

Annex 1

Polyurethane Processing Systems

First published in *Kunststoffe* 7/2004

Authors: Dr.-Ing. Udo Maier, Hans-Guido Wirtz, Jürgen Fietz, Andreas Frahm, Thomas Rüb

PROCESS TECHNOLOGY

In contrast to production of complete molded parts or semi-finished goods by physical means, the primary step in production of polyurethane parts involves a chemical reaction that occurs at the processor. Reliable production equipment for this process is available to manufacture the greatest variety of parts. Starting from low-pressure and high-pressure machine technology, the present article briefly discusses the necessary machine components. The many different approaches to system technology are classified as either continuous or discontinuous in nature.

Manufacturers of polyurethane plastic parts generally receive liquid products - polyols and polyisocyanates or formulated systems - from their material suppliers and then convert these into polyurethane via a chemical reaction. Processing takes place on equipment where, in addition to the polyol and polyisocyanate, additives are incorporated in accordance with a specific recipe, and from which the resulting reaction mixture is dispensed. The technology and machines were initially developed by Bayer in Leverkusen/Germany. Since then, many companies have designed machines for a multitude of important applications based on PUR chemistry.

Processing of foamable reaction mixtures is called Reaction Injection Molding (RIM) [1-4]. Using this process, both integral skin foam parts (where the cellular core has a largely non-cellular skin) and micro cellular foam parts that are microporous and, thus, almost solid can be produced in extremely short cycle times. The term RRIM (Reinforced Reaction Injection Molding) designates the process when granular, flake or fiber additives (fillers) are incorporated to modify the properties of the polyurethane [5].

METERING AND MIXING TECHNOLOGY

The two primary components (polyol and polyisocyanate) are transferred from storage tanks to working vessels called feed tanks (or day-tanks). Often, strictly two-component systems are processed, i. e., all additives, such as activators, stabilizers, flame retardants, pigments and the like, that are essential for the reaction are already contained in the two primary components. However, it is also possible to have premix stations inject the additives directly into lines connected to the metering pumps. Metering pumps convey the components in exact ratios from the day tanks to the mixhead. This mixture is then discharged from the mixhead into either an open mold or, via a runner system, into the cavity of a closed mold. Once the reaction (cure) time has elapsed, the finished part is demolded or the semifinished product is processed further.

Low-pressure machines (Fig. 1) briefly recirculate the components. Control valves assure simultaneous injection of the components into the agitatorequipped mixing chamber. Once filling is complete, any residual mixture must be cleaned from the mixing chamber. This can be accomplished through the use of either compressed air and/or liquid flushing agents. Foam systems that are only slightly reactive can be processed at atmospheric pressure in open molds. For these, the simple, rugged low-pressure machines are still of practical importance and operate with adequate accuracy. In recent years, small low-pressure metering systems that produce parts as small as 0.5 g in a discontinuous manner have been introduced to the market.

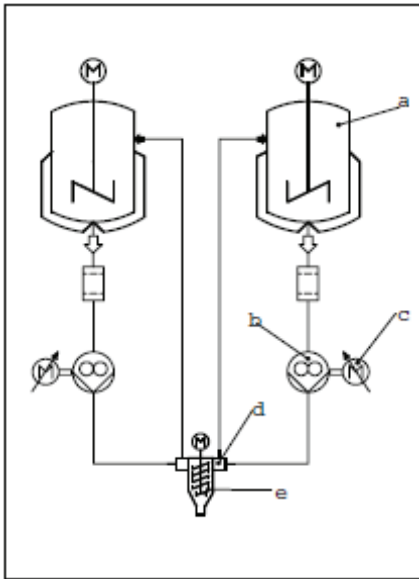


Fig. 1. Schematic of a low-pressure machine
 (a: feed tanks (day tanks), b: metering pumps, c: motor with frequency converter, d: control elements, e: agitator-equipped mixing chamber, M: drive motor)

Recirculating systems have also represented the state of the art for high-pressure machines for many years (Fig. 2). Prior to each mixing and filling cycle, the components recirculate in the specified ratio at the pressure required for injection. Positively actuated control elements shift from recirculation to injection and then back to recirculation in high-pressure mixheads. The reaction mixture that remains in the mixhead after mold filling takes place is purged by either compressed air or by a cleaning piston. In modern high-pressure machines, low-pressure circuits are possible for homogenizing, temperature control and venting of all lines. These permit the temperature of the entire metering and recirculation system to be stabilized under energetically favourable conditions during idle times, while also preventing the settling of fillers.

