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Brief history of the flat glass patent – Sixty years of the float process

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ABSTRACT

This paper deals with one of the single most important innovations made in Great Britain since World War II. It is certainly one of the greatest process inventions of the twentieth century. The float process is one of the most widely used methods for flat glass manufacturing as it ensures security, high quality and productivity. From a historical point this innovation was the beginning of a revolutionary change in the mass production of flat glass for the building and automotive sectors. More specifically this innovation eliminates the traditional operations of rolling, grinding and polishing the glass surface while creating a high quality and inexpensive flat glass product. The first patent was applied for on December 10th, 1953 by Pilkington and Bickerstaff. This paper presents a brief discussion from the 1960s in a historical perspective about this amazing discovery and the main patents related to it. More than 23,900 patents using the term "*flat glass*" have been filed around the world, according to the European Patent Office databases. These numbers just continue to grow as do total sales worldwide. Looking for titles using *flat glass*, we found 2,409 patents filed. Curiously, for the same period 1,131 patents were published with *float glass* in the title and just 3,995 with the term in the title or abstract. So, statistically, there are more published patents using the term 'flat' than 'float' glass process.

1. Introduction

From the stained glass windows of medieval churches to the Renaissance monopoly of Venetian mirror makers, flat glass has brought us protection from our environment, while also reflecting its beauty. As pointed out by Bricknell, "the prime quality of glass is that it 'seems' *invisible*. The less you are conscious of the glass itself (rather than its color or coating), in a window, a car windscreen or a mirror, the more valuable it is" [1].

Through the ages there have been two basic methods of forming flat glass: the window glass and the plate glass processes [2]. For centuries flat glass has been produced by blowing or by casting. In fact, the very first flat glass process was patented in March 22nd, 1848 by the English engineer Henry Bessemer (1813–1898) under number 12,101. Fig. 1 presents the manufacturing of Bessemer's process [3]. He was the first to attempt a continuous ribbon of flat glass by forming the ribbon between rollers, but it was not commercially successful. He also made some improvements to such a process which was published on the 17th February 1848 [4].

Float glass was later patented in the United States by two Americans: William E. Heal in 1902 – *US* patent 710,357 [5], and again in 1925 by Halbert Hitchcock – *US* patent 1,564,240 [6]. In the early 1900's, Emile Fourcault (1862–1919) [7,8] in Belgium and independently Irving Colburn (1861–1917) [9] in the USA invented the technique of producing a continuous ribbon of glass which still involved the glass being drawn through cooled rollers to produce a 'fire-finished' product. Briefly, in the Fourcault process [8] the glass was drawn vertically in a ribbon from a bath of molten glass. The final glass surface was achieved by letting the glass surface cool down on its own without contact while still soft. However, some distortions, irregularities and inhomogeneities suitable to this particular process would appear, mainly as the result of small differences in viscosity due to chemical or even thermal variations. The main goal of glass *i.e.* to be flawless, perfectly flat, totally uniform, and free from any distortion or contamination was not reached by these old processes. Up to the early 1950s before the advent of the float process, perfect results were rare and very expensive. Pilkington reported glass wastage amounting to 20% of total production at the time [2].

Sir Alastair Pilkington was born Lionel Alexander Bethune Pilkington (1920–1995) in Calcutta, India, where his father was employed at the time. According to the *New York Times* (*NYT*)

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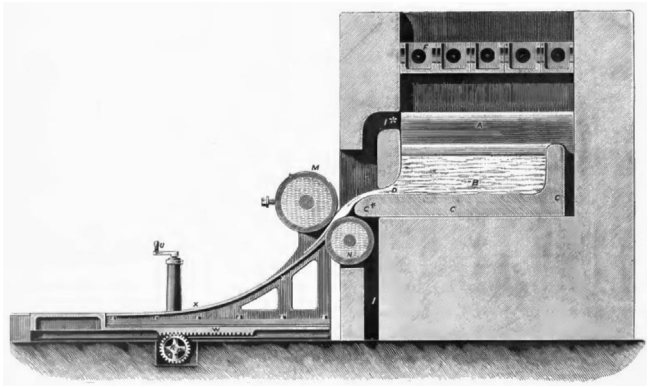

Fig. 1. Bessemer method of rolling sheet glass (1848) [3]. This mechanism is the first attempt to make a continuous ribbon of flat glass by forming the ribbon between rollers.

obituary [10], he later chose Alastair as the name he wished to be known by. He studied at Cambridge University in 1938, majoring in mechanical engineering. His studies were interrupted by the outbreak of World War II. He joined the company of Pilkington Brothers Ltd in 1947 after graduating from Cambridge and by 1953 was a member of the board. In the late 1950's, he pressed the company to continue investing in the float process, despite enormous technical difficulties. Some of these were overcome as we will see below. He developed the world's first commercially successful manufacture of high quality flat glass using their float glass process.

