α_2 of a cyclone separator in the series being $\pm 5\%$ of the angle calculated according to the formula

$$\frac{\cot (90 - 2\alpha_1)}{\cot (90 - 2\alpha_2)} = \frac{\emptyset_1}{\emptyset_2}$$

where α_2 is the cyclone angle of a cyclone separator following a separator with cyclone angle α_1 , and \emptyset_1 and \emptyset_2 represent the geometric mean particle size of the cut of successive separators with these angles.

The invention also provides an apparatus for separating and recovering particulate material which comprises a



plurality of cyclone separators each having an inlet, an overflow outlet and an underflow outlet, wherein said separators are connected in series in a flow direction from a first one to a last one of the separators by means
5 connecting the overflow outlet of each separator other than the last to the inlet of a next separator in the flow direction, means for supplying the particulate material entrained in a liquid to the inlet of the first separator, each cyclone in the series having a cyclone angle which is
10 less than that of its predecessor in the series and conforming to the formula

$$\frac{\cot (90 - 2\alpha_1)}{\cot (90 - 2\alpha_2)} = \frac{\phi_1}{\phi_2}$$

15

where α_1 and α_2 are the cyclone angles of two successive cyclone separators, ϕ_1 and ϕ_2 are the geometric mean particle size of the cut of successive
20 separator stages and α_2 is within $\pm 5\%$ of the calculated value.

Preferably the apparatus is provided with means for supplying the particulate material entrained in a liquid
25 at the same velocity to each of the separators $\pm 10\%$.

It will be appreciated that the bulk or size of a slag heap or tip or R.O.M. is such that the apparatus of the invention would generally be assembled on site and that
30 samples would initially be taken of the raw material in the tip to ascertain density and particle size distribution. From this, the cyclone angle α_1 of the first cyclone in the series can be arrived at given the estimated geometric mean particle size ϕ_1 for the
35 first cut. One can then decide on the range of particle sizes for the cuts of successive separators. From equation 2 above it will be seen that



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$$\frac{\cot (90 - 2\alpha_1)}{\cot (90 - 2\alpha_2)} = \frac{\phi_1}{\phi_2} \text{ ---- 3.}$$

$$\cot (90 - 2\alpha_2) \phi_2$$

5

Having decided initially on the values for α_1 , and ϕ_1 , and having selected ϕ_2 for the second separator, it will be seen that the optimum cyclone angle α_2 for the second separator can be calculated.

10 In the preferred method of the invention, the cyclone angle α_2 of a cyclone separator in a series is $\pm 5\%$ of the angle calculated by the formula

15

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$$\frac{\cot (90 - 2\alpha_1)}{\cot (90 - 2\alpha_2)} = \frac{\phi_1}{\phi_2}$$

where α_2 is the cyclone angle of a cyclone separator following a separator with angle α_1 and ϕ_1 and ϕ_2 represent the geometric mean particle size of the cut of successive separators with these angles.

The liquid medium in which the particles are entrained is preferably water and it should be noted that the angle α controls the size range of washed or clean particulate material reporting to the overflow, ϕ being the geometric mean of this range.

It will be appreciated that for a given input velocity of the material, the larger and more dense particles report to the underflow and the smaller and lighter particles report to the overflow. The particulate material reporting to the overflow will therefore comprise a defined range of particle sizes of the mineral which are washed or clean and a balance of particles of smaller sizes which are not washed. By selecting the angle of the next succeeding cyclone separator, the washed particles within the range from the preceding cyclone separator report to and are recovered from the underflow and a further range of smaller particles which have been washed report to the overflow for recovery at the next succeeding cyclone separator.

If one assumes M to be the maximum size in microns of particles to be recovered, m to be the minimum size in microns, R to be the ratio of the upper and lower limits of particle sizes in the range to be cut in each separator, then the number of stages required would be

$$\frac{M}{m} = R^N$$

or

$$N = \frac{\log\left(\frac{M}{m}\right)}{\log R} \quad \text{----} \quad \underline{4}$$

For example, if the particulate material to be recovered is in the range of $M = 1000 \mu$ and $m = 30 \mu$ and $R = 2$ then

$$N = \frac{\log \frac{1000}{30}}{\log 2} = 5$$

5

Each of the 5 stages would provide a range of washed particles reporting to the overflow as follows,

Stage 1:	500 - 1000 μ
Stage 2:	250 - 500 μ
Stage 3:	125 - 250 μ
Stage 4:	62 - 125 μ
Stage 5:	31 - 62 μ

If $M = 500 \mu$, $m = 30 \mu$ and $R = 2$

then $N = 4$ and this represents the number of stages in the example which follows.

If one assumes an arrangement with N stages and uses the suffix i to identify a stage intermediate stage 1 and stage N then

$$\emptyset_i = \frac{M}{\sqrt{R^{i-1} \cdot R^i}}$$

\emptyset_i being the geometrical mean of the range of particle sizes cut by stage i .

The method of the invention may be regarded as separating and recovering particulate material by feeding the material entrained in a liquid medium to the first of a series of cyclone separators having a cyclone angle selected to cause clean and washed particles within a first defined range of particle sizes to report to the overflow together with particles of lesser size and feeding the material recovered from the overflow to a second cyclone separator having a cyclone angle less than that of the first separator and selected to encourage the cleaned and washed particles within the first defined

range to report to the underflow for recovery and to cause cleaned and washed particles within a second defined range of particle sizes less than those of the first defined range to report to the overflow.

