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UPDATE:

FLOW SORT X-RAY DIAMOND RECOVERY

BASED ON 35 YEARS OF EXPERIENCE IN DESIGN AND MANUFACTURE
OF ELECTRONIC SORTING MACHINES

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CIRCULATION AT THE

SAIMM'S 2ND COLLOQUIUM ON

2005 Diamonds – Source to Use

In the 21st century diamonds are not lost in the final recovery stages of a diamond mine because of a lack of available technology but rather as a result of a lack of understanding the technology that is available!

CONTENTS

1. INTRODUCTION

In every diamond mine or diamond digging no matter how large or small there is a stage that finishes off the diamond recovery process, THE FINAL DIAMOND RECOVERY STAGE.

Any diamond mining operation has put a lot of effort and money into each diamond that finally ends up in the final recovery section of the plant.

It is therefore of utmost importance that all precautions necessary are taken to ensure no diamonds get lost at this vital stage.

Today all the necessary final diamond recovery equipment, for any diamond mining operation, is readily available.

The problem facing many diamond mine owner is to choose the right equipment for a specific application, which is suitable to recover all diamonds under specific conditions.

Often mining equipment suppliers and consultants, interested to sell the product which best serves their own interests, give customers wrong advice, provide incorrect specifications and sell them the wrong equipment.

There are cases where out of sheer ignorance, mines neglect the maintenance of this vital equipment, for the sake of cutting cost! They don't replace wear-parts when they must be replaced, don't use genuine spares etc. How little do they know what price they pay for this mistake!

It is also not that uncommon for the final recovery plant to be left to untrained staff to operate or for unqualified personnel to service!
It's much the same as letting a blind man drive a Ferrari and letting a gardener service it!

In the following few pages we attempt to show what the various types of diamond recovery methods are. What the pros and cons of these various methods are and what current diamond recovery machines can do, and what it cannot do. We also provide some guidelines for choosing the right equipment rather then listening to some twisted sales story and being talked into using second best!

2 DIAMOND PROPERTIES EXPLOITED BY VARIOUS RECOVERY METHODS.

a. S.G.(Specific Gravity) of diamonds
    i. Used in jigs, pans and heavy media separators (HMS), dense media separators (DMS).

b. Non 'wettable' (hydrophobic) surface of diamonds
    i. Utilized in grease tables, grease drums, grease belts, etc.

c. Luminescence (fluorescence and phosphorescence) of diamonds.
    i. Utilized in x-ray based diamond recovery equipment.

d. Translucency and transparency of diamonds.
    i. Utilized in optical sorters.

e. Color of diamonds.
    i. Utilized in optical diamond sorters (diamond grading devices).

f. Scattering of light and specula reflection of light by diamonds.
    i. Can be utilized in optical diamond recovery machines.

g. Infra-Red absorption (heat conduction) of diamonds.
    i. Can be utilized in optical diamond recovery machines.

h. Hardness / elasticity of diamonds.
    i. Has been tried in mechanical recovery / separation of diamonds?

i. Resistance to aggressive chemicals such as acids
    i. Used in 'final' diamond recovery

3 BACKGROUND OF DIAMOND RECOVERY

In basic and rough steps diamond recovery methods and principles went through the following stages:

j. From simple hand jigging

i. Diamond recovery is based on the specific gravity of diamonds (± 3.5) which is higher than most minerals in which diamonds are found.
ii. Recovery efficiency depends much on the skills and motivation of the jig operator.
iii. Security of this process is low as the jig operator comes into direct contact with the recovered diamonds.

1. This recovery process is a wet process

k. To pan plants

i. Once again diamond recovery is based on the relatively high specific gravity of diamonds as compared to the material that the diamonds have to be recovered from. Many different pan-designs exist, each one claiming to be better than the other.
ii. Recovery efficiency relies on many factors such as loading of the pan, sizing of the material, varying composition of the gravel, the amount of water being added to the gravel, the setting and condition of the stirring-paddles, etc. One of the more important factors that influence diamond recovery efficiency of a pan-plant is the specific gravity cut off point setting. Virtually all of these factors are set and influenced by the jig operator. A low cut-off means more concentrate and a high cut-off can lead to diamond losses. Constant supervision is essential.
iii. The degree of security achieved in a pan plant is good. The concentration of diamonds in a pan feed is low. Security depends mainly on the handling of the pan-concentrate. During maintenance work of the pan plant itself there is an increased security risk.

