Technical Report

Glass Batch Preparation – State of the Art

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1. Introduction

Careful processing of glass batch is one of the decisive factors contributing to the quality of finished glass. A certain mixing effect is produced by the melter itself, but even so it is necessary to employ optimum batch preparation technology to ensure glass homogeneity.

With few exceptions glass batch consists of a large number of individual components that differ sometimes considerably with regard, for example, to their

- shares in the formulation,
- bulk densities and specific weights,
- grain size distribution,
- grain shape,
- solubility and wettability,
- tendency to form agglomerates.

Batch preparation technology has to ensure an optimum homogeneity of the mixture. This means that each component must be added to the mixture in accordance with its specified share in the formulation and that it must be distributed evenly through the entire batch [1 to 3].

The required homogeneity of glass will vary, of course, from case to case. Löffler [4 and 5] gave this definition: "Technically homogeneous glass is glass that displays no disturbing heterogeneities." Exactly when heterogeneity is felt to be disturbing depends, of course, very much on the type of glass, its quality and intended use, so a generally valid definition is impossible. For economic considerations alone it would not be reasonable to mix a glass batch to the best possible degree of homogeneity in each and every case. A modern batch processing system should generally be capable of producing an optimum quality of batch (in the technical sense) at an acceptable cost.

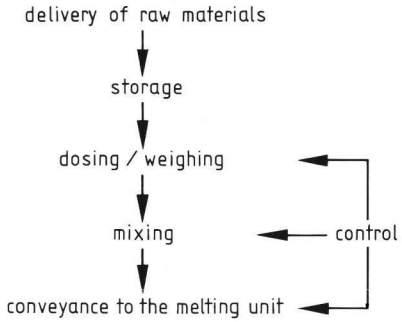

Figure 1. Flow diagram of glass batch processing.

This paper will describe the most important function groups of a modern glass batch processing system (see figure 1) and will quote a number of the typical performance data of such systems.

2. Function groups of a glass batch processing system

2.1. Delivery and storage of raw materials

Raw materials can be delivered in various forms. Usually they are supplied in dry form in order to dispense with having to operate, for example, a sand-drying plant in the glassworks. Dry-bulk road or rail tankers are used for the transportation, while smaller quantities also come in sacks.

Throughout the entire raw materials' delivery area, along in-plant transport routes and in the raw materials' store it is important to guard against the absorption of moisture as this can easily result in caking and problems during silo or hopper discharge, conveyance and dosing of the materials, particularly in the case of soda ash, potash, etc.

Dependent on their shares in the batch formulation the various raw materials are conveyed mainly by pneumatic means into silos of assorted sizes. Apart from using pneumatic conveyor pipelines with distributor points, the silos can be loaded by revolving chutes, reversible conveyor belts, rotary vibrating conveyors, fixed or rearrangeable hoses, belt conveyors with wiper blades, vibrating conveyors or screw conveyors with outlet flaps, and bucket elevators [6]. The silos themselves can be set up in towers, in line or a combination of both (figures 2 and 3). One advantage of the tower arrangement is that the raw materials need to be raised vertically once only, after which the material flow can proceed by force of gravity. Another is that a tower arrangement takes up far less floor space. The in line arrangement, on the other hand, affords the advantage of a lower overall height. This is at the expense, however, of occupying a bigger floor area, and it may also be necessary to raise the material once again from the silo outlet to the weighing system or to the mixer. When modernizing old batch-processing plants, and when redesigning systems within existing production facilities it is often necessary for space reasons to use a combination of tower and in line-type arrangement in which the advantages of each are exploited as far as the local conditions allow.

The level of each raw material in the silos is monitored by level indicators. The latter can take the form of either limit indicators or limit switches that emit a signal when a certain level is reached or which can be designed also to scan the level continuously. These level measurements can be taken by mechanical, electromechanical, capacitive, ultrasonic or radiometric means. Great differences in the fineness, grain shape and density (which can range from approximately 400 kg/m^3 to more than 2000 kg/m^3) of the various raw materials means that they also display highly differentiated flow characteristics, ranging from "very good flowing" (sometimes "racing") to "bridging". To ensure the reliable discharge of materials from the silos it is necessary, therefore, to use not only properly shaped silos but also appropriate material discharge or

distribution elements and, wherever necessary, special discharge aids. The latter have to guarantee a smooth discharge and to get the material moving again in the event of clogging or bridging.

Aeration of the material by means of aeration cushions can be a worthwhile measure for powder components with mediocre to poor flow characteristics. They are made of sintered metal fabric and are installed in the cone of the silo. They can also be retrofitted. With the aeration cushions injecting air into the silo either continuously or intermittently, the powder is sufficiently fluidized to keep the frictional forces low enough to ensure a smooth discharge. For powdery and granular components with better flow characteristics it is recommended to use a vibrating bottom as discharge unit. The latter works by the service-proven vibration principle, which actively supports the mass flow.

2.2. Dosing and weighing equipment

If the quality of mixing is decisive for the quality of a processed batch, so is the accuracy of the dosing and weighing operations. Mistakes in this area cannot be compensated by any mixing system, no matter how good it may be. It is extremely important, therefore, for the dosing system to be coordinated as well as possible with the weighing system and the control system [7]. On the one hand there is the demand for as high a dosing accuracy as possible, on the other hand there are the extreme differences in component shares in the overall formulation. It is necessary, therefore, to use several weighing systems, each with a different range of accuracy. For this reason it is usual to combine several components in so-called dosing groups. Practical divisions are, for example, components with a 20 to 70 %, 5 to 20 %, 1 to 5 % and less than 1 % share in the batch. Other divisions may be used to suit the conditions of the specific formulation. A further possibility is to use blending mixers in order to obtain a higher level of accuracy when dosing small components. In many cases microcomponents are still being weighed by hand and added to the batch manually. Also special devices for precise microcomponent addition are available.

