ABSTRACT
In spite of having long past, due to process, economic and operational limits, sorting has not met big success in mineral processing. However, advances in sensing and quantifying raw material surface characteristics in connection with rapid growth in computing and software technology as well as considerable enhancements in optical resolution and related electronic component made it possible to rely on sorting process more and more. Furthermore, growing technological awareness and skills of the machine users as well as increasing the technical support by sorter manufacturers are other optimistic factors in growing the acceptance of sorting machine. However, lack of consistent, easy to be maintained, and low cost ejector system are big losses. Thus what should be aimed in future is to develop new machines based on reliable sensing and ejection systems to promote sorting application.
Sorting process, its advances and limitations are discussed within this paper. Some new sorting machines, which have been developed based on new technologies, are introduced and possible future for sorting as an option for treating minerals and wastes is pictured.

1. Introduction
Utilization of some property in which the intermingled severed minerals differ either in kind or degree, to effect a differential response to some impulse force is the basis of every concentration methods [1]. One of the most direct beneficiation methods is sorting which in some cases has been found to be the most effective and economic. Ore sorting has a potential to upgrade a range of mineral ores to processing plant leading to substantial reduction in downstream costs, limiting environmental harm by reducing mine wastes and improving ore quality and mineral recovery. Ore sorting techniques give an opportunity to remove gangue and below grade ore prior to main processing step. However, sorting can be considered and successfully utilized for secondary processing, i.e., waste separation and recycling.
On the contrary, costs for installation and operation of sorting machine(s), feeding, sizing and preparation of the feed, as well as loss of valuables to waste are drawbacks in having sorting / pre-concentration step prior to main processing plant [2].

1.1. Hand Sorting
It is worth spending a few lines on the origin of hand picking although it has now been almost superseded. Manual removal of selected grades of material from a mass of broken ore, i.e., hand sorting, is the simplest, most direct, and sometimes most effective method of concentration. Hand sorting, sledging, spalling and cobbing of the rocks and mineral products have been conducted since ancient time, i.e., Stone Age Man made simple implements from hand-sorted flints, and are described by numerous mining historians in details. The romantic imagery, but real misery, of the work belied what became a very efficient concentration method [1, 3, 4].
Even high-grade complex ores had been treated by hand. Picking and cobbing the mined product from Cornwall to produce six different fractions, i.e., (1) rich copper pyrite, (2) coarse rich galena, (3) coarse rich blende, (4) fine tin oxide, (5) pyritiferous milling ore, and (6) waste, is an example. However, at Clausthal, Germany, during the late 19th century up to 16 products were hand-sorted [1,3].

Apart from the necessity to remove refuse material such as rope, wood, steel, dynamite, etc., from any mill feed and dangerously deleterious substances from feed to chemical ore treatment processes the decision as to the advisability and extent of sorting is purely economic. The cheaper the labor, the more inefficient and expensive the mechanical treatment, the further hand sorting can be employed.

Hand picking had been much more common with non-metallic mined ores rather than metalliferous ores. Whenever valuable mineral occurs as coarse aggregates or where considerable waste is mined and the mineral and gangue or milling ore and waste are readily distinguishable by human eye, the economics of hand sorting should be considered and investigated [1].

Hand picking is limited at the coarse end by the mass of particles being moved and at the fine end by the capacity of ore that can be handled. The size limitation from 50/75 to 250/300 mm upper limit seems to be tolerated. There are different operating factors affecting the efficiency and accuracy of the hand sorting:

- a- sorting surface, (i.e., the suitable surface, easy to be installed and maintained)
- b- kind of material picked, (i.e., the picked material must be in least amount in the feed)
- c- washing or cleaning the feed, (it is essential for better recognition of material)
- d- labour’s ability (e.g., younger and quicker labours are preferred)
- e- size of material (average from 2.5 to 12 inches)
- f- lighting (i.e., better lighting condition better is hand sorting performance)

In spite of long history, hand sorting became impractical, impossible, or too expensive due to decreasing of ore grades and liberation sizes, changing the scale and economics of processing plants as well as introducing new technologies. By the late 1960s and early 1970s hand sorting was largely abandoned [3]. Except in very rare circumstances, notably the richest and smallest high grade Hishikari gold mine in Japan [3, 5], nowadays the use of hand picking is precluded.

1.2. Automated Sorting:

Sorting technology for treatment of the coarse ore particles is well established and indeed in some circumstances for some minerals, e.g., diamond and coals, acts as the principal method of extraction. However, for other mineral systems, it may constitute a major component of the overall flow-sheet. General objective of sorting is either concentration, i.e., produce one or more finished products, or pre-concentration, i.e., to upgrade and produce a smaller bulk for further processing or salvage, e.g., to make acceptable feed from a low or marginal grade deposit [2].