1. This process is a wet process.

l. To grease tables and grease belts, grease drums (all these devices are available either vibrating or static).

i. Diamonds are recovered by making use of the hydrophobic surface of diamonds in combination with a hydrophobic substance such as special 'grease'. Grease based diamond recovery apparatuses are numerous in design and obviously each design claims to have advantages over other designs.
ii. Recovery efficiency of any grease based system depends on many different factors. Water temperature, water quality, type (consistency) of grease used etc. Only an experienced operator will get all these things consistently right!
iii. By far the most important recovery efficiency problem is caused by 'coated' diamonds. Such diamonds have either lost their hydrophobic characteristics completely or such properties have become unreliable and hence such diamonds are lost in a grease-based diamond recovery system. Scrubbing (trying to remove the coating from the diamonds surface) before passing them over grease brings only some relief from this problem. Diamonds can re-oxidize within minutes after scrubbing making such a cleaning attempt in vain.
iv. Security is the main concern with grease based recovery technology. Diamonds caught on a grease table or grease belt are highly visible to anyone being in the area. It is further desirable to remove (by hand) a diamond stuck to grease as soon as possible. There is always a chance of a stuck diamond being 'freed' (knocked off) from the grease trap by other passing stones. Permanent observation / operator presence is highly advantageous for this process.

1. Any grease based diamond recovery process is a wet process.

m. To Dense Media Separation (DMS) aka Heavy Media Separation (HMS)

i. This diamond concentration method also utilizes the fact that the S.G. of a diamond is higher than most minerals in which diamonds are commonly found. This S.G. cut-off point can be more accurately controlled than in a pan-plant. This means that much higher diamond concentration levels are achieved.
ii. Recovery efficiency relies on several factors: accurate S.G. control of dense media, gap between diamond S.G. and S.G. of dense media, loading of DMS circuit, etc. A properly setup and operated DMS plant will achieve diamond recovery levels of well above 99%. The concentration level depends on the mineral composition of the material treated and figures of 2% are not uncommon.
iii. Security of DMS plants is high as it is fully enclosed and there is no human contact with diamonds.
iv. DMS is a wet process

n. To optical sorters

i. Diamonds are detected by their optical features such as light reflection, specula reflection and/or transparency, translucency of diamonds.
ii. Diamond recovery efficiency of optical diamond detection depends to a large degree on the optically detectable difference between diamonds and other mineral particles from which diamonds are to be recovered. Acceptable conditions for the use of optical sorters are seldom met and this technology therefore did not find many users.
iii. Security of optical sorters is very good as it is a completely 'hands-off' process that takes place in a secure enclosure and the recovered diamonds are automatically put into a secure concentrate container.
    1. As the presence of water interferes with the detection of optical particle features and the handling of wet material presents a problem to most sorting machine manufacturers optical diamond recovery is a dry process.

o. To basic X-ray sorters

i. X-ray based recovery machines make use of the fact that diamonds luminesce when exposed to x-ray radiation. Once again there are several different designs and makes on the market, and, as expected, each manufacturer claims to have the better product!
ii. Diamond recovery efficiency of x-ray based diamond recovery machines is high. Recovery above 99.9% is not uncommon for a properly set-up and properly operated machine.. There are, however rare and localized in occurrence, diamonds which for any practical purpose, do not fluoresce when exposed to x-rays. Such diamonds can obviously not be recovered by this type of sorter.
iii. Security offered by these sorters is excellent as they provide not only a totally 'hands-off' solution, but the sorting process also has to take place in a radiation proof, light tight enclosure. All diamonds recovered report automatically to a high security concentrate container
    1. Traditionally x-ray based diamond recovery is a dry process
    2. Some x-ray based machines are designed to process wet material of particle sizes above 10 mm.

p. To more sophisticated X-ray sorters

i. X-ray diamond luminescence became the preferred diamond recovery technology. As all the major mining houses around the world resorted to the use of x-ray sorting machines these machines became more and more sophisticated. Sorters were fitted with all kinds of monitoring systems and back-up circuits, remote control facilities etc.

ii. However this added gadgetry did little towards improving recovery efficiency. Even sophisticated 'diamond signal' processing techniques such as signal shape analyses (rise-time, fall-time etc.) did little to better sorting results. Complicated field operation and maintenance, as well as high cost of these machines have however severely restricted their use to large mining operations which have on-site high tech operating and maintenance personnel.

iii. Security of these sophisticated, computer controlled sorters has been improved even further.

