From Glass-Blowing to Blow Molding

Review. Blow molding is one of the most important polymer-processing techniques. Its origins date back to glass-blowing, which has been known for thousands of years. The industrial use of polymer blow molding began about 80 years ago.

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The first material to be blown into the shape of hollow parts was glass. Meyer's "Konversationslexikon" (encyclopedia) mentions a relief in the royal tombs of Ben Hassan that depicts glass-blowers at work [1]. This relief has been dated to 1800 BC. The oldest glass factory is in Egypt and dates from the 14th century BC. The development of Egyptian glass-blowing into modern industrial blow molding to produce hollow plastic parts took a very long time and was in the end essentially driven by the availability of inexpensive raw materials that met the special needs of this processing technology and also led to the development of the first new applications.

America as a Pioneer

In a U.S. patent dated June 24, 1851, entitled "Improvement in Making Gutta-Percha Hollow Ware", S. T. Armstrong describes the formation of a tubular parison that is blown by internal pressure against a mold wall [2]. Gutta-percha is a rubber product which is obtained from the eponymous tree. This patent ushered in the industrial use of blow molding. It was followed by others that describe the processing of celluloid and rubber to mostly make technical articles and toys (**Fig. 1**), e.g. spherical Christmas tree decorations, by blowing steam between two celluloid films so that they soften and take on the shape of the mold as it closes, sealing the edges of the films. Back then, there was limited scope for processing the materials, however.

Further advances in blow molding were not made until new materials were found in the 1930s, when the glass industry in the U.S. began manufacturing containers and packaging from PVC. The new containers were less fragile than glass, and the U.S. glass industry successfully managed to prevent any outside competition in the market until after World War II [4]. A large number of blow molding patents were filed, primarily by the American glass industry, from 1938 to 1945. U.S. Patent No. 2,260,750, entitled "Method of a Machine for Making Hollow Articles from Plastic" by William H. Kopitke (Plax Corp.), dates from 1938 and is particularly noteworthy. It describes the production of a parison and blow molding in first heat. Owens Illinois Glass Corporation produced the first plastic bottles on an industrial scale for the U.S. Army Medical Corps from 1939–1946 [5]. Today, the methods used then would be classified as injection blow molding.

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Fig. 1. Baby rattles made of cellulose nitrate, about 1890 [3] (photos: Kautex Maschinenbau GmbH)

Developments in Europe

In Europe, blow molding did not take off until the late 1940s, somewhat later than in the U.S., and mainly occurred in the glass industry. Consequently, many of the new techniques for processing plastics were based on those for processing glass.

In order not to jeopardize its monopoly, the U.S. glass industry formed a closed group of "plastic blowers". Thus, developments in Europe proceeded completely independently of those in the United States. It was primarily German engineers and entrepreneurs who carved out a name for themselves as blow molding pioneers. The chief protagonists were the brothers Reinold and Norbert Hagen (Kautex Werke, from about 1948 on, **Fig. 2**), Stefan and Rainer Fischer (Maschinenfabrik Johann Fischer, from about 1957 on), Horst Gottfried Mehnert (Bekum, from about 1959 on), M. Rudolf (Rudolf), and Erhard Langecker (Battenfeld).

Kautex Werke, now subsumed into Kautex Maschinenbau GmbH and plastics processor Kautex Textron GmbH & Co. KG, had been located in Bonn since its foundation.

Not far from Bonn, in Troisdorf, was a subsidiary of Dynamit Nobel Group, which was active in the field of plastics development [5]. Alfred Nobel himself had experimented with substitutes for rubber, gutta-percha and leather on the basis of cellulose nitrate. These were the first stirrings of modern polymer chemistry and polymer processing that would

