FLAT GLASS MANUFACTURING BEFORE FLOAT
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Abstract: Flat glass manufacturing before the Float process is surveyed through archival images of glass manufacturing. This photographic study covers the following glassmaking methods:
- Hand-blown Cylinder Glass (1850-1925)
- Machine-drawn Cylinder Glass (1910-1935)
- Vertically-drawn Sheet Glass (1910-1983)
- Plate Glass Cast from Pots (1850-1945)
- Continuous Rolled Plate Glass (1922-1968)
- Twin-Grinding of Plate Glass (1945-1968)

All of these glassmaking techniques were ultimately replaced by the Float Glass process.

Step back in time to the days before the float glass process revolutionized the manufacturing of flat glass. The old glassmaking methods are described and shown through old archival images. My interest in the old glassmaking days was triggered by my first job as a Tank Engineer in 1977 at the old Crystal City, Missouri glass plant of PPG. This illustration depicts the plate glass factory at Crystal City in 1877, exactly 100 years before I started working there.

By the 1940s, the Crystal City plant featured two plate glass lines, a large grinding and polishing department, glass tempering and laminating lines and thousands of workers. By the 1960s, a float line was added, and in 1968, the plate glass lines were shut down. Ten years after that, when I worked there, the two plate glass furnaces (cold but still intact like a museum) and many of the old buildings from the early days were still there.

WINDOW GLASS
- Hand-blown Cylinder Glass
- Machine-drawn Cylinder Glass
- Vertically-drawn Sheet Glass

PLATE GLASS
- Cast from Pots
- Continuous Rolled
- Twin-Grinding
WINDOW GLASS: HAND-BLOWN CYLINDER GLASS

Before float glass there were two different quality grades of flat glass: Window Glass and Plate Glass. Going back to the middle of the 19th century, common window glass was made from hand-blown cylinder glass while plate glass was made by casting from pot melted glass that required grinding and polishing to yield a better but substantially more expensive product. After the turn of the century, window glass production saw improvements with the development of a machine-drawn cylinder glass method and then vertically-drawn sheet glass methods. And plate glass production evolved with the introduction of continuous rolled plate glass methods and more sophisticated and advanced grinding and polishing techniques.

Flat Glass Manufacturing Timeline

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From this timeline one can trace the changes and evolutions that occurred after the turn of the century. Making window glass by hand-blowing into cylinders and flattening into sheets can be traced to the 19th century industrial era. This technique evolved from the hand-blown container and bottle glass shops. Skilled workers called “gatherers” would draw a glob of hot glass from the glass furnace on the end of a blowpipe or “punty.”

The pipe, with the attached “gather” of glass, was then passed on to a glassblower, who applied his mouth to the open end of the pipe and by blowing was able to start the formation of a hollow sphere. The glassblower would then begin to enlarge and shape the “gather”, sometimes using a wooden mold.

The glassblower would reheat the glass “gather” periodically at the "glory hole" in the furnace so that it would remain plastic. By maintaining the air pressure in the cylinder while
swinging it like a pendulum in a pit beneath the working floor, the ball of glass was made to elongate itself into a cylinder of glass of the desired diameter and thickness; cylinders were hand-blown up to 5 feet long. Due to the severe working conditions, hand-blown glass plants usually operated seasonally from about the first of September to the first of May, stopping production during the hot summer months.

After the cylinders were formed, the “caps” were removed by a skilled technique. Craftsmen called “cutters” wrapped a thread of hot glass around each end of the cylinder and then touched the heated area with a cold iron, thus affecting a cut.

There were a number of craft unions in these glass factories. There were the “gatherers,” the “blowers,” the “flatteners” and the “cutters.” Although entirely interdependent, these groups were often in conflict. The quality of hand-blown cylinder glass was poor according to modern standards. The “gatherer” introduced cords, the glass was battered in appearance because of repeated cooling and reheating and the glass was not uniform in thickness.
There was not much automation in those factories in the early part of the 20th century, so large numbers of skilled and unskilled workers were employed. During World War I, women and children assumed many of those jobs. Working conditions in the glass factories were hot, dirty, and sometimes dangerous.