1. Typically x-ray based diamond recovery is a dry process for fine material (<10mm)
2. Some x-ray fluorescence based machines can process wet material with particle sizes above 10 mm.

q. To FLOW SORT'S new generation of x-ray luminescence based diamond recovery machines.

i. In principle these machines are nothing more and nothing less than x-ray sorters utilizing x-ray fluorescence as well as x-ray induced phosphorescence of diamonds. We at Flow Sort have carefully analyzed the diamond miner's and digger's needs and requirements. From this study we obtained a design brief that said: a sorter must be robust, a sorter must be easy and economical to operate, a sorter must be reliable requiring little maintenance and it must guarantee high, sustainable diamond recovery efficiency and cater for any possible problems, the supplier must stand behind his product with an uncompromising after sales service. A clear understanding of all this and over 30 years of experience in the electronic sorting field culminated in a new generation of sorters; FLOW SORT's XR and TSXR machines.

ii. Recover efficiency of Flow Sort x-ray based recovery machines is well above 99% of all fluorescent diamonds.

iii. Security of Flow Sort machines is very high as the sorters are constructed of heavy gauge stainless steel enclosures, all interlocked with one another.

1. All Flow Sort machines sort wet or dry material!

r. Back to grease based recovery methods?

i. There is no change in basic grease diamond recovery technology. Re-introducing grease recovery is driven by fear of loosing non-luminescent diamonds in x-ray based recovery systems. Reality shows that in many cases it is not the presence of non-luminescent diamonds that is the problem but rather the usage of x-ray sorters with outdated technology, x-ray sorters that are not properly maintained and not properly set-up.

ii. Grease recovery technology is the ideal back-up system to x-ray recovery. It is also a good stand-alone diamond recovery technology for the recovery of 'small' diamonds say below 1.5mm. (X-ray sorters throughput figures are rather low at such small material sizes).

iii. Security of the newer generation of grease diamond recovery systems has been improved by adding automatic grease applicators and grease recovery apparatus.

iv. Grease based diamond recovery is naturally a wet process.

s. New optic based diamond recovery technology?

i. A tremendous amount of advancement has taken place in the field of signal processing and system computerization since the first attempts of optical diamond recovery some 35 years ago. Optical sorting systems are today therefore far more efficient. Optical sorters could find practical applications in diamond recovery plants that have to deal with non-luminescent diamonds. Such plants however should not to be mistaken with operations that **claim** to lose diamonds because they do not luminesce under x-ray. The real reason of such (alleged) problems is often due to poor equipment conditions and poor plant maintenance and general lack of training and ignorance of plant operating personnel. **A Flow Sort x-ray recovery plant is on record to have achieved, over a period of 3 months, a diamond recovery efficiency (measured by value of diamonds) of 99.98%.** The time where optical diamond recovery machines will approach an equivalent efficiency, and reliability of x-ray sorters,(if necessary with a back-up grease tables) has yet to come!

ii. Security of future optical diamond recovery systems will remain high.

iii. New optical diamond recovery machines will most likely remain dry-material sorters.

t. There are several other, more exotic, diamond recovery concepts which are not worth mentioning here as they have never found any practical use.

4 The principle of X-ray diamond recovery is a straight forward process.

a. Irradiate a diamond concentrate with X-rays, look for luminescent particles in the x-rayed (irradiated) concentrate and then remove the luminescent particles from the rest.

b. To achieve this there are a few basic rules to observe.

c. The material to be sorted must be presented to the x-ray / optic zone of the sorter in a **mono layer**. (No particles may cover others)

d. The **radiation spectrum** must be such as to induce maximum luminescence of the irradiated diamonds. The parameters for such X-ray generating devices are well known in the industry.

e. A sorters light detection device must be capable to **detect the small amount of light** emitted by a luminescent diamond (down to a fraction of a millionth of a lumen).

f. When a diamond has been detected by the sorters optics, the diamond (with as little as possible of gang material) must be removed (**ejected**) from the rest of feed material.

