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Review Article

Technical Review on Various Separation Methods Used in Mineral Ore Processing Plant

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Abstract

Separation methods are advanced techniques to segregate several components based on their characteristics and phases i.e. solid, liquid, or gas. Mineral ore processing contains proper usage of a series of chemical and mechanical operations. It helps in the extraction of the desired product from its initial stage. Several chemicals are used during the entire process. In this technical paper authors choose alkali and acidic leaching-based unique pitchblende ore for a case study of separation methods. Leaching is the heart of pitchblende mineral ore processing. It is a method for extracting desired products from the solid to liquid phase [1]. Based on ore characteristics, two types of leaching are involved i.e. acidic leaching and alkali leaching. Sodium Carbonate is the main reagent used for the pressurized alkali leaching process of pitchblende ore whereas sulphuric acid is used for acid leaching. In addition to this, several advanced separation techniques i.e. filtration, clarification, thickening, and drying are also performed for the extraction of the final product. This technical paper provides a glimpse of all the main separation techniques involved during mineral ore processing.

Keywords: Advanced separation techniques; Mineral processing; Leaching; Filtration; Chemical plant

Literature Survey

Laboratory-scale investigation conducted to emphasize the key factors impacting the efficiency of a belt filter press. They assessed this efficiency by measuring parameters such as the dry solid content of the final cake, the percentage of solids recovered, and the lateral movement of sludge on the belt [2]. In a separate study, detailed explanation provided for the operational principles and modeling techniques used in thickeners and clarifiers within the mineral processing industry [3]. Valuable insights into mineral ore processing within the context of India offered [4]. Furthermore, the historical progression of fine screening technology was reviewed, tracing its evolution from the early 20th century to contemporary methods. They underscored the economic benefits of modern fine classification techniques, particularly those utilizing the patented Stack Sizer technology [5]. Development of strategies was delved and tools aimed at enhancing the efficiency of mining facilities, thereby improving the utilization of raw materials from both natural and man-made deposits [6]. Comprehensive study was conducted on grinding and mineral separation processes frequently employed in mineral processing industries [7]. Research centered on cesium removal, exploring various separation technologies like chemical precipitation, solvent extraction, membrane separation, and adsorption [8]. Recent Life Cycle Assessment (LCA) studies related to mining and mineral processing operations reviewed meticulously, with a focus on addressing methodological challenges [9]. Under specific SMR conditions, including a roasting temperature of 520 °C, CO flow rate of 4.0m^3/h, N_2 flow rate of 2.0m^3/h, and a feeding rate of 100kg/h, they were able to achieve an iron concentrate with a total iron grade (TFe) of 60.18% and an iron recovery of 90.17% [10]. Valuable insights into several advanced separation techniques commonly applied in mineral processing industries were provided [11]. It was concluded that, from economic and environmental perspectives, magnetic separation stands out as the most effective method for recovering iron oxides. However, it necessitates the modification of the magnetic properties of weakly magnetic iron ores [12]. It was aimed to equip researchers and industrial practitioners with structured knowledge regarding the state of machine learning applications within the field of mineral processing [13]. Furthermore, detailed information on the development of solvent extraction processes designed to separate and recover cobalt and nickel from secondary resources over the past decade was offered [14]. Advanced treatment techniques, including advanced oxidation processes (such as photolysis, ozonation, and catalytic/UV light-based degradation), membrane filtration, reverse osmosis, and adsorption methods were explored [15]. It was concluded that innovative hybrid processes, which combine two or more treatment methods, are promising for reducing energy consumption and enhancing treatment efficiency [16]. Study was conducted on existing technologies for recovering precious metals from industrial waste streams, focusing on sustainability considerations [17]. Review of microwave heating applications in separation and purification processes in chemical engineering, emphasizing its unique features, including rapid heating, selective heating, and specific microscopic effects was provided [18]. Three most explored and mature separation techniques identified between 2015 and 2020, encompassing both solid and liquid phases: leaching, solvent extraction, and plasma. Top three fields of study: chemistry, engineering, and metallurgy are also highlighted. Additionally, it was noted that the predominant method for Rare Earth Elements (REE) separation across various research domains involved the use of acids, bases, ionic liquids, and salts for leaching REEs [19]. It was found that, through optimization, leaching efficiency of 79.85% can be achieved under the optimal conditions for physical separation products [20].