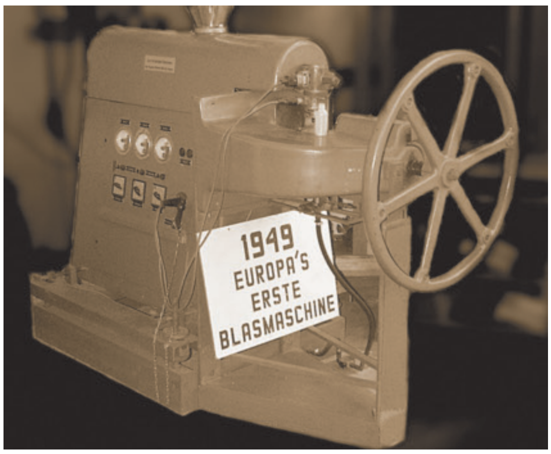

Fig. 2. The Kautex Werke produced Europe's first blow molding machine in 1949

become so significant for Dynamit Nobel. In 1905, the Troisdorf factory produced the first industrially useful plastic by converting cellulose nitrate, an explosives raw material, into celluloid. In 1923, the world's first injection molding compound came onto the market, and the production of molded plastic parts began. In 1930, Rheinisches Spritzguss-Werk GmbH (RSW) in Cologne, forerunner of Dynamit Nobel Kunststoff GmbH, took up production.

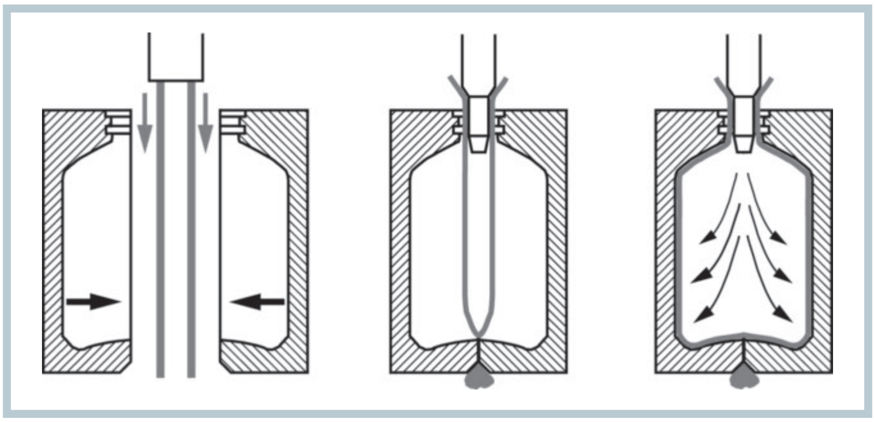

Fig. 3. Calibration of the neck opening through mandrel movement [2]

The First Extrusion Blow Molding Machine

Inspired by the developments at Dynamit Nobel, the Hagen brothers made the first molded parts from plastic sheets. The construction was derived from sheet metal processing, and entailed the steps of bending and welding. To simplify production and make it more efficient, the Ha-

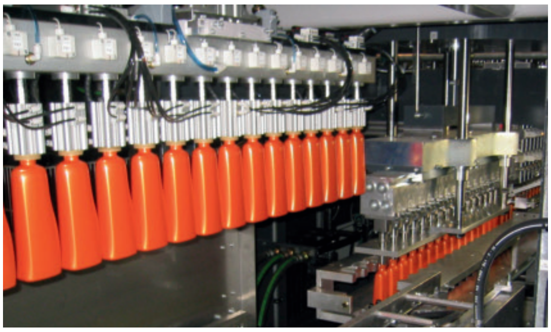

Fig. 4. 16-cavity production on a long-stroke machine

gen brothers developed the first extrusion blow molding machine in 1949 that was capable of manufacturing bottles, containers and other hollow parts from plastics [6]. Characteristics of the machine, such as the arrangement of the blow pin, still feature today in modern blow molding machines. A replica of this blow molding machine stands in the technical center of the Dr. Reinold Hagen Foundation, Bonn, which Dr. Reinold Hagen founded from the proceeds obtained by selling the company in 1988. In the following years, blow-molded plastic packaging established itself because it was unbreakable and chemically resistant. The blow molding process enabled much more intricate shapes to be produced than was possible in metal or steel sheet [2].

Extrusion blow molding, especially in the form that evolved in Germany, soon found international acclaim and went on to dominate further developments in all industrial nations. Around 1955, the first Kautex automatic blow molding machines crossed the Atlantic to the U.S.A., where they spawned further developments. By the 1960s, the majority of the principles underpinning modern market and technology for extrusion blow molding had been developed [2].

A comprehensive list of American and German patents is contained in the book "Blasformen von Kunststoffhohlkörpern" (Blow Molding of Hollow Plastic Ware) [7].