5 What is really behind Flow Sort's success story:

a. In a nutshell its 35 years of experience in the field of electronic sorting.

b. Its 35 years of careful observation of what is required from a diamond recovery machine.

c. Its 35 years of designing, building and servicing diamond recovery machines.

d. Its 35 years of critical analyses of what makes a good sorter and what must be avoided.

e. 35 years of trying to find a balance between operational requirements and available (practically possible not laboratory based) technical solutions.

6 The 1992 design brief for Flow Sort X-ray recovery machines.

The product must be such that the small diamond miner and digger gains confidence in the products simplicity, reliability and performance.

Traditional diamond miners and diggers are extremely conservative and automatically mistrust anything 'new' especially if the "new" is a black box and they can't see what is going on inside the black-box! To convince them to use Flow Sort X-ray Recovery machines we have set ourselves the following goals:

a. Sorter must be extremely **robust**

b. Sorter must be **easy to modify and upgrade**

c. Sorter must be **easy to operate**

d. Sorter must require **low maintenance**

e. Sorter **maintenance** must be **simple**

f. Sorter must be **automatic** 'self adjusting' and self testing

g. It must give **long term performance stability**

h. The **operating costs** must be **low**

i. The sorter must offer **high security**, hands-off operation

j. The sorters must be **100% safe** to operate

k. There must be a **guaranteed back-up service and spares supply**

l. Back-up **service must be 'fast'** (7 days a week)

Have we, at Flow Sort, achieved our goals? This question can only be answered by our customers who currently operate **400 Flow Sort machines in 16 countries** around the world.

7 Flow Sort x-ray diamond recovery machine features!

a. A most important feature of Flow Sort diamond recovery machines is that they are designed to handle wet (fresh or sea water) diamond concentrates.

b. **The obvious advantage** is that there is no requirement for **costly drying** a diamond concentrate before passing it through an electronic sorting machine!

c. Recovering diamond from wet feed provides a straight forward, **seamless integration into any processes** upstream of the sorter. Be it sorting material originating from a simple washing and sizing screen, concentrate from a pan plant or the sink fraction of a dense media separation (DMS) plant. All these processes are wet processes.

d. **The 'not so obvious'** advantages of passing wet concentrates through an x-ray diamond recovery machine, all adding to improved recovery of 'low-luminescent' diamonds are:

   i. **Keeping the diamonds cool** (at water temperature) is important as diamond luminescence decreases as their temperature increases! This can have a distinct negative effect on diamond recovery efficiency when concentrates are dried by means of heating before passing through an x-ray sorter.

   ii. **Avoiding dust** being generated within a sorter which often interferes with diamond detection.

   iii. **Avoiding** the build up of **thermo-luminescence** and **tribo-luminescence** in mineral particles such a calcite, feldspars, fluorite, quartz etc. Luminescence of any particles other then that of diamonds is a nuisance. Especially if such luminescence is of a similar color spectrum to that of a diamond.

   iv. Thermo luminescence starts to come into play when material with temperatures above 50°C is passed through a sorter.

   v. Tribo luminescence is caused by friction between dry particles and between dry particles and feed chutes and conveyor belts etc.

e. **Mechanical (diamond) ejection gates,** one of Flow Sort's key feature.

   i. This Flow Sort invention means that **no** additional equipment such as compressors, air dryers, oil absorbers etc are required as is the case with traditional pneumatic ejection devices. (No hidden capital or operating costs).

ii. A mechanical ejector gate is a more positive way of dealing with closely following diamonds. (Aerodynamics causes problems in pneumatic ejection systems).

iii. Flow Sort ejector gates are 'intelligent ejection devices'. Software controlled stepper-motors change gate movement as and when required.

iv. Mechanical gates make for clean material cuts. Compressed air jets 'atomize' feed-water with all the dirt and grit it contains. Not a very nice thing near a sensitive optical device!

f. **Indirect x-ray tube water cooling** is another Flow Sort development.