Introduction to mineral ore processing

Figure 1 describes a detailed flow sheet of mineral ore processing which includes several advanced chemical separation processes mainly dewatering, filtration, clarification, crystallization, drying, thickening, etc [21].

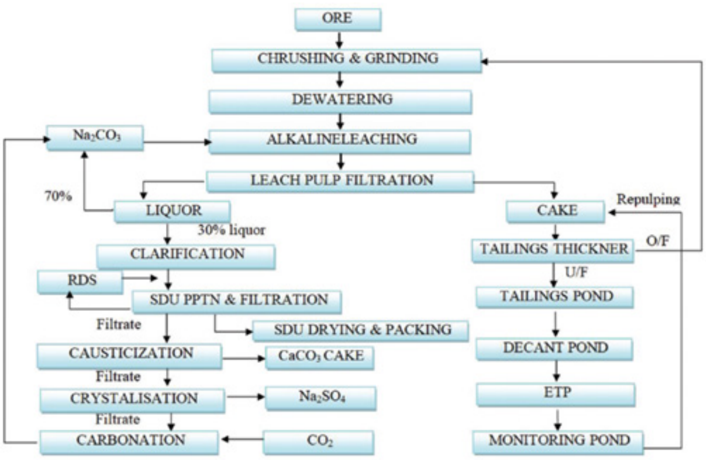

Figure 1: Process flow sheet of mineral ore processing plant [21].

Methods of separation techniques used in mineral ore processing industries

Detailed explanations about these process steps are mentioned as follows:

Screening (solid-solid separation): Ore mining is a critical process that is being done by several specific mining methods. Big boulders are mined out from underground using belt conveyors or mine ore trucks as per convenience and further processed in a series of chemical operations. Crushing and screening is an initial size reduction operation. Desired ore size material moves further through a series of belt conveyors for chemical processing whereas oversized ore moves for recycling after screening operation. Jaw crushers and cone crushers are the main size reduction equipment used in mineral ore processing industries. In this way solid-solid separation takes place.

Dust extraction system (gas-solid separation): Crushing operations in mineral ore processing industries cause dust generation. Fine dust can be harmful to working employees if crosses permissible limits provided by regulatory bodies i.e. CPCB, AERB, MoEFCC, DGMS, etc. Bag filters and cyclone separators are mainly used as dust extraction systems to control dust emissions in crushing and screening units. Bag filters are commonly used in such industries which are connected through DE (dust extraction) fans through pipelines. During the operation of equipment, dust is extracted from generation places and further sticks on the surface of specific bags of bags filters. Due to frequent timer/intervals, dust passes through the bottom chutes of bag filters and is recycled in the system through belt conveyors. Figures 2(a), 2(b) & 2(c) describe the overall view of the DE system, cross-sectional view, and types of filter media used in mineral ore processing industries [22-25].