After the “caps” were removed the cylinders were slit lengthwise in preparation for flattening. The glass cylinders were then put into a reheating oven for flattening. However the flattening process introduced sand marks, burns, and other defects into the glass. Workers helped prod the unfolding cylinder into a flat sheet by working over the surface with a wooden flattening tool. After many hours in the annealing oven, the flattened cylinder glass was stacked on buggies and taken to the cutting and packing warehouse.

The hand-blown cylinder glass process is shown here – step by step: Starting with a blob of hot glass on the end of a blowpipe, a cylinder about 5 feet long and 1 foot in diameter was blown, then one end was cut off, the blowpipe was cracked off, the end near the blowpipe was trimmed off, and the cylinder was slit, reheated and opened out into a flat sheet.

Illustration from K. M. Wilson’s drawing in Glass in New England, an Old Sturbridge Village booklet.

Hand-blown cylinder glass was produced from before the 1850s to the 1920s. Cylinders were hand-blown up to 5 feet long and typically 12 to 18 inches in diameter. The hand-blown glass plants began to be replaced by machine-drawn cylinder glass processes about 1910.

**WINDOW GLASS: MACHINE-DRAWN CYLINDER GLASS**

Around the turn of the century, a skilled glass worker named John Lubbers convinced the owner of the glass factory, James Chambers, to try to convert the hand-blown cylinder glass process to a machine-drawn cylinder glass process. Between 1900 and 1906 John Lubbers worked to perfect his process, but James Chambers went bankrupt from his investment in the development. The glass plants were sold, but Lubbers persisted and eventually Lubber’s process would become financially successful. The machine drawing process utilized a metal “bait” attached to a long pipe. Compressed air inflated the cylinder as the “bait” and pipe were raised slowly upward.

Once perfected, the machines could draw glass cylinders that were 40 feet long and up to 40 inches in diameter. This
mechanical process was not seasonal and was carried on throughout the year. Once fully formed, the cylinders were cut free, the open-ended cylinders were then lowered to the horizontal by means of mechanically operated equipment called a “take-down”, and the pipes removed.

Glass cutters then divided up the long cylinders into segments that were typically about 5 feet long. This operation was accomplished with an electrically heated wire instead of the hot glass thread previously used for cutting the hand-blown cylinders.

The divided cylinders were then slit length-wise, called “shawling.” Splitting the cylinder was carried out using a diamond mounted on a long handle so that it could be drawn in a straight line inside the cylinder. The cut cylinders (or “shawls”) were then inventoried prior to
flattening. The machine-blown window glass improved in quality because the continuous tank furnaces produced better quality molten glass and the gathering process was eliminated. The machine-made cylinder was more uniform in thickness.

The slit cylinder glass was then placed into a re-heating oven on a clay flattening stone. The split cylinder of glass was advanced through zones of increasing temperature until it had softened enough that the oven operator or “flattener” could unfold the cylinder and produce a relatively flat sheet by ironing over the surface with a heavy wooden flattening block.

By 1921, 2/3rds of all window glass made in North America, was made using the machine-drawn cylinder-glass process. The hand-blown window glass plants grew fewer in number and practically disappeared about 1925. The skilled craftsmen that were “gatherers” and “glassblowers” found themselves out of work and had to take unskilled jobs.

Flattening was improved somewhat over the earlier processes, but burn marks from the flattening tools were still evident and the sheets always retained a certain amount of crown or belly. After flattening, the glass sheets were placed in an annealing oven. Although not up to plate glass quality standards, machine-drawn cylinder glass was much less expensive to produce.