In a modern dosing system a distinction is drawn between rough and precision dosing. At the beginning of the dosing operation the system works at a high dosing speed. Automatic switchover to the precision flow mode does not take place until the actual value nears the set-point. The point for switching over from the rough flow to the precision flow mode can be set individually. For most batch components it is possible to use dosing screws of diverse types as the feeding device, often with a disaggregating mechanism installed in the inlet. Switchover from rough to precision dosing is performed by changing the screw speed with the aid of frequency converters. By this method it is possible to achieve dosing rate ratios of around 10 : 1. Vibrating chutes or vibrating tubes with solenoid actuators can also be used for batch components with particularly good dosing characteristics.

After switching off the dosing unit a certain amount of the material continues to run out even when operating at very low dosing speeds. This "tail fraction" is the material that has already left the dosing unit but which has not yet been able to cause any change to the balance. For this reason the dosing units are equipped with pneumatically operated shut-off flaps at their outlets. Once the control system stops the dosing, the valves are closed automatically, thus ensuring a minimum as well as constant tail fraction. The shut-off flaps serve in addition to keep control of the type of materials which have a tendency to race. As a further possibility the software for the dosing control system has a tail fraction optimization feature which adjusts the end of the dosing cycle in accordance with the tail fraction that is actually determined from the dosing operation.

In a modern plant all the batch components are dosed by gravimetric means, and the only type of weighing system chosen nowadays for this job is the electromechanical balance. The latter works with a weighing container resting on one or more load cells. Inside the load cells there are strain gauges which produce an electric voltage through weight-dependent changes in their resistance. This voltage acts as the measurement signal, is amplified,

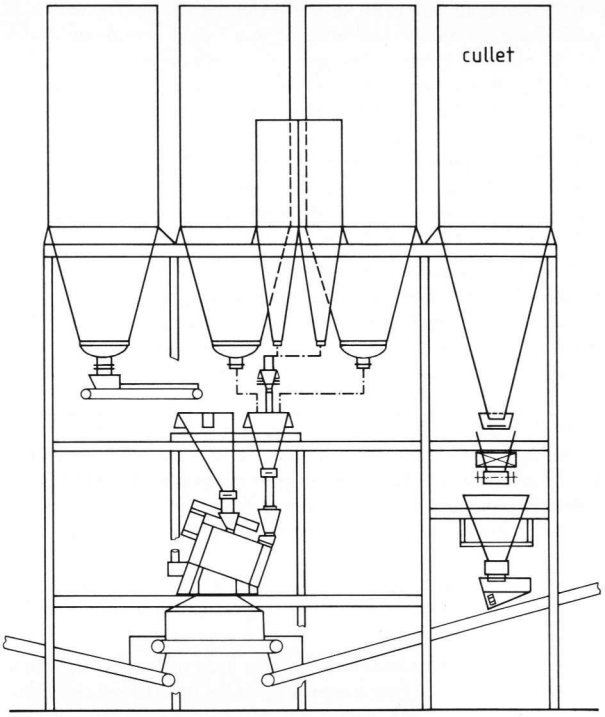

Figure 2. Tower-type dosing and mixing system.

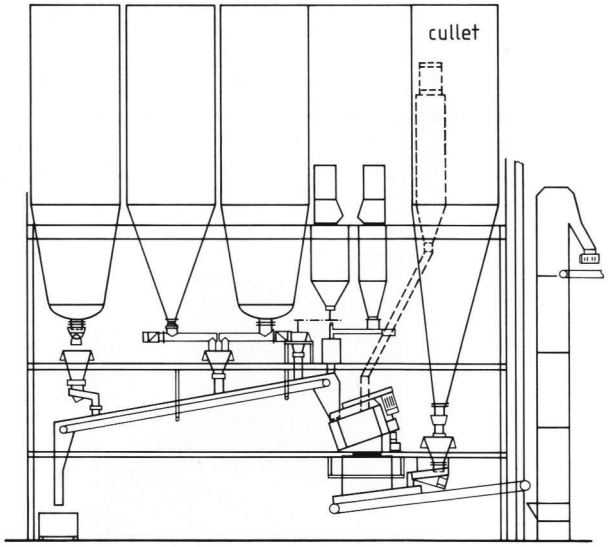

Figure 3. In line-type dosing and mixing system with ascending conveyor belt for feeding the mixer.

processed and displayed. A dosing computer can use this signal to control the balance exactly. Advantages of the electromechanical weighing system are:

- It is insensitive to dirt.
- Taking measurements without displacement means no wear and protection from ambient influences.
- Thanks to the small dimensions of the load cells the system is also suitable for difficult installation conditions.
- Various classes of accuracy are available.
- Straightforward transmission of the measurement signal is possible in analog or digital form over large distances.

A measurement amplifier frequently used in glass batch systems is model ITG 3030 (Analogic GmbH, Wiesbaden (Ger-

many)). It has an analog/digital converter with a conversion rate of 16 Hz and it shows the result directly as a 7-digit reading in 14 mm high illuminated figures. The measured value is relayed simultaneously to the dosing control system via an analog interface. A keyboard at the front can be used to enter and delete weight values such as gross, net and tare, as well as to enter, check and change up to 20 different parameters (e.g. unit of measure, resolution, stop range, transmission rate). A very high degree of local user flexibility is thus assured. New settings required for each change of application are easy and quick to make.

For dry batch components it is customary to use container balances that are chosen as regards their weighing capacities on the basis of the given formulation data. It is typical to use balances with weighing ranges of 1 to 10 kg for microcomponents, 5 to 50 kg for small components, and 50 kg and above for large components.