5

It will be appreciated that according to another aspect of the invention there is provided an apparatus for separating and recovering particulate material which comprises a plurality of cyclone separators connected in series with means for supplying the particulate material entrained in a liquid to the inlet of the first separator of the series and means for supplying the overflow from each separator to the inlet of the next separator, the cyclone angle of each cyclone in the series being less than that of its predecessor in the series.

With advantage, the cyclone angles of successive cyclone separators conform to the formula

$$\frac{\cot (90 - 2\alpha_1)}{\cot (90 - 2\alpha_2)} = \frac{\phi_1}{\phi_2}$$

where α_1 , α_2 , ϕ_1 and ϕ_2 represent the parameters identified above in relation to equation 3.

25

It will be appreciated that for a given specific gravity (S.G.) the coarser particles report to the underflow of a separator and the finer particles to the overflow, although there will inevitably be some that report to the wrong exit. Our research has further identified that the diameter of the cyclone is a parameter which affects the efficiency of operation of a cyclone separator in relation to the particle sizes which report to the underflow or which exit through the overflow, and preferably is utilised for this purpose. By selecting this diameter it is possible to achieve a higher efficiency for the finer or smaller particles reporting to the overflow than for the larger particles reporting to the overflow. Thus, by selecting the cyclone angle, one can select a



range of particle sizes to report to the overflow and, by selecting the cyclone diameter, one can reduce the chance of larger particle sizes reporting to the overflow and enhance the quantity reporting to the underflow.

5

With a plurality of cyclone separators in series, decreasing the diameter of the cyclones from one to the next has the effect of enhancing the quantity of coarser particles reporting to the underflow with respect to the quantity of coarser particles undesirably reporting to the overflow.

10

In its preferred form, the invention provides a method of separating and removing particles from waste material and unprocessed R.O.M. which comprises feeding the raw material suspended in water through a plurality of cyclone separators in series connected by their overflow in which both the cyclone angle and the diameter of the cyclones decrease from one separator to the next.

15

20

The invention also provides an apparatus for separating and removing particles from waste material and R.O.M. which comprises a plurality of cyclone separators arranged serially and having both a cyclone angle ^{preferably also} and a diameter smaller than the preceding cyclone separator in the series and means for feeding the waste material entrained in water to the first separator in the series.

25

30

It will be appreciated from the above discussion that the present invention provides a plurality of serially connected cyclone separators each of which has a cyclone angle selected to encourage coarser particles in a range of sizes to report to the underflow, which range is within the particle size of the finer particles reporting to the overflow of the preceding separator and each of which separators ^{preferably} has a diameter which decreases from cyclone separator to cyclone separator in the direction of flow in the series and which enhances the quantity of coarser

35



particles in the range of sizes reporting to the underflow of the separators.

The efficiency E_i of a stage is considered to be the ratio of the actual weight of particles of size ϕ_i reporting to the overflow of stage i cyclone with respect to the theoretical weight which should report in ideal conditions at the desired maximum specific gravity admitted in the clean product.

For cyclone stages 1 to $N-1$, the efficiency should be at least 0.9 whereas for last stage N it should be not greater than 0.05.

E_i is a function of the diameter of the cylindrical part of the cyclone separator so that this diameter D_i is an important parameter in optimising the method and apparatus of the present invention.

In fact for cyclone stage 1 to $N-1$, the diameter D_i is given by the equation

$$\left[D_i \right]_{i=1}^{i=N-1} \geq \sqrt{2.79 \cdot \phi_i \cdot \frac{\sqrt{\tan(90 - 2\alpha_i)}}{\cos \alpha_i}} \quad \text{-----} \quad \underline{5}$$

where D_i is in inches and ϕ_i is in microns. For the last stage D_N where $i = N$ we have

$$D_N \leq \sqrt{0.6293 \cdot \phi_N \cdot \frac{\sqrt{\tan(90 - 2\alpha_N)}}{\cos \alpha_N}} \quad \text{-----} \quad \underline{6}$$

The underflow at stage i cyclones is composed of wanted, clean, washed products of the desired S.G. and of a size equal to or greater than S_i together with unwanted ashy products of a size equal to or less than S_i .

S_i may be considered to be the cut size to be made by a screen placed below the underflow of stage i cyclone.

$$S_i = \phi_i \cdot \sqrt{R} \quad \text{-----} \quad \underline{7}$$

It will be noted that with $N = 5$; $R = 2$. $M = 1000 \mu$ and $m = 30 \mu$. The following values for S_i are given

5	<u>underflow of stage</u>	<u>cut size of screen (μ)</u>
	1	990 μ
	2	795 μ
	3	647 μ
	4	523.7 μ
10	5	419 μ

It is desirable that the input velocity of the material slurry should be substantially the same at each stage and should be between 1.4 to 1.75 m/sec.

It is also to be preferred that the diameter of the underflow outlet should progressively decrease from one separator to the next in the series. The diameter of the underflow of a separator stage can be varied to adjust the performance of a stage to provide a degree of fine tuning.

The invention provides an apparatus designed to "cut" or separate at a predetermined S.G., between 1.5 and 2.5, an assembly or collection of particles inferior to 1 mm in size, using a plurality of cyclones connected in series by the overflow and feeding adequately chosen screening arrangements by the underflow.

Such apparatus is operable to wash particles of a size between M and m microns where M is not greater than 1 mm by cutting or separating at d_M (maximum S.G. admitted in the clean product). For a given d_m the ratio $R = \frac{\text{maximum size}}{\text{minimum size}}$

washed by any cyclone of the series varies with the washability of the raw material. For a given application R has a determined value comprised between 1 and 5.

