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Mathews

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[54] **ORE SEPARATION**

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[52] **U.S. Cl.** **209/74,** 209/111.5

[51] **Int. Cl.** **B07c 5/34**

[58] **Field of Search** 209/74, 111.5, 115

[56] **References Cited**

UNITED STATES PATENTS

3,472,375 10/1969 Mathews .... 209/111.5 X

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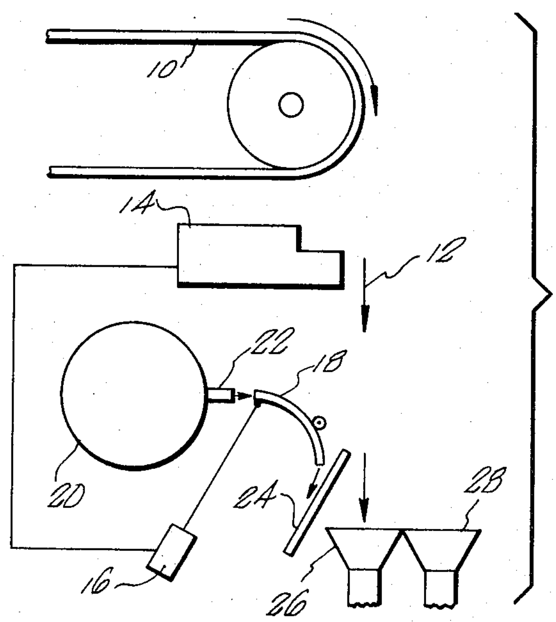
[57] **ABSTRACT**

There is disclosed herein an apparatus for detecting and separating a desired ore or mineral from a quantity of ore. The apparatus includes a plurality of selectively deflectable flowing fluid streams. The streams are controlled to displace the desired mineral particles from the quantity of ore. Pivotally mounted arcuate tubes normally divert the fluid streams when then are not acting to displace particles, but these tubes are selectively movable to allow the streams to hit desired particles. A screen is used for conveying the ore past the fluid streams in such a manner that the streams may act through the screen to displace the selected particles.

10 Claims, 4 Drawing Figures



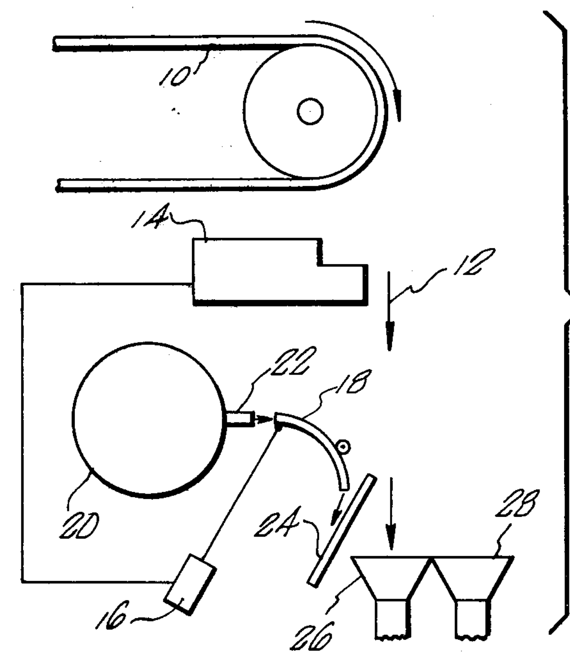


FIG. 1.

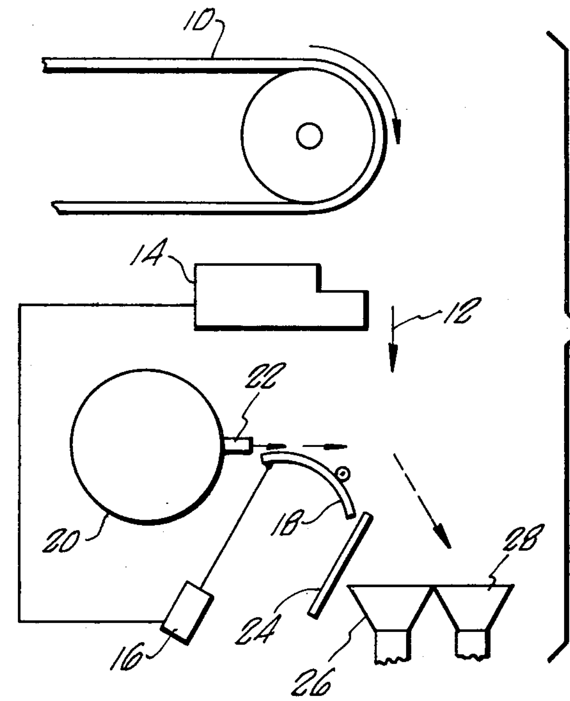


FIG. 2.