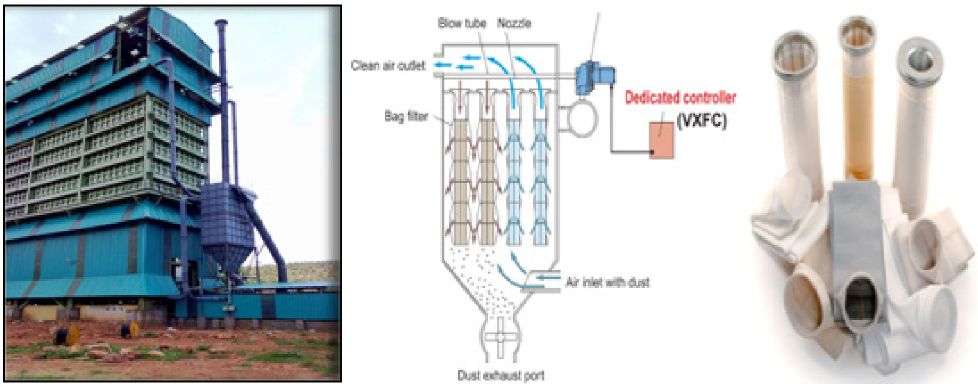

Figure 2: (a). DE System at mineral ore processing industry [22,23], (b). Cross-section view [24], (c). Types of filter media [25].

Grinding: It is one of the important mineral processing steps. Leaching is main heart of most of the chemical processing industries. Leaching directly depends on the surface area of the particles. Grinding helps in increasing the surface area of the particles [26,27]. Crushed ore of desired input size enters into the primary mill. Rods are used as grinding media in the primary mill (rod mill). Discharge of primary and secondary mills (ball mill) is being collected in the discharge tank. Figure 3 represents the overall view of grinding circuits in mineral processing industries.

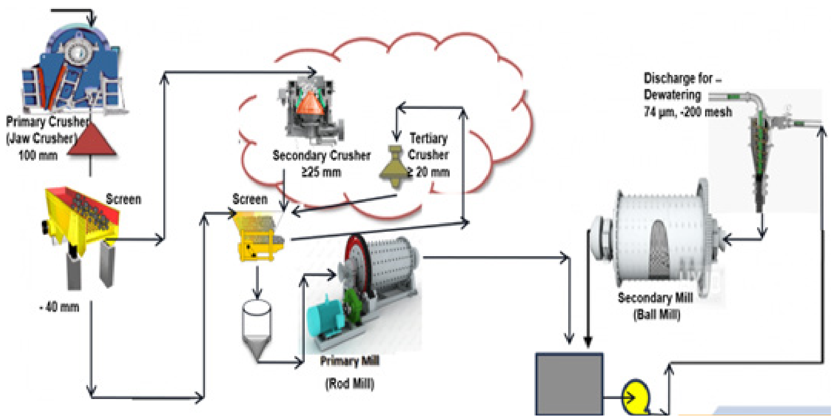

Figure 3: Grinding circuit with various mineral processing plant operations.

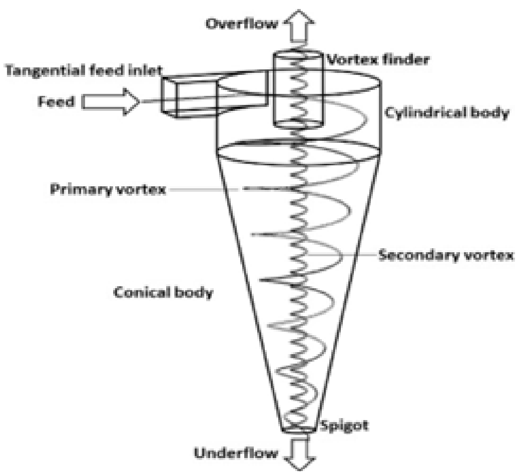

Figure 4: Cross sectional diagram of hydro cyclone.

Hydrocyclone (liquid-liquid separation): A hydrocyclone consists of a cylindrical feed section with a tangential inlet; an upper section with a vortex finder; and a conical part with an apex. Substance from the mill discharge reservoir is pumped into the hydrocyclone tangentially under specific pressure [28]. This initiates a centrifugal motion, propelling the denser phase outward and downward along the conical section's surface. The hydro cyclone's discharge serves as the input for the secondary rod mill, while the underflow is directed to subsequent dewatering processes as mentioned in Figure 4.