One embodiment of the invention will now be described by way of example, reference being made to the accompanying drawings in which:-

5 Fig. 1 is a flow diagram of a typical arrangement for recovering larger sized coal,

10 Figs. 2A and 2B together represent a flow diagram of an arrangement according to the present invention for recovering coal particles of 1 mm and less in size,

Fig. 3 is a continuation of Figs. 2A and 2B, and

Fig. 4 is a graph which is illustrative of the principle of the invention.

The example to be described is concerned with the recovery of coal particles of a size of 1 mm or less from raw material which is usually available in bulk as slag heaps, tips or ponds adjacent worked-out coal mines. Commonly such reserves will contain between 20 and 80% by weight of coal of a particle size of 1 mm or less which was not previously believed to be economically viable to retrieve.

In order to avoid the expense of transporting the raw material, it is intended that the coal particles should be separated at the site of the reserve. The apparatus of the present invention can therefore be custom built on site to suit the characteristics of any particular raw material. The raw material to be treated is therefore initially examined to obtain a measure of the quantity of coal particles in given size ranges and their distribution within the raw material. The apparatus is then designed and assembled,

35 As illustrated in Fig. 1, the raw material is delivered to a feed trough 1 from which it passes to a distributor 2 which delivers it to a further conveyor 3 which conveys it to a vibrating screen 4. Water is sprayed on to the

material on the screen 4 and is supplied along pipes 10 from a tank 10a. The large sized material of the order of 25 to 120 mm passes down a spout 5 to a conveyor 9 which conveys this material to a dump. A permanent magnet 6 is associated with the spout 5 to remove any iron that may be present. Smaller sized pieces are diverted through a crusher and sizer 7 to a conveyor 11 for recycling to the conveyor 3.

10 The material passing through the vibrating screen 4 is passed to a sieve bend 8 which separates the particles into larger and smaller sizes such that the smaller sizes of about 1 mm and less are passed to a desliming sump 101 (Figs. 1 and 2B). The larger sizes are passed over a desliming screen 12 which allows smaller sizes which are trapped to escape to the desliming sump 101. The larger sizes travel on from the screen 12 to a dense medium cyclone washer which separates coal from the clay and other undesirable impurities present. Such coal would generally be greater than 1 mm in size and usually about 1 to 25 mm.

The desliming sump 101 represents the source from which coal particles of a size of 1 mm and less are to be recovered. The slurry in sump 101 is pumped by pump 102 (Fig. 2) through manifold 103 to the inlet of cyclone separator 104 which is the first of a series of four stages of cyclone separators in this example represented by separators 104, 112, 118 and a multi-cyclone ring of separators 125. The material entrained in water is fed to each of the separators 104, 112, 118 and 125 at the same velocity.

35 The cyclone separator 104 is intended to wash through the overflow washed, clean coal particles of a size of 250 μ to 500 μ of the desired S.G. together with unwashed particles of lesser size. It has a cyclone angle of 31° and a cyclone diameter of 30 ins.

It is intended to remove by the underflow particles of a size of 0.5 to 1 mm which are unwashed and are passed to the dense medium cyclone washer previously referred to and which receives the larger sizes from the screen 12.

5

The particle size of 0.5 to 1 mm could have been washed in an additional cyclone separator preceding the separator 104 and having a diameter of 35 ins and a cyclone angle of 38° . This would bring the number of cyclone separators to five in conformity with equation 4.

10

The cyclone separator 112 is intended to wash through the overflow washed, clean coal particles of a size of 125 μ to 250 μ . It has a cyclone angle of 21° and a diameter of 25 ins. The washed, clean particles in the range of 250 μ to 500 μ from the previous stage 104 report to the underflow for recovery.

The cyclone separator 118 is intended to wash through the overflow washed, clean coal particles of a size of 65 μ to 125 μ . It has a cyclone angle of 10° and a diameter of 20 ins.

The washed, clean particles in the range of 125 μ to 250 μ from the previous stage 112 exit through the underflow for recovery.

The cyclone separators 125 are intended to remove by the underflow coal particles of a size of 65 μ and coarser. They have a cyclone angle of 3° and a diameter of 9 ins.

30

The first cyclone separator 104 is effective to remove from the slurry the finer coal particles roughly of the size of 0 to 0.5 mm and cause these to exit through the overflow to the sump 109 from which this finer slurry is pumped by pump 110 to manifold inlet 111 to the second cyclone separator 112.

35

Fig. 4 shows some characteristic curves A for different cyclone angles of plots of density to particle size reporting to the overflow. It will be seen that the cyclone angle of 31° offers a reasonable compromise in order to exit at the overflow the majority of particles of a size less than 500μ with particles of the specific gravity concerned in the size range of 250 to 500μ (geometric mean 350μ) in the washed condition. On the same graph can be seen curves B representing efficiency relative to particle size reporting at the overflow. It can be seen that this efficiency falls away for particle sizes of 500μ and upwards and that the curve B for the cyclone angle of 31° again offers the best compromise for encouraging the particles of a size greater than 500μ not to report to the overflow but rather to the underflow.

As previously mentioned, the larger particles of size 500μ to 1 mm exit from the underflow 104 as unwashed coal and pass over a sieve bend 106 followed by a vibrating screen 107 to a conveyor 108 and are conveyed in this example to the dense medium washer previously referred to. The unwanted clay and slurry is taken from the screen 107 to a tank 132. The 500μ to 1 mm could have been washed by an additional hydrocyclone preceding the separator 104 as previously mentioned so that the latter would be fed with washed, clean coal in this size range.

The succeeding cyclone separator stages perform similar operations, the particle size being separated reducing with each separator. Thus cyclone separator 112 sends washed coal particles of a size of 250- 500μ from its underflow to the vibrating screen 114 and then through screw conveyor 306 to centrifuges 308 which dry out the material. The unwanted clay and slurry is passed from the screen 114 to the tank 132.

