COLUMN FLOTATION MACHINES - TRENDS AND APPLICATIONS

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ABSTRACT. The rapid development of the flotation technique, which began in the first quarter of the twentieth century, led to the development of a large number of flotation machineryconstructions, a small number of which had come into practice. In the middle of the previous century, great attention was paid to hydrodynamic processes in the flotation machines design and operation. Column flotation is a physical improvement in the flotation separation process. Due to the excellent results, column flotation was studied on raw materials containing fluorite, manganese, platinum, palladium, titanium and other minerals. The paper presents the trends of column flotation machines use according to the model, processed raw material and distribution area.

Keywords: column flotation machines

КОЛОННИ ФЛОТАЦИОННИ МАШИНИ – ТЕНДЕНЦИИ И ПРИЛОЖЕНИЯ

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РЕЗЮМЕ. Бурното развитие на флотационната техника, започнало през първата четвърт на XX век, довежда до разработването на голям брой конструкции флотационни машини, малка част от които са навлезли в практиката. В средата на предходното столетие при конструирането и оперирането с флотационните машини е обърнато голямо внимание на хидродинамичните процеси в тях. Колонната флотация се явява физическо усъвършенстване в процеса на флотационно разделяне. Поради постигнатите отлични резултати колонната флотация е изследвана на суровини съдържащи флуорит, манган, платина, паладий, титан и др. минерали. В настоящата работа е направен преглед на тенденциите в използването на колонните флотационни машини според техния модел, преработвана суровина и област на разпространение.

Ключови думи: колонни флотационни машини

Introduction

In 1980s the column flotation was patented for first time. This led to numerous studies and subsequent publication of the obtained results in specialized scientific literature. Originally, the column flotation machines have been developed for application in flotation cleaning stage and expected to be adopted in both rougher and scavenger flotation operations, as well as completely displace the mechanical cells. (Willis, 2010).

According to a number of authors, the column ("columns") flotation machines represent a non-mechanical or non-sub aeration flotation cells, a definition popularized during the 1990s (Rubinstein, 1995; Sastry, 1988; Agar et al., 1991; Gomez and Finch, 1996; Finch, 1995). The term ''tall columns" refer to counter current columns, with a height generally greater than twice the diameter, and they are often referred to as ''conventional" columns. Short ''columns" refer to other non-mechanical flotation cells, variously referred to as novel columns, pneumatic cells and high intensity cells (Harbort, Clarke, 2017).

Development of column flotation

The development of column flotation machines can be divided into six stages:

- **Early columns (1905-1925)**

This period covers the time from the initial stage of the development of the flotation process by 1905 to 1925. The majority of the installations were what are now referred to as short columns, the most popular being the Callow machine, the MacIntosh machine and the Forrester machine. Tall columns were also tested, with a notable installation being that of Inspiration (Lynch et al., 2010).

- **The long decline (1926-1960)**

In 1926 the Minerals Separation Company launched its subaeration mechanical flotation cell, which was considered to have significant advantages over the non-mechanical short and tall columns. This was to start a long decline in the popularity of flotation columns that continued to 1960 (Harbort, Clarke, 2017).

- **Revival of Colonial Flotation (1960-1980)**

This period lasted between 1960 and 1980. In the 1960s it was driven by developments in China (Hu and Liu, 1988), the Soviet Union and Australia. Notable events included the first column installed in metalliferous flotation in China by the China MolybdenumCompany (Ananthan, 2013), as well as the Chinese free jet cell (Wu and Ma, 1998), the development of the Multisectional Column in the Soviet Union (Rubinstein and Badenicov, 1995) and the Davcra cell in Australia (Cusack and Oley, 1971). The 1970s were to see an increased emphasis on tall flotation column development with the Diester Flotaire Column (Zipperian and Svensson, 1988), the Canadian Flotation Column (Wheeler, 1986) and the Cominco/CESL Column (Murdock, 1991).

- **The first wave of column flotation (1980-1994)**

This period represents 15 years of sustained growth in flotation column capacity installed from 1980 to 1994, followed by four years of declining installations, to 1999. Major flotation column development occurred, with 14 new significant models of flotation column installed around the world. Many of these would not survive the period of decline, but those that continue in manufacture today include the Jameson Cell (Harbort et al.,1994), the Microcel (Luttrell et al., 1991) and the Pneuflot Cell (Markworth et al., 2007).

