Technical improvements in 19th-century Belgian window glass production

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ABSTRACT

Glass was used since the Roman age in the building envelope, but it became widely applied together with iron since the 19th century. Belgium was a major producer of window glass during the nineteenth century and the majority of the produced window glass was exported all over the world. Investigating the literature on the development of 19th century Belgian window glass production is therefore internationally relevant.

In the 17th century, wood was replaced as a fuel by coal. In the 19th century, the regenerative tank furnace applied gas as a fuel in a continuous glass production process. The advantages were a clean production, a more constant and higher temperature in the furnace and a fuel saving.

The French chemist Nicolas Leblanc (1787-1793) and later the Belgian chemist Ernest Solvay (1863) invented processes to produce alkali out of common salt. The artificial soda ash improved the quality and aesthetics of the glass plates.

During the 19th century, the glass production was industrialized, influencing the operation of furnaces, the improvement of raw materials as well as the applied energy sources. Although the production process was industrialized, glassblowing was still the work of an individual. By improving his work tools, he was able to create larger glass plates. The developments in the annealing process followed this evolution. The industry had to wait until the invention of the drawn glass in the beginning of the 20th century to fully industrialise the window glass manufacture process.

Keywords: 19th century, Belgium, window glass production, literature research, cylinder glass, crown glass, Leblanc soda, Solvay soda, regenerative tank furnace

1 THE HISTORY OF GLASS PRODUCTION

During the 19th century, Belgium evolved from an agricultural to an industrialised country. The Industrial Revolution influenced the whole building industry, creating new functions and activities for which new types of buildings arose (e.g., factories, railway stations, department stores, exhibition buildings and palm houses). Architects and engineers could deviate from the established style principles and developed a new architectural language, which was supported by the developments in iron and glass. Glass was used since the Roman age in the building envelope, but it was widely applied together with iron since the 19th century.

Glass is an amorphous material made from silica (sand), alkali (sodium and potassium) and a stabilizer (calcium, magnesium, etc). These three constituents melt at 1400-1500°C (just below the melting temperature of iron\textsuperscript{1}) and have to settle (cool down) to make the glass workable. When the geometry of the glass product has been formed, the material has to be annealed. Annealing means that the glass has to be cooled down to solidify again at 500°C\textsuperscript{1}, not too fast because then the material gets brittle but also not to slow because then devitrification (crystalline instead of amorphous structure) can occur\textsuperscript{2}.

Two methods for producing sheet glass were developed by Syrian craftsmen and applied in Western Europe. Blown cylinder glass was invented in the 1st century AD while crown glass was known since the 4th century AD\textsuperscript{3}. Cylinder glass was made by blowing a bulb, elongating it by swinging and turning and finally cutting and flattening it to a large sheet. Crown glass started the same, but the sheet was achieved by spinning the bulb and then cutting small panes out of the circular sheet.

Crown glass was dominating in England and Normandy (north-west France), while cylinder glass was the major production technique in Lorraine (north-east France), along the river Rhine and in Belgium.

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During the Middle Ages, glass was very expensive and thus merely used in stained-glass windows in churches, cathedrals and monasteries. From the 15th century, Venice became a centre for the production of decorative glassware and mirrors. The Venetian craftsmen were able to produce very pure glass without any colour. Encouraged by the immigration of Italian craftsmen during the 15th century, there was a revival of the glass production in the Belgian region. Glassworks were founded in Belgium in the region of the river Sambre (Figure 7), where forests were close-by. In the 16th century, Antwerp as a harbour and Belgium in general experienced an economic welfare so more people could afford glass windows. The use of glass was spread to more applications than only the clerical ones. In the 17th and 18th centuries, glass became standard in palaces and houses in the cities. Due to the fast disappearance of forests, experiments for using coal instead of wood as a fuel started in the 17th century. As a consequence, glassworks were concentrating around the coal supplies in Europe, of which Belgium was one of the most important. A third production process, cast glass (later called plate glass) was developed mainly in the second half of the 17th century in France. The production process involved casting the liquid glass on a table and grinding and polishing the surfaces after annealing. The resulting product was of excellent quality but more expensive and thus mainly used for luxury purposes and mirrors.