5 The balance of the material exits from the overflow of the separator 112 and comprises washed, clean coal particles in the range of 125-250 μ and unwashed particles of lesser size. This material passes through sump 115 and pump 116 to the manifold inlet 117 of the next cyclone separator 118. Here, washed coal particles of a size in the range 125 μ to 250 μ exit through the underflow through a tank 120 and a feeder 121 to a centrifugal screener 122 from which they are supplied to a conveyor 130. The unwanted clay and slurry is fed from the centrifugal screener 122 to the tank 132.

10 The overflow from the separator 118 passes through sump 123 and pump 124 to the multicyclones 125. Washed coal particles of a size in the range of 65 μ to 125 μ exit from the underflows through tank 127 and feeder 128 to a centrifugal screener 129 whence they are supplied to the conveyor 130. The conveyor 130 advances the particles of size 65 μ to 250 μ through conveyors 131 and 305 to the screw conveyor 306 and hence to centrifuges 308 which dry out the material. The dried material from the centrifuges passes along conveyor 313 to elevator 315 for collection. The unwanted water or slurry is collected in tank 309 and pumped by pump 310 either directly to tank 132 or to a further cyclone separator 311 which gives a final separation, the separated coal particles going through the underflow to the screw conveyor 306 and the waste slurry going to the tank 132.

30 It will be appreciated that although ranges of particle size are referred to, it is inevitable that there is an overlap in practice in the particle sizes extracted at each separator. Nevertheless, by utilising a plurality of cyclone separators in series and by constructing these
35 selectively to discard reducing bands of particle sizes, it is now possible economically to extract coal particles of 1 mm and less from waste tips and R.O.M.. In consequence, the volume of waste is materially reduced and

unsightly slag heaps, tips and ponds can be replaced by landscaping to improve the environment.

5 The waste slurry from the tank 132 is disposed of by dewatering in precipitator 135 and pumping to an aqueous resting place such as a pond or lake (145,151,152) or even a river 143.

10 It will be appreciated that although the specific description is concerned with the recovery of coal particles, the invention has application to the recovery of other minerals which are to be found in large volumes of presently discarded material. Initially, one needs to ascertain the density and particle size of the mineral to be recovered and how a given cyclone separator responds to these parameters. It is then possible, by varying the cyclone angle, the diameter of the cyclone and preferably also the diameter of the underflow outlet, to modify the cyclone separator characteristics to suit the particular application in view.

The diameters of successive cyclones in the series, ^{preferably} are related by the formula

25

$$\frac{D_1^2}{D_2^2} = K \cdot \frac{\rho_1}{\rho_2} \cdot \frac{\cos \alpha_2}{\cos \alpha_1} \cdot \frac{\sqrt{\tan(90 - 2\alpha_1)}}{\sqrt{\tan(90 - 2\alpha_2)}}$$

where K = 1 for all but the last cyclone in the series and K = 4.4335 for the last cyclone.

30

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THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method of separating and recovering particulate material by means of a plurality of cyclone separators each having an inlet, an overflow outlet and an underflow outlet, wherein said separators are connected in series in a flow direction from a first one to a last one of the separators by the overflow outlet of each separator other than the last being connected to the inlet of a next separator in the flow direction, and wherein the material entrained in a liquid medium is fed in the flow direction through the separators, each separator having a cyclone angle such that the cyclone angle of successive separators decreases in the direction of flow and the cyclone angle α_2 of a cyclone separator in the series being $\pm 5\%$ of the angle calculated according to the formula

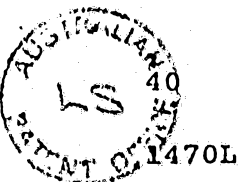
$$\frac{\cot (90 - 2\alpha_1)}{\cot (90 - 2\alpha_2)} = \frac{\phi_1}{\phi_2}$$

where α_2 is the cyclone angle of a cyclone separator following a separator with cyclone angle α_1 , and ϕ_1 and ϕ_2 represent the geometric mean particle size of the cut of successive separators with these angles.

2. A method according to claim 1 in which there is a decrease in underflow outlet diameter from at least one separator to the next in the series.

3. A method according to claim 1 or 2 in which there is a decrease in overflow outlet diameter for successive separators in the direction of flow.

4. A method according to claim 3 in which diameters D_1 and D_2 of successive cyclone separators are related by the formula



$$\frac{D_1^2}{D_2^2} = K \cdot \frac{\phi_1}{\phi_2} \cdot \frac{\cos \alpha_2}{\cos \alpha_1} \cdot \sqrt{\frac{\tan(90^\circ - 2\alpha_1)}{\tan(90^\circ - 2\alpha_2)}}$$

5 K = 1 for all cyclones but the last and K = 4.4335 for the last cyclone.

5. A method according to any one of the preceding claims in which the particulate material entrained in the
10 liquid medium is of a size of 1mm or less.

6. A method according to claim 5 in which the specific gravity of the material is between 1.5 and 2.5.

15 7. A method according to claim 6 in which the specific gravity of the material is in the range of 1.8 to 2.

8. A method according to claim 5, 6 or 7 in which the particulate material is coal and the liquid medium is
20 water.

9. A method according to any one of the preceding claims in which the particulate material entrained in the liquid medium is injected into each of the cyclone
25 separators of the series at substantially the same velocity.

10. A method according to claim 9 in which the input velocity is between 1.4 to 1.75 m/sec.
30

11. A method according to any one of claims 1 to 10 in which the material is fed through a series of N cyclone separator stages of which the efficiency of stages 1 to N-1 is at least 0.9 and the efficiency of the last stage
35 is not greater than 0.05.