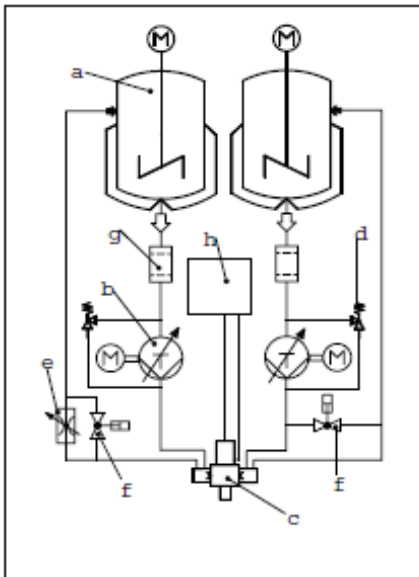


Fig. 2. Schematic of a high-pressure machine with recirculation system
 (a: feed tanks (day tanks), b: metering pumps, c: mixhead, d: safety valve, e: recirculation throttle, f: low-pressure recirculation valve, g: filter, h: hydraulics for mixhead, M: drive motor)

The starting materials are brought to and maintained in a processible condition in the feed tanks (Fig.3). This involves primarily exact temperature control. Every temperature fluctuation, especially in the polyols, results in a change in viscosity that, in turn, can lead to problems during subsequent processing. For this reason, the feed tanks are generally of double-walled construction. Since heat transfer between the tank wall and tank contents is only moderate under low convection conditions in the feed tank, agitators (and often special temperature control circuits) assure that the desired processing temperature is maintained exactly. The metering pumps are supplied from the feed tanks. With this in mind, the feed tanks are usually designed as pressure vessels so that the components flow to the metering pumps under a certain pressure (often provided by dry compressed air above the liquid in the tank).

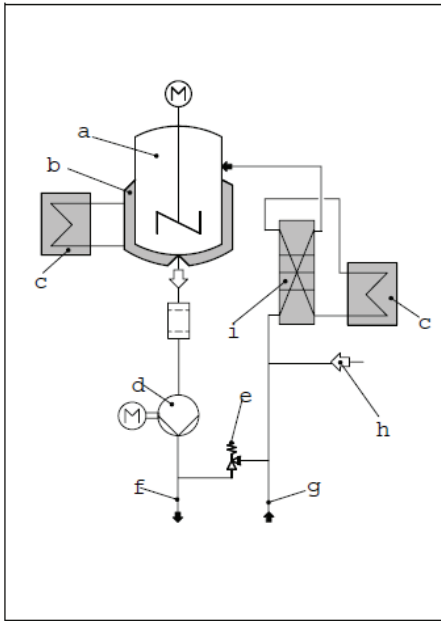


Fig. 3. Schematic of a temperature control circuit in a day tank
 (a: feed tank (day tank), b: double wall, c: heating/cooling unit, d: pump, e: overflow valve, f: supply line to metering pump, g: return line, h: refill line from bulk storage tank, i: plate-type heat exchanger, M: drive motor)

Metering of the components in the proper ratio must be reproducible and occur with a high degree of accuracy. Accordingly, highly precise pumps are utilized in both low-pressure machines and high-pressure machines. Many types of pumps find use, and only a few will be discussed by way of example.

External gear pumps are the preferred type in low-pressure machines. When using these, attention must be given to leakage losses as the viscosity drops and to increasing back pressure. In addition to their use as metering pumps, they – along with screw pumps – are employed as recirculation pumps. For dispensing rates of 12 to 150 l/min, low-noise, and likewise valveless, axial piston pumps find use (Fig. 4).

An important limitation for axial piston pumps results from the occasionally high viscosities of the liquid to be processed. In addition, no abrasive fillers can be present in the liquid component. For this reason, cylinder-type metering devices (so-called plunger pumps) are the preferred type for the RRIM process. Such single-stroke pumps can be driven by a stepping motor, hydraulic linear amplifier (Fig. 5) or other electro-hydraulic means. In recent years, the market has also started to offer fully electric plunger pumps.