Lubbers’ process was such an elegant early 20th century invention, if only the end product being made did not need to be flattened. The extra steps needed to turn the cylinders into flat sheets were ultimately its Achilles’ heel. The machine-drawn cylinder glass process was utilized commercially between the 1910s and the 1930s. Developed by John Lubbers and financed by James Chambers, the process could produce cylinders up to 40-feet in length and up to 40-inches in diameter. The glass was used for window applications where plate glass was just too expensive. This process began to be replaced by flat sheet processes in the 1920s. Those new processes were the Colburn process, the Fourcault process and the Pennvernon process.
WINDOW GLASS: VERTICALLY-DRAWN SHEET GLASS

COLBURN SHEET GLASS PROCESS

Irving Colburn said: “Why create a cylinder for what would become a piece of flat glass?” So he tried to develop a novel sheet glass process but went bankrupt in 1912. Even after Colburn sold all his assets, he continued to try to develop it. Colburn’s process involved drawing a ribbon of glass vertically for about 24-inches, then bending that ribbon over a roller, where the glass ribbon then proceeded into a horizontal annealing lehr.

Working together, Michael Owens and Irving Colburn collaborated to improve the process and in 1916 formed the Libbey–Owens Sheet Glass Company. However, the bending from vertical to horizontal imparted a lot of distortion and surface damage into the glass. Later the company added a grinding and polishing factory, so that glass from the Colburn lines could be used for Henry Ford’s new Model A which included as standard equipment a windshield of safety glass made from laminated window glass.

VERTICALLY-DRAWN SHEET GLASS (Fourcault)

In 1904, a patent for a vertically-draw sheet glass process was issued to Émile Fourcault of Belgium. In this process, a ribbon of hot glass was drawn thru a slot in a clay bar – the “débiteuse”. The drawn glass ribbon ascended vertically through cooling until the glass ribbon was cut off into pieces at the top of the line. In the 1920s, rights were purchased by Saint-Gobain Glass, and this process was then licensed to many glass manufacturers around the world.
VERTICALLY-DRAWN SHEET GLASS (Pennvernon)

In 1918 a patent was issued to Harry Slingluff of Mt. Vernon, Ohio for another vertically-drawn sheet glass process. Further developed by Pittsburgh Plate Glass, the Pennvernon process utilized a submerged clay “drawbar” to assist with stability of the glass ribbon. The Pennvernon vertically-draw sheet glass process was developed in the 1920s, and over the years, the relative merits of the two similar techniques – Pennvernon versus Fourcault – were debated.

Both vertically-draw sheet glass processes utilized continuous glass melting furnaces to feed the forehearth of typically 5 to 8 draw kilns. The draw kilns pulled 4- to 7-foot wide ribbons of glass vertically up through the controlled cooling of annealing lehrs. Vertical sheet lines were designed so that the glass did not contact the rollers until it had cooled sufficiently so as not to be affected by the contact. Although glass produced on these vertical sheet lines never achieved the optical clarity of polished plate glass, the glass was generally superior to the glass produced on the Colburn horizontal window glass lines.

Sheet glass machines could make window glass in “single strength” = 1.6mm (1/16”); 2.4mm (3/32”); “double strength” = 3.2mm (1/8”). The ribbon of glass was pulled vertically up from the draw kiln through the annealing lehr about 4 floors. The vertical annealing lehrs were typically passive enclosures which provided controlled cooling with minimal reheating of the
glass. However, a split or cross-break in these vertical lehrs often resulted in a cascade of broken glass falling back down to the draw kiln, and then restarting of the ribbon of glass by using a metal “bait”.

The cut-off floor was 5 floors above the draw kiln. Automatic scoring and snapping of the cut-off glass was typical for those lines. There was a lot of manual handling of glass on the cut-off floor; eventually automation eliminated some of this. These factories had many large elevators for moving glass inventory for further processing.

Sheet glass processes were commercially operated by many different glass companies between the 1910s up until the 1980s. They continued for some time to produce inexpensive window glass for uses that could not justify the more expensive plate glass or float glass in the early years of its development. Eventually, even in developing parts of the world, float glass factories were built to replace the aging sheet glass lines.

PLATE GLASS CAST FROM POTS

Plate glass was considered superior to window glass because it was ground and polished yielding much better optical quality. Plate glass was initially made by casting sheets or plates from pots of molten glass. By the beginning of the 20th century, plate glass was being commercially produced in Europe and North America. Typical pot furnaces were built with capacity to melt 10-20 pots of glass at a time.