Hi-rate thickener (solid-liquid separation): Another separation unit, HRT (high rate thickener) is used in plants to increase the solid concentration of feed subjected to leaching by sedimentation. The addition of flocculating agent in HRT improves the sedimentation process. After hydrocyclone operations, the slurry enters into a thickener in which clear overflow water is recycled back to the plant and thickened underflow goes for further processing on horizontal belt filters. Settling regimes depend upon the closeness of particles to each other which is defined in Figure 5; [29].

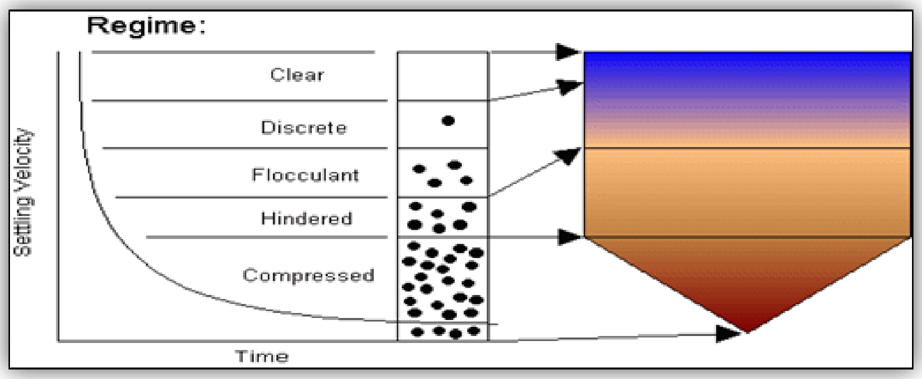

Figure 5: Graph: settling velocity vs time [29].

Filtration (solid-liquid separation) before leaching: The plant employs a horizontal vacuum belt filter as a device for separating solids from liquids, primarily used for dewatering neutral and leached slurries. The filtration process primarily involves passing a set of filtering fabrics and belts through a series of rollers. The system takes slurry as input and segregates it into a filtrate and a solid cake. Decreasing the belt speed enhances the filtration rate. To ensure the plant's capacity is not compromised, the optimal speed is consistently maintained in all horizontal vacuum belt filters (HBFs). Neutral slurry passes on HBF (horizontal belt filter). After filtration, the cake goes for a leaching operation, and the filtrate goes for recycling to hi rate thickener. Table 1 represents the basic technical specifications required for polymeric filtration media in mineral processing plants [30].

Table 1: Technical specification of neutral and alkaline filter media [30].

Parameter	Value	Unit
Permeability	145-175 (approx.)	lt/m^2.Sec@ 200Pa pressure
Thickness	1.4 (approx.)	mm
Nominal Pore Size	81	µm
Weight	960	gm/m^2
Material of Construction	Polyester	-
Yarn type (warp)	Mono Filament	-
Yarn type (weft)	Mono (Top) and Multifilament (Bottom)	-
Dimension	4.35 X 71.2	meter
Effective Filtration Area	110	Square meter