12. An apparatus for separating and recovering particulate material which comprises a plurality of cyclone separators each having an inlet, an overflow



outlet and an underflow outlet, wherein said separators
 are connected in series in a flow direction from a first
 one to a last one of the separators by means connecting
 the overflow outlet of each separator other than the last
 5 to the inlet of a next separator in the flow direction,
 means for supplying the particulate material entrained in
 a liquid to the inlet of the first separator, each cyclone
 in the series having a cyclone angle which is less than
 that of its predecessor in the series and conforming to
 10 the formula

$$\frac{\cot (90 - 2\alpha_1)}{\cot (90 - 2\alpha_2)} = \frac{\phi_1}{\phi_2}$$

15 where α_1 and α_2 are the cyclone angles of two
 successive cyclone separators, ϕ_1 and ϕ_2 are the
 geometric mean particle size of the cut of successive
 separator stages and α_2 is within $\pm 5\%$ of the calculated
 20 value.

13. An apparatus according to claim 12 in which there is
 a decrease in overflow outlet diameter of successive
 separators in the direction of flow.

25 14. An apparatus according to claim 12 or 13 in which
 the diameters D_1 and D_2 of the successive separators
 are related by the formula

30

$$\frac{D_1^2}{D_2^2} = K \cdot \frac{\phi_1}{\phi_2} \cdot \frac{\cos \alpha_2}{\cos \alpha_1} \cdot \frac{\sqrt{\tan (90^\circ - 2\alpha_1)}}{\sqrt{\tan (90^\circ - 2\alpha_2)}}$$

35 where $k = 1$ for all cyclones but the last, $K = 4.4335$ for
 the last cyclone.

15. Apparatus according to any one of claims 12, 13 or
 14 in which the diameter of the underflow outlet in the
 separators decreases from at least one separator to the



next in the direction of flow.

16. Apparatus according to any one of claims 12 to 15 in which there are N stages of cyclone separators connected
5 in series and the efficiency of stages 1 to N-1 is at least 0.9 and the efficiency of the last stage is not greater than 0.05.

17. An apparatus according to any one of claims 12 to 16
10 in which means is provided for supplying the particulate material entrained in a liquid at the same velocity to each of the separators $\pm 10\%$.

18. An apparatus according to claim 17 in which the
15 means for supplying the particulate material entrained in a liquid is arranged to supply the material entrained in the liquid to the cyclone separators at a velocity of between 1.4 to 1.75 m/sec.

19. A method according to claim 1, substantially as
20 herein described with reference to the accompanying drawings.

20. An apparatus according to claim 12, substantially as
25 herein described with reference to the accompanying drawings.