Either as a concentration, pre-concentration or salvage objective, sorting, has numerous advantages including significant energy saving from reduction or extraction of fine comminution techniques and product drying, reduction in disposal coasts and its related problems due to plunging in fines and slurries generation, etc. In addition when sorting is employed as a major concentration technique, a unique method for recovery of particular mineral or elimination of one mineral from another is offered. Although, some sorting methods are well established in some cases, e.g., in diamond industry and to some extent for uranium and gold ores, they have not met a big success in mining and mineral industries, especially when during the 1980s, for a number of reasons, unwillingness against the use of sorters came into view [3-4].
Sorting techniques are not limited to uranium, gold and diamonds ores. Since 1946 sorting techniques in different countries such as Australia, South Africa, USA, Canada, Finland, France, UK, Greece, and India has treated wide range of ore types. Due to the economical and technical assessments sorters have been installed at different locations of production plants.

A feature of the historical development of mechanized sorting during 20th century is highlighted by Salter [3-4]. It is obvious that the development of ore sorters has been closely linked with both the development of analytical techniques and methods used in food processing industry. For example the emergence of “Carboscope” for coal preparation that provided x-ray attenuation images of coal and mineral matter in 1898 had been the pioneer for developing of a fully automated potato/stone sorter in 1960s that in turn was developed into a coal/waste sorter.

Sorting applications proved successful at various times however, changing economical and process conditions have led to the de-commissioning of some. The benefits in front of the use of sorting machines can be summarized as:

a- In a way that finished product can be obtained by sorting that no other process can match

b- If sorting can provide a pre-concentrated product for crushing, grinding, or further processing plant. In this case its benefits are more clear:

b.1. overall plant capital costs are reduced (if new plant is going to be erected)
b.2. reduction of operating costs as well as the ore transportation cost, especially when the process plant is far from the exploitation plant
b.3. increasing overall plant metallurgical and economic performance
b.4. achieving higher overall economic metallurgical recovery (if the sorting reject grade is lower than the final tailings grade)
b.5. some small and uneconomic deposits may be made profitable due to lowering the transportation and operation costs.
b.6. increasing the life time for a mine by increasing reserves to include in-situ and stockpiled previously below the cut-off grade material.
b.7. reducing environmental impact by rejecting materials that can be either used for construction purpose or stockpiled in a dry form, i.e., generating less fines as the waste
b.8. rejection of wastes containing harmful components, e.g., arsenic, prior to fine grinding

On the other hand sorting application encounters some technical, operational and economical limits. Those limitations are summarized as the following and will be discussed later on.

- high capital costs for installing sorter(s)
- high operation costs
- difficulties to maintain the sorting machines
- requirements for feed preparation
- narrow size fraction(s) that can be treated by sorters
- low throughputs for sorters
- low efficiency for special use
- insufficient liberation of ore for sorting
- autogenous milling option
- variability of the ore for sorting purpose (too variable ore deposit)
- existence of too much fines in feed
- complexity of the sorting process in comparison with other pre-concentrating method
- absence of discrimination technique for specific ore
- deposit size (either too small or too large)
2. Sorting Machines

Sorting machines contain the following elements as the basic requirements [2,3]:

A method for presentation or feeding: Particles must be introduced to the identification and separation zones in a proper manner. Feed presentation system may consist of several steps, such as sizing, washing, feed rate control, particle alignment, wetting, acceleration and stabilization. Most feeding systems use vibratory feeders however, in some cases a direct slide chute are used to feed material into a particular path. In some cases, accelerating the feed to high speed, then stabilizing it to ensure defined positions in the separation zone are needed. Most sorters use a slower feeding system, most often directly fed from a vibrating feeder into a free-fall area or onto a slow moving belt. The sensing system may be either mounted above or installed under the conveyor belt or the particles may drop into free-fall zone to be detected by sensors.

Method(s) for sensing (i.e., particle examination): To detect and identify particles the raw material is carried through a zone where the detectors generate data describing each particle. The sensing technique may be either a surface or bulk based analytical detecting method.

Method(s) for comprehending and utilizing the information achieved from sensing zone: Electronic data processor is used to analyze the data generated by sensors and to identify the particles to be separated in separation zone. Before mid 1990s detecting processors, such as laser sorters or scan cameras, were faster and more suitable than microcomputers. However, rapid advance of computer technology has changed the situation. Nowadays huge volume of data can be processed in several orders of magnitude greater than for laser and scan cameras. By taking advantage of sophisticated computing technology more approachable sorting machines are manufactured.