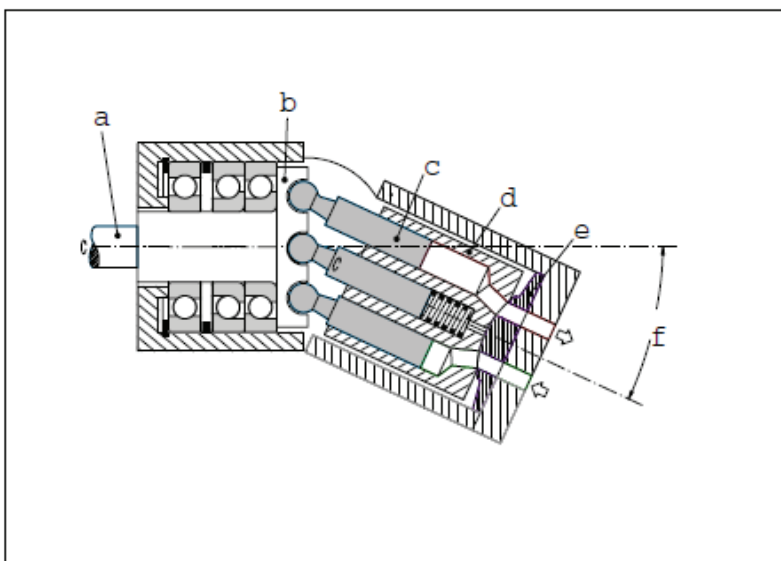


Fig. 4. Schematic of an axial piston pump
 (a: drive shaft, b: driver plate, c: piston, d: barrel, e: control plate, f: angle of adjustment)

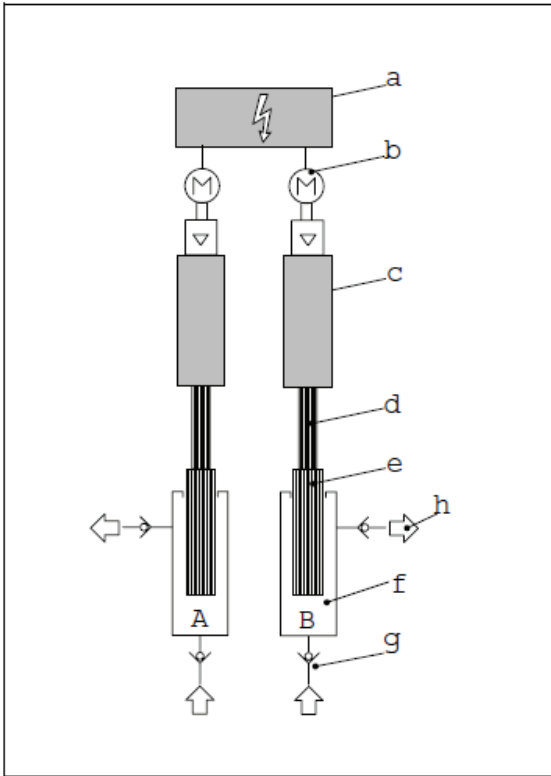


Fig. 5. Schematic of a metering system with individually powered plunger pumps and pulse frequency control

(a: electronic control unit, b: stepping motor, c: hydraulic linear amplifier with hydraulic cylinder piston, d: hydraulic piston rod, e: metering plunger, f: metering cylinder, g: shutoff valve, suction line, h: shutoff valve, pressure line)

MIXHEAD TECHNOLOGY

The most important component in a reaction injection molding machine is the mixhead. While agitators find use in the low-pressure process, a completely new method resulted from introduction of high-pressure impingement mixing. It is only because of this invention that short cycle times became possible when processing polyurethane resins. Component velocities through the injection nozzles range from 100 to 150 m/s. The liquid components are injected through the orifices into a mixing chamber, where they become thoroughly mixed as a result of their kinetic energy (Fig. 6). While the classical counterflow principle (impingement mixing) was used initially, arrangements where the nozzle axes are angled at less than 180° are also encountered today.