In the interest of quality assurance it is possible to carry out a component summation check in addition to the normal weighing. In this case either the intermediate hopper is designed as a single-component balance or the mixer itself is used as a summation check balance. For this purpose the mixer is set on 4 load cells, and the actual post-filling value is determined and compared with the summation set-point of all the components that have been fed into the mixer. A fault signal is issued whenever the set tolerance is exceeded.

In modern plants balances are also used for water, in which case the water balance container is suspended from a load cell. This uniformity of dosing and weighing systems for all the components within a batch processing operation affords some considerable advantages:

- All the mechanical components and the control concept are the same.
- Dosing and weighing accuracies are comparable.
- Simplified spare parts service and maintenance is possible.
- Calculation und recording of formulations is easier.

Figure 4. Mixing principle of a countercurrent intensive mixer.

- If moist sand is processed and the system has a reliable moisture meter, it will be possible to make sand/water adjustments without extra effort.

2.3. Mixing systems

The mixing unit has to distribute all the batch components evenly throughout the mixture, regardless of their share in the formulation and their other characteristics. Modern batch processing systems use only forced-circulation mixers for this job. In addition to turbulent mixers, ring trough mixers, and other mixer types [8 and 9], the countercurrent intensive mixer has proven to be exceptionally well suited for this work [6, 7, 10]. The mixing system of the latter is based on the following principle: The mix container ("mixing pan") rotates in clockwise direction and transports the material to the mixing tools in the form of a rotor or mixing star. These tools are set in an eccentric position to the centre of the mixing pan and rotate in counterclockwise direction. The mixing star and rotor are fitted on various levels with tools of a particular shape and arrangement to produce an intensive mixing of the materials in both horizontal and vertical direction. The high-speed rotor can also serve simultaneously to disagglomerate components that have a tendency to form agglomerates. Movement of the material in the mixture is intensified by the combined wall/bottom scraper elements which serve on the one hand to deflect the material and on the other hand to prevent caking on the wall and bottom of the mix container. Figure 4 shows a schematic diagram of the mixing principle in a countercurrent intensive mixer.

The mixing pan can be arranged either horizontally or at an incline. It is set on a ball-bearing slewing ring and is driven by a standard motor via a gear rim or with a friction gear. The inclined mixers have just a single moving tool, i.e. the high-speed rotor, whereas the horizontal mixers have either one or two mixing stars or (as is always the case for high-duty applications) a combination of mixing stars and rotor.

The combination of the various moving elements makes it impossible for any less well mixed "dead" zones to form because every part of the material mixture is moved to the rotor or mixing star in quick succession.

The mixers are emptied through a tightly sealing discharge opening at the centre of the mixing pan bottom. The closing mechanism is actuated by an own hydraulic system. Mixing pan, rotor and discharge closure are equipped with standard single drives that ensure a high degree of operational reliability. An automatic central lubrication system supplies lubricant independently of maintenance staff. To facilitate maintenance work the mixers are fitted with a large door that provides easy access to the inside. On account of the small number of tools inside the mixer it is a very easy matter to exchange tools or to carry out any other cleaning and maintenance jobs.

Public awareness of environmental issues has increased considerably and with it the importance of avoiding dust emission from the batch processing area. To this end the mixer can be equipped with an expansion pipe (see figure 5) designed to prevent

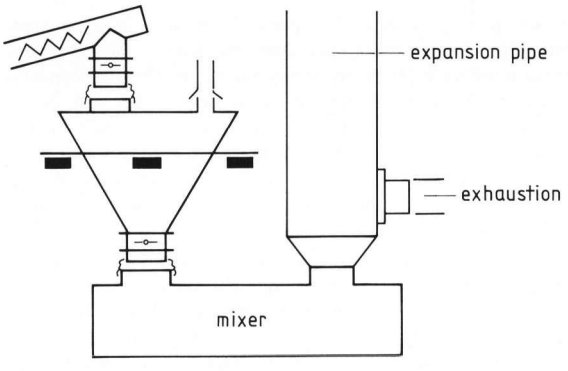

Figure 5. Schematic arrangement of an expansion pipe mounted on the mixer.

the escape of dust-laden air into the environment due to the abrupt compression that occurs during the mixer charging operation. The enlargement of the pipe diameter immediately above the connecting flange to the mixer results in a drastic deceleration of air velocity. A part of the dust thus drops straight back into the mixer, while the rest of the dust-laden air is drawn off through a pipe union that is situated in the bottom section of the expansion pipe and connected with the dedusting system. During the charging operation and the entire mixing cycle a multiple of the batch volume is drawn off this way and replaced continually with fresh air. This means that when the next charging operation begins, the expansion pipe is completely full of fresh air. Hence the dust-laden air that now enters the expansion pipe during the charging will displace only clean air upwards and out of the expansion pipe. To prevent caking on the wall of the expansion pipe and to simplify cleaning, the expansion pipe can be made of rubber.

The seal between the rotary pan and the stationary dust hood also serves to prevent environmental pollution. It is possible to choose between a single-lip seal and a double-lip seal to suit the particular requirements. In the case of the single-lip seal a rubber ring slides over a sealing face on the rotating mixing pan. The double-lip seal, which is designed for higher requirements, features 2 rubber rings – the one is fixed to the dust hood and makes contact with a sealing face on the mixing pan; the other is fixed to the rotating mixing pan and slides over the stationary sealing face of the mixer cover. The two rubber rings thus form an annular channel which is connected to the exhaustion system.

2.4. Wetting the batch

A further measure for reducing secondary dust but more especially for preventing segregation phenomena is to wet the batch [6, 11 to 13]. Adding around 2 to 5 wt% of water is sufficient to form a liquid film around the individual particles. The adhesion resulting from capillary forces keeps the mixture dust-free and stops any tendency to segregate. The water can be injected into the mixer using a stationary distribution pipe connected to a water balance or a flow meter.