During the 19th century, the glass production was industrialized, influencing the operation of furnaces, the improvement of raw materials as well as the applied energy sources. France was the largest industrial glass manufacturer in the world in the beginning of the 19th century, but from around 1830s until 1880 Belgium became the main producer (in m² of glass production). The majority of the produced glass was exported and Belgian glass was used all over the world in the building envelope (with Great-Britain, the United States, the Netherlands, Hamburg and the Turkish Empire as the main buyers). The developments of the glass production in Belgium during this period of enormous export are therefore internationally relevant. In the 1880s, the dominant position of Belgium got a first setback with the introduction of the new tank furnace which saved on specialized craftsmen. With the invention of the Fourcault process, Belgium contributed to the development of mechanised production techniques in the beginning of the 20th century. Nevertheless, this strive for production processes which saved on labour, reduced the need for skilled craftsmen. It made it easier for non-producing countries to start up their own glass production and as a consequence reduced the international role of Belgium. The invention of the float glass process by Alastair Pilkington in the 1950s blew a wind of change through the international industry of glass production.

2 DATING HISTORIC WINDOW GLASS

The history of window glass production can be divided in several periods (Figure 1). Several researches already made use of this chronological development to set up a dating technique based on the chemical composition of flat glass. English Heritage carried out a broad investigation on English window glass and summarized the results in a flow chart to date the glass panes based on their chemical composition (Figure 2). By using a portable X-ray fluorescence (pXRF) spectrometer for non-destructive chemical analysis, this dating technique can be used on-site (but the quality of the analysis depends strongly on the surface condition of the glass panes). Belgian researchers carried out a similar research on Belgian window glass from between the 12th and 18th century. The introduction of new raw materials and new glassmaking recipes are linked to the chemical composition of archaeological finds from both plane and stained-glass windows (Figure 3).

By investigating the literature on the development of Belgian window glass production, a first step in extending this methodology to 19th century Belgian window glass can be obtained.

![Figure 1: Overview of the history of window glass production](image-url)
3 BELGIAN WINDOW GLASS PRODUCTION IN THE 19TH CENTURY

- 1815 Belgium annexed by the Netherlands
- 1821 Revival of Belgian economy
- 1830 Belgian independence
- 1845 Repeal of excise duties and decrease of import duties in UK
- 1870-72 Loss of (UK and US) export
- 1860 Social conflicts
- 1890 Strikes 1900-01 and 1904
- 1914 Close-down of all production

- 1836 "Société Anonyme des Manufactures de Glaces, Verre à Vitrer, Cristaux et Gobelettes"
- 1872 "Le Comité des Verriers"
- 1882 "L'Union Verrier" and "Nouvelle Union Verrier" 1894
- 1895 Syndicat des Magasiniers Verriers
- 1900-12 "Manuelité des Maîtres de Verriers"

- 1782 Invention Leblanc soda
- 1810-1850 Production Leblanc soda
- 1854 Start using sodium sulphate in France
- 1863 Invention Solvay soda
- 1863-65 First Solvay factory in Couillet

- 1643 Introduction of coal furnaces in Belgium
- 1856 Patent of regenerative furnace by F. Siemens
- 1862 Application of regenerative furnace in Belgian glass production
- 1980 No crucible furnaces for window glass production left

- 1737 Introduction of cylinder glass in Belgium
- 1825-26 Rotating stones annealing oven
- 1862-63 Industrial application of Lubben process in US
- 1827 "Chancet" annealing tunnel
- 1845 "le crochet d'ouvreur"
- 1867 "tirianne"
Technical improvements were guided by the need to reduce the fuel consumption and by improving the aesthetics of glass: the colour (mainly defined by the raw materials) and the opacity, defects, thickness variation and surface finish (defined by melting and working the glass).

The development of the glass production techniques will be discussed chronologically while focussing on both technical (raw materials, melting and processing) and economic issues (Figure 4).