A method for separating one mineral from another: After identification of the feed, wanted and unwanted pieces must be separated from each other. Air jet, water jet and mechanical separating systems are applied for this purpose. Mechanical systems may consist of variety of pistons and plungers. They normally suffer because of speed-limited. So if fast moving is needed the fluid media separating system must be considered.

![General configuration of a sorting machine](image_url)
Although, application of sorting technique for specific run of mine or stream of raw material meets success if all above items work in desirable manner but what seems to be more important and the sorting techniques are named and classified accordingly is the technique(s) used for identification and discriminating of one material from another. Table 1 introduces the common sensing methods and related detection devices.

<table>
<thead>
<tr>
<th>Property to be sensed</th>
<th>Sensing Device</th>
</tr>
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<tbody>
<tr>
<td>Natural Radioactivity</td>
<td>Scintillation counter and pulse analyser</td>
</tr>
<tr>
<td>Induced Radioactivity</td>
<td>Scintillation counter and pulse analyser</td>
</tr>
<tr>
<td>X-ray transparency</td>
<td>Scintillation counter and pulse analyser</td>
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<tr>
<td>X-ray fluorescence</td>
<td>Phototube</td>
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<tr>
<td>Ultraviolet fluorescence</td>
<td>Phototube</td>
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<td>Visible reflectance</td>
<td>Phototube</td>
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<tr>
<td>Visible transparency</td>
<td>Phototube</td>
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<tr>
<td>Differential heating</td>
<td>Infrared scanner</td>
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<tr>
<td>High voltage conductance</td>
<td>Resistance/conductance or current flow network</td>
</tr>
<tr>
<td>Low voltage conductance</td>
<td>Resistance/conductance or current flow network</td>
</tr>
<tr>
<td>Laser induced fluorescence</td>
<td>Optical receiver (fibre optic)</td>
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<tr>
<td>Laser induced plasma</td>
<td>Optical receiver (e.g., photodiode)</td>
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<tr>
<td>Laser light scattering</td>
<td>Optical receiver</td>
</tr>
<tr>
<td>NIR identification</td>
<td>Reflected light scanner</td>
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<tr>
<td>SG (Specific gravity)</td>
<td>Gas pycnometry</td>
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3. Technical Parameters to be Considered for Material Sorting

First of all it is worth noticing that from the sorting point of view the accept fraction must be liberated from the reject fraction at the size to be treated by a specific sorting machine. Then accepted and rejected fractions must be consistently identified by some means within the time available for examination by the machine. If these requirements are met then the others will come into consideration.

3.1. Deposit Size

In fact, even if sorting machines were an option, large-scale operations, such as porphyry copper or iron ore mines, would have difficulties justifying the use of large number of the sorting machines [2-4]. So that small and medium scale operations are ideal for sorters, however, it seems that for small-scale operations the feasibility of utilizing sorting machine(s) and the attendant feed preparation cannot be tolerated.

3.2. Particle Size

Maximum and minimum sortable size fraction is very important criterion to be considered for a successful sorting procedure. In fact the maximum particle size is mainly determined by the capability of mechanical ejecting system. For example when standard compressed air ejector is utilized, an effective and optimal air blast outlines the maximum size about 200 mm for a rock having a density about 3 t/m$^3$ [6]. However, in practice other economic design factors such as distance between the particles and also the blast manifold, etc., must be taken into account.

On the other hand in order to achieve the best grade/recovery relationship, the liberation of the valuable component(s) is the crucial factor. It does not mean that the particles must be liberated
completely before introducing to the sorting machine but the economic liberation is needed to
determine by the reasonable amount of valuable component(s) in the waste portion.
Nowadays sorting machines can process the particle size done to 1 mm, but the economic limit
may be higher. Accordingly, the value of raw material or/and product(s) dictates the minimum
particle size possible to be treated. For example, food-sorting machines with low capacity about 1
to 5 t/h are able to sort rock salts with few millimetres and modified grape sorters are used for
talc. But for low value commodities such as limestone the economic limit is much higher and
may be close to 10 or 15 mm with the size [6].
Furthermore, for an efficient sorting it is vital to process narrowly size fraction(s). Typically a top
to bottom size ratios of 2:1 or less and 3:1 are satisfactory for coarsest and finest size fractions
respectively. These ratios are identical with other processes [2, 3, 4, 6]. Again these ratios could
be relaxed due to the precision requirement and the mass distribution of the fractions.