When wetting glass batches it is important, however, to observe the hydration characteristics of soda ash, which is a constituent of most batches [14]. The decahydrate $Na_2CO_3 \cdot 10\,H_2O$ is stable below 32 °C, the heptahydrate $Na_2CO_3 \cdot 7\,H_2O$ is stable at 32 to 35 °C, and the monohydrate $Na_2CO_3 \cdot 1\,H_2O$ is stable above 35 °C (see figure 6). Temperature thus plays a crucial role for the amount of moisture that is actually available. Below around 35 °C the soda binds a large quantity of water in the form of crystal water – water which is then no longer free for the wetting described above. For this reason it is advantageous to inject the water as steam into the mixture, thus raising the temperature and preventing the unwanted drying effect. Introducing 0.5 wt% of steam causes a temperature rise of around 10 K in the batch. It is very easy to inject steam into a mixer with a rotating pan through a stationary feed pipe dipped into the batch. As the result of the movement of material in the mixer the steam is evenly distributed and completely absorbed by the batch layer.

An alternative method for preventing soda hydration problems is to replace the soda ash – at least partly – by caustic soda. The outlay for the storage and dosing systems required for this method is higher, however, due to the strong corrosiveness of the 50 % NaOH solution mostly used and due to its high viscosity (particularly at low temperatures).

2.5. Cullet as a batch component

Cullet is playing an increasingly important role as a raw material in glass production [15]. Cullet arising from the own production of a manufacturer and which therefore more or less has the same composition as the new glass melt has been recycled in all branches of the glass industry for a long time already. More and more cullet from external sources (refuse glass collections) is also being used, however, particularly in the container glass industry. In Germany, for example, 1.79 million tons of refuse glass were recycled by the container glass industry in 1990; this equals 54 % of total container glass sales [16].

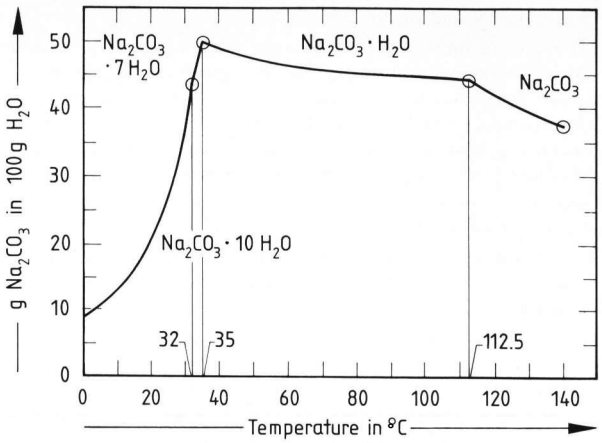

Figure 6. Temperature-dependent solubility for soda in water.

Table 1. Quality requirements for container glass cullet

contamination	maximum permissible quantity per ton of cullet
stones	100 pieces
aluminium	15 g
organic matter	500 g
iron	1 to 2 g
other heavy metals (e.g. lead, tin, zinc)	1 to 10 g

plus: = grain size 3 to 25 mm with as small a grain size distribution as possible
– largely sorted into colours

When cullet is used, appropriate measures are needed to ensure that no critical contaminants enter the glass melt. Table 1 lists a number of quality requirements that must be met by container glass cullet. Self-produced cullet can be assumed generally to display far higher degrees of purity. For an optimum melting process the cullet should measure less than 25 mm in diameter, and it is also desirable for the range of grain sizes to be as small as possible. The surplus glass produced when working glass from the melt. e.g. from the feeder, can be granulated continuously in water and then be removed by means of scraper chains. Larger-sized cullet, e.g. the production scrap left after forming flat or hollow glass, can be reduced to the required grain size by means of hammer, impact or oscillator type crushers, with follow-up magnet separators used where necessary. The advantage of using cullet as a raw material for glass production is that it enables a reduction in melting energy of up to around 3 % per 10 % cullet input [17 and 18]. Given proper adjustment of the refinement stage and provided contaminants are eliminated, it is possible to use cullet shares of over 80 %, dependent on the type of glass in question.

Cullet can be added to the glass batch at two points:

- First, the cullet can be fed directly into the mixer, in which case the other raw materials are usually already mixed and the cullet is added shortly before discharge. Cullet boosts the mixing effect by increasing the internal friction, but it will also cause distinctly more wear to the mixing elements if it dwells in the mixer for long. It is necessary moreover for the mixer to be accordingly larger in volume in order to accommodate the extra volume of cullet.
- Second, the cullet can be added to the finish-mixed batch, e.g. using the so-called sandwich process downstream from the mixer (see figures 2 and 3). The cullet is dosed by weight or volume.

2.6. Control and documentation

The control unit manages the sequence control of the complete dosing, weighing and mixing facilities in a central control room, which usually serves as the control junction for the upstream and downstream plants, too. At the same time the control unit also enables a host of batch processing system parameters to be monitored, with documentation available on practically any scale. Various control versions are distinguished according to their degree of automation:

- The pushbutton control system requires each individual operation to be triggered by pressing a corresponding key by hand.
- The semiautomatic control system allows for certain phases to be started manually, after which they can be left to run automatically. It is possible, for example, to carry out a dosing operation manually, load the mixer and then call up the mixer routine. While the automatic mixing routine is being executed, the batch for the next cycle can be prepared manually.
- In the fully automatic version, all the functions are executed completely without manual intervention after the plant has been started.

State of the art in modern glass batch plants is the fully automatic control system using a programmable logic controller (PLC). The specific mixing program is saved in EPROMs and can be adapted any time, e.g. if the plant is modified or extended, by entering corresponding changes with a programming unit. Formulation-specific parameters, which sometimes need to be changed at short notice, can be entered directly at a keyboard.