3.1 Up to the 18th century

Up to the 17th century, glass had a greenish-yellowish tint due to impure and varying raw materials and uncertain melting circumstances. Kelp (English marine plant ashes), barilla (Spanish plant ashes) and potash (burnt wood) were used as alkali sources. All plant ashes gave colour to the glass due to iron traces and can be detected by the phosphorous content in the chemical composition of the glass. The furnaces used up to the 18th century could probably not reach temperatures above 1200°C, which resulted in glass with more bubbles, defects, etc. Incomplete melting could lead to inclusions of unmelted material in the glass. The glass was coloured by the raw materials as described above, but also by interaction with the fumes of burning wood to heat the furnace.

The first half of the 17th century, a major change took place in the furnace technology. Due to the fast disappearance of the forests, the use of wood for the glass production was prohibited in England in 1615. The price of wood in Belgium also reached high peaks since 1625. Coal was its replacement. It had a higher heat capacity then wood and so larger crucibles and larger furnaces were possible. The first use of coal for glass production was in 1619 in Rouen in France (obliged by the French parliament) and in 1635 in England. Thiry Lambotte, the master glassworker of the glassworks in Namur, was the first to apply coal as a fuel in Belgium in 1643. The only coal with adequate quality came from the region of Charleroi. Glassworks were concentrating around this southern Belgian city (Figure 7). Coal furnaces were closed constructions to prevent sulphurous fumes to act on the glass.

The cylinder glass production process was introduced in Belgium in the first half of the 18th century by immigrating German craftsmen. In archives, 1727 is mentioned as the start of cylinder glass production by Nicolas de Moreau in Belgium. By 1770, all houses in Belgian cities were glazed.

3.2 The 19th century in general

The production cost of window glass was defined by three major parameters: the labour costs, the fuel and the raw materials (Figure 5). The total cost contribution of the raw materials overall decreased from 1840 to 1910, mostly due to the price decrease of alkali. The price of the fuel increased but the coal consumption per square meter of glass decreased. The total cost contribution of the fuel was very sensitive to the evolution of both the consumption efficiency and the price of coal, but was almost the same in 1910 as in 1840. In the same period, there was an increase of the salaries but also of the work efficiency. The contribution of labour in the total production cost was slightly higher in 1910 compared to 1840.

Labour was cheaper in Belgium than in England and France, but coal was less expensive in England. Probably not the production cost but the assertive Belgian export policy was decisive for its success.

The Belgian export of window glass was nearly sixty times larger in 1910 than in 1840 (Figure 6). This growth was directly linked to the evolution of the production cost, from which four periods can be defined in the graph in Figure 5: - the production cost from 1840 to 1852 decreased very little while the export increased with an annual growth of 9.80%; - from 1852 to 1872 the production cost rose but the Belgian manufacturers found new export markets so the export amount was stable; - a third period 1872-1895 again had a decrease of production cost and so an increase of the export; - because of the distribution of the tank furnace, the export numbers from 1895 became very variable.

The whole 19th century, 90 to 95% of the production got exported to all over the world except to France and Russia with whom Belgium had non-import agreements. Belgian manufacturers mainly exported to countries that did not have any glass production, to avoid concurrence. In 1906, the glass production in Belgium did represent 1/5th of the European and 1/6th of the worldwide production, of which 88% got exported.
Belgium had supplies for most of the raw materials used in the 19th century to produce glass. Sand was found in two Belgian regions (Figure 7). The sand from Waterloo contained a small proportion of iron oxide\textsuperscript{18}, while the sand from Mol was almost free of iron oxide and was exported to glass factories in West-Europe\textsuperscript{19}. The colour of the sand was not representative for its purity. For window glass production, the iron oxide content had to be lower than 0.5\%\textsuperscript{18}. 
Calcium could be obtained from limestone or chalk. The valleys of the rivers Meuse and Sambre were the suppliers of limestone (Figure 7). Limestone could contain iron traces, while chalk was often more pure. Calcium increased the hardness and the lustre of the glass, but increased the tendency of the glass to devitrify.