In 1952 Alastair Pilkington conceived the idea of forming a ribbon of glass by floating the melted raw materials at high temperature over a bath of molten tin (Fig. 2). According to *The Telegraph* [11], it is said that one evening in that year Pilkington had the idea of float glass when he was washing dishes at home. He was fascinated by the sight of a plate floating on water and wondered whether the principle could be applied to glass making [11]. Thus he daydreamed as he watched a bar of soap float in the greasy water, visualizing glass floating like a bar of soap. It was probably the way he suddenly conceived this idea that revolutionized the glass industry. In 1954 there was a pilot plant working [2] and the first British patent (GB 769,692 [12]) was published, but it took seven years and more than £7 million (£80 million in today's money – according to Pilkington Company History [2]) to develop the full process. According to *US* patent 2,911,759 [13], applied for one year later, the ribbon is held in a chemically controlled atmosphere at high enough temperature for a long enough time for the irregularities to melt out and for the surfaces to become flat and parallel [2]. Because the surface of molten tin is flat (melting point at 231.9 °C), the glass is also flat – and operates from its melt at around 1,200 °C to near 600 °C, when it is still a supercooled liquid, turning to glass a few Celsius degrees below. It is important to note here that the density of tin is greater than that of glass at the same temperature, and due to buoyancy an upward force exerted by tin opposes the weight of the flat glass. The ribbon is continuously cooled down while still advancing across the molten tin until the surfaces are hard enough for it to be taken out of the bath without the rollers marking the bottom surface. Therefore a uniform thickness and bright fire polished surfaces without any need for grinding or polishing are achieved. Pilkington's invention thus set out to replace the twin grinding and polishing process for making plate glass. In the event, the float glass innovation superseded not only the old process, but also the ancient sheet glass process for making ordinary windows. It was to become the universal procedure for the manufacture of high quality flat glass. The company patented the technology and licensed it to other glass producers around the world.

The process, originally able to make only 6 mm thick glass [2,12], now makes it as thin as 0.4 mm and as thick as 25 mm and in widths up to 3 m [14]. Thickness is controlled by the speed at which solidifying glass ribbon is drawn off from the bath. A modern float plant makes around 6,000 km of glass a year [14]. The composition of the raw materials has not changed much over the years: high quality sand, soda ash, limestone, saltcake and dolomite. This is transformed into molten glass at 1,500 °C in a melter. In brief, several processes – melting, refining, homogenizing – take place simultaneously in approximately 2,000 tones of molten glass in the furnace. They occur in separate zones in a complex glass flow driven by high temperatures. It adds up to a continuous melting process, lasting as long as 50 h, that delivers glass at 1,100 °C which is free from inclusions and bubbles, smoothly and continuously to the float bath. Finally, the glass from the melter flows gently over a refractory spout onto the mirror-like surface of molten tin, starting at 1,100 °C and leaves the float bath as a solid ribbon at 600 °C. The end product is more economical and made available high class glass for shop windows, cars and mirrors free from the distortions and irregularities inherent in the products using the old manufacturing processes.

It took four years from publishing the patent to float glass becoming profitable. However, the production technique revolutionized the industry. Pilkington became the largest flat glass company in the world, mainly as a result of Sir Alastair's emphasis on using the flotation process, which produces glass with two smooth sides that do not require polishing. Such glass is now used in cars and homes and buildings all over the world [14]. However, he found it not easy to convince the company board to engage in such a project at the very beginning [1,2]. According to the obituary in *NYT* [10], he was apparently not related to the family that founded Pilkington PLC. Among its other holdings, the Pilkington Company controlled the Libbey-Owens-Ford Company, the second largest glass maker in the United States [14]. In June 2006, Nippon Sheet Glass Co., Ltd (www.nsg.com) acquired Pilkington PLC [14].

'Float' is so innovative that since 1959 it has supplanted all other techniques for forming flat glass. Alastair Pilkington played a leading role in licensing his invention throughout the world. The first foreign license went to the Pittsburgh Plate Glass Company (P.P.G.) in 1962, and this was quickly followed by manufacturers in Europe, Japan, Czechoslovakia, the former Soviet Union, Brazil and others in the USA. He was elected a Fellow of the Royal Society in 1969, knighted in 1970, and received doctorates and fellowships from 13 academic institutions, as well as numerous scientific awards. In 1978 he was awarded the Alan A. Griffith Medal and Prize by the Institute of Materials, Minerals and Mining. The Society of Glass Technology (www.sgt.org) announced in 2011 the inauguration of a prize in his honor. Thus, our goal with this work is to provide a global view of the historical trends and current status of float glass S&T. We hope this paper will help contribute to an overall discussion on future directions for flat glass research, building on the immense framework of understanding and literature published in the field.

2. A brief history of old glass technology

Among the disordered systems in nature, glass belongs to the most fascinating of materials. Natural glass like the volcanic obsidian glass has been used by man from the earliest times. There is archaeological evidence for this, *e.g.* for carving arrowheads, knives, and other things needed for daily survival.

The first glass objects produced by man date back to about 7000 BC and were found in Egypt and Mesopotamia. According to Pilkington [2], Egyptians around 1500 BC seem to have been the first people to realize what could be done with glass when heated, and the first manual of glass making appeared millennia latter. Glass