The parameters and functions monitored by the control system include, for example, mixing duration, rotor speed, energy consumption by the rotor and mixing pan drive, mixer discharge time, and many others besides. The dosing control system is integrated on the software level as part of the PLC. Dosing control includes, for instance, a plausibility check on the entered formulations, automatic zero taring of the balances, an actual/set-point value comparison of balance readings, automatic tail fraction optimization of the dosing units, triggering of discharge aids, tolerance checks, etc. Incorporation of the dosing module in the PLC is only worthwhile, however, when working with around 3 to 5 balances and a limited number of formulations. For more balances a better solution is to use a separate dosing computer. These are microcomputers with their own processor and own special software that have proven successful in several hundred cases of application world-wide. They allow for connecting up 8 to 16 balances and come with their own A/D converters and interfaces for exchanging data with other computers, e.g. a higher level host. Up to 250 recipes can be saved in the formulation memory.

Documentation, e.g. the output of batch logs (possibly with graphics), consumption logs (component-related) or production checks (formulation-related) can be viewed on screen or as hard copy from a printer. The data can also be transferred to other computer systems. For particularly demanding applications it is even possible to implement a combination of PLC and dosing computer that leaves no wishes unanswered.

For the convenience of the operators in the control room it is customary to use illuminated mimic diagrams as combined control and information systems. In this case the batch processing system is reproduced schematically in an illuminated diagram, with pushbuttons and pilot lamps integrated directly in the symbols of the various units. With small to medium-size plants this makes for simple operation and a good overview of the process. A better solution for plants of greater complexity or for a higher degree of flexibility in handling the available volume of information is a process control system integrated in the automation system and allowing for process visualization and operation by way of a computer monitor and keyboard. Flow diagrams, batch masks, formulation masks and all the data masks can be called up by using function keys.

3. Factors influencing the quality of batch processing

The ultimately attainable degree of homogeneity of a glass batch to be fed into the furnace is dependent on a large number of factors. The following points are worth mentioning as being particularly important:

- Quality of raw materials: With natural raw materials in particular it is important to ensure that the distribution of any accompanying constituents and contaminants remains constant physically and throughout the course of time. Grain size distribution, grain shape, etc. must fluctuate as little as possible.
- Accuracy of dosing and weighing: Even the best mixing technology is unable to compensate any errors made in the dosing and weighing operations. It is vital, therefore, to ensure exact dosing and weighing, preferably using high-quality and properly coordinated plant components. Here it is important for the dosing or weighing capacity of the particular unit to match

Table 2. Statistical variables for the assessment of mixing trials

designation	symbol	calculation formulae	notes
number of samples	i	–	set-point: 10 to 20
individual value	x_i	–	determined analytically
arithmetic mean	$\bar{x}$	$\bar{x} = \frac{\Sigma x_i}{i}$	–
variance, scatter	S^2	$S^2 = \frac{\Sigma (x_i - \bar{x})^2}{i-1}$	dimensional quantity
standard deviation	σ	$\sigma = \sqrt{\frac{\Sigma (x_i - \bar{x})^2}{i-1}}$	dimensional quantity
coefficient of variation in %	V	$V = \frac{\sigma}{\bar{x}} \cdot 100$	non-dimensional quantity
χ^2 value	χ^2	$\chi^2 = \sum_{j=1}^{m} \frac{\theta_{j,i} - E_j}{E_j}$	θ = measured value E = set-point value m = number of components j = component number i = sample number (assessment on a multiple component basis, high analytical effort)

the quantity in question, i.e. separate dosing and weighing systems with graded degrees of accuracy must be used for large, medium and small batch components. Repeat accuracy plays a key role along with absolute accuracy.

- Quality of mixing: It is necessary to distinguish between two things, namely

  a) homogeneity of the mix achieved at the end of the mixing cycle, i.e. the variance in the shares by weight in a set of samples taken either at the end of the mixing cycle from various points of the mixer or at short intervals during discharge from a point downstream from the mixer; and

  b) the uniformity of mixing quality, i.e. the reproducibility of the attained degree of homogeneity from one mixture to the next.

- Segregation during further conveyance of the batch after the mixer: This point is often overlooked in discussions of the attainable quality of mixing. Yet much of the homogeneity produced in the mixer can be lost again as the result of a poorly arranged transport route, e.g. with numerous transfer points from one conveyor unit to another or with excessively high falls at the transfer points, through the use of unsuitable vibrating conveyors, and through many other factors [19 to 21]. This applies in particular to dry batches, which are far more inclined to segregate than mixtures with an adequate amount of moisture. In this connection attention is drawn to the newly discussed possibility of preheating the batch, in which case the finish-mixed batch is heated directly in front of the glass furnace using available waste heat in order to save valuable primary energy in the actual melting operation. In this process, too, care must be taken to prevent additional segregation as the mixture passes through the heat exchanger.

The melting unit itself does not affect the homogeneity of the glass batch. It does, however, have a considerable influence on the homogeneity of the finished glass since many a case of nonhomogeneity can still be compensated by the various movements of the melt (convection currents, etc.). This additional mixing effect depends greatly on the type of melting unit used and the degree of its capacity utilization.

4. Efficiency of modern batch processing systems

4.1. Homogeneity

In any discussion of "mixing quality" or of the homogeneity of mixtures it is essential to clearly define the terms used and to specify in full the respective boundary conditions in order to have a basis for drawing comparisons. Some highly differentiated statistical variables are used for assessment purposes (table 2). As is the case with any statement based on statistics, conclusions are permissible only from a sufficiently large number of samples. It is recommended, therefore, to take a set of approximately 10 to 20 samples per measurement. First step is to calculate the arithmetic mean from the samples. Comparing it with the formulation set-point value throws light on the dosing accuracy but not on the mixing quality. A further variable is the so-called variance or scatter. The root of this value is the standard deviation σ. It states that given a Gaussian distribution of measurement values, 68.3 % of the values lie in the $\bar{x} \pm \sigma$ range and 99.73 % in the $\bar{x} \pm 3\sigma$ range. By reducing the divisor to $i-1$, the calculated S^2 and σ values increase disproportionately to the decreasing number of samples. Both variance and the standard deviation are dimensional quantities, and they are dependent in their absolute numerical values on the value of the specific measured variable. Dividing the standard deviation by the mean value and multiplying by 100 produces the non-dimensional coefficient of variation V in %, whose value is independent of the numerical value of the measured variables. Other occasionally used variables such as "mixing quality", "mixer efficiency", "segregation index", "variation range", etc. are calculated using sometimes varying formulae; the results they provide are often misleading or not informative and should not be used.