3.3. Crushing and Milling
First of all, crushers that produce excessive fines are usually less attractive as they reduce the
quantity of acceptable sorter. Jaw, gyratory, cone or roll crushers normally provide suitable shape
product for sorters. Second, rounded products as generally produced by autogeneous or ball mills
are less desirable since tend to roll and are less stable in sorting machines and thus the machine
performance is reduced by increasing deflection, i.e., blast losses. Although, it is thought that
sorting option is avoided if autogenous milling is utilized but sorting of near critical size material
coming out of such a mill should be possible. Freer and Bohme [7] have presented examples.
Thin flaky materials are also less pleasant for sorting than the materials with nearer cubic
dimensions. In the case of low-density material due to the aerodynamic effects both of which
exhibit more variable flight trajectories in sorting machine and hence the sorter performance is
reduced [6].

3.4. Surface Conditions
In fact the partial’s surface must be clean enough to be detected and identified. Masking of the
surface by dust, dirt, mist, etc., prevents the effective detection of the particles. As an example, in
most applications but not all when optical sorting is utilized, dry surface distorts the true
identification, however, the most effective optical properties are revealed by the moist rock
surface. On the other hand extreme wet surface is not good too. This may mask the surface
properties by having too high reflectivity that blinds the optics.
In some cases feed should be near dry or bone dry. This is important when small sized material
are processed as surface tension effects due to free moisture cause particles to stick together
and/or take on unpredictable trajectories within the sorting machine and hence cause blast losses.
Finally it must be mentioned that surface conditioning, using some chemicals, are suggested and
applied in some circumstances [8, 9].

3.5. Operation Efficiency
Like other separation systems, it is really no reason to expect 100% efficiency for a sorting
machine and so the use of two or more passes of the material may be considered. Consequently,
efficient operation can be gained by using correct discriminating criteria with properly
maintained sorter.

3.6. Ore Variability
To avoid any unsatisfactory condition one can consider ore variation when the primary evaluation
test is carried out [6, 10]. This allows for fine-tuning of the sort criteria ahead of anticipated
operation.
3.7. Location of the Sorter in Plant Flow-sheet
It is rational to place the sorter immediately after the primary or secondary crushers depending upon ore liberation size so that the sorting machine can remove the waste after the minimum of processing circuit.
It may also be considered to run sorters in series either to purify the product, or to clean up the tails, or both if an ore is well liberated in its near final commercial form [10].

3.8. Sizing of Sorters:
Sorters are normally sized to accept as much of the plant throughput as is economic. However, it may be well economic to by pass the higher-grade ore and just put marginal ore through a sorting plant.
In industry scale sorters having capacity up to 500 t/h do exist [11]. However, capital and operational cost are determining for sizing a sorter in a plant. Typically the capital cost of a given sorting machine per tonne per hour feed varies either inversely as the square of the geometric mean of the feed mesh size for a single or multi-stream machine or inversely as the arithmetic mean of mesh size for random stream machines [2-4].

3.9. Colour Criteria (in the case of photometric sorting)
If separation of black from white colour components is aimed it is the best to blast the white colour component(s) because the black or very dark pieces may not be able to distinguished from the reference surface [6]. Although new optical systems are more refined and are available with better reference media for accurate colour recognition but the problem still exist especially if the reference medium become dirty. Despite availability of very high intensity light sources, enabling sharp distinction of relatively small differences in average brightness, color, hue, etc., in practice problems may arise since particles having different appearance may be viewed from just one side. Therefore the selection of light source for special application is paramount important [2, 6].

3.10. Testing
Machine suppliers testing facilities are available to conduct the initial technical feasibility tests to see the feasibility of installation a sorting machines for specific raw material and to establish the proper sorting criteria. Professional knowledge, e.g., geological, mineralogical, optical recognition and particle liberation knowledge, is needed for selection the testing sample since the sorting performance during life-time of a plant is dependent on the feed properties of recognition, liberation and friability remaining within acceptable limits at all times [6, 10].
Once the first requirements were met large-scale/pilot tests is normally conducted. Then after the prediction of sorter performance is available but the sorter performance can only be accurately predicted when extensive test work at design throughput on full sized sorting machines, using representative feed properly crushed, screened and washed, are done. Computer model of a sorter performance may be generated from the tests results. This computer model may be used to predict overall sorter plant performance for any configuration of the sorters within a plant over the full range of throughput [10]. This model can be utilized to study the effect of changes to any combination of the main parameters, such as feed rate, feed grade and size, liberation, etc., for number of plant configurations. Nowadays due to the existence of advanced fuzzy logics and programming the extensive test procedures of the recent past are no longer required.