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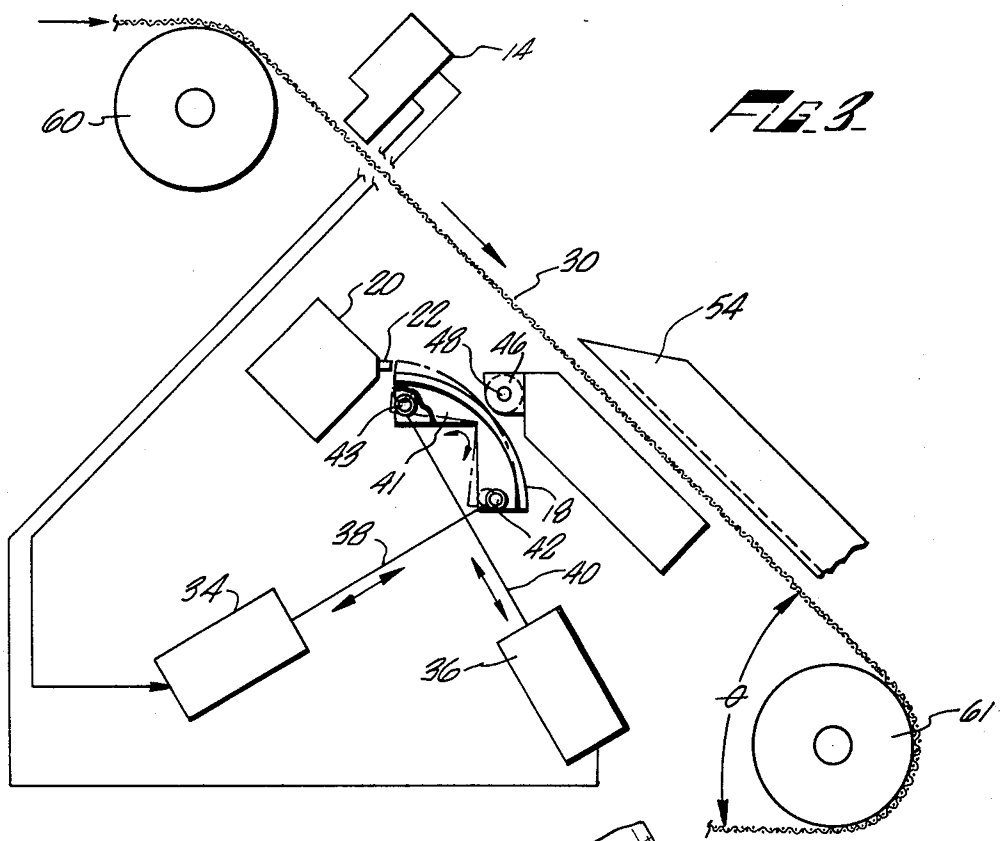

