Innovation in Flotation Technology

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ABSTRACT

In 1905, the first Minerals Separation test plant was built at Broken Hill. Since that time there have been hundreds of innovations in the design and operation of mechanical flotation machines. Given the wide variety of ores that are processed, and the potential for high financial returns when ores are processed successfully, this is not surprising. What is surprising is that only a limited number of innovations have become standard features in modern flotation practice. Why did Minerals Separation so quickly become the dominant technology at Broken Hill? Half a century later, why were more than half the flotation cells in the world were made in by the Denver Equipment Company? An analysis of those lasting innovations, considered in the light of the current needs of the industry, can provide valuable insights in to the flotation plants of the future.

THE NATURE OF INNOVATION

In general, innovation may be thought of as the creation of better products, processes, technologies, or ideas that affect markets, governments, and society. Innovation differs from invention in that an invention may become an innovation if it is widely used, but an innovation may not new or novel enough to be considered an invention. Similarly, innovation differs from renovation in that innovation signifies a substantial change as opposed to incremental improvements.

As an example, consider aircraft engines. When the Wright brothers flew their first plane in 1903, it was fitted with a 4-cylinder, 8.8-kW engine that weighed more than 81 kg. Progress in engine design arose from the obvious, technical need to build lighter, more powerful engines, and from the commercial need to circumvent the Wright brothers' patents. Early innovations included radial and rotary designs, as well as marked improvements in the in-line V-type engines. By 1932, the 625-kW Pratt & Whitney R-1690 Hornet, at 585 kg, had a power-to-weight ratio 10 times higher than that of the original Wright engine. In the 1930s engine sizes increased rapidly. Figure 1 shows how the design changes made a transition from innovation to incremental improvement. Engine power and engine weight increased rapidly, but as engine power exceeded 2000 then 3000 kW, power-to-weight ratio began to decrease. The time was ripe for another innovation, and it came in the form of the jet engine.

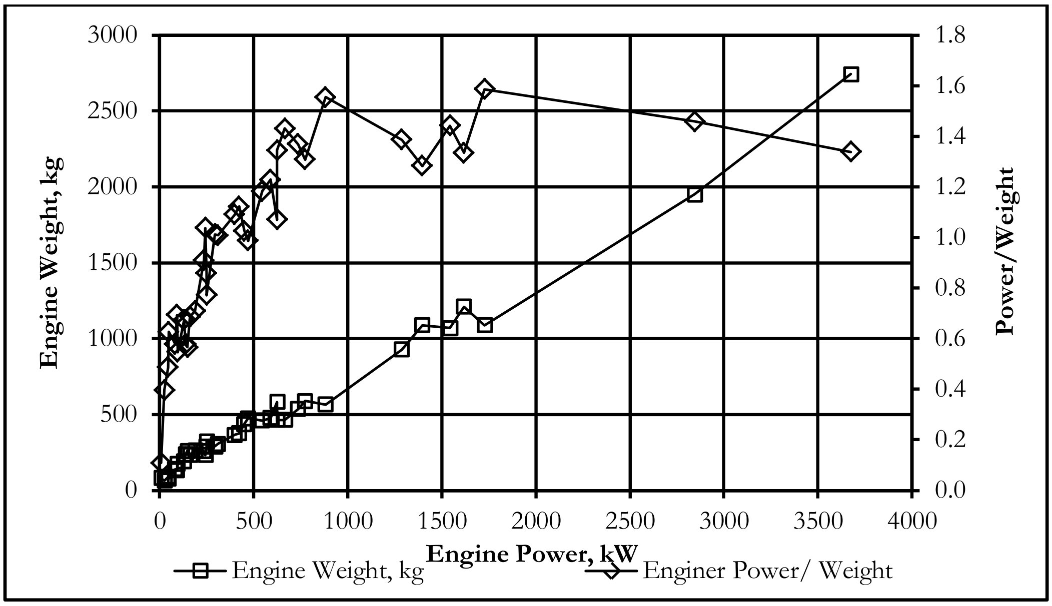

Figure 1. Development of piston-type aircraft engines

The first jet engine, the Heinkel HeS 3, was introduced in 1939. Delivering almost 1213 kW and weighing just over 886 kg, this engine had a power-to-weight ratio of 1.368, close to the 1.587 achieved by the Pratt & Whitney R-2160 Tornado, the most efficient piston engine at the time. Figure 2 shows how rapidly jet engine performance surpassed that of piston engines.