4. Some Requirements for Sorting Plant Design
Few points to be considered are remarked herein for designing the sorter plants [6, 10].

4.1. Dust and moist air extraction
The environment inside the machine may be polluted by small dust or mist particles, produced by high-pressure air ejectors. Installation of dust and moist air extraction system is beneficial to keep the optical or/and other discriminative systems as well as whole machine environment in a proper condition.

4.2. Adequate compressed air system
The air system must be designed for a short piping length, sufficient buffer volume, and low-pressure drop. Normal air cleaning to remove dust, water and avoid freezing, must be considered too.

4.3. Monitoring of the feed and product(s) streams
It is helpful to view and monitor the product streams so the installation of viewing mechanism is recommended.

4.4. Water and particle collection system
Due to the water spraying and fast moving of the feed, substantial spillage may be caused. For easy housekeeping and maintenance collection and disposal should be engineered.

5. Economical Considerations
Although installation of the sorting plant brings several benefits but the decision whether a sorting plant can be installed as an adjunct to the solution of a mineral recovery or waste utilization problem or not is defined by the economic criteria. In fact capital and operating costs are two determining factors.

Increasing revenue and accelerating return are two important benefits can be gained through sorting process [2]. In fact development of salable new products, improved products, or increased recovery would produce revenue. The value of mineral reserve would increase if sorting allowed the mining of lower grades. However, if sorting helped to reduce overall processing costs the value of mineral reserves would increase as well.

The mining costs are reduced when sorting replaces selective mining. In addition, pre-concentrating of the mill feed can increase the mining rate. Furthermore, sorting offers a saving in processing costs through improved recovery as well as increased mill capacity. Saving may be realized in transport and other costs through upgrading by sorting, particularly if sorting can be done underground or in-situ and discard used as backfill. The sorting process will be more beneficial if occasionally waste product is salable for some other purpose such as road building, concrete aggregate or other similar propose.

5.1. Capital Cost
The following items cover the capital cost.
- the price for the machine(s)
- the cost of accessory equipment, such as the facilities for providing the compressed air, dust removal, washing system, etc.,
- the overall installation cost
- the cost of additional crushing, sizing, and conveying equipment, (if is needed)

In practice, total capital cost can be pictured by considering the high-capital cost of sorting machine and the costs for substantial quantity of additional required equipment. According to the Salter [3,4] certain sorting machines are not competitively priced if other process options exist, especially given the age and nature of the sorting technology on offer. The capital cost of a sorter will vary inversely as somewhere between the size and the square of the size of the material being sorted.
Mechanical engineering of the feed presentation and ejection systems consume most of the cost. Majority of the sorters employ multi-channel conveyor belt systems. These expensive conveying systems, however, have prevailed to date and necessitated the use of complex and expensive ejection and data processing systems. Replacement of such expensive systems by simpler and of course cheaper conveying systems such as gravity-fed having pinched roll and rotating disc systems to reduce the capital cost should be aimed [2, 3, 4, 6, 10].

According to Arvidson [6] in 1980s when M16 photometric sorting, excluding compressor cost, sold for $520000 to 650000 the cost for a complete single sorter plant could be estimated at a factor of 2 times the sorter cost in the USA since the construction cost and cost for mature relevant equipment such as compressors and screens were relatively the same. Today the real cost for sorter is considerably cheaper, typically 25% for the same capacity. Therefore the multiplier based on a single sorter is currently much higher, i.e., in the range of 5-8 depending on the location and the sorter machine selected.

Based on constant dollars, the capital cost per ton of sorter feed has been reduced by nearly 50% in 20 years. This capital cost per unit of product is decided mainly by the plant’s capacity and the product(s) yield. The plant capacity, however, is determined by the particle size range and the portion of feed needed to be blasted. According to the Fig. 2 the capacity is an almost linear of the average particle size for a narrow size fraction.

Fig. 2- Sorting capacity as a function of rock size and percent of reject [6]

According to the Fig. 3 the capital cost per ton of feed for photometric sorter as a function of the average particle size in narrowly sized fractions is approximated by assuming the a capital cost of 10% per year [6]. Accordingly, if the product’s yield is known, the capital cost per ton of product can be calculated by dividing the cost per ton of feed by the product yield.

Fig. 3- Approximate capital cost per T/H feed (7200 hrs/year) [6]
5.2. Operation Cost
The main contributors to determine the total operation cost are *power consumption, spare parts inventory, repair and maintenance, and labor costs*.