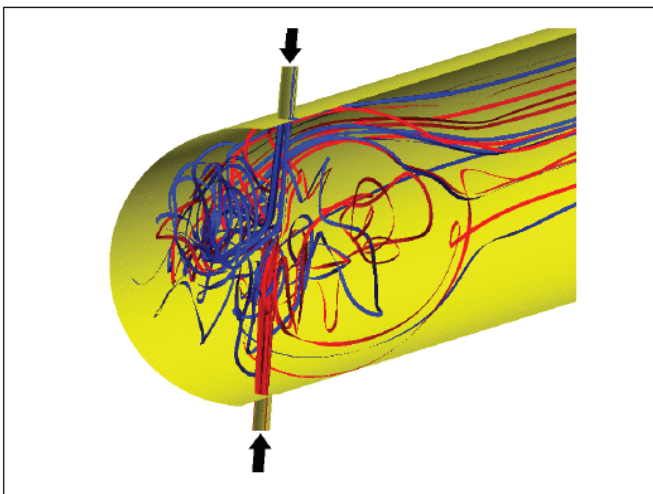


Fig. 6. Mixing action during impingement mixing (view of the sectioned mixing chamber and discharge channel)

In high-pressure mixheads, integrated and controlled shifting of the component streams from recirculation to injection at 150 to 250 bar occurs along with the actual impingement mixing. This assures that the start and end of injection are synchronized exactly for each component. High-pressure mixheads can be designated as with or without integrated after-mixing. For mixheads without after-mixing, the closed-mold filling technique allows aftermixing elements to be placed in the runner system (Fig. 7). In the open-pour method, L-type mixheads slow the flow rate of the reaction mixture as the result of a change in flow cross-sections between the mixing chamber and discharge channel. This principle satisfies the requirement for the lowest possible dispensing rate when using the open-pour technique. When processing injectable abrasive fillers and reinforcements, wear-resistant mixhead designs are necessary. These employ special surface treatments or hard, wear-resistant inserts. Without any claims to completeness, the following presents detailed descriptions and schematic representations of a few important mixhead designs. These designs are, however, limited to mixheads for processing of two components. For some applications, mixhead designs for up to six components are available in the market.

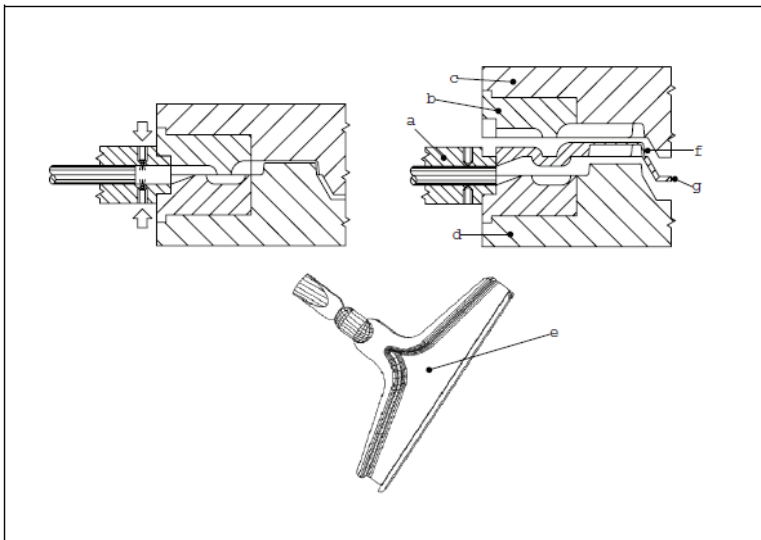


Fig. 7. Runner system with diverters and dam (a: mixhead, b: insert with throttles and diverters for after-mixing, c: upper mold half, d: lower mold half, e: dam gate, demolded, f: gate, g: molded part)

Piston-actuated mixhead with grooves. When the mixhead is in the recirculation position, both components flow back to the feed tanks through grooves in the control and cleaning piston (Fig. 8). As the control piston retracts, the mixing chamber opens and the components impinge against each other. As the control piston advances once again, mixing is interrupted, recirculation is re-established and residual reaction mixture is purged from the mixhead.