FIG. 3

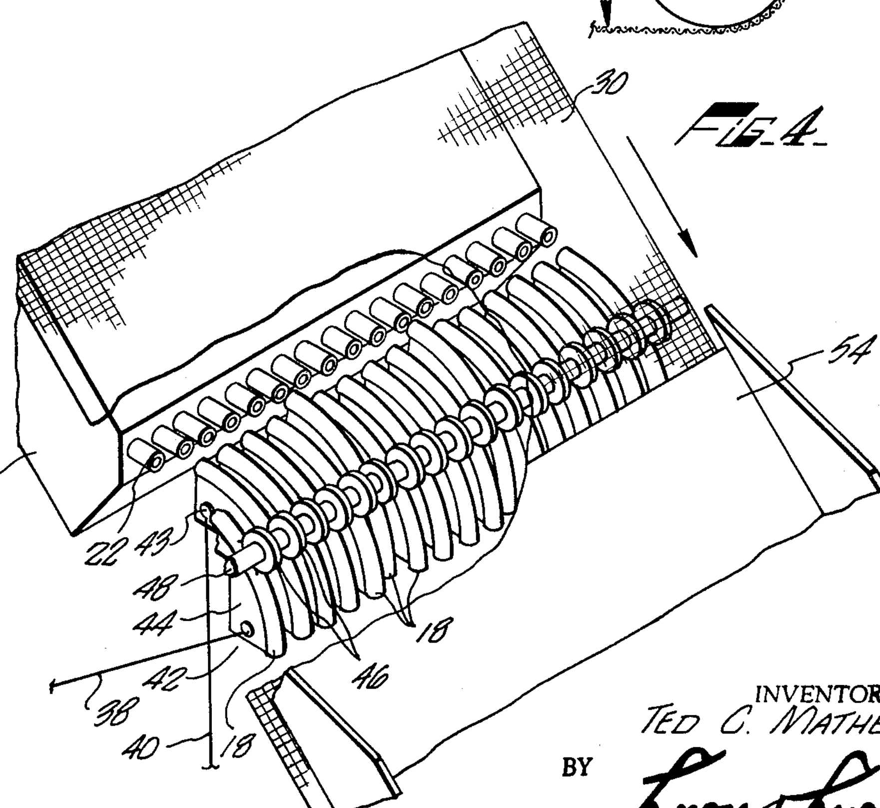

FIG. 4

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ORE SEPARATION

FIELD OF THE INVENTION

This invention relates to ore and mineral separation and more particularly to improved devices and equipment for separating a desired ore or mineral from a quantity of ore.

CROSS-REFERENCE TO RELATED PATENTS

Reference is made to U.S. Pat. No. 3,356,211 entitled "Ore Separation Process" and U.S. Pat. No. 3,472,375 entitled "Apparatus and Method for Separating Ore," the disclosures of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

As noted in the above referenced patents, there are known systems for primary separation of valuable and worthless minerals wherein a difference in physical properties is used to trigger a physical separation of the desired mineral. The use of fluid streams to selectively accomplish the separation function is described, for example, in said U.S. Pat. No. 3,472,375. The general overall scheme of such systems is to cause crushed or partially crushed ore particles to fall from a moving belt past a sensor. The sensor detects a unique physical characteristic of the desired mineral. A unique characteristic can be imparted to the material by processing the ore in such a way that a physical property associated with the desired ore acquires a second property which is more easily measured. When the measurable property is sensed, it triggers means to cause a fluid stream to be activated and to impinge upon the discriminated particle to physically separate it from the main body of ore.

Some systems heretofore imployed in making a primary separation of minerals have significant limitations based on mandatory requirements on ore input. One factor constraining such an input is the speed with which the selecting means can separate. This reaction speed affects the volume of material which can be processed in a given time, and is particularly important when small particles or low grade material is to be separated. The reaction time of the system also may reduce the accuracy of selection because the process is less able to initiate and terminate a selection response in an almost instantaneous period of time. With reduced accuracy, the density of particle input must correspondingly be reduced. The constraint on the density of particles input also reduces the amount of material which can be processed in a given period of time.

The methods and apparatus disclosed in said above patents provide a significant improvement over prior separation approaches. However, further improvement is desired in certain cases, such as in the selection of small particles. The selection of small particles is desirable and important where the mineral is quite valuable, an example being diamonds.

Another factor which acts as a limitation on the input is the need for an accurate trajectory for the particles passing the selection device. When the particles are allowed to fall past the selection device, their original release should impart a particular velocity to the particles. The particles will then reach the sensor and selection means at a predicted location and time. This is desirable because of the usual reduction in the sensitivity of sensing devices, and the accuracy of separating means, as the distance from the desired particles becomes greater or changes. In some separations it has been found desirable to use a slurry of ore, such as where the size of desired particles is small. However, because of the moisture, the particles tend to adhere to one another and to the feed belt or other feed means, and an undesirable velocity component frequently is imparted to some of the material as it leaves the belt. Because of this, unpredictable trajectories result thereby giving rise to improper or erratic detection or separation.