However, the cost for operating and supervision of sorting plants is highly variable due to the plant’s size and complexity of the sorting process. In almost all cases, especially for photometric sorting, the operating cost is dominant, exception would be small particle sorting, i.e., \(<10\text{ mm}\). Salter reported a typical operating costs about \(\$1\) per ton of feed for sorting \(-120 +60\text{ mm}\) material in South Africa [3].

The main part of operating cost is covered by the compressed air consumption. Blasting small piece requires somewhat more air per ton of blasted material than large piece however difference is not significant. Estimated values are about 40 and 50 \(\text{m}^3/\text{ton}\) for large and small particle respectively. According to Arvidson [6] those quoted numbers, for low energy cost country, e.g., USA, cost about \$0.3 to 0.7 per ton of feed but, the cost needs to be prorated according to the energy cost for other places.

Regarding to the maintenance cost, it is reported that the cost vary roughly from \$0.35 per ton for some large rock M16 sorter to a few pennies for free fall sorter processing intermediate size fraction. Generally, sorter machine can be either low or high maintenance-intensive based on the technology used for its manufacturing.

5.3. Other Costs
To add the above costs, one must consider the cost of alteration to mining and processing methods to accommodate sorting, the value of losses to sorting discards or the cost for recovering valuable material(s) from sorting rejects that are not acceptable as feed to an existing process but require an alternative process, as well as cost of waste disposal accruing to the sorting process. After assessing all the cost effective factors, one can justify whether sorting is beneficial or not?

6. Sorting Future
Salter [3–4] believed that a radical change in thinking is needed if new generation of the sorters is going to be developed and accepted. The opportunity for this to happen exists since it appears that the companies formerly involved in rock and mineral sorter manufacturing and marketing have left the marketplace. Further, it is clear that potential sorter users and such people do exist want simple, easily maintained sorters backed-up with high-level technical support, i.e., appropriate technology with appropriate back-up.

Sorting machines should be built as simple as possible whilst incorporating modern technology makes operation and maintenance a low-level task. For high tonnage applications, multiple streams should be used rather than attempting to sort in megalithic machines. Some of these machines are, admittedly, excellent examples of smart engineering design and construction. Availability of cheap and reliable microelectronics has also paved the way of using parallel streaming simple sorter modules at lower velocities. It is remarkable that high tonnage sorter design philosophy has not been adapted by food industry.

Maintenance, repair, and adjustment should be simply possible at the minimum consuming time and low costs to offer. These factors ensure the potential users a high level of comfort with their equipment. Effective pre-delivery and on-site training schemes must be developed together with regular site visit as well as open communication through web site(s). Those aforementioned factors can be sought without major disturbance. But the new technology must come and should be preferred through the following factors:

- development in food sorting technology: It is clear that modern sorting technology, mainly based on optical discriminating systems, exists in food industry but has yet to be applied
in the mineral and waste processing. It is worth to consider the application of such techniques.

b- the application of laboratory analytical technology exists as well as the emergence of new analytical techniques: A promising outlook can be sought in future by considering the progress made in the analytical sciences during last two decades. It is hard to believe that so little of this technology has found its way into sorting machines. Techniques such as FTIR Raman and laser spectroscopy, scanning electron microscopy, XPS, X-ray diffraction and fluorescence, gas and ion chromatography, mass spectrometry, thermal analysis, inductive coupled plasma, neutron activation analysis, radon and radioactivity measurements, particle size analysis, NMR, etc., should be considered although some of these techniques admittedly have been the subject of applications for sorting patents but few have made the transition from laboratory to industry.

c- development in ejection technology: Ejectors are critical components of sorting machines and despite high cost and somehow low efficiency, compressed air ejector has been industry standard. Variety of other ejectors such as, water jets, mechanical deflectors, fluidic, corona discharge, and suction nozzles have been tried and can be carefully planned to develop. Success of water ejectors in diamond industry [12] and special designed pressurized water ejector [13] as well as the high speed air ejectors in food industry have proved the possibility to change the scope.

d- development in mineral liberation: Milling circuit is capital intensive, however, its cost is effectively reduced by introducing liberation processes such as high pressure rolling mill. That provides opportunity to design a cost efficient sorting/liberation circuits. Coupling this to other processes, such as flash column flotation, can radically change the philosophy of plant design [3].

e- growing technical awareness and skills: Due to introducing of on-line adaptive control systems in mineral processing plants as well as instrumentation, it has been an evolution of more electronically-skilled workforce. This will continue and thus increases the personnel’s cleverness and capability that lead to a greater acceptability and ease operation/maintenance of the machines.