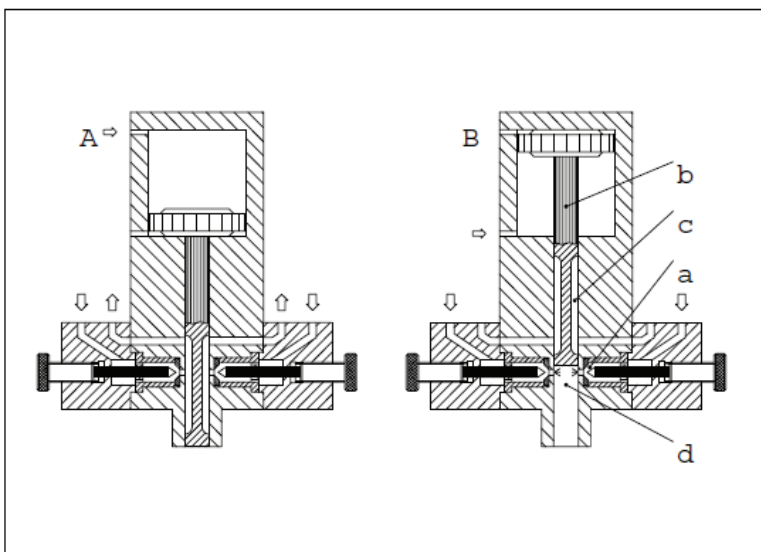


Fig. 8. Schematic of a piston-actuated mixhead with recirculation grooves (A: recirculation/cleaning, B: mixing, a: injection nozzles, b: control and cleaning piston, c: recirculation grooves, d: mixing chamber)

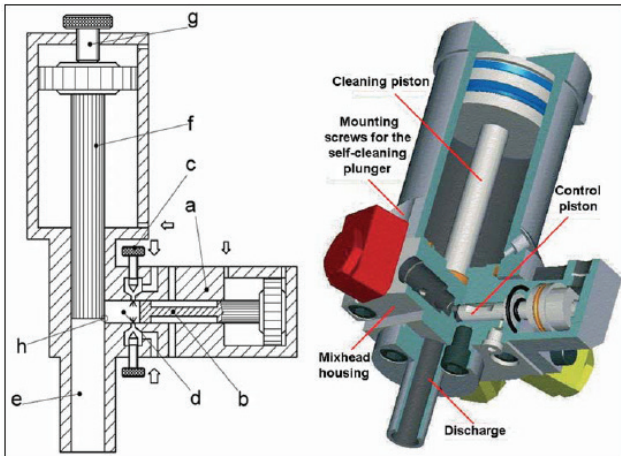


Fig. 9. Left: Schematic of an L-type mixhead with mechanism for adjusting the throttle cross section

(a: impingement mixer, b: control and cleaning piston, c: injection nozzles, d: mixing chamber, e: discharge channel, f: discharge cleaning piston, g: mechanism for adjusting throttle cross section, h: throttle cross section). Right: Sectioned 3-D CAD model (source: Cannon)

L-type mixheads. In the so-called L-type mixhead (Fig. 9), a piston-cleaned discharge channel connects directly to the mixhead at an angle of 90° . The diameter of the discharge channel is larger than that of the mixing chamber. As a result, it is possible to achieve close nozzle spacing for efficient impingement mixing in the mixing chamber, while providing a reduced flow velocity of the reaction mixture for dispensing. The adjustable gap (h) determines the pressure in the mixing chamber and assures after-mixing of the reaction mixture. An alternative to the L-type mixhead described above utilizes a coaxial sleeve to throttle the flow (Fig. 10). The adjustable sleeve creates an annular channel that is variable in height. The chamber at the lower end of the sleeve provides for gentler redirection of the flow and a reduced velocity of the reaction mixture as it is dispensed.

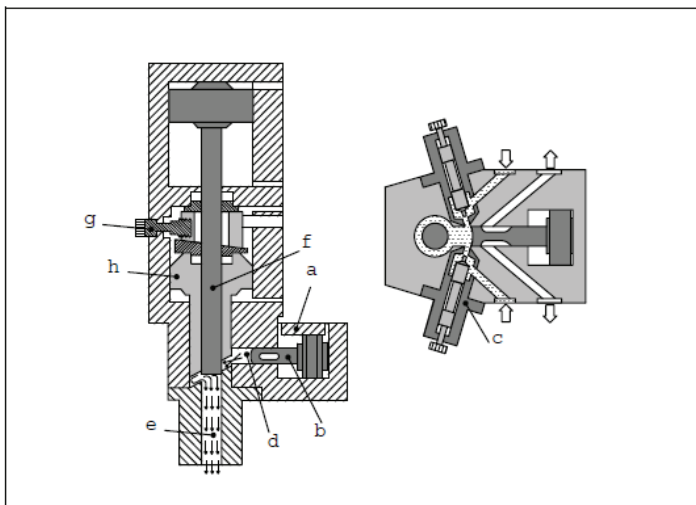


Fig. 10. Schematic of an L-type mixhead with mechanism for adjusting the coaxial sleeve (grade MX) - manufacturer: Hennecke