Natural alkali sources were mainly the forest in the region of the Sambre and the Meuse valleys. Scientist knew that the use of sodium chloride (normal salt) was not possible for glass production. Other insights were that alumina entered the glass composition as an impurity due to disintegration of the crucible or furnace clay and that adding cullet (broken glass) did ease the melting of the other constituents. Manganese gave the glass a pink colour and was thus used to balance out the greenish tint originating from the iron oxide, with a slight greyish glass as a result.

3.3 1790-1823: Introduction of Leblanc soda

From the 1790s to the 1810s, Belgium was part of the French Empire. In 1787-93, the French chemist Nicolas Leblanc invented a process to produce alkali out of common salt. The process consisted of two stages:

- common salt (sodium chloride NaCl) was heated with sulphuric acid, forming saltcake (sodium sulphate Na₂SO₄);
- saltcake was heated with lime and charcoal or coal, to obtain artificial soda ash (sodium carbonate Na₂CO₃).

The last reaction could be less effective, resulting in a proportion of saltcake in a batch of soda ash.

In the 1810s and 1820s, the production of Leblanc soda was industrialized. Glass produced with Leblanc sodium carbonate as alkali source was of better quality and colour compared to natural alkali glass. Due to the application of artificial soda ash, lime had to be added separately to improve the chemical durability of the glass.

In 1815, Belgium got annexed by the Netherlands. The first economical setback was compensated by a general (but slow) revival from 1821 with the export to the Netherlands and its colonies.

3.4 1823-1840: Switch to Leblanc sodium sulphate

After the independence of Belgium in 1830, the country developed from an agricultural to an industrial state. In 1836, the union Manufactures de Glaces, Verre à Vitrer, Cristaux et Gobeletries was found which united several glass manufacturers in the financial institution Société Générale. It brought capital into the industry. However the investments remained relatively low.

In 1825, the prohibition in France of the use of sodium sulphate for the glass production was abandoned. Together with the invention that saltcake reacted with sand when some coal was added to the batch, the French gradually started to use saltcake. This intermediate product from the Leblanc process gave more colour to the glass then sodium carbonate. M. Pelouze is said to have solved this by removing the iron from the original salt with the use of lime, to obtain a refined sodium sulphate.

Due to the use of sodium sulphate instead of carbonate, the glass was less liable to devitrification, thus there could be more lime added so that the glass was harder and more durable. Another effect of saltcake was the higher melting temperature of the glass, so it encouraged the search for furnace improvements.

There was a close knowledge exchange between Belgium and France (e.g. by exchanging craftsmen), but it is unclear when the use of sodium sulphate started in Belgium. It was only in 1832 that the Chance Brothers introduced cylinder glass together with the use of Leblanc sodium carbonate in England.

The processing of the melted glass to glass plates underwent improvements in the 1820s and 1830s. In 1822-25, the lanceman was invented, which was a support for the blowing pipe handled by the helper. It saved energy from the
Another improvement of annealing the glass was necessary to handle the increased glass production and to reduce fuel and labour costs. In 1844-46, the Chance Brothers developed an annealing tunnel (also imported in Belgium) of 12 to 15 metres long where the glass plates were manually moved each time further from the heat source

In 1840-1852: Improving the efficiency
All adjustments made by the Belgian manufacturers aimed to increase the production volume. The repeal of the excise duties in England was accompanied by the gradual decrease of the import duties. The import of cheap Belgian glass in the UK from 1853 onwards, promoted the English glassmakers to come up with technical improvements to increase the efficiency to be able to compete with the Belgian glass. In 1845, le crochet d'ouvreau replaced the lanceman. It was a hook attached to the furnace for supporting the blowing pipe during reheating the cylinder. Nevertheless these constant adjustments to save energy from the glass blower, the reorganisation of the work probably had more influence than these tools on improving the efficiency of the work. From 1845, the largest possible glass plate measured 120x72cm.