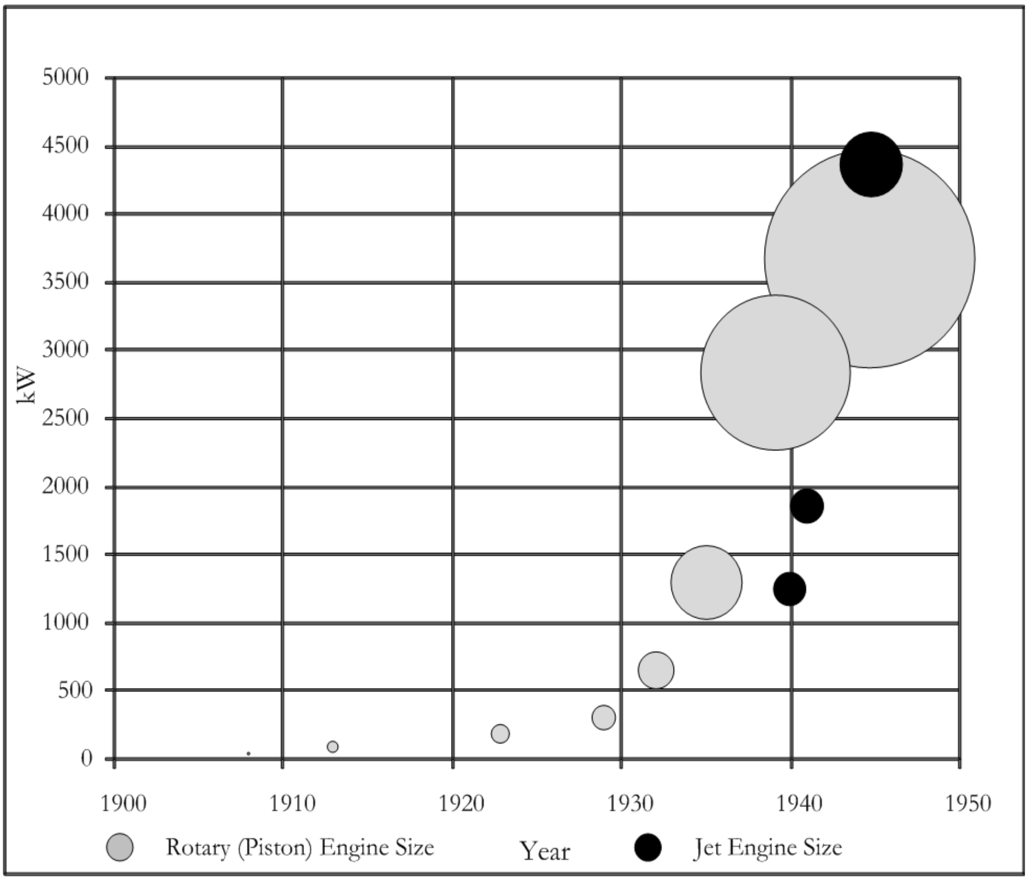

Figure 2. Sizes of piston-type and jet aircraft engines, with circle size proportional to engine weight

Why did jet engine technology develop so rapidly? There are of course many reasons, but the most obvious include the following:

- There was a widespread interest in aviation. The fact that people could now fly brought excitement to almost all sectors of society, and many of the brightest and best pursued careers in aviation.
- The unfortunate motivation of impending war also spurred development among all the countries that had capabilities in aviation technology.
- Concurrent to the development of interest in aviation, there was a rapid accumulation of technical understanding in areas such as physics, fluid mechanics, thermodynamics, and of course aeronautical engineering.
- The right people were available at the right time, (at least in part because of the reasons just listed).

PROGRESS IN FLOTATION TECHNOLOGY

Flotation technology and practice have progressed continually since the first installations at Broken Hill. A brief analysis of that progress can be useful in Table 1 shows a list of significant improvements in flotation technology that might be considered. The list is not meant to be exhaustive. For example, it does not include developments in flotation reagents.