(a: impingement mixer, b: control and cleaning piston, c: injection nozzles, d: mixing chamber, e: discharge channel, f: discharge cleaning piston, g: mechanism for adjusting annular (ring) channel, h: coaxial sleeve)

Mixhead for long fibers. While the RRIM process can accommodate maximum fiber lengths of 0.1 to 0.2 mm, various manufacturers have developed techniques that permit processing of long fibers of up to 100 mm in length. Because of the potential for clogging and the viscosity-increasing nature of such fibers, however, they can no longer be mixed with the liquid components. Wet-out takes place after mixing and, with the implementation of special measures, can start in the mixhead (Fig. 11).

With the aid of a chopper attached to the mixhead, the rovings are cut to length and subsequently drawn by vacuum (generated by the annular nozzle) into the hollow piston [6]. At the lower end of the hollow piston, the reaction mixture created by high-pressure mixing surrounds the stream of moving chopped glass. Numerous downward-pointing air nozzles (through which compressed air pulses) placed around the discharge opening spread the exiting reaction mixture stream as required in order to achieve broader deposition of the glass fibers. Immediately upon exiting the cleaning plunger, the reaction mixture wets out the glass filaments, a process that the spreading action facilitates. The stream leaving the mixhead also possesses enough kinetic energy to cover the usual distance of 100 to 400 mm between the mixhead and surface of the open mold cavity. A robot guides the mixhead over the surface of the open cavity.

The reaction mixture subsequently foams in the closed mold under pressure while undergoing an exothermic reaction and, after the cure time elapses, a lightweight long-fiber-reinforced part can be removed from the mold.

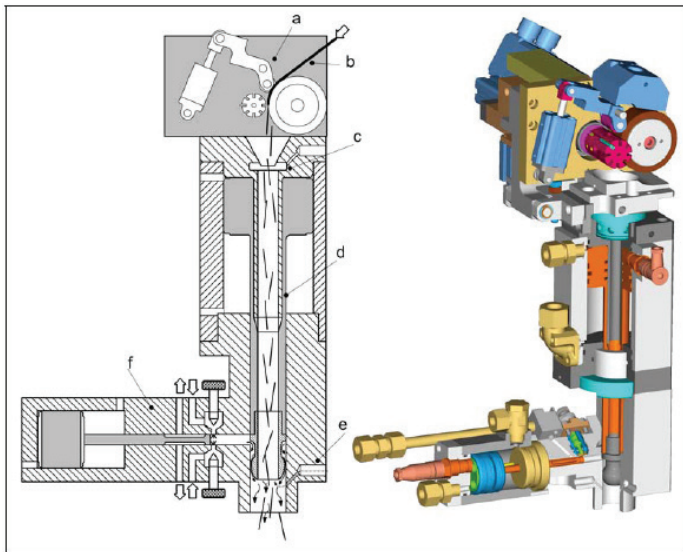


Fig. 11. Left: Schematic of the mixhead for processing long fibers - manufacturer: Krauss Maffei (a: chopper, b: roving, c: annular (ring) nozzle, d: hollow piston/cleaning piston, e: compressed-air nozzle, pulsed, f: impingement mixer). Right: Sectioned 3-D CAD model (source: Krauss Maffei)

PROCESSING PLANTS

A production system comprises the reaction injection molding machine (feed tanks, recirculation/ metering pumps, mixhead, etc.), a mold to form the part and, possibly, additional equipment. Systems are classified as being either continuous or discontinuous in nature.

In a discontinuous system, molds or cavities are filled with reaction mixture one shot at a time, i. e., as a rule, finished parts are produced. By way of example, Fig. 12 shows a system for producing polyurethane foam parts in which a robot guides the mixhead to fill the cavities in an open-pour technique. In conjunction with a robot, a single dispensing machine supplies two mold carriers in the system shown.



Fig. 12. Photo of a reaction injection molding system for production of automobile seats; manufacturer: Cannon (company photo: Bayer Material-Science)

Since the cavity pressures encountered when producing polyurethane foam parts via the conventional reaction injection molding process are quite low, prototype parts can be produced even in epoxy molds, for instance. To improve the thermal conductivity of such molds, aluminum grains are often added. For temperature control, cooling lines are cast into the mold. Because of the above, polyurethanes offer advantages over competing polymers when preproduction parts or short runs are involved.