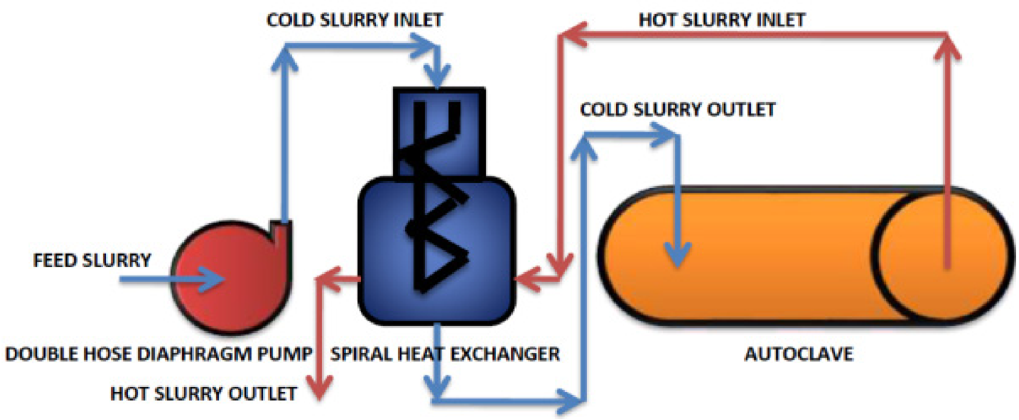

Figure 6: Schematic representation of pressurized alkali leaching into autoclaves [34].

Pressurized alkali leaching into autoclaves (solid-liquid extraction): This mineral processing step is the heart of the entire process. Slurry passes through a double hose diaphragm pump, and spiral heat exchanger and enters into a pressurized autoclave at ~90 °C. Exothermic reactions take place inside autoclaves at ~140 °C temperature and ~8 bar pressure [31,32] as mentioned in Figure

6. The main chemical reactions [33,34] are as follows:

(1) $UO_2 + ½O_2 \rightarrow UO_3$

(2) $UO_3 + 3Na_2CO_3 + H_2O \rightarrow Na_4UO_2(CO_3)_3 + 2NaOH$

(3) $NaHCO_3 + NaOH \rightarrow Na_2CO_3 + H_2O$

(4) $SiO_2 + 2NaOH \rightarrow Na_2SiO_3 + H_2O$

Leaching is a chemical process for extraction of required minerals from its ore using certain reagents, oxidation material, etc. Before leaching, minerals used to be in ore in the form of a solid. After leaching, it converts from solid to liquor form due to certain chemical reactions in the presence of desired process parameters.

Filtration (solid-liquid separation) after leaching: After leaching, the leached slurry is filtered again using HBF for extraction of the desired mineral from solid to liquor form. Solid with unleached mineral goes to tailings for disposal and filtrate moves for further chemical processing. Figure 7 represents a description of several counter-current steps being used to increase the concentration of liquor. It is very important in the case of low-grade ore. The required concentration of liquor helps in the precipitation of fine particles more efficiently [35]. In Figure 7, c0, c1, c2, c3, c4, and c5 are five stages for counter-current washing zones of HBF, and w0, w1, w2, w3, w4, and w5 are known as weak liquor filtrates being collected from all zones.

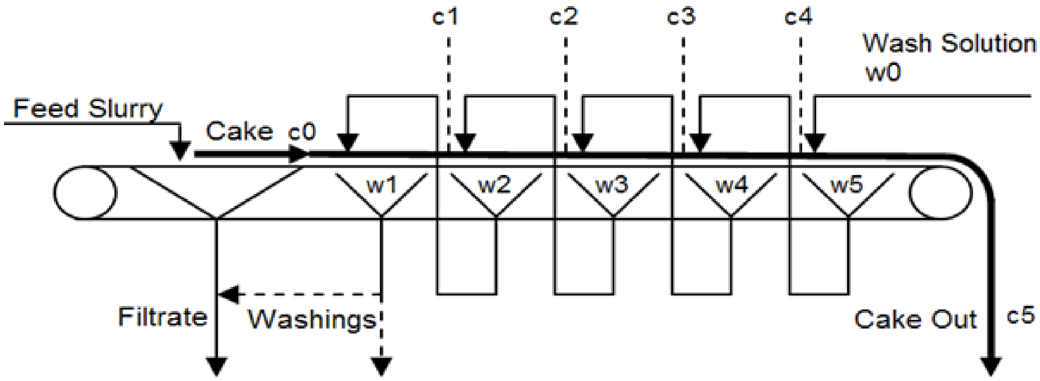

Figure 7: Counter wash on leach horizontal belt filter [35].