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3.6 1852-1872: Larger crucibles and Solvay soda
In 1863, the Belgian chemist Ernest Solvay invented a new production process to make soda ash (sodium carbonate Na\textsubscript{2}CO\textsubscript{3} out of common salt (sodium chloride NaCl) and limestone (calcium carbonate CaCO\textsubscript{3}) by using ammonia (NH\textsubscript{3}). This ammonia-soda process was more efficient and therefore cheaper and less polluting than the Leblanc process. In 1863-65, the first Solvay factory in Couillet near Charleroi was founded. An economic struggle between Solvay and Leblanc manufacturers followed and by 1890 already half of the production of sodium carbonate was carried out by Solvay factories.

Since 1845, the production of window glass constantly enlarged (Figure 6). To fulfil the growing demand, the glass manufacturers enlarged the crucibles so they contained more molten glass. However as a consequence, the fuel consumption per unit of glass increased. The glass manufacturers were looking for ways to improve the furnaces to reduce the fuel cost. With the experiments of Joule in the 1840s, the physical sciences and the insights in the heat phenomenon grew, which was applied in the development of furnaces.

In 1856, (the naturalised Englishman of German origin) Frederick Siemens patented the regenerative furnace both in Great-Britain and Germany. His brother Charles William Siemens explained the regenerative principle in a paper in 1857 and mentioned experiments in iron (but none in glass) production. The furnace was heated by gas flames produced from burning coal from which the residual heat was used to preheat the fuel that would be used afterwards. In 1861, both brothers C.W. and F. Siemens took a British patent on "improved furnaces", where they produced the combustible gas outside the furnace. A report of tests of the application of the regenerative furnace in glass production in England was written in a paper by C.W. Siemens in 1860-61. The advantages were a clean production, a more constant and higher temperature in the furnace and a fuel saving (30% by gasification, increased to 45-50% by regenerative principle).

With the crucible method of glass production, the molten glass stayed in the crucible which was heated and cooled down in several cycles, consuming a lot of fuel. Several experiments were carried out to invent a continuous process, where the glass was transported to locations on different temperatures. The Siemens brothers were finally the ones who were successful. On the 1st October 1867, Frederick Siemens applied this continuous principle in the tank furnace. This was a tub heated by gas where raw materials were added on one side and molten glass was taken out at the other curved end (Figure 8). It was a continuous process where the glass crosses three chambers (the melting, refining and working chamber) by pushing the glass to the next chamber by making use of the fact that the density of glass increases while melting. Charles William Siemens gave an extensive description of this tank furnace in 1870.
The pursuit for larger glass plates led to a final tool used for cylinder glass production. In 1867, the *manique* or *iron man* was introduced, which was a mobile support to help swinging and turning the blowing pipe. One source says it was invented in Belgium, but that it got out of use in Belgium by 1883. The largest plate that could be produced in 1870 was 144x96cm, which did not enlarge any more until the introduction of mechanised blowing in the beginning of the 20th century.

The annealing furnace also got an important improvement. In 1857, the *stracou Frison-Biévez* was invented by Frison. The process was improved by Désiré Biévez in the Mariemont glassworks in the Charleroi region. The annealing tunnel with mobile rods where glass cooled down in 20 to 25 minutes, was finally applied in 1862-70.

Since 1845, the production of window glass constantly increased. More skilled craftsmen were needed to fulfil the demand, which lead to increasing salaries. The master glassworkers were trying to lower the salaries, but provoked strikes as a reaction. In 1872, the glass manufacturers founded *Le Comité des Verriers* as a union for the master glassworkers to try to lower the labour cost, but not much agreement was found between the companies. In 1870-72, the export to the UK was lost for the benefit of France due to the high labour and fuel costs, while the export to the US was lost due to import duties. The strong decrease of the export (Figure 6 1870-72) encouraged the glassworkers to introduce technical improvements.

