

## Glass conditioning by viscosity control<sup>1)</sup>

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During the forming process of a glass melt the viscosity is the dominant process parameter. Up to now in the industrial container glass production only temperature-controlled systems have been used. With these control elements only thermally induced variations of the viscosity are visible. Variations in the composition, the redox state, the water and the SO<sub>3</sub> content in the melting process cause a shift in the viscosity. Up to now these changes have not been detectable and therefore, it has not been possible to compensate them. A measuring device for the continuous determination of the viscosity in the glass was developed and tested for several months in a container glass plant. All measured variations of the viscosity can now be corrected by the existing control elements for the thermally controlled glass conditioning. Dependent on the position of the viscosimeter in the feeder channel, a feedforward or feedback controlling concept is practicable.

### Viskositätsgesteuerte Glaskonditionierung

Beim Formgebungsprozeß einer Schmelze ist die Viskosität des Glaspostens die physikalisch dominierende Prozeßgröße. In der industriellen Behälterglasherstellung wird bisher im Rahmen der Meß- und Regelungstechnik nur versucht, eine konstante Temperatur der Schmelze zu gewährleisten. Damit können aber nur thermisch induzierte Viskositätsveränderungen erfaßt werden. Die über Veränderungen im Bruttochemismus, im Redoxzustand, im Wasser- und SO<sub>3</sub>-Gehalt der Schmelze bewirkten Viskositätsverschiebungen sind nicht erkennbar und werden damit nicht ausgeglichen. Ein Aufbau zur kontinuierlichen Viskositätsmessung im Glasbad wurde entwickelt und kam in einer Hohlglasshütte für mehrere Monate zum Einsatz. Alle gemessenen Viskositätsabweichungen können damit über die vorhandenen Einrichtungen zur temperaturgesteuerten Glaskonditionierung thermisch korrigiert werden. Abhängig von der Einbaustelle im Feederkanal ist ein vorausschauendes oder ein rückwärts ausgerichtetes Regelungskonzept möglich.

## 1. Introduction

During the forming process of a glass melt the viscosity is the dominant process parameter. The present situation in the glass producing process is that the controlling elements guarantee only a constant temperature control of the fusion. With this controlling strategy for constant process conditions only thermally induced variations of the viscosity are visible. But in practice several parameters additionally have an influence on the variations of the viscosity.

## 2. Influences on the viscosity

Beside the temperature the variations in the composition, the redox state, the water and the SO<sub>3</sub> content in the melt cause a change of the viscosity. Scholze and

Dietzel [1] estimated the water content to be in the range of 0.007 to 0.53 wt% in different glass compositions by infrared spectroscopy. The influences of small variations in the water content in a soda–lime–silica glass on the workability were reported by Scholze [2]. The reduction from 0.03 to 0.01 wt% H<sub>2</sub>O in the same glass caused a difference in the transformation temperature of 18 K. Dreier [3] showed that the water content of a soda–lime–silica glass fused in the container glass production by oil firing is in a range of 0.03 up to 0.04 wt%. Variations up to 20 wt% are possible and induce a similar shifting of the viscosity of 2 K. Übel [4] confirmed the decreasing effect of the water content in the glass melt by laboratory tests and some further measurements in a forehearth in a container glass plant. Hessenkemper and Brückner [5] showed that the viscosity of a soda–lime–silica glass is influenced by the Fe<sup>2+</sup> concentration, the Fe<sup>2+</sup>/Fe<sup>3+</sup> ratio and the total iron content. Brown [6] compared the different influences of water in air-fuel and oxy-fuel melts on melting process and workability. The variations of the water content result from variable moisture of recycled cullet,

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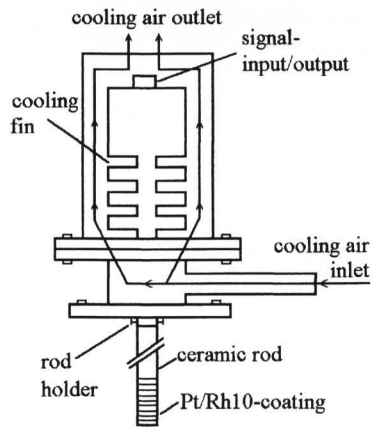


Figure 1. Schematic set-up of the viscosity measuring head.