Special clay pots were made specifically for the melting of plate glass, and each could hold from 1 to 2 tons of glass. These clay pots were made by the plate glass companies, usually in a separate small factory adjoining the plate glass factory. Raw materials for melting glass in pots was delivered in buckets to the furnace area, and charged into the pots using manually operated, long-arm cantilevered “shovels”.

Debris (or dross) from the batching of the pots and other spillage had to be scraped out from the floor of the pot furnaces regularly. The clay pots were reused a number of times, but ultimately cracks would render them unusable. The old pots were crushed up and the clay was recycled to make new pots. A long curing and aging process was needed to make high quality clay pots (typically 2-3 years), yet the pots typically lasted less than 30 days in service.
The cycle for melting glass in pots was 36 to 72 hours, allowing about 12 hours for the bubbles and seeds to rise to the surface. The large clay pots were moved in and out of the furnace while clamped in the jaws of the electric teeming crane. Those electric teeming cranes required a crane operator who worked in tandem with a floor operator to move the plate glass pots into and out of the furnaces.

Before pouring the pot of molten glass, the pot had to be manually “skimmed” to remove the inferior glass at the top surface. The hot pot was then attached to a hoist and lifted above the casting table. Molten glass was then poured out on the large cast-iron table, which had been covered with sand to keep the glass from sticking. A large water-cooled steel roller, weighing as much as five tons, was then drawn along the casting table flattening the molten glass into a plate.
of glass. Casting tables could be as large as sixteen feet wide by thirty feet long. Large overhead cranes were installed in the casting halls to facilitate the lifting and pouring of the molten glass from the clay pots. One-and-a-half to two tons of molten glass was typically poured out onto the casting table.

After rolling out on the casting table, the solidified glass plate was transferred to an annealing chamber, where cooling and annealing could take up to five days. After annealing, the unpolished rough plate glass was typically stored in large warehouses until being sent thru the grinding and polishing operation. At the start of the grinding step, rough plate glass was “bedded” in a calcined gypsum slurry (plaster of Paris) on circular grinding tables. Each plate was manually “bedded” into the paste, which, as it set, made for a firm support and freed the glass from strain. Before the plaster of Paris set, workers “danced” on the plate: this was called “swimming the plate.”

Various sizes of plate glass were configured to fill the large circular grinding and polishing tables. Preparing the grinding and polishing tables was a time-consuming affair. Before the advent of continuous grinding and polishing lines, start-to-finish of one piece of plate
glass could take a week. To grind the surface of glass, large circular “runners” held hundreds of cast-iron grinding blocks. These would rotate against the top surface of the bedded plate glass with a slurry of grinding sand dispersed as a grinding medium. Typically two circular grinding “runners” rotated above a circular grinding table with the glass embedded on it.

The circular tables with bedded glass moved through a sequence of finer and finer grinding media, until polishing would commence using a fine rouge (iron oxide) slurry. Circular polishing machines were often complex, with counter-rotating “spider wheels” fitted with felt pads that contacted the glass surface. Many large electric motors were needed to rotate the numerous grinding and polishing wheels of a plate glass factory, necessitating large electric substations. G&P operations were huge energy consumers.

After many grinding and polishing steps, the plate glass was half-finished. The whole process had to be repeated on the other surface. At the end of the line, workers had the delicate task of removing the glass from the plaster bed, after which it would be flipped over and re-bedded in fresh plaster of Paris slurry. And after grinding and polishing was complete on both sides, the plate glass had to be washed to remove the plaster of Paris and polishing rouge from the surface. Manufacturing plate glass was energy and labor intensive, but yielded flat glass of unsurpassed quality. Grinding and polishing removed a lot of glass from each plate. In order to produce 6mm-thick polished plate glass, the manufacturer would cast rough plate glass at least 8mm-thick.

Plate glass was commercially produced by casting from pots since before 1850 up until the 1930s for traditional large-scale applications, and continues to be produced by this method even today for some specialty glasses. Most of the plate glass that had been cast from pots began to be replaced by continuous plate glass operations in the 1930s.