- **The second wave of column flotation (1999-2004)**

The period includes an ascending period of application of flotation columns between 1999 and 2004. The major impetus was refurbishment and growth in the Chinese coal industry, initially through refitting of mechanical cells with free jet aerators, and later via new greenfield installations. The end of the period approximately coincides with the Global Financial Crisis. Once again it represented a time of extensive development with nine new significant models of flotation column installed around the world. These included the FCSMC (Zhou et al., 2008) and BGRIMM tall columns in China (Hu, 2015), modifications to earlier Chinese jet aeration machines to make to the FJC free jet machine (Wu et al., 2010), development of the Prequip Column in South Africa (PreQuip, 2009) and the Imhoflot short column. Also during this period the CESL Column would become part of Canadian Process Technologies and by the end of the period part of the Eriez Flotation Division, with a number of new column designs (Kohmuench et al., 2007; Kiser et al., 2012).

- **The third wave of column flotation (2005-2012)**

This period represents another period of rapid column flotation growth to 2012, driven by high commodity prices, followed by a spectacular decline in installations to 2014, as commodity prices plummeted. A significant event to arise from this period was the increased installation of Chinese flotation columns in other countries and the development and installation of the Staged Flotation Reactor (Kosick, 2015).

Fig. 1 provides a timeline of the various types of flotation column installed between 1961 and 2016s.

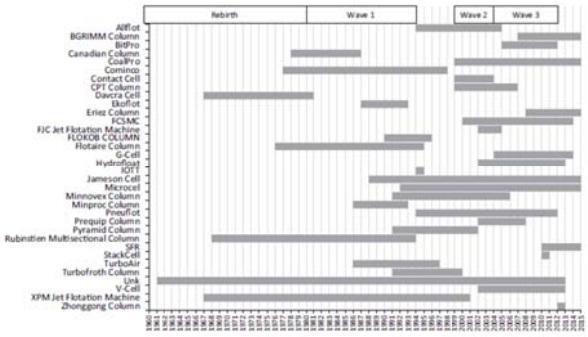

Fig. 1. Application of the different types of flotation columns for the period 1961 – 2016.

Spreading of column flotation capacity

According to the data from Amec Foster Wheeler (Harbort, Clarke, 2017) with details for the number of individual columns installed per year, three peaks, followed by a period of decline in the column flotation timeline, could be distinguished (fig. 2).

- 1994 – Wave 1, with 118 flotation columns installed.
- 2004 – Wave 2, with 521 flotation columns installed.
- 2012 – Wave 3, with 199 flotation columns installed.

Each peak is matched by a subsequent trough,

- 1998 – installed flotation columns decreased to 39.
- 2011 – installed flotation columns decreased to 96.
- 2014 – installed flotation columns decreased to 62.

Of note is the year 2015, which witnessed a rebound in the number of flotation columns installed to 90.

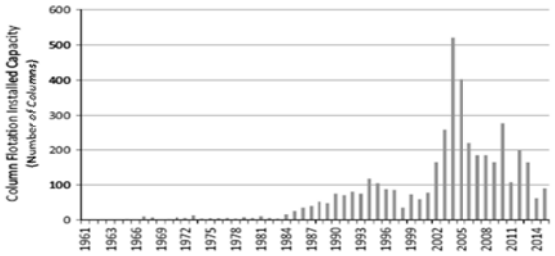

Fig. 2. Number of columns installed. (Harbort, Clarke, 2017)

Determining the flotation column capacity by the number of flotation columns installed can be misleading, as differing throughputs, differing duties and commodities which are being treated, require different flotation column diameters. For example, a molybdenum cleaner column could be 0.5 m in diameter, compared to a coal flotation column of 6.0 m in diameter (Harbort, Clarke, 2017).

Figure 3 presents some details about the average yearly column flotation diameter across all column types, commodities and duties. Many of the early tall flotation columns were in small, base metals cleaning duties. The short flotation column Davcra Cells were also initially lower capacity and cross section area machines, although by the early 1970s they had achieved substantial increases in unit capacity and resulted in a net increase in average column flotation diameter 2.5 m). This was maintained by installation of Flotaire Columns in larger capacity phosphate and coal duties in the late 1979s

and early 1980s. The increased use of flotation columns in base metals cleaning roles (specifically molybdenum) resulted in a decrease in average column flotation diameter to 1.5 m by 1986 (Harbort, Clarke, 2017).