Potential future markets for sorters are those which have been discussed by various authors for many years, i.e., pre-concentration of complex or low-grade ore, underground or in-pit scalping, dump reprocessing, bulk treatment of low value commodities, metallurgical scrap recycling/secondary processing. However, Plastic, glass, ceramic, paper, rubber and construction material recovery and recycling should be added to the aforementioned items especially due to the new legislations for cleaner and safer environment.

Although during last two/three decades lack of interest from potential users and equipment manufactures, coupled with a depressed uranium market and advancing mechanization in gold mining industry, especially in South Africa, sounded the death knell for sorting. It is now apparent that sorting has a future in minerals and waste processing industries but this future is dependent firstly on the understanding how the existed machines can be optimally used and developed. Even now, except in diamond industry, photometric sorting is a quite unknown in mining and minerals industry. The potential users must realize that sorting is an option, that sorters can be built up to fulfill their needs and sorting machines can and will be supported properly. New machines based on reliable new technologies must be manufactured to accomplish further needs.
Designers must look at existed accurate and reliable techniques in connection with new ones to come to build new machines. For example, utilization of triaxial particle examination techniques would considerably improve the performance of sorting machines. Using such techniques in conjunction with image analysis correction techniques allow a relaxation of feed size top to bottom ratio. That means wider particle size fractions can be sorted.

Other optimistic points are to consider that price for machines has been gradually reduced during last two decades. That is true for analytical techniques used as discriminative part of machine as well as computers and softwears for data processing.

Advances in technology and manufacturing made it possible to easily design and utilize machines based on multi-sensor recognition system. This has a great potential since it is theoretically understood that the quality of classification is dramatically improved by simultaneously detecting of the several features with sensors of different detection principal. Therefore, integration of sensor-controlled sorting should be taken into account in order to increase the reliability and efficiency of the sorting machines to come.

Nowadays the future application and potential of sorting techniques are high-lighted since the techniques reach a high level of sophistication and in some cases, unique methods for separation of a wide variety of different minerals and wastes can be offered. Sorting may play a major role in minerals and wastes industries if a rational approach on the assessment of the advantages and disadvantages of the sorting process is well thought-out. This can be based on a comprehensive understanding of the past and current situations of the sorting techniques and to see what can be offered by sorting for future in the mining, mineral processing and wastes recycling. Further, possibilities of using new electronics with appropriate designs as well as utilization of applicable new discriminative techniques show promising prospects. Progresses in laboratory techniques in medical instrumentation for diagnosis as well as well logging are other considerable items too.

Author believe that future for sorting technology in mining, mineral processing and recycling hangs on development of multi-sensor based sorting machines containing of an optical characterization mechanism in connection with other discriminating system(s) that offers high quality and more accurate sorting performance. Efficient sorting of materials requires multiple parallel processing with many sampling points. Additionally improving ejecting technology must be highly considered in order to increase the capacity and reduce the operational cost.

Possible area of investigations for new generation of the sorting machines would be X-ray radiometric, x-ray fluorescence, laser induced fluorescence, microwave attenuation and electrical conductivity based techniques. However, image analysis offers efficient recognition based on complex shape and color that in turn allows estimating the material composition. High-resolution CCD and TV cameras allow to better identification of particles through RGB (red, green, blue) components and further HSL (hue, saturation, light). High resolution and fast identification vision systems are available and operate with one or more high resolution color line-scanning camera supplying over millions pixels by which up to 4000 objects per second can be examined [11].

Some other discriminative techniques that would be beneficial for minerals and wastes sorting can be named as:

a- Electrical density sorting and estimation of solid content
b- Dynamic tomographic imaging
c- Electronic noses systems
d- Dry Magnus separation
7. Introducing Some New Sorting Machines
Ultrasort, Applied Sorting, Elexso, Mogensen, Satake and Scan Master, Barco, Haver & Boecker, TiTech, SSE, S+S, LIF Gmbh, Binder+Co, etc., are some sorting manufacturers. Information regarding to their products can be generally achieved through their web-sites. Nowadays most of the sorting machines are designed based on optical systems. The following lines and figures describing some new sorting machines.

7.1. Barco Camera Sorting & Barco Dual Sorters [14]:

Fig. 4- Configuration of Barco Camera Sorting

*Principle:* Cameras are positioned above the center of the belt or at the end on a reference roller and scan products when they pass. Each camera is strategically located to detect discoloration on or in between the products. A powerful computer processes the data. Machine can be equipped with *monochromatic* and/or *full color cameras*. Fast and accurate nozzles blow the unwanted product away just as it begins its ballistics.