When producing thin-walled parts in a closed mold with long flow paths that must be filled in seconds because of the

high reactivity of the reaction mixture, flow pressures on the order of 50 bar are not uncommon. Because of the required clamping force in such cases, prototype molds generally incorporate metal reinforcements. To achieve good surface quality, aluminum cavity surfaces can be used in a cast resin mold that also contains metal reinforcements in order to withstand the higher load. For long production runs in excess of 50,000 parts, steel molds become unavoidable. For moderate production runs of 50 to 50,000 parts, or for flexible foam applications, cast aluminum, wrought aluminium or zinc alloys as well as reinforced electroformed shells can be used as mold materials.

In contrast, continuous systems produce semifinished goods in the form of blocks or panels. For production of flexible or rigid foam blocks, the foamable reaction mixture from either a high- or low-pressure machine is dispensed into a continuously moving trough, usually made of paper (Fig. 13). For flexible foam blocks, for instance, dimensions of 2 m wide by about 1 m high have proven to be optimal. The resulting densities range from 15 to 60 kg/m³, with belt speeds between 2 and 10 m/min.

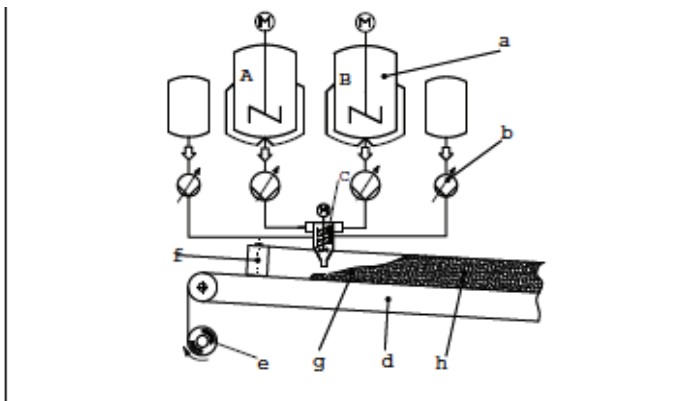


Fig. 13. Schematic of a system for continuous production of foam blocks

(a: feed tanks (day tanks), b: metering pumps, c: agitator-equipped mixhead, d: conveyor, e: bottom paper, f: side paper, g: reaction mixture, h: cured foam, M: drive motor)

Fig. 14 shows the agitator, pouring plate, rising section, conveyor and paper pull-off in a modern system for continuous production of rectangular flexible foam blocks.

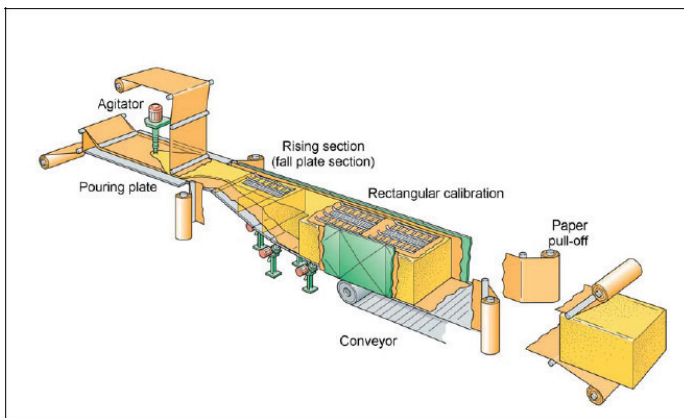


Fig. 14. 3-D representation of a system – without metering device and cut-off saw – for continuous production of flexible rectangular foam blocks by means of the QFM process (source: Hennecke)

Insulation boards are produced on double-conveyor systems (Fig. 15). The reaction mixture - produced, once again, by either a high-pressure or a low-pressure machine - is dispensed in an oscillating motion onto the lower facer. During the foaming process, the foam bonds to the facer supplied by the upper conveyor. The remaining design details of such systems depend on the type of facer employed. For instance, sheet with roll-fed, sheet-fed or profiled facing materials can also be produced in a continuous manner. Purchasers of boards nowadays demand variable dimensions of 0.5 to 1.3 m width and 20 to 240 mm thickness. Production speeds range from 2 to 15 m/min. High-speed systems operate as fast as 40 m/min. Densities vary from 20 to 60 kg/m³. The double-conveyor section usually has a length between 12 and 45 m. Complete systems for production of metal sandwich elements (Fig. 16) usually measure about 200 m in length, from the profiling mechanism for the metal facing to the stacking and packing area for the cut-to-length sheet.