Precoat/drum filter (solid-liquid separation): After filtration of leached slurry over HBF, filtrate goes for further settling into the clarifier. After initial clarification into the clarifier, the overflow of the clarifier is passed through a precoat / vacuum drum filter. Clarified liquor is obtained from the drum filter after the removal of desired solid particles. Table 2 provides technical specifications of an ideal precoat / vacuum drum filter used in mineral ore processing industries [36].

Table 2: Technical specification of precoat / drum filter [36].

Parameter	Value	Unit
Type	Rotary Vaccum Drum Filter	-
Sectors	24	numbers
Filter area	55	meter^2
Filter size	3.65 m dia x 4.87 m length	meter
Vat shape	Hemispherical	-
Feed Slurry solid	50	ppm
Slurry sp. Gr	1.1 - 1.3	-
Precoat material	Perlite	-
MOC	SS316L, SS304L, MS	-

Mineral ore precipitation: Clarified liquor goes for further precipitation for extraction of the desired mineral from the ore. A required chemical of a particular concentration is used for precipitation reaction. Chemical reaction 5 represents usage of 47% conc. NaOH solution for extraction of $Na_2U_2O_7$ from mineral ore with suitable retention time of liquor inside vessels [37].

(5) $2Na_4UO_2(CO_3)_3 + 6NaOH \rightarrow Na_2U_2O_7 + 6Na_2CO_3 + 3H_2O$ [38]

Product horizontal belt filtration (solid-liquid separation): Precipitated liquor further goes for thickening operation after the addition of suitable flocculent. Overflow liquor of thickener is used for recycling in circuits after extraction of byproduct. Underflow precipitated slurry of thickener moves on horizontal belt filter for removal of the filtrate by using sufficient vacuum from pumps and further recycling in plant circuit. Product discharge cake is repulped inside the tank by the addition of water. Water addition helps in product-grade purification. Table 3 provides technical specifications of filter media used for product belt filters in mineral ore processing industries [39].

Table 3: Technical specification of product HBF media [39].

Parameter	Value	Unit
Material	100% Polyester Non-Woven	-
Size	1270 x 20200	mm
Weight of Filter Media	800	gms/meter^2
Air Permeability under differential pressure of 20mm WG	50	liter/dm^2 surface area per minute
Fabric Thickness	2.4	mm
Breaking Strength (warp)	150	kgs
Breaking Strength (weft)	30	kgs

Product drying (solid-moisture separation): Repulped product cake enters into the drying chamber/atomizer from the top as mentioned in Figure 8. Hot air passes from one end with the help of an FD fan. Product slurry converts into powder form within a fraction of a second due to the very high rotation speed of the motor situated at the top of the atomizer. A bag filter and HEPA filter are being used in between drying operations [40,41].

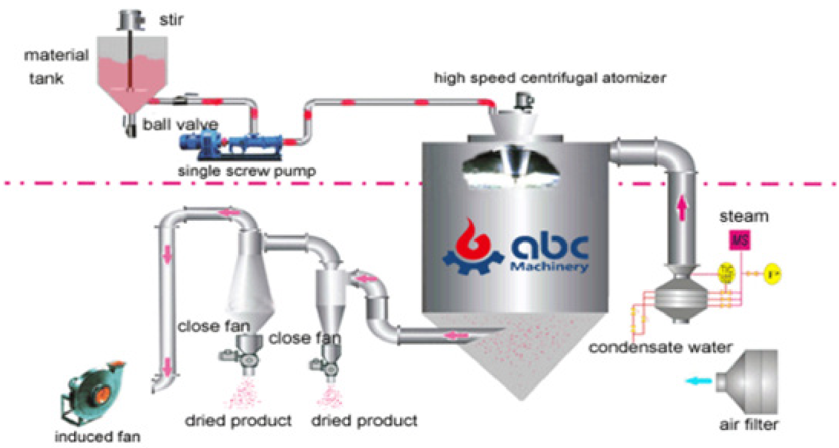

Figure 8: Product drying operation in mineral processing industries [41].