SUMMARY OF THE INVENTION

The present invention involves several novel concepts particularly useful in separations where the desired particles are relatively small. An example, although not intending to be limined thereby, is the separation of diamonds as small as one twenty thousandth inch. The separation of small particles requires the use of a separation device of relatively low mass which can be actuated rapidly, and which can be made sufficiently small so as to separate out the desired particles without also separating out undesired particles. The present concepts accordingly involve means for controlling a flowing fluid stream in a rapid and precise manner.

A plurality of arcuate tubes are employed to normally divert a like number of flowing fluid streams away from the particle selection area. These tubes are pivotally mounted so as to greatly reduce the inertia which must be overcome in controlling the fluid streams. In selecting a particle, an arcuate tube is displaced or moved out of the natural path of the flowing stream to allow the stream to impinge upon the particle being selected. In this manner the trajectory of the selected particle is changed so that it may be collected in a suitable receptacle. Inasmuch as the arcuate tubes can be made relatively small, and actuated rapidly, they allow short and precise pulses of fluid to impinge upon the desired particles for separation, and function well in separating either wet or dry particles.

Additionally, in the separation of relatively small particles, such as diamonds as noted above, it is desired to slurry the same with liquid so as to provide a layer approximately one particle size thick on the feed belt or conveyor. It is difficult to otherwise provide such a thin layer unless the material is completely dry which is difficult to achieve. On the other hand, if the material is wet, as it will be when originally fed as a slurry to the feed belt, the trajectory of the material as it leaves the end of the conveyor will be significantly affected because much of the material will tend to adhere to the belt.

Accordingly, the concepts of the present invention also include the use of a perforated conveyor in the form of a screen. The slurry preferably is applied to the screen in a layer approximately one particle thick. The screen type belt allows the liquid from the slurry to drain off as the material is conveyed to the detection and separation area. The use of a screen also allows separation of the desired particles through the belt. The belt conveys the material past sensors which detect the characteristic of the desired particles, such as radiation thereof or radiation from a preferential coating thereon as described in said above patents. The arcuate tubes are mounted under the belt and are actuated in response to the signals from the sensing system to cause liquid to flow through the screen belt and deflect desired particles therefrom into a receptacle. This arrangement eliminates the problems associated with developing a desired trajectory for the particles. The screen arrangement further allows the material to be introduced in either a wet state or a dry state, and allows the use of a wide range of belt feed speeds.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic illustration of the separating apparatus according to the present invention showing an arcuate tube in a position to normally deflect flowing liquid streams away from the separation area;

FIG. 2 is a similar illustration showing an arcuate tube displaced to allow a flowing stream to impinge upon, and thus change the trajectory of, a desired particle;

FIG. 3 is a detailed side elevational view of apparatus similar to that of FIGS. 1 and 2 but including a screen type conveyor; and

FIG. 4 is a partial perspective view of the arrangement of FIG. 3.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGS. 1 and 2 schematically illustrate apparatus according to the present concepts employing a plurality of pivotally mounted arcuate tubes which are used to normally deflect a like plurality of continuously flowing liquid streams, but which may be moved or otherwise displaced about a pivot axis to allow one or more streams to impinge upon one or more respective desired particles to be separated. FIGS. 3 and 4 illustrate construction details of this arrangement, and further illustrate its use in conjunction with a moving screen type conveyor or belt wherein the deflecting apparatus is mounted beneath the belt to displace desired particles from the belt rather than accomplishing this operation during free-fall of the particles as schematically illustrated in FIGS. 1 and 2. The latter screen type belt arrangement is particularly advantageous, as noted earlier, where particles are wet, in in a slurry, or otherwise moist whereby the mormal free-fall trajectory thereof would be affected by their tendency to adhere to the belt when falling therefrom. This arrangement is particularly suitable for fine particle separations which have been applied to the belt in a slurry, and is particularly useful for separation of diamonds and diamond particles from other material.