Table 1. Significant improvements in flotation technology

	Individual	Date	Affiliation	Country
Sulfide flotation by adhesion	Everson	1885	(Self)	USA
	Delprat and Potter	1899-1904	BHP	Australia
Concentration in a froth	Sulman, Picard, and Hebbard	1905	Minerals Separation	England/ Australia
Aeration and froth formation by agitation	Hoover	1909	Minerals Separation	Australia
Product stream retreatment	Hyde	1911	(Self)	USA
Air addition	Fagergren	1913	(Self)	USA
	Owen		Junction North	Australia
Level control	Callow	1914	General Engineering	USA
Special impellers and stators	Fahrenwald, Daman, Booth, Fagergren, etc.	beginning ~1920 & continuing	Denver, Cyanamid	USA
Standpipes and draft tubes	Drake, Fagergren, Daman, Reck	beginning ~1940 & continuing	General Engineering, Cyanamid, WEMCO	USA
Hydrodynamic design	Arbiter, Harris, and Yap	1969	Columbia University	USA
Large (>2.8 m^3) rectangular machines		beginning ~1962 & continuing	Denver, Galigher, WEMCO	USA
Large (>50 m^3) cylindrical machines	Maxwell	1972	Opemiska Copper	Canada
		1982	Outokumpu	Finland
Improved feed and discharge systems		beginning ~1995 & continuing	Dorr-Oliver, METSO, Outokumpu, WEMCO	Worldwide

It is interesting to note that six of the 12 improvements in Table 1 occurred within 11 years (1903-1914) of the beginning of industrial-scale flotation at Broken Hill. Furthermore, three of those six improvements were by people affiliated with Minerals Separation, and a fourth was by James M. Hyde, who left Minerals Separation shortly before patenting his improvement. During this period, Minerals Separation dominated the market for flotation equipment, at Broken Hill and elsewhere. In addition, it could be reasonably stated that the first six *improvements* listed in Table 1 were true *innovations*. Two questions then are pertinent: First, why did so many innovations take place so quickly, and second, why did Minerals Separation dominate the market so completely in those early years?

Reasons for the rapid innovation in flotation technology in the years following 1903 include the following:

- There was a general, widespread interest in mining. Starting with the California (USA) Gold Rush in 1849, an ongoing series of rushes for gold and other minerals led to the popular perception that a career in mining was the route to prosperity, and many capable individuals entered the industry.
- As industrialization and then electrification proceeded apace in much of the world, there was an increasing demand for almost all mineral commodities.
- The industry had recognized the existence of large, unrecoverable resources, such as the tailings at Broken Hill.
- It was relatively easy to test new products and processes, because the high demand for commodities led to the availability of funding and sites for large-scale testing.
- Once again, the right people were available at the right time.

The domination of the market by Minerals Separation during these years is reflected in Table 2, which shows the flotation processes used at Broken Hill during 1908-1913.

Table 2. Flotation processes at Broken Hill, 1908-1913

	Concentrate Treated, %		Total Tons Treated
Process	1908	1913	1908-13
Potter-Delprat	41.6	21.5	463,000
DeBavay	20	35.1	582,000
Minerals Separation	27.4	43.4	1,075,000
Elmore	11	-	193,000

The reasons for the success of Minerals Separation include the following:

- The company entered the market early.
- The company pursued technical innovation vigorously, in its laboratories and in the field.
- The company took strong patent positions, and protected them vigorously.
- The company marketed its technology effectively, establishing laboratories for testing various ores at key locations throughout the world.

The favored position of Minerals Separation was short-lived. When Arbiter (1999) listed the world's 10 largest copper flotation plants in 1945, only one of them (Anaconda in Montana USA) was using Minerals Separation machines. In 1951, Anaconda replaced its Minerals Separation machines with 1296 Galigher Agitairs. In fact, by 1950, three American companies, Denver, Galigher, and WEMCO, dominated the market for flotation machines. Minerals Separation lost its market position for the following reasons:

- Minerals Separation's vigorous protection of its patents, along with the production royalties it assessed for use of its equipment and reagents, provided significant incentive for development and adoption of alternate technologies.
- The three American companies emulated Mineral Separations' successful practices in marketing, testing, and continuing improvement of the technology.

- Those companies were fortunately located near the largest market at the time, the big porphyry copper mines in the western US, Mexico, Chile, and Peru.
- The three companies made a point of offering excellent, consistent customer service, including laboratory testing and process development, startup assistance, and immediate availability of skilled technical personnel.
- All three companies, and Denver in particular, communicated with their customers very effectively. Denver published handbooks, flowsheets, and a monthly magazine, all of which were used widely in mills throughout the world.

Innovation or Improvement?

As the mechanical flotation machines provided by Denver, Galigher, and WEMCO came to dominate the market, true innovation gave way to incremental improvement. In fact, one of the mottoes of the Denver Equipment Company was, “No new models, but continuing improvement.”