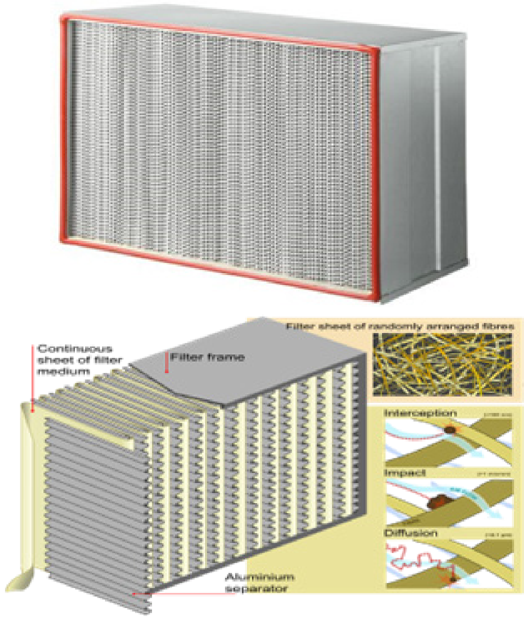

Figure 9: Manufacturing details of HEPA filter for gas-solid separation; (a). Outer view of HEPA filter [42,43], (b). Cross-sectional view of HEPA filter [41].

HEPA, which stands for high-efficiency particulate arrestance, is a standard for the effectiveness of air filters. A HEPA air filter is required to eliminate no less than 99.95% (according to ISO and European standards) or 99.97% (as per ASME and the U.S. DOE) of particles with a 0.3μm diameter as they pass through it. The filtration efficiency increases for particles with diameters smaller or larger than 0.3μm. HEPA filters are constructed from a non-uniformly distributed mat of fibers, as depicted in Figures 9(a) & 9(b) [42,43].

The fibers are usually made of polypropylene or fiberglass and have diameters ranging from 0.5 to 2.0 micrometers. To prolong the lifespan of the costlier HEPA filter, a HEPA bag filter can be employed alongside a pre-filter, typically activated carbon. In this arrangement, the initial phase of the filtration process involves the use of a pre-filter, which effectively eliminates the majority of larger dust, hair, PM10, and pollen particles from the air. The drying chamber helps in the removal of moisture completely from the product slurry and the dried product is being collected in drums for further packing and dispatch. The technical specification of a typical HEPA filter is mentioned in Table 4.

Table 4: Technical specification of HEPA filter [39].

Parameter	Value	Unit
Type	HEPA filter element	-
Size (flange)	610 x 610 x 300	mm
Size (box)	550 x 550	mm
Capacity (each filter element)	1100	cfm
Pressure drop	Initial 25 in clean condition & final 75 in chocked condition	mm w.c.
Efficiency	99.997% down to 0.3 micron	%
M.O.C. (filter casing)	SS304	-
M.O.C. (filter media)	Filter element constructed from micro-glass filter paper imported from Sagicofim, Italy	-