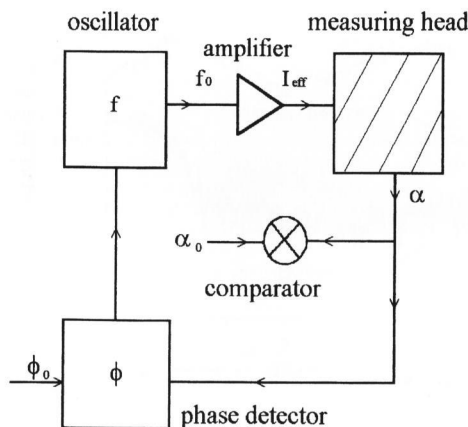


Figure 2. Schematic figure of the viscosity measuring circuit.

input of hydroxidic raw materials (filter dust), variations in dwell time and bath flows, atmosphere above the melt and different amounts of crystal water in soda.

### 3. Viscosimeter

The used viscosimeter was developed in Portugal within the scope of an Esprit program. The principle of operation is vibrational. A ceramic rod mechanically connected to the vibrating shaft of a head sensor is continuously controlled in amplitude and frequency (figure 1). The resonance frequency and amplitude of ultrasonic vibration are controlled automatically. When the

viscosity of the molten glass increases (decreases), the amplitude of vibration has a tendency to decrease (increase) and the feedback current supplied by an electronic unit automatically increases (decreases) controlling the amplitude of vibration (figure 2). A linear relation between viscosity and feedback current is obtained and the output 4 to 20 mA can be used for indication, control or recording purposes. The technical characteristics of the viscosimeter are listed in table 1.

The whole measuring head is fixed to an electronically controlled linear slit to vary the immersion depth of the measuring rod in the glass melt. The present prototype is controlled by a PC with a program for the movement of the measuring head and for the calculation of a corrected viscosity signal.

### 4. Methodical problems and modifications of the viscosimeter

At the beginning of the test period in the feeder channel several problems had to be solved. An enlarged holding device for the measuring head had to be constructed. The insulation against heat radiation and the cooling air supply were improved.

The first used mullite rod was corroded in a few hours. An alumina rod resisted corrosion by the container glass melt for several weeks, but the surface reduction of the rod was too high and caused a drift in the viscosity signal.

A solution is to take a mullite rod which is coated by a platinum/rhodium layer. The resistance to the glass melt is very good and if there is a defect in the layer the corrosion rate of the mullite rod is so high that the drifting of the viscosity signal is obvious.

On the original measuring equipment only the viscosity signal is recorded as a function of time. In practice this integral viscosity signal is insufficient for the use as a control input signal for the glass conditioning.

Variations in the glass level caused a varied contact area between glass and measuring rod. The viscosity signal is proportional to the contact area between glass melt and measuring rod. An additional glass level measuring sensor beside the viscosity measuring head is indispensable.

To differentiate between a purely thermally induced change of the viscosity and a change caused by non-thermal sources, a quintuple thermocouple is installed

Table 1. Technical characteristics of the viscosimeter

	related to 120 Pa s and 1200 °C for a container glass composition	
	viscosity	temperature equivalent
viscosity range (measured)	50 to 500 Pa s	
resolution	± 0.5 %	± 0.5 K
repeatability	± 0.25 %	± 0.25 K
accuracy	± 2.5 %	± 2.5 K

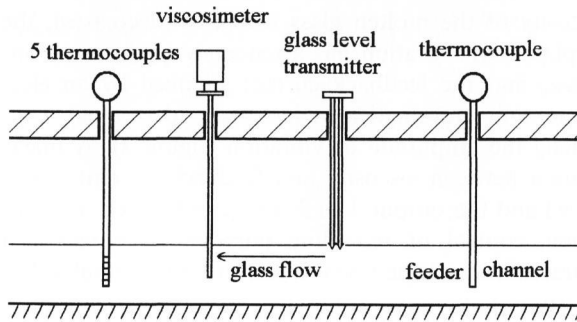


Figure 3. Layout of the measuring devices in the feeder channel.