Turning now to a discussion of FIGS. 1 and 2, a conveyor **10** is shown onto which ore material is applied for feeding the ore into a trajectory plane symbolically illustrated by an arrow **12**. In separating desired materials, the latter have a measurable property not possessed by the other material fed to the conveyor. Examples of such property are natural radiation, or fluorescence imparted by minerals to electromagnetic radiation to cause at least a portion thereof to fluorescence at a characteristic wavelength. The latter can be achieved by preferentially coating some of the particles with a liquid fluorescent material, as more particularly described in said aforementioned patents. A sensor **14** is located adjacent the trajectory plane **12** and generates a timed response when a desired or preferred particle passes any one of many discrete areas of observation across the trajectory plane **12** respectively associated with the plural tubes.

The sensor response is supplied to one of a bank of double acting actuators **16** which are mechanically linked to pivotally mounted arcuate tubes **18**. A typical conveyor belt is 30 to 40 inches wide and, thus, a large plurality of actuators and tubes are employed to select particles falling from any point along the width of the belt; likewise, the sensor **14** includes a like plurality of sensors to completely cover the plane **12** of interest. That is, there is a sensor corresponding to each tube, each sensor observing the area of its respective tube. The actuators **16** serve to pivot respective arcuate tubes **18** to the position shown in FIG. **2** and to return the tubes to the normal position shown in FIG. **1**. Continuous fluid streams are supplied to the inlet ends of the arcuate tubes **18** from a manifold **20** through respective nozzles **22**.

In the normal or non-selection mode as illustrated in FIG. **1**, the arcuate tubes **18** are positioned relative to the streams so that each stream is chanelled through a corresponding arcuate tube **18** onto a deflection plate **24** which diverts the fluid from the system. In this mode, the ore particles fall along the trajectory plane **12** and into an ore receptacle **26**. When the sensor **14** observes a particle which is to be separated from the main body of the ore, the sensor **14** responds to the observation by triggering the appropriate actuator **16**. The actuator pivots its respective arcuate tube **18** for the sensed area away from the continuous fluid stream thereby allowing the stream to directly impinge upon the selected particle, causing the particle to be diverted into the mineral receptacle **28**. With a 40 inch wide belt approximately 320 actuators **16**, tubes **18** and nozzles **22** are employed, and the sensor **14** includes a like number of detectors.

With typical separating apparatus for separating relatively small particles, such as diamonds as noted earlier, the arcuate tubes **18** are mounted apart on ⅛ inch centers, and the water jet from each nozzle **22** is approximately 1/16 inch in diameter. The conveyor belt may be approximately 30 inches wide.

The arcuate tube arrangement is particularly advantageous in providing a fast acting deflection system. The arcuate tubes can be made relatively small and light weight so that the same can be moved rapidly by an electromagnetic actuator **16**. Furthermore, in the normal position shown in FIG. **1**, the water flow through the arcuate tube **18** tends to maintain the tube in the fluid-deflecting position as shown, but when the arcuate tube is partially deflected (rotated counterclockwise as seen in FIGS. **1** and **2**) by the actuator **16**, the fluid jet on the entry end of the tube from the nozzle **22** and partial amount of fluid remaining toward the outlet end of the tube aids in quickly deflecting the tube **18** to the position shown in FIG. **2**. On the other hand, when the arcuate tube is returned from the deflected position of FIG. **2** toward the normal position of FIG. **1** by the actuator **16**, the fluid stream from the nozzle **22** aids in quickly repositioning the arcuate tube

18 when the entry end of the tube intercepts the fluid stream.

Turning now to a more detailed description of the concepts of the present invention, and particularly to the arrangement illustrated in FIGS. 3 and 4, there is shown a screen type conveyor 30 and the sensor 14 mounted above the screen, and the actuator assembly mounted beneath the screen for deflecting desired particles therefrom rather than deflecting the particles from the free-fall trajectory 12 upon leaving the conveyor as illustrated in FIG. 1. Even material such as 1/2 inch particles, tends to stick to a belt when wet thereby adversely affecting the trajectory thereof. The sensor 14 may be any of several types of sensors incorporating a plurality of sensing elements across the lateral dimension, or width, of the conveyor for sensing the unique characteristic of desired particles. Exemplary sensing arrangements are disclosed in said aforementioned patents. Suitable sensing devices include electromagnetic radiation sensors, color sensors, reflectivity sensors, radioactivity sensors, thermo-magnetic sensors, and the like. The sensing system employed is principally dictated by the characteristics of the ore to be separated.