DATED: 4 May 1992

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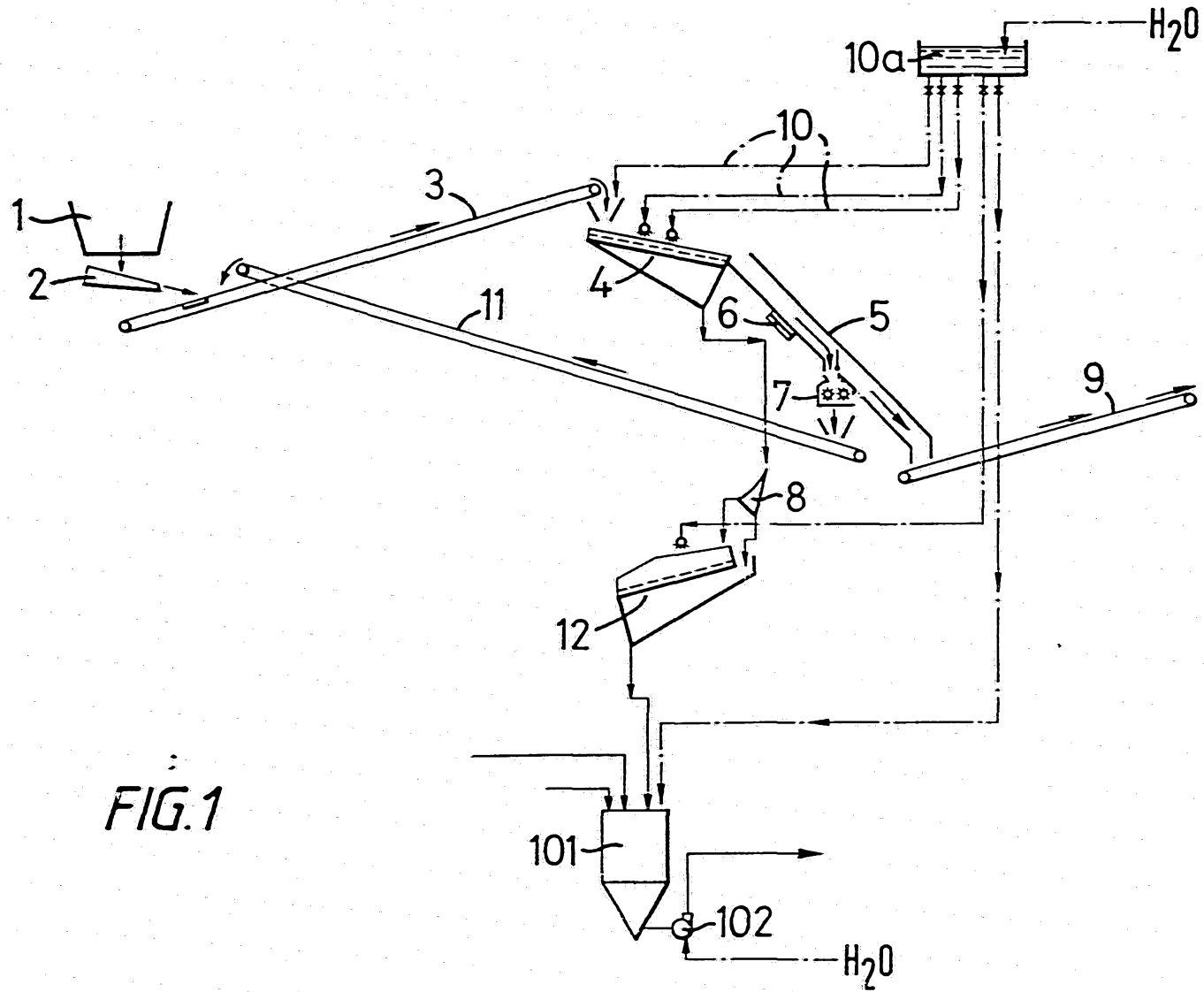
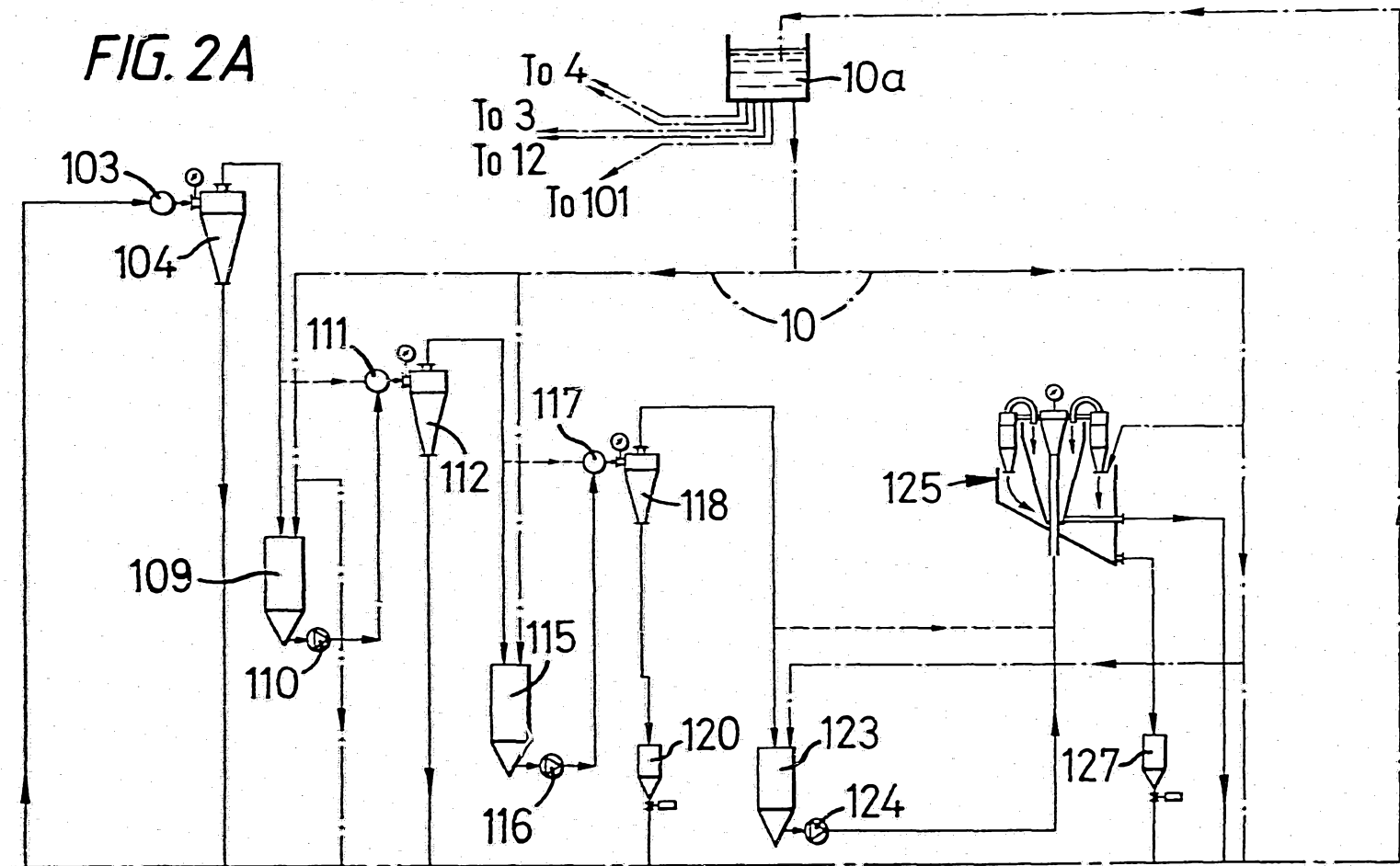