When checking mixer results it is necessary to observe a number of points that can have a sometimes appreciable effect on the analysis findings:

- Sampling: Samples can be taken straight from the mixer, from the descending current of material after it is discharged from the mixer, or from a belt. Care must be taken to draw the samples from the centre of the material and not, for example, to simply scoop off from the top of the belt. When taking samples from the stationary mixer, allowance should be made for the fact that segregation may already have occurred again since the mixer was switched off.
- Sample size: This can vary greatly with the method of analysis to be used. Typical sizes are, for example, less than 1 cm^3 (with physicochemical measuring methods) and up to approximately 200 cm^3 (e.g. when determining water-soluble or acid-insoluble contents). Sample splitting should be avoided where possible at all. If unavoidable it must certainly be conducted in accordance with the proven rules of technology (e.g. "coning and quartering") or by using appropriate instruments (e.g. a riffler) in order to obtain a sample fraction that is similar in its properties as closely as possible to the whole sample [22].
- Number of samples: As already mentioned, no less than 10

Table 3. Some typical performance data of countercurrent intensive mixers for glass batch processing

type series	type designation	nominal volume in l	throughput rate (approx. t/h)	power rating in kw	number of tools rotor	star
Type R	R 08	75	1.12	5	1	=
	R 09	150	2.25	9	1	–
	R 11	250	3.75	13	1	–
	RV 11	350	5.25	17	1	–
	R 15	500	7.5	19	1	–
	RV 15	750	11.2	26	1	–
	R 19	1125	16.8	37	1	–
	RV 19	1500	22.5	45	1	–
	R 23	2250	33.7	82	1	–
	RV 23	3000	45.0	92	1	–
Type D	DE 22	1500	22.5	37 (+ 30)	0 to 1	1
	DEV 22	2250	33.7	55 (+ 45)	0 to 1	1
	DE 29	3000	45.0	44 (+ 45)	0 to 1	1
	DZ 29	3000	45.0	66 (+ 45)	0 to 1	2
	DEV 29	4000	60.0	112	1	1
	DZV 29	4000	60.0	104 (+ 45)	0 to 1	2
	DW 31/7	7000	100.0	300	2	–

individual samples should be taken. On the other hand, it is not customary to take more than 20 samples due to the analytical effort involved.

– Analysis method: It is only logical that the analysis result for even a perfect mixture cannot be better than that permitted by the accuracy of the analysis method used. The following analytical methods are among those applied to assess glass batches [10, 23, 24]:

a) determination of the water-soluble content (particularly for alkaline compounds, such as soda ash, potash, etc.) through extraction by boiling with water, combined if necessary with titration of the (base) solution obtained;

b) determination of the acid-insoluble content through extraction by boiling with semi-concentrated hydrochloric acid;

c) physicochemical methods, such as luminescence or conductivity measurement, X-ray fluorescence analysis, etc.

The attainable coefficient of variation is determined to a considerable extent by the choice of measurement variable to be analyzed and by the method of analysis. With careful determination of the water-soluble content, which lies e.g. at 16 wt%, using a well adjusted mixing unit, it is possible to obtain a coefficient of variation of less than 0.5 %. Even a slight deterioration of the initial conditions, e.g. partial drying out of the batch, negative conditions when emptying the mixer, or a less than optimum sampling routine, can result in an increase of the coefficient to, for example, 0.7 to 1 %. On the other hand, when low-share batch components are determined, the typical coefficients of variation even under optimum conditions are usually distinctly higher. For example, a coefficient of variation of approximately 2.5 % was determined for 0.1 % ZnO added to a mixer with a useful capacity of 3000 l after a mixing period of 150 s (determined by the X-ray fluorescence method). In a similar test a coefficient of variation of approximately 3 % was determined by photometric analysis for 50 ppm CoO added to a 3000 l mixer. For a comparative assessment of attained or attainable mixer results it is vital, therefore, for the measured components, the number of samples and the method of analysis to be specified along with the actual value (e.g. the coefficient of variation).

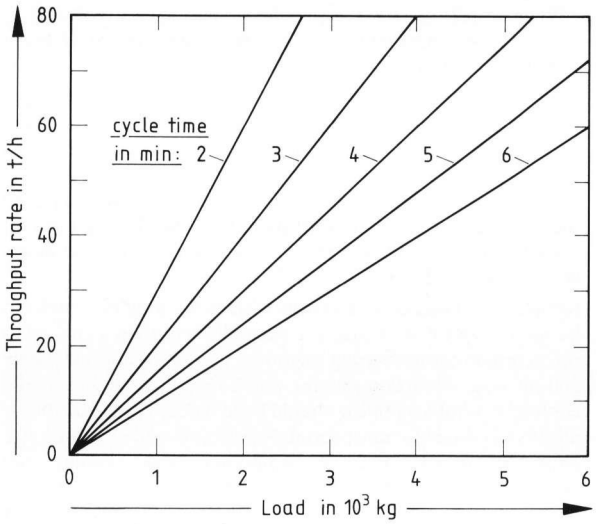

Figure 7. Throughput rates as a function of mixer size and mixing time.