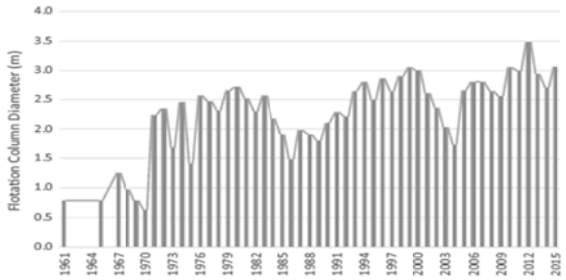

Fig. 3. Column flotation cells – average diameter

The advent of short columns such as the Jameson Cell, Ekoflot, Allflot, and Pneufloat heralded a new age where their cell diameters increased rapidly. This, coupled with increased flotation column use in coal in Australia (Murphy et al., 2000) and the USA (Luttrell et al., 1999), phosphate and iron ore in Brazil (Araújo et al., 2005), larger porphyry copper cleaning roles in Chile (Schena and Casali, 1994) and a number of significant rougher applications for the Jameson Cell (Harbort et al., 1997) witnessed a net increase in average column flotation diameter to 3.0 m by the year 2000. By 2012 the average yearly column flotation diameter had peaked at 3.5 m.

The trend of installed flotation column capacity expressed in terms of flotation area is similar to that of the number of columns installed. A significant change occurred in 2012, when the installed flotation column flotation area increased to 3000 m^2. The Amec Foster Wheeler database indicates that since 1961, 34,742 m^2 of column flotation area has been installed. This would represent approximately 3600 columns of 3.5 m diameter. (Harbort, Clarke, 2017).

Fig. 4 indicates the flotation column mechanical cell equivalent volume. It shows that, approximately 210,000 m^3 (mechanical cell equivalent) has been installed since 1961. The peak year was 2012 when approximately 19,000 m^3 (mechanical cell equivalent) was installed (Harbort, Clarke, 2017).

Fig. 5 presents the number of different varieties of flotation columns installed in industry per year, across all commodity groups. The graph clearly shows the proliferation of flotation column designs that occurred in the first wave of column flotation from 1980 to 1994. (Harbort, Clarke, 2017).

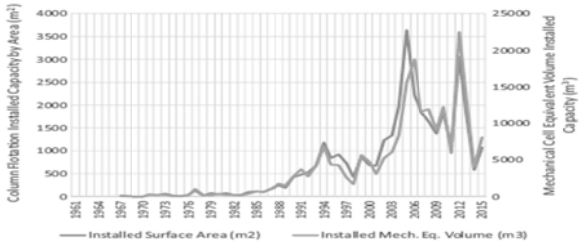

Fig. 4. Column and mechanical flotation machines installed capacity

Different typesof flotation columns installed included the Cominco/CESL Column, XPM Jet Flotation, Machine Multisectional Column, Flotaire Column, ‘‘Canadian Column”, Bahr Cell (Cordes, 1997; Ventert and van Loggerenbergt, 1992), KenFlote (Peters and Parekh, 1992), TurboAir Column (McKay and Foot Jr, 1990), Ekoflot (Heintges et al., 1984; Alizadeh and Simonis, 1985), Microcel, MinnovEX Column (Shaw, 1992), Minproc Column (Newell et al., 1988), Pyramid Column (Foot Jr et al., 1993), Jameson Cell, FLOKOB Column (Brzezina and Sablik, 1995), Allflot (Jungmann and Reilard, 1988), Pneuflot, Turbofroth Column (Arnold and Terblanche, 2001) and IOTT Column (Rubinstein,1995).

Many of the flotation columns manufactured during the first wave of column flotation would not maintain popularity by the time the second wave commenced in 1999. Those that appear to have disappeared from installation lists include the Multisectional Column, Flotaire Column, ‘‘Canadian Column”, Bahr Cell, KenFlote, TurboAir Column, Ekoflot, Minproc Column, FLOKOB Column, Turbofroth Column and IOTT Column (Rubenstein, 1995; Harbort, Clarke, 2017).

The second wave of column flotation between 1999 and 2009 would once again see a significant number of different types of flotation columns being installed. New varieties of flotation columns included the BGRIMM Column, BitPro, CoalPro, CPT Column, Dual Extraction Column (maxFLOT, 2008), Eriez Column, FCSMC Column (Zhou et al., 2008), FJC Jet Flotation Machine, Hydrofloat, Imhoflot G-Cell (Imhof et al., 2007) and V-Cell (Imhof et al., 2005), MultiCell (Opperman et al., 2002), Packed Column (Yang, 1991; Kawatra and Eisele, 1994), Prequip Column and Contact Cell (Amelunxen, 1993).

Flotation columns that successfully survived the first wave to enter the second wave of column flotation included the Microcel, MinnovEX Column, Pyramid Column, Jameson Cell, XPM Jet Flotation Machine, Allflot and Pneuflot cells. Attrition during the period resulted in a decrease in the production of flotation columns before the third wave of column flotation commenced in 2009. This would include the Dual Extraction Column, FJC Jet Flotation Machine, MultiCell, Packed Column, Contact Cell, MinnovEX Column, Pyramid Column, XPM Jet Flotation Machine and Allflot Cell. Flotation columns that appear to have achieved longevity and year on year installations include the Cominco/CESL/CPT/ Eriez columns, the Microcell, Chinese free jet machines and the Jameson Cell (Harbort, Clarke, 2017).