The sensor 14 includes a row of individual sensing units, as noted above, the number and spacing thereof depending upon the width of the conveyor and the size of the particles to be selected, in order to determine the lateral location of such particles on the screen 30, or in the trajectory plane 12 if the free-fall arrangement of FIGS. 1 and 2 is used. Furthermore, the sensor system 14 includes appropriate electrical circuits for detecting the responses of the respective sensing elements upon detection of a desired particle, and for translating such signals into respective gating signals timed to actuate the selection system at the appropriate instant, and to allow or enable return of the selection system to its normal state following the selection. An exemplary system and sircuits are described and illustrated in said U.S. Pat. No. 3,472,375. The arrangement thereon illustrated describes an exemplary arrangement wherein ore has been treated with a fluorescent material, is irradiated by a radiation source, and the characteristic radiation emitted by desired particles of ore is detected by an electromagnetic wave sensing means, such as a plurality of photomultiplyers. The sensing or detecting means then provides signals to an amplifier and control circuit which in turn actuates one or more electromagnetic actuators, the particular one or more actuated depends upon the number and position of desired particles when were detected. These actuators, according to said U.S. Pat. No. 3,472,375, then pivot tubes flexibly coupled with a manifold to supply a stream of fluid for deflecting the desired particle or particles from the normal trajectory thereof.

The use of arcuate tubes 18 allows a more closely spaced selection apparatus and eliminates the need for flexible connections. These tubes may be operated in any suitable manner, such as by means of electromagnetic actuators of the nature of those illustrated in said U.S. Pat. No. 3,472,375. Any other suitable arrangement may be employed, such as a staggered arrangement of groups of electromagnetic actuators 34 and 36 mounted approximately 90° apart, each of which is double acting for moving its respective tube in two directions. These actuators are staggered to allow a more compact, or close, spacing of the tubes. Thus the actuators 34 operate the first, third, fifth, etc., tubes and the actuators 36 operate the second, fourth, sixth, etc., tubes. As will be apparent from an examination of FIG. 3, energization of actuator 34 will pivot the arcuate tube 18 counter-clockwise and thus allow a stream of fluid, such as water, from the nozzle 22 to flow through the screen 30 and impinge upon a particle thereon. Reverse energization of the actuator 34 will return the tube to its normal, fluid deflecting, position. The actuator 36 similarly rotates the next arcuate tube. Any other suitable arrangement for moving the arcuate tubes 18 may be employed, such as a pair of single-acting electromagnetic actuators coupled to each tube, one actuator for moving the tube in one direction and the other actuator for moving the tube in the other direction; a single actuator 34 or 36 for pivoting the tube 18 counter-clockwise and a spring for returning it to its normal position; and the like. The arrangement as illustrated in FIG. 3 employs mechanical linkages 38 and 40 for the respective actuators 34 and 36. These linkages may be formed of wire. Finer wire may be used if pairs of single-acting actuators are used for each tube inasmuch as both actuators in this case operate in a "-pull" mode only rather than in a push-pull, or double-acting, mode. Where relatively fine particles are to be separated, it is, of course, desirable that the plurality of actuators employed be relatively compact in the lateral dimension, or width dimension, of the conveyor screen 30. In this regard, instead of employing cylindrical coil type actuators other configurations can be used, such as a plurality of flat coils mounted on relatively thin forms to allow close center-to-center spacing of the actuators and arcuate tubes 18.