Fig. 5- Configuration of Dual Sorter

*Principle:* Dual Sorters are the newest developments like the combination of camera and laser scan or a configuration with a cutting machine in it. Dual Sorters are systems with different technologies combined into one machine. For example, where both lasers and cameras are simultaneously scanning the products. Barco Machine Vision is unique in this in the world of sorting and inspection.

7.2. TiTech Fast NIR Identification and Sorting [15]:

*Principle:* A fast-scanning spectrometer analyses the moving objects by reflected near-infrared light (NIR). It rapidly recognizes the unique molecular structure that identifies commonly used materials. The detectors generate a two-dimensional image and the software analysis determines whether the desired material, or combination of materials, is passing, the position of the object of the selected material and the size and shape of the object.

Fig. 6- Titech NIR Sorting Machine
7.3. SINTF Optical Sorting [11]:

*Principle:* The image analysis system includes optical camera installed over the transport belt with particle rejection unit at its discharge end. The images are taken in dynamic conditions. Each particle is identified as regards the material or combination materials, its dimension, shape, structure, and its position on conveying belt. Color analysis is done by converting video signals to RGB component and further to HSL.

Fig. 7- SINTF Image Analysis Optical Sorting

7.4. Electromagnetic Sensor (EMS) for Non-ferrous Characterization and Sorting (Delft University & S+S Metallsuchgeräte) [16]:

*Principle:* System contains two main parts: transmitter coil unit to generate an alternative magnetic field and receiver coil unit to measure the interaction between a metal particle and the field. Computer analyses the recorded parameters, i.e., the variation of the voltage amplitude from the receiver coils (U), the phase shift (ϕ) between signals from the transmitter and the receiver coil.

Fig. 8- Experimental set-up for EMS (a) and sensor geometry (b)

7.5. Laser Induced Fluorescence for Ore and Waste Qualification and Control (LIF Gmbh) [17]:

*Principle:* Laser beam firstly targets the surface. Some part of beam is absorbed (at selected emission wavelength) then emitted beam from the surface is considered. Life time (τ) and quantum efficiency of the beam is measured as the basis for identification.

Fig. 9- LIF analyzer
7.6. **MOGENSEN MikroSort (Using CCD Cameras)** [18]:

*Principal:* The feed stream is separated into individual pieces on an integrated 1200 mm-wide vibratory feeder and then passes a CCD colour line camera in free fall, where classification according to real colour takes place.

![Fig. 10- Configuration of the MikroSort (left) and principal of colour sorting process (right)](image)

7.7. **HAVER OptoSort Machine (Using High Speed RGB digital Cameras)** [19]:

*Principle:* Either one or two high speed RGB digital cameras are used to detect objects. Every electronic eye is calibrated to recognize distinctive characteristics as well as several million color shades and, in combination with control system, are the basis of the artificial intelligence of the sorting unit. By using self-learning software, adaptation to different product types is done in a matter of minutes. Optical signals up to 10 million pixels are evaluated by computer program and are converted into impulses. Pulses are transmitted to a jet strip to eject wanted/unwanted particles. Up to 4000 particles per second can be rejected.

![Fig. 11- General configuration of the OptoSort](image)
8. Concluding Remarks
Sorting is probably not well known in mining and mineral industry due to very few applications and lack of awareness of the potential users. But when the process is technically effective and accepted, the economical conditions preside over whether the sorting process can be used or not? As like as other separation process the liberation of the particles is paramount important factor affecting performance of the sorter. However, feed rate, particle size, the kind and sensitivity of identification technique(s) used for discriminating particles are other important factors. The pace of change that technology has brought to today’s sensing, hard wear, and software technologies is mind boggling and make it possible to increase, efficiency, accuracy, productivity and reliability. Smaller, more sophisticated and economic unites now are available at much lower prices, which have led to emergence of more consistent and profitable sorting machines. Potential users must realize that sorting machines can be built to suit their needs and sorters can and will be supported properly. On the other hand sorter manufacturers must make their efforts to perform that high technology based sorters, but easy to install, maintain, operate and repair are available more to fulfill the needs.

In addition, emergence of accurate new ejection system(s) having lower energy consumption is vital for further development and acceptance of sorting technology. Nowadays sorting machines are available for particle size down to 1mm. Radical changing in feed presentation system may improve the machine’s capability to accept particle sizes down to several hundreds of microns. This must be goal to gain for future.

Development of advanced sensors and data processing, which can be expected in the near future, will bring many more new opportunities for the introduction of automatic detection and sorting system. Further automation in sorting includes integration of sensor-controlled sorting and effective mechanical separation steps. Using multi sensors based sorters to simultaneous detecting of several features with sensors having different detection principles is a key for improving the efficiency and accuracy of the sorting process for the future.

References