Targeted Development Taps New Markets

On the raw materials side, polyolefins and rigid PVC soon proved to be the best blow molding materials. Whereas polyethylene could be processed relatively easily in terms of its processing window (temperature control and rheology), PVC initially suffered from its thermal sensitivity and reprocessability. Yet there was strong demand at home and abroad for transparent PVC food packaging. Containers for cooking oil, vinegar, beverages, spices and for pharmaceutical and cosmetic products offered promising applications for blow-molded hollow parts [2].

As blow-molded hollow parts became more widespread, as machinery exports rose and, not least as competition increased, there arose an increasing awareness of the need to focus on quality and performance. To this end, targeted development work and specialization was pursued in the various fields of machinery, process engineering and application technology. Examples include:

- Calibration techniques for forming customized bottle neck openings **(Fig. 3)**.
- Control of the thickness of parison walls with the aim of producing blow-molded parts with walls of uniform thickness. "Normal" axial wall thickness control, which compensates circumferential differences along the part length, was supplemented in the 1990s by statically flexible die rings (SFDR) and partial wall thickness control (PWDS) [8].
- Mechanization of workflows with automatic deflashing inside and outside the blow mold.

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Fig. 5. 6-layer, co-extrusion blow-molded plastic fuel tank

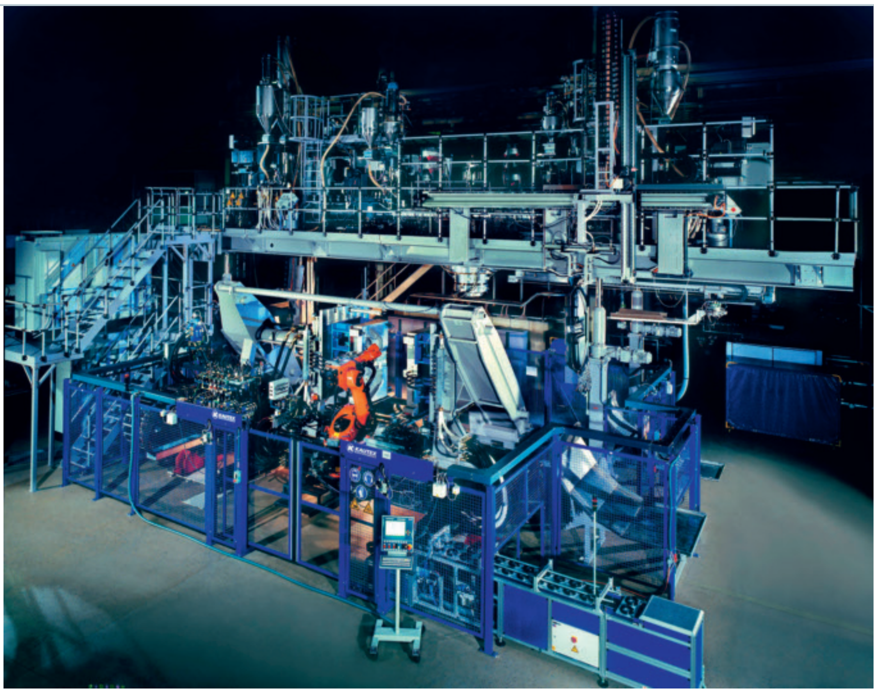

Fig. 6. Twin stations of a 6-layer, co-extrusion tank blow molding installation with robots supplying parisons for the stationary blow molds

- Use of multiple heads to boost machine performance **(Fig. 4)**.
- Machine designs for producing large hollow parts, such as canisters, drums, IBCs up to 10,000-liter fuel oil tanks [9].
- Manufacture of intricate, industrial hollow parts; especially in the 1990s, the development of 3-D blow molding for low-waste production of three-dimensionally curved pipes [10].
- Production of multilayer hollow parts, e.g., three layers with a middle layer of recycled material.
- Development of continuous 6-layer co-extrusion for plastic fuel tanks **(Fig. 5)** with a barrier layer of EVOH [11].
- And finally, the development of the microprocessor control.