Each arcuate tube 18 is secured to a suitable bracket 41, and the linkages 38 and 40 are pivotally coupled with the brackets for respective pairs of tubes at 42 and 43. That is, the linkages 38 are connected at the lower ends of the brackets at 42 for the first, third, etc., tubes; whereas, the linkages 40 are connected at the upper ends of the brackets at 43 for the second, third, etc. tubes. Pivot rings 46 are secured to the arcuate tubes 18, and these rings are pivotally mounted on a rod 48. The rings 46 are mounted at a position on the arcuate tubes 18 so as not to interfere with fluid streams from the nozzles 22. The radius of the tubes 18 is selected to sufficiently divert the fluid streams so that the streams will not come in contact with the ore when the tube is in a normal, fluid deflecting, position as indicated at FIG. 1 so as to prevent inadvertant selection of worthless material. Similarly, the stroke of each actuator 34 and 36 is selected to provide sufficient clearence in swinging the upper end of a respective tube 18 from the path of a stream from a nozzle 22 upon particle selection. The number of arcuate tubes 18 is selected to correspond with the number of sensing elements in the sensor system 14, and is sufficient to cover the width of the selection area. With a 30 inch wide screen, an arrangement for selecting relatively small particles as described previously may include approximately 240 arcuate tubes 18 mounted on ⅛ inch centers across the width of the screen.

A receptacle or collection box 54 is located relatively close to the outer surface of the screen 30, and extends across the width of the screen, to receive desired particles deflected from the screen by the streams and from nozzles 22. It will be apparent to those skilled in the art that the manifold 20 likewise extends across the width of the screen, and provides a plurality of fluid streams from the nozzles 22 equal in number to the number of arcuate tubes 18 and of sufficient velocity and force to suitably deflect the desired particles from the screen and into the receptacle 54. The fluid stream energy required and the proximity of the receptacle and precise positioning thereof are dependent upon the size and weight of the desired particles to be selected.

Where a screen 30 is employed, and particularly with a slurry of material, it has been found to be particularly advantageous to arrange the portion of the screen 30 in the selection area at an angle θ as illustrated in FIG. 3. The greater the angle θ the easier it becomes to lift or deflect particles from the surface of the screen 30 to the receptacle 34. Conversely, if the angle becomes too great, the particles tend to accelerate down the screen 30 in a partial free-fall or free-roll and move too quickly to be hit by streams from the nozzles 22. On the other hand, the smaller the angle θ, the greater the force required to deflect the particles from the screen.

With wet material, for example, the trajectory of the material falling from the screen is relatively unpredictable as noted earlier; on the other hand, it is relatively difficult to selectively remove desired particles from a horizontal portion of the screen. With the angled arrangement of FIG. 3, with θ being approximately 45° for example, the force of gravity on retaining particles on the screen is reduced by approximately 50 to 80 percent. This reduces the force required in deflecting a particle from the outer surface of the screen, while obviating the problems of sensing and deflecting particles freely falling from the screen. The angle of the belt in the separation area also aids in collecting particles in the container 54. The angled portion of the screen may be provided by employing single or plural (so as not to abruptly change the direction of the belt) rollers at upper and lower locations 60 and 61.

The screen size or mesh is determined by the minimum particle size desired to be separated. The optimum size is that which will barely retain the smallest desired particle on the screen. With a coarser screen, the fluid streams are more effective in deflecting particles therefrom.

Although not intended to be limited thereby, an example of construction and operation of the apparatus in FIGS. 3–4 for use in diamond separation will be described. Typical prior separation devices do not separate particles less than ⅛ inch in size, and it is necessary that the material be dry. However, in the separation of diamonds and similar minerals it is economically feasible to separate relatively small particles, such as down to one-twenty thousandth inch and smaller. Thus, although the value of the material should be relatively high to make separation of fine particles economical, the concentration of diamond particles in the ore material does not have to be great inasmuch as an economical and efficient separation can take place according to the present concepts. In separating diamonds as small as one-twenty thousandth of an inch, the screen belt 30 has approximately one-twenty thousandth inch openings. The ore material is mined, crushed, and put through "heavy media separation" to derive a material having particle sizes in the range desired. This material is slurred with water to provide a dispersion sufficient to spread on the screen, such as approximately two to five parts of water per one part material, and then is spread on the feed end of the screen belt 30 in a thin layer approximately one particle size thick. The screen has openings of approximately one-twenty thousandth inch, and allows dewatering of the slurry without loss of the material. The screen 30 may be approximately 30 inches wide and be formed of stainless steel thirteen thousandths diameter wire, and be moved at approximately 400 feet per minute. The tubes 18 may be mounted on approximately ⅛ inch centers. The desired material such as diamonds as noted above, are preferentially coated with a fluorescent agent prior to slurrying or as part of the slurry.