i. It means that there is no requirement for a separate water-cooling system not even at installations where only sea water is available! (No hidden capital or operating costs).

g. Sea water (marine) operation

i. Flow Sort machines are constructed in 316 S/S. They can be safely operated with sea-water.

ii. No fresh water is required for sorter operation on marine diamond mining vessels (special feed slides are supplied for marine applications to neutralize the rolling and pitching movements of ships).

h. X-ray pre-excitation of diamonds

i. Another **key feature**. In a Flow Sort machine the diamonds are exposed to x-rays for as long as practically possible, to allow their phosphorescence level to build up before they pass the optical detection point. This ensures higher luminescence levels which is of particular importance when dealing with 'low-luminescent' diamonds.

i. The **self cleaning optic-system** window in a Flow Sort machine ensures long term maintenance free diamond detection stability.

j. Flow Sort machines functionality is **continuously monitored** and the entire sorter is subjected to a complete automatic system test every 20 minutes.

i. **No operator supervision** required, a sorter will automatically shut down if it is not 100% functional.
ii. Full **remote controlled** sorter operation is available.

k. **Luminescence detection from opposite side of x-ray excitation.**

   i. This is yet another **key feature** of a Flow Sort machine. Detecting the luminescence of particles passing through the sorter from the opposite side from which they were exposed to x-ray radiation eliminates unwanted detection of many "surface" luminescent minerals!

l. **Automatic background compensation** ensures long term stability of sorting parameters under changing sorter operating conditions.

m. **Automatic feed rate control** prevents over-feeding of a sorter. In practice one of the most common problems encountered. Prevents overfeeding

n. **Preset sorting programs** allow changing a sorters set-up for a specific sorting task (material size, etc.) to another by the flick of a switch!

o. **Modular sorter design** makes not only service and maintenance easy, it also makes it possible to convert and upgrade Flow Sort machines. (From a single stage sorter into a twin stage sorter and visa versa, from a re-concentration model into a primary recovery machine, etc.)

8 WHAT ARE THE LIMITS OF X-RAY DIAMOND RECOVERY TECHNOLOGY?

How to measure performance of diamond recovery machines?

Fluorescent diamonds or non-luminescent diamonds, this is the question!

a) The difference between luminescence levels of diamonds and luminescence levels (in the same color spectrum of a diamond) of other mineral particles in the feed to a sorter is what sets the limits! Not a sorters capability to detect a fluorescent diamond!

b) Not many things in nature come either in black or white, there are usually some 'shades of gray' in-between! With the level (amount) of light emitted by diamonds exposed to x-rays it is no different. It is not as simple as one diamond does luminesce and the other one does not. Some diamonds (size for size) luminesce many times more than others. Even the same diamond often shows vastly different luminescence levels when irradiated / viewed from different angles! To preempt the question of whether the luminescence level of a diamond depends on or is related to its quality or clarity? The answer is no!

c) And now we come to the big question, down to what level of luminescence can an x-ray sorter detect (recover) a diamond?

d) If this question is put to a supplier of x-ray sorters he will claim that his sorters can detect and recover 'low-fluorescent' diamonds.

e) This reply unfortunately does not answer the question. Under laboratory conditions luminescence can be detected from virtually all diamonds when exposed to x-rays. Even most of the so called 'non-fluorescent diamonds' show minute amounts of luminescence.

f) The fact is that it is not a sorters limitation to detect weakly luminescent diamonds but rather to distinguish such diamonds from other minerals which also exhibit some luminescence properties when exposed to x-rays!

g) To create more confusion and make a comparison of different sorter capabilities totally impossible, do diamond recovery machine suppliers brag about their machines being capable of recovering diamonds with lower luminescence than their competitors can recover! As proof of such nebulous claims they demonstrate that their sorters can recover luminescent tracers of a given mV (milli Volt) rating!

h) Volt is of course the unit of measure of an electric charge and not of light intensity (lux) or light emission (lumen)!

i) To illustrate this problem let us compare this to car manufacturers specifying a vehicles top speed in "liters of petrol consumed per minute" rather then km/h. Such a value can be calculated for a specific vehicle driving under specific conditions but it cannot be used for comparing top-speeds of different car makes and models. If the top speeds of cars are specified in "kilometers traveled per hour" (achieved at sea-level on a flat road with no head or tail wind) then such comparison is easy!