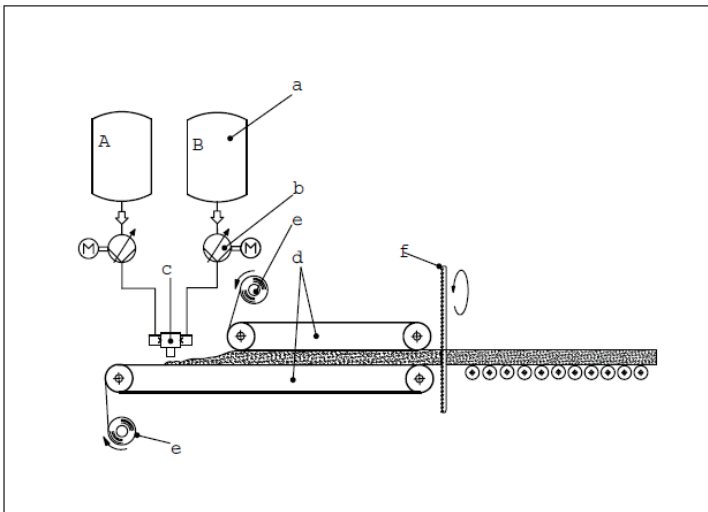


Fig. 15. Schematic of a system for continuous production of insulation boards
(a: feed tanks (day tanks), b: metering pumps, c: mix head, d: double conveyor, e: roll-fed facing material, f: cutting device, M: drive motor)

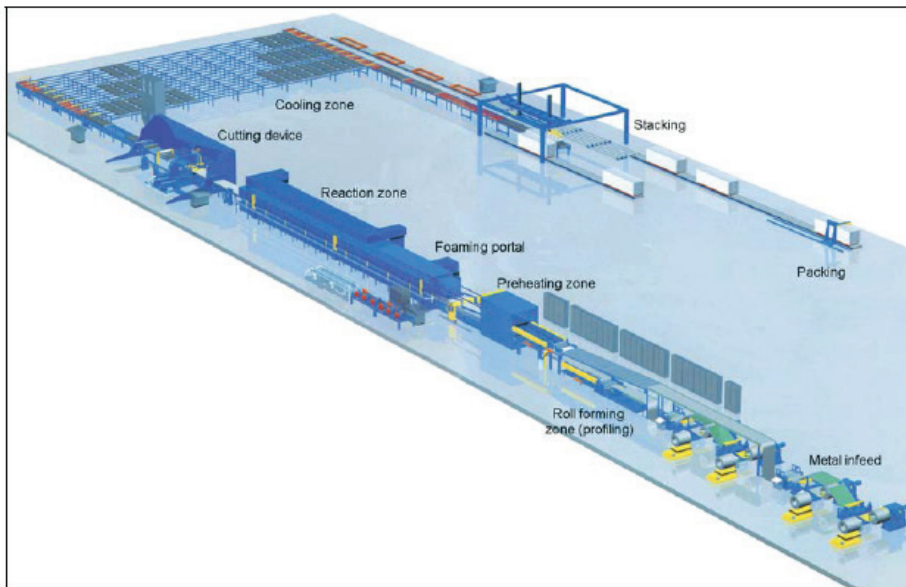


Fig. 16. 3-D representation of a production for metal sandwich elements
(source: Hennecke)

REFERENCES

1. Begriffe des Reaktionsgießens (VDI): Kunststoffe 69 (1979) 2, S. A 47
2. Knipp, U.: Herstellung von Großteilen aus PUR-Schaumstoffen. Zechner & Hüthig Verlag, Speyer 1974
3. Becker, W: Reaction Injection Moulding. Van Nostrand Reinhold Company, New York 1979
4. Piechota, H.; Röhr, H.: Integralschaumstoffe. Carl Hanser Verlag, München 1975
5. 5 Becker, G. W.; Braun, D.; Oertel, G. (Hrsg.): Kunststoff-Handbuch, Band 7: Polyurethane, Carl Hanser Verlag, München 1993
6. 6 Söchtig, W.: LFI-PUR® Maschinen- und Anlagentechnik. In: Polyurethane Engineering 2000. VDI-Verlag, Düsseldorf 2000