The sensor 14 is mounted relatively close to the layer of material, and preferably as close as possible inasmuch as the radiation from the material diminishes as the square of the distance from the material. This characteristic of radiation is an important reason for eliminating the unpredictable trajectory problem associated with wet material. The length of the belt prior to the sensing and separation area is selected to be sufficient to allow suitable dewatering of the slurry. This length variew, of course, with the material type and size, inasmuch as some materials drain more easily than others. In the exemplary apparatus, described above, and at a belt speed of 400 feet per minute, approximately 6 feet of belt prior to the detecting and separating area thereof is sufficient to allow the material to sufficiently drain, unless the material includes clay which requires a longer draining time. Each arcuate tube 18 may have an inside diameter of approximately 1/16 inch and a radius of approximately 2 inches, with the pivot at rod 48 falling on a radial line essentially half-way between the ends of the tube.

The present embodiments of this invention are to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than the foregoing description, and all changes which come within the meaning and range of equivalency of the claims therefore are intended to be embraced therein.

What is claimed is:

1. Apparatus for separating first and second solid particles wherein the first type particle has a particular measurable characteristic, comprising

means for moving the first and second particles in a uniform path,

sensing means for detecting the measurable characteristic of the first type particle and for providing control signals,

nozzle means for forming a plurality of flowing fluid streams, and

a plurality of separating means responsive to said signals for allowing selective impingement of the flowing fluid streams on the first type of particle to separate the first type of particles from the second type of particle, said plurality of separating means each including an actuator coupled with pivotally mounted arcuate means, said actuator being responsive to a control signal for moving said arcuate means from a normal position to another position for allowing said selective impingement of a flowing fluid stream from a nozzle means on a first type of particle.

2. The apparatus of claim **1**, wherein
said means for moving the unseparated ore particles in a uniform path includes perforated conveyor means through which said fluid streams can pass to impinge upon the first type particles.

3. The apparatus of claim **2** wherein
the conveyor means has an inclined separation area, said separating means being mounted beneath said conveyor means to cause fluid streams to flow through said inclined separation area.

4. The apparatus of claim **1** wherein
each of said plurality of arcuate means comprises a pivotally mounted arcuate tube, said actuators being actuated by said control signals to rotate each of said tubes independently into and out of the path of a respective flowing fluid stream from said nozzle means.

5. The apparatus of claim **1** wherein
said arcuate means includes a plurality of arcuate tubes pivotally mounted and positioned to normally intercept and deflect the respective flowing fluid streams from said nozzle means, and the actuators coupled with said tubes selectively pivot respective tubes out of the paths of said flowing streams.

6. Apparatus for separating first and second types of ore particles wherein the first type of ore particles has a measurable property not associated with the second type of ore particles comprising
a screen conveyor having an inclined separation section,
sensing means extending across the width of said section for detecting the measurable property of the first type of ore particles along said width and providing control signals,
means forming a plurality of flowing fluid streams,
a plurality of separating means extending along the width of said section on an opposite side of said section from said sensing means, said separating means being responsive to said signals for causing the flowing fluid streams to flow through said conveyor to provide selective impingement of the flowing fluid streams on the first type of particles to separate the first type of particles from the second type of particles.

7. The apparatus of claim **6** wherein
said separating means comprises a plurality of arcuate tubes through which the fluid streams normally pass and which are selectively pivotable to allow fluid streams to flow through said conveyor.

8. Apparatus as in claim **6** wherein
said conveyor has a relatively flat section preceeding said inclined separation section, and
said sensing means is mounted above said separation section and said separating means are mounted below said separation section.

9. The apparatus of claim **6** wherein
said separating means includes a plurality of actuators coupled with a respective plurality of pivotally mounted arcuate tubes, said actuators being responsive to said control signals from said sensing means to rotate respective tubes independently into and out of the path of respective flowing fluid streams.

10. Apparatus as in claim **6** wherein
said separating means are mounted beneath said separation section of said conveyor, and
said separating means includes a plurality of pivotally mounted arcuate tubes positioned to normally intercept and deflect the respective flowing fluid streams, and includes actuators coupled with said tubes to selectively pivot respective tubes out of the paths of said flowing streams in response to control signals from said sensing means.

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