4.2. Throughput rate and availability

Generally it is possible to quote only typical values for the throughput rates attainable with a particular system because in some cases they can fluctuate severely depending on the peripheral equipment, the quality of raw materials, the required quality of finished glass, etc.

Table 3 lists the series of available countercurrent intensive mixers together with their typical power ratings and normally attainable throughput rates. The attainable throughput rate is conditional not only on the size of mixer, of course, but also on the required intensity of mixing. For each application it is necessary to check, therefore, whether a mixing cycle of, for example, 2 min produces the required homogeneity or whether longer mixing cycles of up to 5 min are necessary. As can be seen in figure 7, very different sizes of mixer may be needed for a specific throughput rate depending on the permissible batch time. Batch times, it should be noted, consist of the pure mixing time and the peripheral times for loading and emptying the mixer. Depending on the size of mixer, up to around 1 min must be allowed for these peripheral times.

An availability factor of approximately 95 % can be assumed for a batch processing system when properly maintained. It may be necessary, however, depending on the type of production, to supply the glass furnace with batches around the clock with 100 % availability. In such cases either an appropriately large intermediate hopper (e.g. for 36 to 48 h melting capacity) is installed between the mixing plant and the furnace feed hopper in order to uphold the supply of batch material during scheduled maintenance

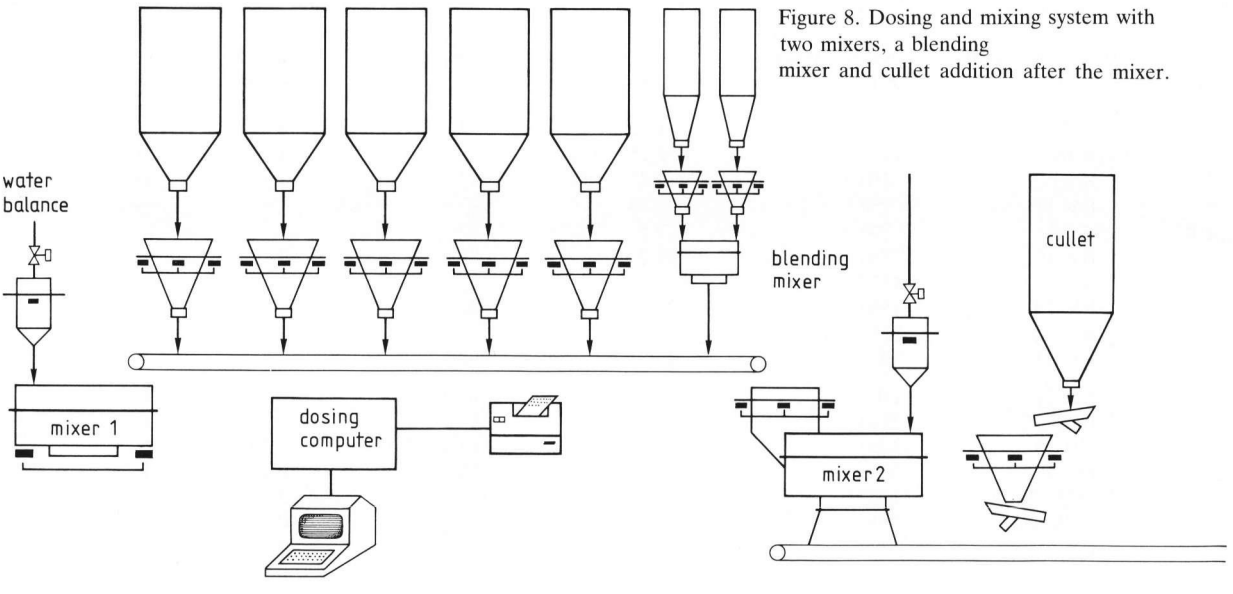

Figure 8. Dosing and mixing system with two mixers, a blending mixer and cullet addition after the mixer.

work on the processing plant, or provision is made for two parallel processing lines, each of which is able to work at the full capacity required (figure 8).

4.3. Wear

Stoppages are necessary in particular for the replacement of wearing parts. Those parts affected by the greatest wear are the rotor tool beaters and the wearing edges of the scraper blades. Their lifetime depends heavily on the raw materials used and on the intensity of processing. As a rule the wearing parts feature an anti-wear armouring. Replacement intervals normally lie, for example, at between 4 and 6 months, but considerably longer and shorter maintenance intervals (especially when cullet is added to the mixer) are also possible.

In this connection it should be stressed that wear is normally so slight as to have no notable negative effect on the glass batch, e.g. through contamination with iron or any other alloy constituents. Among other things the amount of contamination is determined by the surface area in contact with the product and the number of mixing tools. A ring trough mixer, for example, has over 50 % more wall surface area and several times more mixing tools than a countercurrent intensive mixer with the same useful volume.

The time which is necessary for maintenance work can be kept short when there is a good access to the inside of the mixer and when the tools are designed to allow an easy replacement.

5. Pelletizing of glass batches

There can be considerable advantages to compacting the glass batch. They include, for example, preventing the formation of dust, eliminating segregation and hence improving transportability and storability, enhancing melting characteristics and reducing the consumption of melting energy [25–31]. For this reason detailed investigations of the possibilities of batch pelletizing and briquetting have been carried out. Briquetting shows the disadvantage of higher wear and the product contamination it causes. This risk does not exist when pelletizing on a pelletizing pan or in a pelletizing drum. Pelletizing will only succeed, however, if the individual components are present in a sufficient degree of fineness, which with most of the customary batches is not the case. Figure 9 compares the typical grain size distributions of a number of important glass raw materials with the particle size distribution of a variety of cement grades or similar products. The fineness of these materials represents just about the minimum necessary for a smooth pelletizing process. As can be seen, most glass raw materials are far coarser.