Of the improvements listed in Table 2 that took place after 1950, one of the most significant might be considered the development of bigger cells. It is worthwhile to consider how this occurred. In 1944, and anonymous author in the *Engineering & Mining Journal* stated that An article in the *Engineering and Mining Journal* of January 1944 addressed the needs of the mining industry as the world emerged from World War II:

> One demand for the future will certainly be for flotation cells of larger individual capacity. Consider the new Morenci concentrator of Phelps Dodge Corp. Here, before a recent expansion in capacity, there were operating 332 Fagergren cells…There are 332 motors, shafts, bearings, impellers, and gears, to look after, lubricate, and replace, to say nothing of all the incidental wiring, switches, and launder connections...It is not beyond the abilities of present-day metallurgists to design a mechanical cell so large that 30 roughers and 10 cleaners like it could handle 25,000 tons daily of Morenci's ore. When machines like that are built one may expect a considerable drop in the “Power" item under flotation costs.

The need was recognized, but larger cells were not introduced for almost 20 years. In 1944, the largest Denver cell was the No. 30 Sub-A, which had a volume of 2.8 m^3. Larger cells were introduced with some hesitation. Denver’s first 5.6-m^3 cell was simply two, 2.8-m^3 cells bolted together, with two mechanisms installed. Figure 2 shows the caution with which larger rectangular cells were introduced in the 1960s. Note that the first cells from Outokumpu (now Outotec) developed in this period were rectangular, with volumes of 2.5 and 16 m^3.

The development of larger rectangular cells was eventually superseded by the introduction of cylindrical cells. The Maxwell cells, with volumes of 17 and 57 m^3, were introduced in 1971 and 1972 respectively. However, they were used only in a few Canadian mills. Outokumpu introduced its 60-m^3 TankCell in 1982, and larger sizes from METSO, Outokumpu, and

WEMCO followed in the 1990s, as shown in Figure 3. These cells have become standard in large mills throughout the world.