FIG. 1

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FIG. 2A



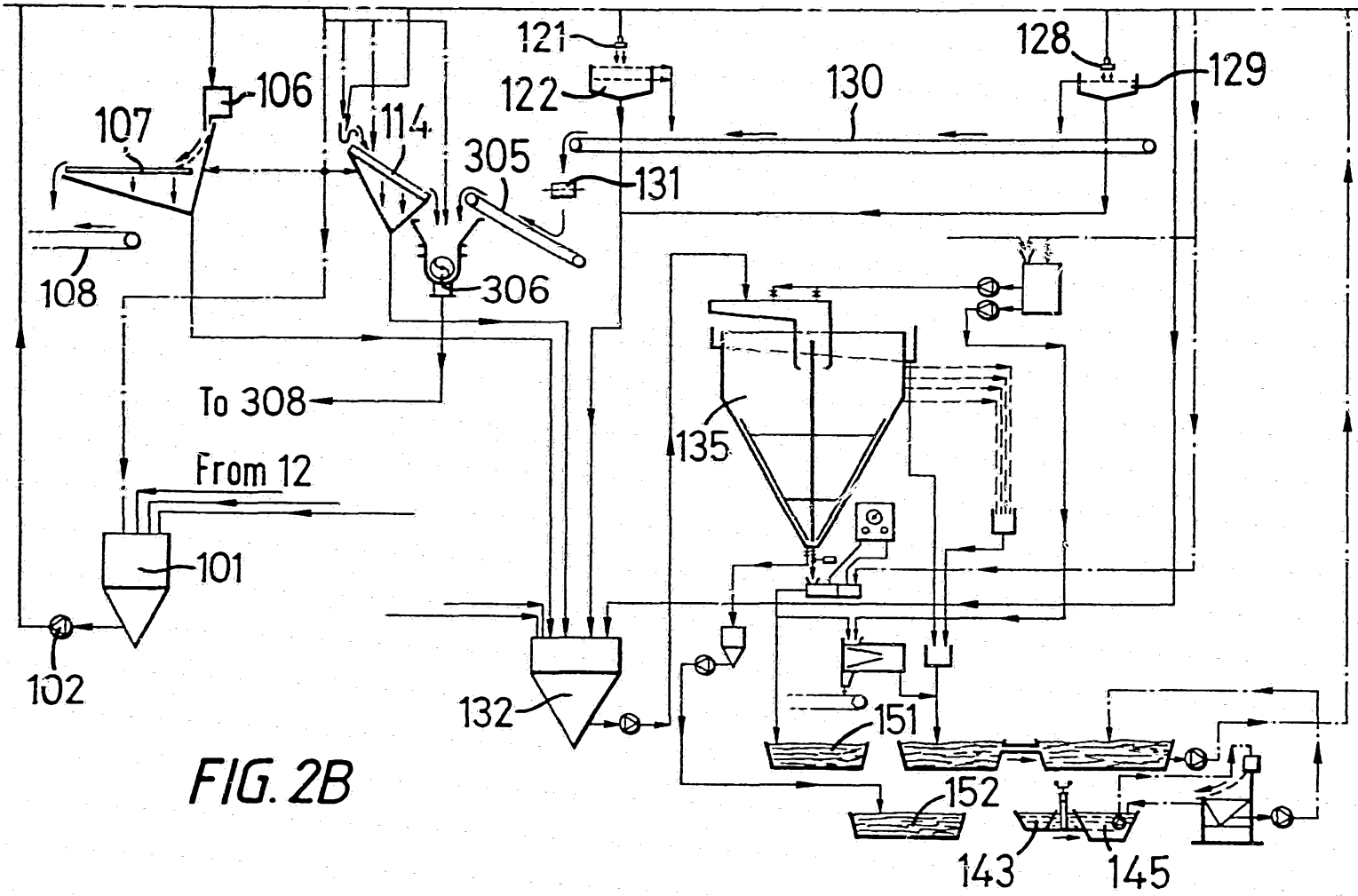


FIG. 2B