### 3.7 1872-1895: Application of the tank furnace

The need for technical improvements to reduce the fuel consumption and the labour costs was paid off by the replacement of old crucible furnaces by the new regenerative tank furnaces. It was a large investment for master glassworkers, which resulted in the disappearance of a lot of glassworks. Although the coal of the region of Charleroi was not suitable for gasification due to its low volatile content, the window glass production was concentrating around Charleroi for its specialized craftsmen.

The adaption of the tank furnace for the glass production was carried out in the 1870s and finally applied between 1878 and 1881. The role of the Siemens brothers and the engineer Martine André Oppermann in this adaption process is not clear. Chambon and Lefebvre mention experiments carried out by Oppermann, while Engen says that he installed the first regenerative tank furnace in glassworks in Faubourg near Charleroi. Also his nationality is not clear: German or Belgian. Douglas attributes the development of the regenerative tank furnace completely to the Siemens brothers. Nevertheless, in 1894 there were no crucible furnaces left in Belgium for window glass production.

The regenerative principle got spread together with the tank furnace. The gas furnace was also applied for the annealing tunnel since 1872. In 1883, the blown cylinders were cut with a diamond in the UK while an iron rod was still used in Europe.

In the 1880s, social conflicts were regular in the Belgian glassworks. Periods of high export volume and of overproduction were alternating, resulting in periods of expanding the glassworks and of high unemployment. The time
shifts between the production and the export numbers (Figure 6 1880-1895) explain why glass manufacturers built up stocks. In 1882, L'Union Verrière was founded which united all "warm" glassworkers (blowers, gatherers, flatteners and gasmen). One year later in 1883 Le Comité des Verriers tried to lower the salaries, followed by a heavy strike in 1884. Strikes continued to return during the 1880s and 1890s. In 1894, the Nouvelle Union Verrière was founded by Edmond Gilles, which initially united all workmen but later only the "warm" craftsmen. In 1895, the "cold" craftsmen (cutters, grinders, packers, cashiers) were united in Syndicat des Magasiniens verriers founded by Henri Bastin. Because of the large difference in salaries between these two groups of workers, there was a lot of concurrence and discussion during the successive social conflicts.

3.8 1895-1914: Improving the efficiency

After 1896, no relevant technical improvements were made to the traditional production processes. There was a constant overproduction so master glassworkers were trying to lower the labour costs, with strikes in 1900-01 and 1904 as a result. After insisting of the Nouvelle Union Verrière for a partner to negotiate with, the Mutualité des Maîtres de Verreries was founded in 1909. Agreements were signed about the regulation of the work, improving the efficiency. The production of all glassworks was regulated, avoiding overproduction and so massive unemployment. At the start of the First World War in 1914, the Nouvelle Union Verrière closed down all window glass production.

At the beginning of the 20th century, the hand-blown glass production processes were gradually abandoned (Figure 9). A first adjustment was the replacement by mechanically blown glass with the Lubbers process. It was applied in the US since 1900-1905, but was not used in Europe.

In 1901, Emile Fourcault took a Belgian patent on vertically drawn glass out of the molten material. The idea of drawing glass was already patented in 1857 by William Clark of Pittsburgh, but he was not successful with preventing the glass plate to narrow. At the same time as Fourcault, Irving Colburn was developing a method in the US for vertically drawing glass but turning it horizontally. This Libbey-Owens process was patented in 1903-05. The First World War slowed down the development of the Fourcault process, of which the first factory in Dampremy was founded only in 1912-14. 1916-17 was the start of the production with the Libbey-Owens process. A third drawing process, the Pittsburgh drawing process, combined the advantages of both processes and started production in 1921.

4 CONCLUSION

Belgium was a major producer of window glass during the nineteenth century and the majority of the produced window glass was exported all over the world. Technical innovations were driven by the increasing fuel prices; the regenerative oven and tank furnace improved the energy-efficiency. The invention of Leblanc and later Solvay soda improved the quality and aesthetics of the glass plates. Although the production process was industrialized, glassblowing was still the work of an individual. By improving his work tools, he was able to create larger glass planes, but the industry had to wait until the invention of the drawn glass in the beginning of the 20th century to fully industrialise the process and the annealing path.
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