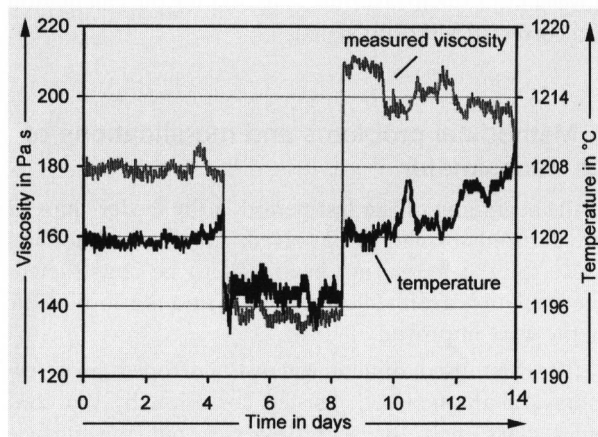


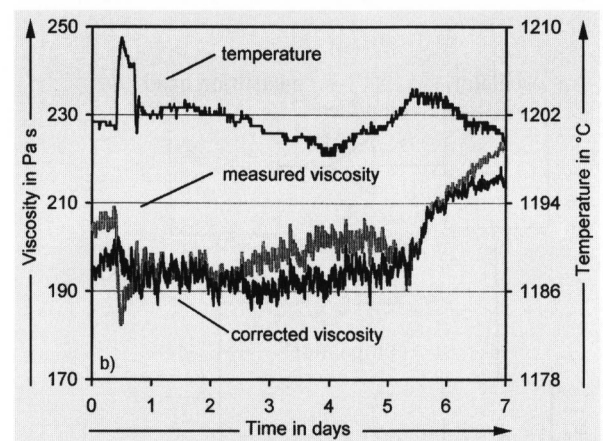
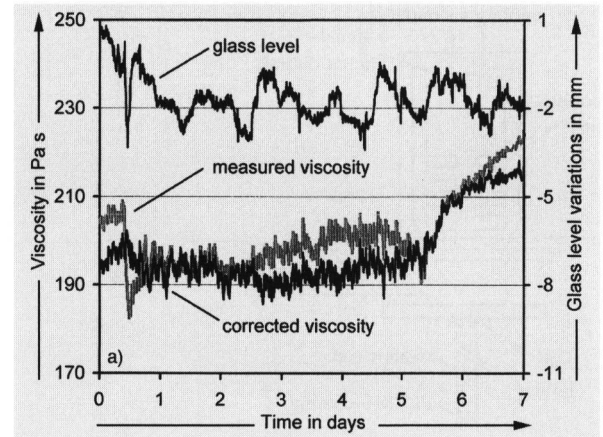
Figure 4. Measured viscosity and averaged temperature presented over a 14 day interval in amber glass.

near by the viscosimeter (figure 3). In relation to the immersion depth of the rod in the glass melt the corresponding number of thermocouples is used to get an averaged temperature. The thermally caused change of the viscosity can be calculated by the VFT function as the change of temperature is known.

The viscosimeter is not calibrated because the absolute viscosity is not essential. The relative change of the viscosity corrected to glass level variations, the immersion depth of the rod in the glass and the thermally reduced viscosity value is of interest for the control of glass conditioning.

## 5. Results of viscosity measurements

Figure 4 shows the measured viscosity signal and the averaged temperature over a 14 day interval in amber glass. After the fourth day there was a job change combined with a new pull rate and glass temperature. After eight days there was a second job change. The viscosity signal correlates with the temperature signal, but there are some remarkable variations in the viscosity signal without a temperature change. In spite of the reduced temperature after the first job change, the viscosity signal decreases. After the second job change the temperature was set to the same value as four days before,

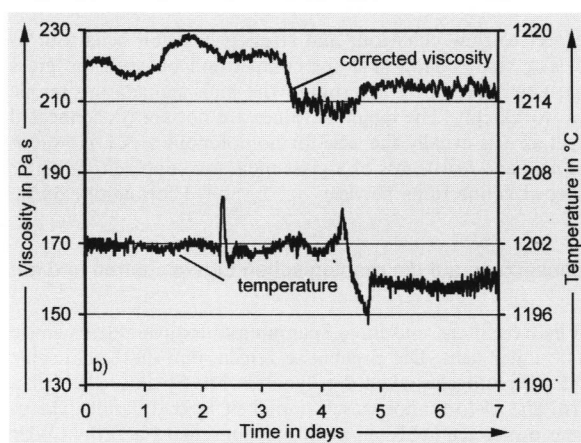
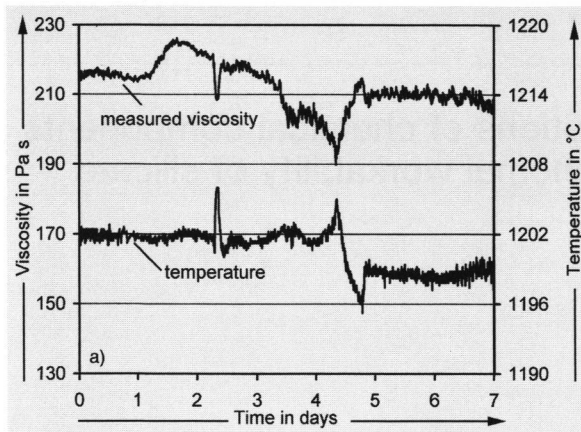