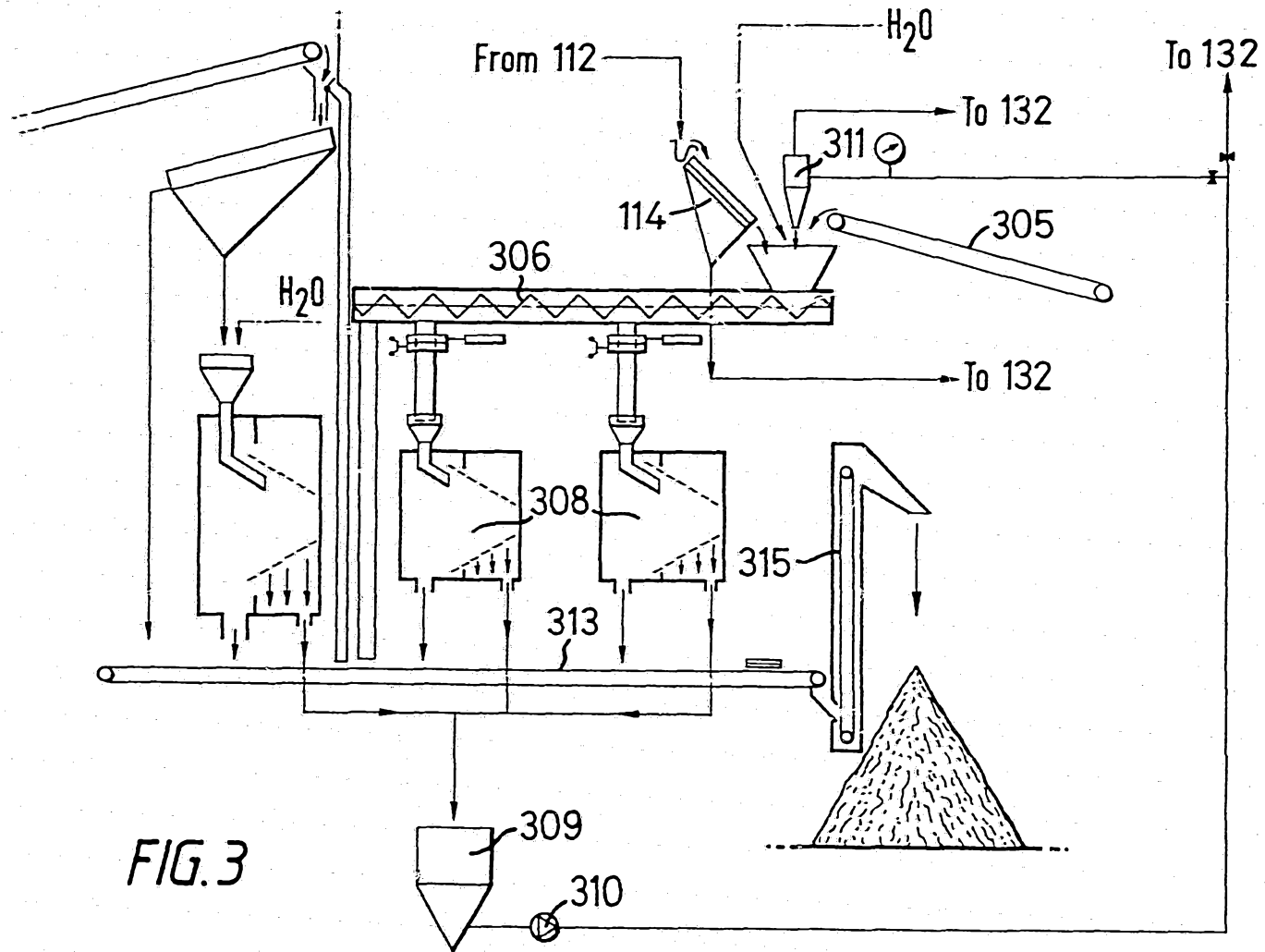


FIG. 3

0 1 1 0 0 2 4 0 1 7

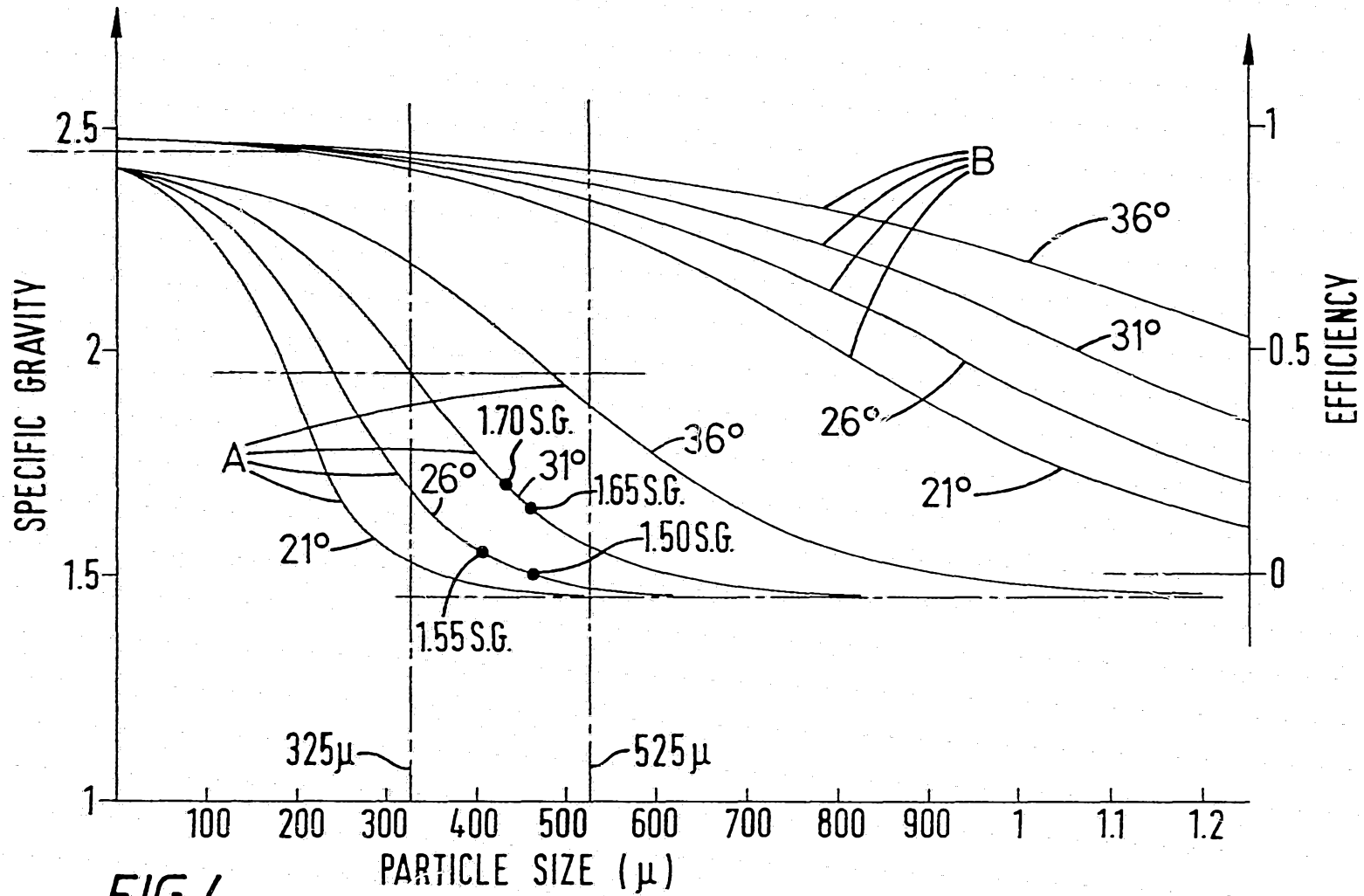


FIG. 4