Accordingly, a wide range of different types of machines was created. The differences lay mainly in the calibration and inflator mechanisms, the movement of the mold between the parison head and blow pin, and the different types of flash separation. Industrial blow molding machines **(Fig. 6)** differed essentially in the type of material accumulation and the design features of accumulator heads. Screw and reciprocating barrel accumulators competed against melt accumulators, especially tubular ram accumulators. The former designs, adapted from the injection molding machine, failed to become established despite intensive efforts and cooperation on the part of the raw materials industry. Nowadays, only sequential co-extrusion ("hard-soft-hard" production of 3-D parts) still makes some use of reciprocating barrel accumulators. A mechanical variant that proved a major success in injection molding – the all-electric machine – failed to become properly established in blow molding, despite some good approaches.

Process Developments Driven by Materials

In the late 1960s, high-molecular polyethylene came onto the market. These materials provided new development impetus for the blow molding industry and opened up additional applications in the field of large blow-molded parts and industrial parts. Initially, this development was plagued with difficulties because the existing extruder concepts, the head designs, the machine clamping forces and the pinch-off edges of the blow molds no longer met the more rigorous requirements. It can be assumed that, not least on account of the availability of and possibilities afforded by these new polymer materials, the process engineering, which was adapted to the new raw materials, played a substantial role in boosting general acceptance for machine designs and has now been state of the art for many years now. The following keywords may be mentioned in this regard:

- Introduction of forced conveying extruder concepts with grooved and cooled extruder feed zone,
- application of mixing and shear parts as homogenization aids,
- eventual breakthrough of the tubular ram accumulator,
- realization of such demanding blow-molded parts as the aforementioned fuel oil tanks, plastic fuel tanks and drums for transporting dangerous goods,
- optimization of the flow paths in the parison die, overlapping heart-shaped curves and offset spider-type mandrel holders,
- fast and accurate wall thickness controllers with integrated parison length control,
- controlled pre-blowing of the parison.

Fig. 7. Low-waste, three-dimensionally curved tubes, made by 3-D blow molding

The close cooperation by raw material producers, machine manufacturers and processors has played a major role in the successful implementation of these developments.

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Summary

Whereas glass has been blow-molded successfully for the last 4,000 years, the first attempts to apply this technology to thermoplastics date back only about 130 years. The industrial use of polymer blow molding began about 80 years ago. The chronicler of the year 1979 (see [2]) expressed a wish that the chronicler of the

Fig. 8. Water bottles made of crystal-clear polypropylene NX 8000

year 2000 would be able to report more successful developments for the first century of blow molding in polymer processing. The chronicler of 2011 hopes that he has accomplished this.

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Chronology

1900 to 1930:
Celluloid is thermoformed. The resultant developments cannot be fully exploited, as the thermoplastics better suited to the process have not yet been discovered.

1930 to 1950:
In the U.S.A., fundamental engineering work is done, mainly on injection blow molding as an alternative to glass processing.

1950 to 1960:
Polyethylene comes onto the market, thereby enabling the widespread use of blow molding technology. Development of extrusion blow molding opens up totally new applications for plastics.

1960 to 1970:
PVC, crystal-clear and physiologically safe, becomes the preferred packaging material. The adaptation of blow molding technology to this material requires a redesign of the machines. A new generation of blowing machines comes into being. This opens up huge export opportunities for German industrial blow molding machines. Wall thickness control for parisons becomes established.

1970 to 1980:
High-molecular polyethylene conquers the market for industrial-sized packaging and tanks. The industry is forced to concentrate more intensively and extensively on engineering details. Two "oil crises" bring a new appreciation for plastics; processing methods based on efficiency and quality prevail.

1980 to 2000:
Extrusion blow-molded 20-liter water bottles made of unbreakable, crystal-clear polycarbonate replace the heavier glass bottles as dispensers more and more. Development of multilayer blow molding to as far as 6-layer co-extrusion of plastic fuel tanks opens up new possibilities. Further advances in wall thickness control. Statically flexible die ring and partial wall thickness control allow uniform wall thickness, even for intricate containers. Low-waste production, three-dimensionally curved pipes become possible through advent of 3-D blow molding (parison manipulation or suction-blow molding technique) in combination with sequential co-extrusion **(Fig. 7)**.

2000 to 2010:
Quick-change systems for head tools and blow molding tools increase productivity. Bisphenol A in polycarbonate causes problems for water dispenser bottles. The newly developed crystal-clear polypropylene emerges as an alternative **(Fig. 8)**.