j) X-ray fluorescent tracers, commonly used by the industry are further not very good diamond substitutes at all. They have only limited use in specific x-ray recovery machine designs and models and do not provide a general platform of comparison with different sorter designs and models.

k) The fact remains that the x-ray / optic / diamond geometry is different from one sorter model (make) to another and so is the x-ray spectrum and x-ray intensity that reaches the diamond causing it to become luminescent.

l) There is a very significant and important difference between a Flow Sort x-ray sorter and other makes of x-ray diamond recovery machines. Flow Sort x-ray machines are designed to detect the luminescence on opposite sides of a particle (diamonds, tracers) to the side which has been exposed to x-rays!

m) Most x-ray luminescent tracers consist of some heavy metal powder (for achieving the density of a diamond) and a fluorescent substance and a coloring agent (for identification) mixed into a resin.

n) Heavy metal particles (Ferro-silicone for instance) prevent x-rays from penetrating to the inside of the tracer. Coloring agents prevent luminescence generated within a tracer to reach the tracer surface.

o) Such tracers therefore are only luminescent on their x-rayed surface unlike a diamond which is luminescent throughout.

p) **This type of tracer is not suitable for testing and or evaluating the recovery efficiency of a Flow Sort x-ray diamond recovery machine**.

q) Flow Sort x-ray machines can only be tested with Flow Sort approved luminescent tracers which exhibit the same x-ray absorption characteristics and translucency as a diamond.

r) Field tests of Flow Sort x-ray machines have shown that these machines are capable of recovering diamonds with a luminescence level of **as little as 0,01µlm** (one hundredth of a millionth of a lumen!)

s) The problem is that in order to recover diamonds with such a low level of luminescence many other (unwanted) particles which show similar or even higher luminescence will also be colleted to concentrate!

t) What follows from the above is:

   a) X-ray diamond recovery machines can be and should be used to sort any type of diamondiferous concentrate. X-ray diamond recovery is a well established and well proven technology that has long sidelined any other diamond recovery method.

   b) The recovery efficiency of an x-ray sorting machine is governed by the presence of other, (unwanted) luminescent mineral particles in the feed material to the sorter.

   c) If the feed to a sorter contains large quantities of mineral particles which show luminescence levels as high (or higher) then the luminescence levels of the diamonds to be recovered, which is rather the exception than the rule, a compromise must be reached.

   d) Either accept a higher yield or run the risk of failing to recover low-luminescent diamonds.

   e) If neither of these two options are acceptable, the best solution is to pass the tailings of the x-ray diamond recovery machines over a ‘grease’ based diamond recovery system. Grease diamond recovery is also an old well proven concept.

u) The shortfalls of grease recovery such as low security, recovery inefficiency of coated diamonds etc. are all well known and measurable. Considering that in such a “dual-sorting-system” the x-ray sorter will recover by far most of diamonds leaving only a few very low luminescent diamond to be recovered by grease, the ‘grease problems and risks’ are significantly reduced.

v) Flow Sort offers a free diamond / mineral luminescence analyses service to all its customers and potential customers. Analyzing a representative material sample on Flow Sort's FPA (Fluorescent Particle Analyzer) ensures that the performance that can be expected from of a Flow Sort x-ray diamond recovery plant is known before it is built!

9 SUMMARY

a) Today's best long term proven diamond recovery systems are grease based and x-ray based diamond recovery machines.

b) For recovering diamonds in material sizes of less than 2mm grease based recovery has the economical edge over x-ray machines.

c) For diamond recovery of plus 2mm material x-ray diamond recovery machines are superior because of their high recovery efficiency and high security.

d) In rare cases, where it has been established (not suspected) that 'non-luminescent' diamonds are present we recommend a dual stage recovery system. First pass the material through an x-ray machine (which brings all the benefits of x-ray recovery to the vast majority of diamonds) than pass the tailings of the x-ray machine over a grease table to pick-up any non-luminescent diamonds.

e) When it comes to choosing a brand or model of x-ray diamond recovery machine consider the many advantages that Flow Sort diamond recovery machines offer and make use of the free consulting services which Flow Sort provides.