Figures 5a and b. Comparison of measured and corrected viscosity shown over a 7 day interval (after the 5th day alkali reduction by 0.16%) in amber glass; a) with glass level variations, b) with averaged temperature.

but the viscosity signal increased to a higher value. The noncorrelation between viscosity and temperature is caused by greater glass level variations because of strong changes in the pull rates.

In figure 5a the glass level variations, the measured and corrected viscosity over a 7 day interval are shown. After the first half day of the interval there is a job change with an increased pull rate from 110 to 132 t/d. The decrease of the glass level of more than 3 mm causes a significant change in the measured viscosity signal. The corrected viscosity signal qualifies the measured signal. In figure 5b the averaged temperature, the measured and corrected viscosity are shown for the same time period as in figure 5a. After the fifth day the  $R_2O$  percentage of the batch composition was reduced. After two days the  $R_2O$  percentage was 0.16% less. The corrected viscosity obviously indicates the increase of the viscosity.

In figure 6a the measured viscosity and temperature are shown over a 7 day interval in amber glass. After the third day in a time interval of about 8 h the addition of recycled flint glass cullet increased from 0 to 7% of the batch composition with 60% cullet and 40% raw materials. In figure 6b the corrected viscosity curve indicates



Figures 6a and b. Comparison of average temperature shown over a 7 day interval (after the 3rd day flint cullet addition of 7%) in amber glass; a) with measured viscosity, b) with corrected viscosity.

unmistakably the decreasing viscosity caused by the addition of flint glass cullet. The temperature equivalent to this decreasing viscosity is 5 K.

The possibility to measure at different positions in the glass bath up to now has shown insufficient results. The separation between the viscosity and the rest signal

is limited. The optimal measuring conditions are found at a stationary rod position about 3 cm above the forehearth bottom. The viscosity signal represents an integral viscosity over the glass bath depth. The present forehearth control systems can control only the whole forehearth. It is impossible to control the viscosity at different glass levels separately.

## 6. Summary and outlook

It is shown that an on-line determination of the glass viscosity in an industrial process is practicable with an equivalent precision compared to the present temperature measurements. Additionally, all variations of the viscosity not only those caused by temperature changes are visible. This present information gap for the complete control of the glass conditioning can be closed.

The next step in the further development will be the junction of the new sensor to the existing forehearth process control system. The viscosity measurement will be the master value for the existing control elements for the thermally controlled glass conditioning.

## 7. References

- [1] Scholze, H.; Dietzel, A.: Untersuchungen über den Wassergehalt von Gläsern durch Bestimmung der Ultrarot-Absorption im Bereich von 1 bis 5  $\mu$ . *Glastech. Ber.* **28** (1955) no. 10, p. 375–380.
- [2] Merker, L.; Scholze, H.: Der Einfluß des Wassergehaltes von Silikatgläsern auf ihr Transformations- und Erweichungsverhalten. *Glastech. Ber.* **35** (1962) no. 1, p. 37–43.
- [3] Dreier, R.: Untersuchungen zum Wassergehalt und Redoxzustand industrieller Hohlgläser. Institut für Nichtmetallische-Anorganische Werkstoffe, Technische Universität Berlin, Diplomarbeit 1994.
- [4] Übel, M.: In-situ-Viskositätsmessungen im Feeder einer Weiß-Hohlglaswanne, ergänzt durch Laboruntersuchungen. Institut für Nichtmetallische-Anorganische Werkstoffe, Technische Universität Berlin, Diplomarbeit 1995.
- [5] Hessenkemper, H.; Brückner, R.: Influence of redox conditions on the isothermal workability of glass melts. *Glastech. Ber.* **63** (1990) no. 9, p. 244–254.
- [6] Brown, J. T.: Oxy-fuel – beyond melting. *Glass Technol.* **36** (1995) no. 4, p. 103–106.

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