CONTINUOUS ROLLED PLATE GLASS

In the 1920s and 1930s, plate glass manufacturers developed continuous rolled plate glass methods. Many of these lines could form a continuous ribbon of glass that was up to 124 inches (3.1 meters) wide. Pot furnaces were replaced with large continuous melting furnaces. These continuous furnaces had melting and refining zones that fed molten glass between two large water-cooled forming rolls. The hot ribbon of glass was then conveyed over a number of closely-spaced rollers.
The continuous ribbon was carefully cooled until it became rigid and was flat. The ribbon of rough plate glass then proceeded on hundreds of rolls in a long annealing lehr. At the exit of the annealing lehr of a continuous plate glass line, the long ribbon of glass continued to cool to room temperature before being separated into individual plates. The continuous ribbon of rough plate glass on the cooling conveyor looked a lot like a float glass line of today – except that the glass still needed to go through the grinding and polishing operation.

The continuous rolled plate glass processes enabled the production of larger plates than could previously be produced with the pot methods. By the 1940s, plates as large as 124 inches x 220 inches (3.1 meters x 5.6 meters) could be made. The advent of continuous-rolled plate glass manufacturing was paired with semi-continuous grinding and polishing lines. The grinding tables used for this method were rectangular instead of round.

The train of heavy cast-iron rectangular grinding tables proceeded under a long sequence of larger and more powerful grinders and polishers. The continuous grinding and polishing process increased throughput such that what used to take about a week from start-to-finish with the pot glass process could now be accomplished in under 24 hours. The slurry used in the polishing process consisted of a mixture of ferric oxide (Fe$_2$O$_3$) and ferrous sulfate.
Continuous Rolled Plate Glass lines were in operation from the 1920s until the late 1960s. This continuous process was faster than pot glass at producing glass. Larger plates of glass were able to be made. However, because of the high cost associated with grinding and polishing, plate glass was rapidly replaced by float glass starting in the 1960s.

**TWIN GRINDING OF PLATE GLASS**

Between the 1940s and 1960s manufacturers developed continuous twin-grinding of plate glass. On these lines a continuous ribbon of rough plate glass proceeded directly from the cooling conveyor to twin-grinders. Initially these lines continuously ground the top and bottom surface of the ribbon, and the polishing steps were carried out on individual plates, similar to the older processes. Development continued until lines were successfully grinding and polishing the entire continuous ribbon of glass. These lines featured long rows of large industrial motors rotating the grinding “runners,” running around-the-clock.

The grinding and polishing motors and wheels were designed for rapid servicing via the perpendicular support tracks they were mounted on. All the plate glass manufacturers invested heavily in this twin-grinding technology, even Pilkington Brothers, who would soon obsolete all of this with float glass.

The continuous twin-polishing line used iron oxide (called rouge) as in the past as a mild abrasive, and the glass was polished by felts rotating at high speed. When the whirring felts became worn, at regular intervals, without a break in the work, a new polishing battery of reconditioned felts was swapped into place.

The whole process was on a scale more massive than one can imagine today. At the end of the continuous twin polishing line, the glass was washed and rinsed. By the early 1960s, with the commercialization of the float glass process by Pilkington Brothers, twin-grinding was called “the most modern obsolete process in the world” by David Hill, president of Pittsburgh Plate Glass. Although it was unclear at that time if float glass could be made to match the superb optical quality of plate glass, it became quickly clear that the days of plate glass manufacturing were numbered.
Flat glass manufacturers invested heavily in twin grinding plate glass processes. Twin grinding lines were built at:

- Rossford, Ohio (USA) by Libbey-Owens-Ford
- Cumberland, Maryland (USA) by Pittsburgh Plate Glass
- St Helens, UK by Pilkington Brothers
- Chantereine, France by Saint-Gobain
- Kingsport, Tenn. (USA) by American St-Gobain

Twin Grinding of Plate Glass was quickly made obsolete by the rapid development of the float glass process. Manufacturers were quick to adopt the new process, and those expensive Twin-Grinding plants were moth-balled. A new era of flat glassmaking had begun.

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