To pelletize glass batches it is necessary, therefore, to use finer raw materials, e.g. by replacing the silica sand with finer sand (< 0.15 mm) or at least part of it with quartz powder, by replacing limestone powder with calcium hydrate or burnt lime, by using finely dispersed minium instead of lead oxide melt granules, etc. Pelletizing also requires around 12 to 17 % and more water addition, depending on the batch in question. This calls in turn for additional drying, which has a distinctly negative effect on the energy balance and on the economic efficiency, even if waste heat can be used for the drying and valuable primary energy can be saved during the melting process due to the pelletizing. It should also be noted that a pelletizing plant always needs a certain amount of supervision and monitoring, unlike a fully automatic batch processing system.

The advantages of pelletizing can well justify the extra effort, however, particularly in centralized batch processing systems for various end-users (with usually smaller rates of throughput) or in the case of special glass grades (e.g. with high contents of PbO and other toxic components). A number of plants are known where pelletizing takes place not only for their own use but also for external customers on a contract basis. A melting energy saving of 10 % and more has been reported when using pelletized batches as opposed to normal batches in glassworks. The use of caustic soda instead of soda ash for the pelletizing has also been investigated.

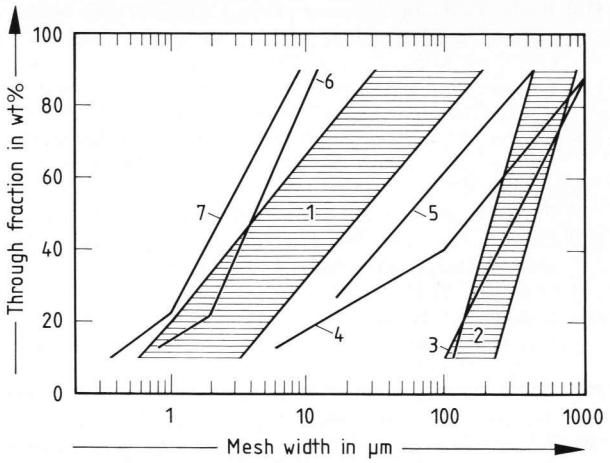

Figure 9. Particle size distribution curves of a number of typical glass raw materials compared with cement (no. 1: cement or similar materials, no. 2: sand, no. 3: soda ash, no. 4: dolomite, no. 5: lime, no. 6: minium, no. 7: limestone powder).

6. Summary

Modern glass batch processing systems are capable of supplying the glass furnace with a batch of virtually any required quality, and they do so with a high degree of reliability in practically fully automatic mode. For an optimum quality of processing it is essential to use an accordingly efficient dosing and weighing system, high-performance mixers, and modern electronics for the control system.

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Scientific/Technical News

53rd Conference on Glass Problems

In 1992, the Conference on Glass Problems was organized by the Ohio State University, Columbus OH (USA) on November 17 and 18. The topics attracted nearly 600 attendees, mainly from American glass companies, suppliers of raw materials and suppliers of glass furnace parts. The two-day meeting was held in a very friendly informal atmosphere.

The topics of this conference covered a wide field of practical glass-relating aspects. About half of the 24 presented papers dealt with environmental or health aspects of glass production and glass fibre applications. Disposal problems and solutions for recovery of industrial waste were topics on the forefront. Among these papers were three European and one Asiatic contribution. One of the underlying messages of most papers was today's requirement of high-quality products by the international market which challenges the glass industry to optimize or change the traditional manufacturing processes.

The very first paper illustrated the importance of fundamental research at universities for the glass industry. One of the historic examples mentioned in this presentation was the foundation of the Schott and Carl Zeiss companies, the first glassworks to produce advanced high-quality optical products using fundamental approaches. Manufacturing management and process control for quality improvement during glass production were roughly presented in the following papers. The application, organization and constraints of Computer Integrated Manufacturing were outlined. However, the possibilities to apply this method in the glass industry appeared to be not very clear. Overviews of glass production in Europe and the industrial Asiatic countries showed the position of the US glass industry in the world. The global market for float glass, container glass and fibre glass shows a slow but steady growth. Remarkable is the advance of glass production in South Korea in the last decade, as one of the papers demonstrated. The tough international competition on the world market for high-quality glass products was very clearly shown through the presented figures.

Process and production management involving ISO 9000 and the installation of batch house control systems and feeder temperature control are examples showing possible ways of production rationalization. The experiences with in-process replacement of a sophisticated PLC (Programmable Logic Control)-based system for the batch house involving weighing, loading and mixing were presented in a paper showing a practical solution for complex changes in an industrial process without disturbing the continuous production. New developments in regenerator construction, checker-brick materials as alternatives for chromium-containing refractories and practical hints to stabilize checker works and to reduce fouling or plugging were presented in another paper. The economics of regenerators dependent on size, design and achievable air-preheat temperatures were discussed for float-glass furnaces. Glass tank modelling as a tool to optimize the performance of melting, homogenizing and fining, was demonstrated by one of the European papers. The influence of pull rate, forced bubbling, redox state of the batch and fuel distribution on glass quality was analyzed using mathematical modelling in combination with submodels describing melting kinetics and fining.

The advance of oxygen-fuel firing for melting appears to be an irreversible process for the North American glass companies. Container, special glass and fibre glass producers convert their furnaces more and more into all oxy-fuel fired melters as several papers showed. The most important mainsprings for these conversions are an increase in energy efficiency and a reduction in nitrogen oxide emissions. Furthermore, one example of the performance of an oxy-fuel fired furnace showed improvements in batch blanket consistency, which results in extra benefits for the product quality and process stability. The importance of a well-designed and optimum-positioned burner to obtain low NO_x levels and high heat transfer rates to the molten glass was explained in another paper also given by a company for industrial gases. Other considerations like the influence of oxy-fuel firing on particulate emissions, process stability, furnace lifetime and flexibility were also discussed. Oxy-fuel firing on a recuperative