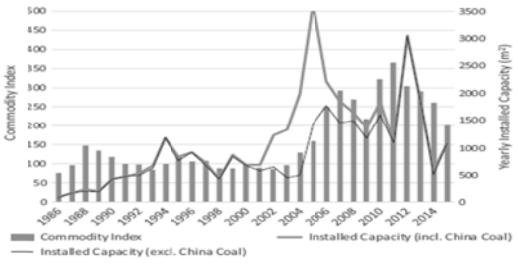

Fig. 5. Number of different varieties of flotation columns installed in industry per year

Figure 6 provides a snapshot of the total number of flotation columns installed per country, as at the end of 2015. It is evident that column flotation is widespread around the world, with northern Africa the only region without registered installations. Considering that all installations are not recorded in the database on Amec Foster Wheeler this figure may underestimate the number of flotation columns installed.(Rubenstein, 1995; Harbort, Clarke, 2017).

Most flotation columns are situated in China, Australia, Canada, USA, Chile, Peru and Brazil. Column flotation also plays a significant role in Mexico, South Africa and Russia.

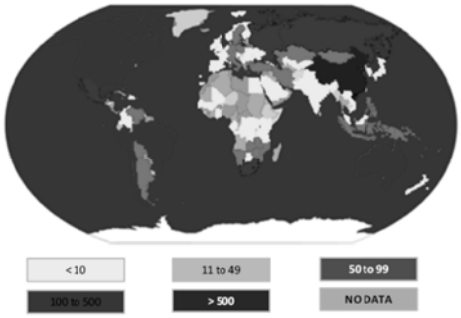

Fig. 6 Total number of flotation columns installed per country

The popularity of flotation columns has fluctuated in geographic regions over the last five decades. Fig. 7 provides (a) details of changes in the distribution of installed flotation column area per decade per major geographical area, and (b) the cumulative distribution of installed flotation column area per geographical region since 1961s (Harbort, Clarke, 2017).

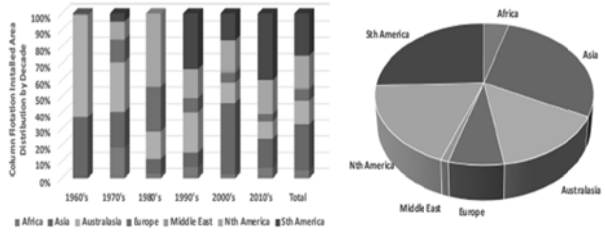

Fig. 7. Flotation columns installed per geographical region

During the 1960s flotation columns use dominated in Australasia, through the installation of the Davcra Cell in the Zinc Corporation's Broken Hill operations. Approximately 30% of flotation column capacity was installed in China in a variety of duties. The 1970s were again dominated by Australasia, with ongoing Davrca Cell installations including the Bougainville copper mine, PNG and the Coal Cliffs mine. The late 1970s also witnessed the introduction of the Cominco/CESL column to Australasia. As a proportion their share in Asia decreased during the decade, with a limited number of XPM Jet Flotation Machines installed. European flotation column capacity increased significantly, largely due to the installation of Multisectional Columns in sites such as Kafansky and Kuznetsk. During the decade Africa also represented a significant proportion of installed flotation capacity with several Davcra Cell installations. The initial growth of column flotation in North America also commenced with the installations of the Flotaire Column, Cominco/CESL column and Canadian Column. (Harbort, Clarke, 2017).

In the 1980s a quantum shift in the geographical regions using column flotation occurred, with North America dominating column flotation capacity. By proportion Europe had the second largest installed capacity with the spread of the Multisectional Column in Russia and other countries of the Soviet Union. The distribution of flotation in Africa, Asia and Australasia decreased dramatically. In Australia and Africa this was largely due to the removal of the high capacity Davcra Cell from the flotation market (Harbort., Clarke, 2017).

In the 1990s South America was to overtake North America as the dominant region for flotation column installations, driven by the large porphyry copper mines of Chile and numerous installations across multiple commodities in Brazil. Australasia witnessed a surge in column flotation popularity, primarily due to installations of the Jameson Cell and Microcel in coal operations (Araújo and Peres, 1995).