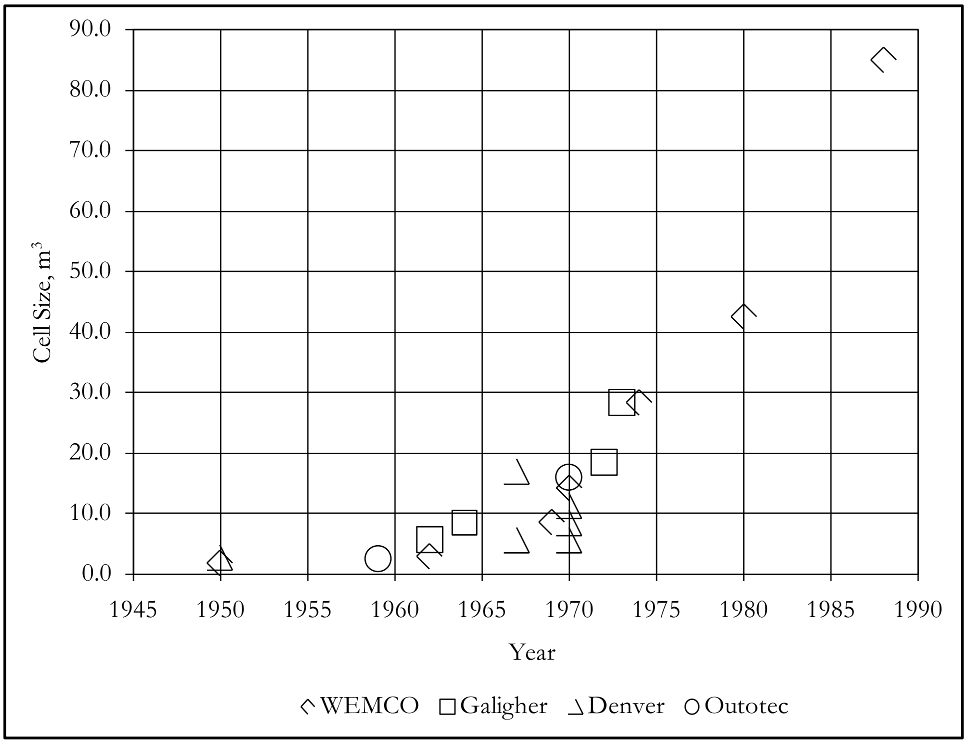

Figure 3. Sizes of rectangular flotation machines

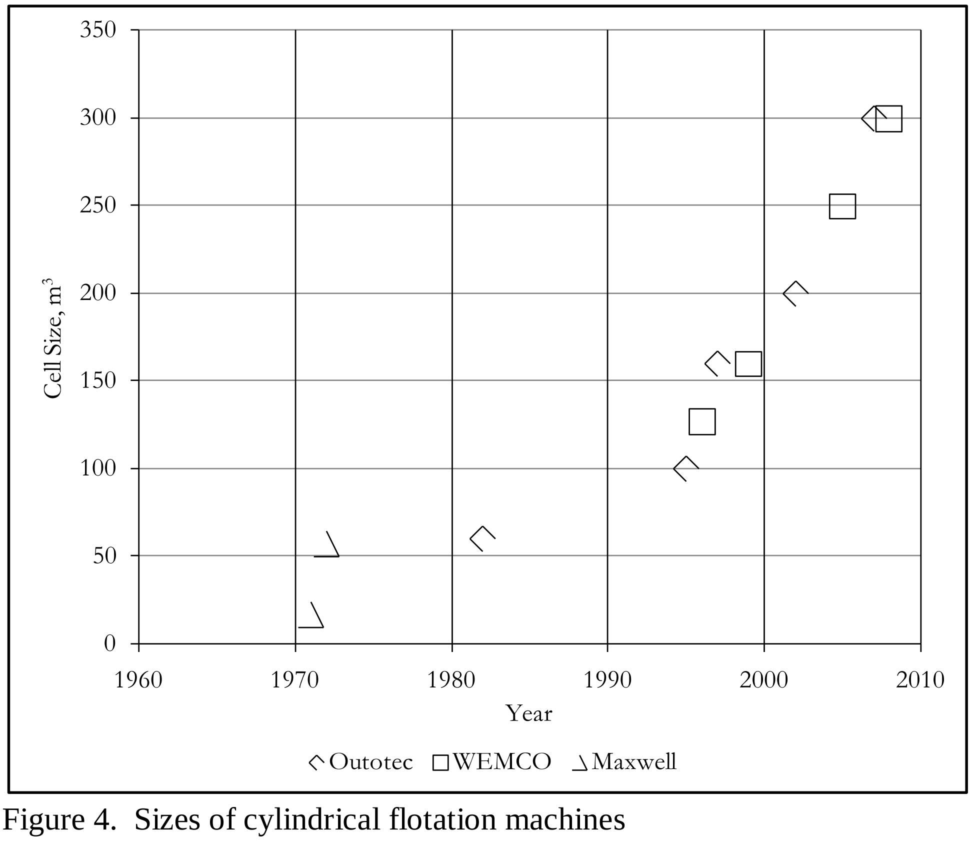

Figure 4. Sizes of cylindrical flotation machines

The State of the Art

In preparation for the recent inaugural series of the G D Delprat Distinguished Lecture on Flotation, the author asked two of manufacturers of large flotation machines, FLSmidth and Outotec, to list the most significant improvements or innovations in their respective machines in the last 10 years. The responses are summarized below.

FLSmidth

- Improved froth recovery, using new designs for froth crowders and launders.
- Flash flotation for rapid recovery of quick-floating minerals.
- Inert gas flotation for minerals that are easily oxidized.
- Mixed rows and circuits using induced and forced air machines to achieve improved grades and recovery throughout an entire plant.
- Decreased maintenance requirements through the use of external dart valves and standardized machine designs.
- Improved scaleup procedures, using computational fluid dynamics and hydrodynamic modeling.
- New research methods, including improved bubble sizing methods and isokinetic, high-speed cameras, for optimization of machine design.

Outotec

- Large cells that can accommodate high tonnage, high pulp densities, and coarse grinds, while also showing improved metallurgical performance.
- Reliable scaleup methods, which are being used in the design 500-m^3 cell to be introduced 'soon.'
- The new FloatForce® mechanism, which provides increased recovery, improved pumping, lower power draw, and lower maintenance costs.
- An optional, auxiliary agitator to enhance flow in the upper part of cell.
- Successful application of flash flotation in large cells.

These are notable improvements, and have been well received in the industry. However, the author respectfully suggests that they are, in fact, improvements and not innovations.

ACHIEVING INNOVATION

Recall the factors that led to innovation in flotation technology in the early 1900s:

- A general, widespread interest in mining.
- An increasing demand for almost all mineral commodities.
- The existence of large, unrecoverable resources, such as the tailings at Broken Hill.
- It was relatively easy to test new products and processes, because the high demand for commodities led to the availability of funding and sites for large-scale testing.
- Once again, the right people were available at the right time.

- The company entered the market early.
- The company pursued technical innovation vigorously, in its laboratories and in the field.
- The company took strong patent positions, and protected them vigorously.
- The company marketed its technology effectively, establishing laboratories for testing various ores at key locations throughout the world.
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REFERENCES

Arbiter, N, 1999. Development and Scale-Up of Large Flotation Cells, in *Advance in Flotation Technology*, pp 345-352 (SME: Littleton CO USA).