Results and Discussion

The results and discussions section of this technical review on various separation methods employed in mineral ore processing plants presents a comprehensive analysis of the findings obtained through literature review and empirical data. Through meticulous examination, it becomes evident that several separation techniques, including froth flotation, magnetic separation, gravity separation, and electrostatic separation, play crucial roles in the efficient extraction of valuable minerals from ores. Each method offers distinct advantages and limitations, influencing its applicability in different scenarios. The discussion delves into the factors influencing the selection of a particular separation method, such as mineral properties, particle size distribution, and economic considerations. Furthermore, the section explores recent advancements and emerging trends in mineral processing technology, shedding light on potential future developments that could enhance separation efficiency and sustainability in ore processing operations. This comprehensive analysis serves to deepen understanding and guide decision-making processes in the optimization of mineral processing plants. In the field of mineral ore processing, separation is one major process that is being done through several methods and advanced techniques. This case study is based on low-grade nuclear ore found at Andhra Pradesh in India [44-47]. Several technical papers were reviewed and found that purification of the technical grade of the final product and maximum recovery depends on the proper handling of mineral ore at several step-by-step procedures of mineral ore processing [48-51]. Among all these chemical processing steps, advanced separation techniques play a vital role from start to end. Due to continuous experience in the field of such industries, there is always a huge scope for improvement in the case of technical specifications of filter media and processing equipment. Characteristics of filter media used to change from time to time based on necessary modifications required for process recovery enhancement. In the case of alkali leaching, the concentration of salts used to be more in process liquor which can further chock the filter cloth of the horizontal belt filter. Based on operations it was found that a few steps were very helpful for improvement in the case of maximum solid liquid separation i.e. (a). Usage of hot liquor for counter-current wash on HBF, (b). The pore size of HBF filters media to be modified for maximum extraction of filtrate, (c). MOC of polymer filter media to be modified based on liquor characteristics, (d). Design of washing nozzles for HBF cloths should be specific for proper washing, (e). Proper lab tests are required for the evaluation of the filtration rate for suitable flocculent and suitable filter media.

Conclusion

Thus, the mineral ore processing plant includes several advanced novel separation techniques as briefly mentioned in Figure 10. An overall combination of separation methods includes all three major forms of chemicals i.e. solid, liquid, and gas. The latest research helps in modifications of equipment used for separation techniques [52-55]. Technical specifications of filtration media are also used to change accordingly. This technical paper describes an overall combination of those advanced separation techniques used in several mineral ore processing industries all over the world [56-59]. In addition to this, research is being done in the field of extraction of CO_2 from flue gas generated by mineral processing industries [60-63]. The boiler is used in all mineral ore processing industries for the usage of steam in several steps of the chemical plant. These boilers emit a sufficient number of SO_x, NO_x, CO_x, and particulate matter in the atmosphere [64-66]. Although, these emissions are as per permissible limits defined by regulatory boards further scope of extraction of these gaseous components was found by Vipin et al. [34] for useful purposes in mining and mineral ore processing industries. In conclusion, this comprehensive technical review has elucidated the diverse array of separation methods integral to mineral ore processing plants. From traditional techniques like gravity separation and flotation to more advanced methods such as magnetic separation and electrostatic separation, each approach offers distinct advantages and limitations in efficiently extracting valuable minerals from ore deposits [67-72]. Through meticulous analysis and comparison of these techniques, it is evident that a combination of methods tailored to specific ore characteristics and processing requirements yields optimal results. Moreover, ongoing advancements in technology continue to enhance the efficacy and sustainability of mineral separation processes, promising further innovation and optimization in the field. As mineral processing remains a cornerstone of various industries, the insights gleaned from this review serve to inform future research and development endeavors aimed at maximizing resource utilization and minimizing environmental impact in ore processing operations.

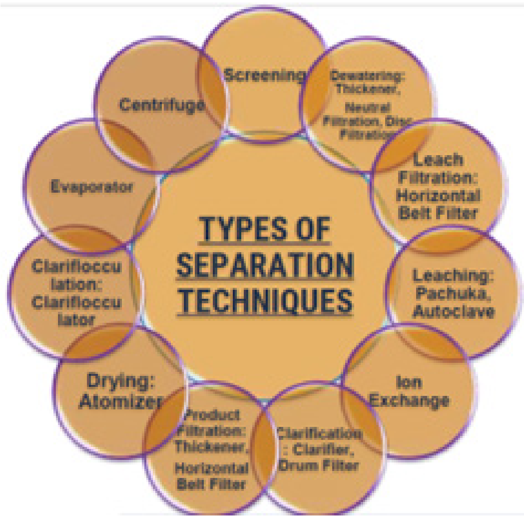

Figure 10: Types of separation techniques in mineral processing plant.

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