The 2000s were dominated by the China growth phenomenon, which witnessed nearly half of all column flotation capacity installed in Asia. By the 2010 a change had commenced and North and South America both accounted for 60% of the decade's flotation column installations (Harbort, Clarke, 2017).

Flotation columns installed by raw materials type

One reason for the fluctuating fortunes of flotation columns has been their varying acceptance in treatment of different commodities. Fig. 8 provides (a) details of changes in the distribution of installed flotation column area per decade per commodity, and (b) the cumulative distribution of installed flotation column area per commodity since 1961. (Harbort, Clarke, 2017).

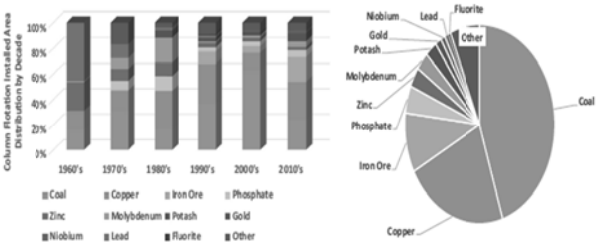

Fig. 8. Installed flotation columns by raw materials type

Overall, coal easily represents the commodity in which most flotation column capacity is installed (42%). The reasons for this are multiple and include the dilute nature and high volume of coal feeds, changing mining methods that generate more fines and the increased need for flotation, stringent contaminant requirements for coking coal and increasingly stringent product specifications in thermal coal for environmental reasons. Copper also makes a major contribution, with 21% of column flotation capacity which has been installed since 1961 being in this commodity. Primarily these installations occur in the large porphyry operations of Chile, Peru and the USA (Harbort, Clarke, 2017).

Flotation column capacity in iron ore is also significant, representing 9% of the installed total. The majority of this is in Brazil (67% of installed iron ore column flotation capacity), with other countries utilizing columns for iron ore flotation including, at various times, China, Peru, USA, Russia, India, Mexico, South Africa, Venezuela and Chile. Rounding out the top four column flotation commodities is phosphate, representing 4% of total installed column flotation capacity. An assortment of commodities including zinc, molybdenum, potash, gold, niobium, lead and fluorite represent a further 10% of installed capacity. The remainder of column flotation capacity includes more than sixty other commodities. Flotation columns installed in the 1960s were overwhelmingly in base metals, with 45% in lead, 25% in zinc operations and 20% in copper operations. The remaining 10% of flotation columns were installed in coal operations (Harbort, Clarke, 2017).

During the 1970s there was a major transition away from column flotation use in both zinc and lead, and a minor increase in use in copper. Flotation column use in coal operations increased dramatically during the decade, representing 30% of the capacity of those installed. Increased use in both phosphate and molybdenum is also apparent, with each amounting to approximately 5% of the decade total. During the 1980s the popularity of flotation columns in North America witnessed major increases in the use for copper and molybdenum (to 30% and 20% of the decade total, respectively). Phosphate use also increased to approximately 10% due to the use of flotation columns in both the USA and Brazil phosphate operations. A significant rationalization of the flotation columns distribution capacity occurred in the 1990s with coal increasing to 35%, due to increased use in Australia, USA and China. Copper maintained its proportion, due largely to use in the South American porphyry copper mines. This decade also represented the first significant use of column flotation in the iron ore industry, for the removal of silica. Largely in Brazil, iron ore composed approximately 10% of flotation used installed flotation column capacity. In comparison with the 1980s the distribution of column use in other commodities decreased significantly, with the most apparent decline being in molybdenum. Phenomenal growth in the use of column flotation in China's coal industry during the 2000s distorts the distribution for this entire decade, with coal representing 60% of capacity. During the last six years the trends have returned to more normal levels, with coal and copper representing the two most popular commodities for column flotation use (20% and 30% of installed capacity respectively). Considering the current market price of iron ore, this commodity with 20% of installed capacity is surprising. (Harbort, Clarke, 2017).

Conclusion

Over the years, flotation column machines have undergone various modifications. Since 1961, the flotation column machines have passed through three development and implementation periods, largely related to the variations in commodity prices. In addition, the following secondary causes for the growing interest in flotation column machines development and implementation could be mentioned: specific raw materials requirements, market needs, spare parts, auxiliary equipment, etc. Flotation column machines are widely used in Australia, China and the United States for coal production, as well as for iron ore processing in the United States and Brazil. In the world practice of non-ferrous metals treatment, the flotation columns are mainly used in the cleaning flotation stage. Furthermore, column flotation machines have been successfully implemented in Bulgaria. Examples are Dundee Precious Metals Chelopech and Rudmethal JSC, Rudozem. The interest in column flotation machines has been growing quickly and over the years different modifications for various raw material processing have been installed.

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