Simulation Analysis of the Homogenisation Process in Glass Melting through Agitation and Diffusion Processes

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By

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Homogenisation in glass melts was investigated in a simulation analysis in whic ı the behaviour of one-dimensional models was calculated with a computer, the concentration profile being simulated by a series of numerical values. The roles of diffusion and agitation in the homogenistaion process in glass melts were discussed. It can be concluded that there is an appropriate combination of diffusion and agitation processes which will result in a desired homogenisation when the levels of intensity and scale of heterogeneity in the glass melts and in finished product are given.

Introduction

Heterogeneous glass has different concentrations of a component from point to point. It is desired to reduce the uneveness of the concentration which affects the physical properties of finished products. The equalization of the concentration, that is, the homogenisation process in glass melt is carried out by diffusion and agitation. This paper gives some results obtained by a simiulation experiment in which the behaviour of one-dimensional models was calculated with a computer.

Heterogeneity of glass is characterized by two parameters, i.e., intensity and

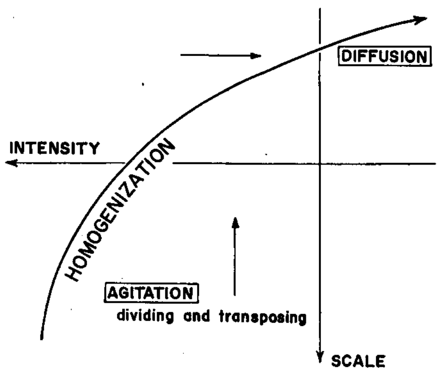

Fig. 1. Diffusion and Agitation in Homogenisation Process.

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scale of heterogeneity. The intensity of heterogeneity, such as variance of the distribution, represents the differences between the concentrations at points. The scale of heterogeneity represents the distances between points. The homogenisation of a glass melt can be regarded as reduction of the intensity by diffusion, and as reduction of the scale of heterogeneity by agitation as shown in Fig. 1. The roles of diffusion and agitation in the homogenisation process in glass melts will be discussed.

Simulation Analysis of the Homogenisation Process in Glass Melting

The examples of the one-dimensional models of concentration distribution of a component in glass melt are given in Fig. 2. They were made by the synthesis of series of random numbers. The variances have the same value, but the scale of heterogeneity of lower example is greater than upper ones.

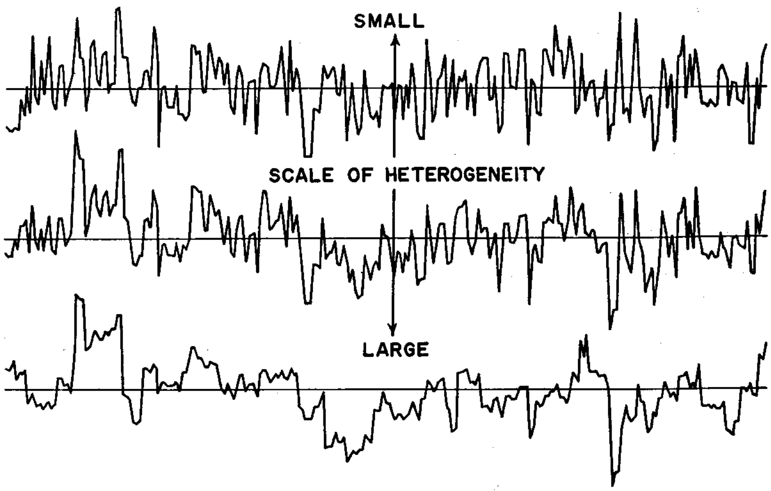

Fig. 2. One-dimensional Models of Concentration Distribution.

Fig. 3 indicates depression of the intensity of heterogeneity by diffusion. The diffusion process was simulated by Schmidt's method, that is, the set of operations to find the averages of adjoining values. If we assume that the length of the model is 10 centimeters and the diffusion coefficient is 10^{-7} cm^2/sec, then the time interval required from curve I to curve II is about one hour, and from curve II to curve III requires three hours. The variance S^2 was reduced from 1.00 to 0.71, and then to 0.54. The heterogeneities of smaller scale were rapidly reduced by diffusion, but the heterogeneities of larger scale still remained.

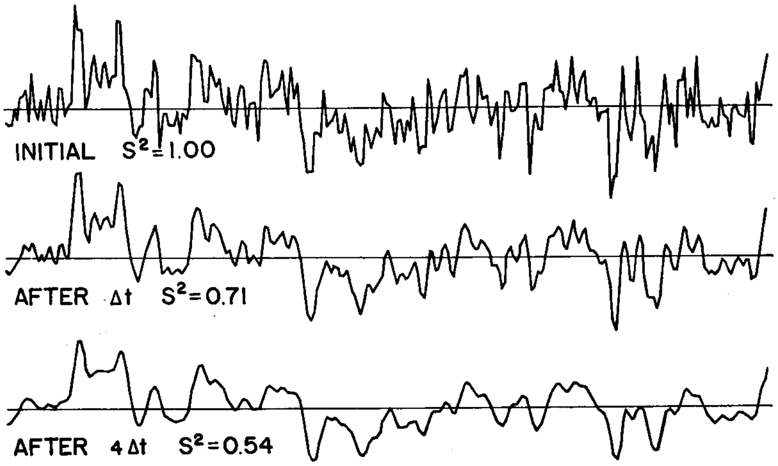

Fig. 3. Depression of Intensity of Heterogeneity by Diffusion.

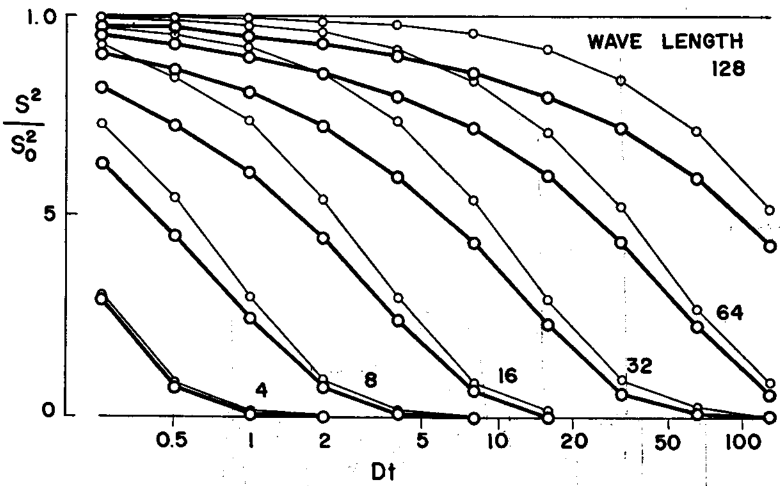

Fig. 4. Reduction of Variance S^2 by Diffusion Process.

Fig. 4 shows the reduction of the variance S^2 by diffusion process as a function of the time for the simple and regular distributions with various wave lengths. The abscissa indicates the diffusion time ratio, Dt. The thick lines are for rectangular distributions and the thin lines are for the sinusoidal distributions. The larger the scale of heterogeneity is, the more the time is required to reduce the variance.

Reducing of variance for complex types of distribution is shown in Fig. 5. Curve A, E and H represent the reducing of variance for the types of distribution

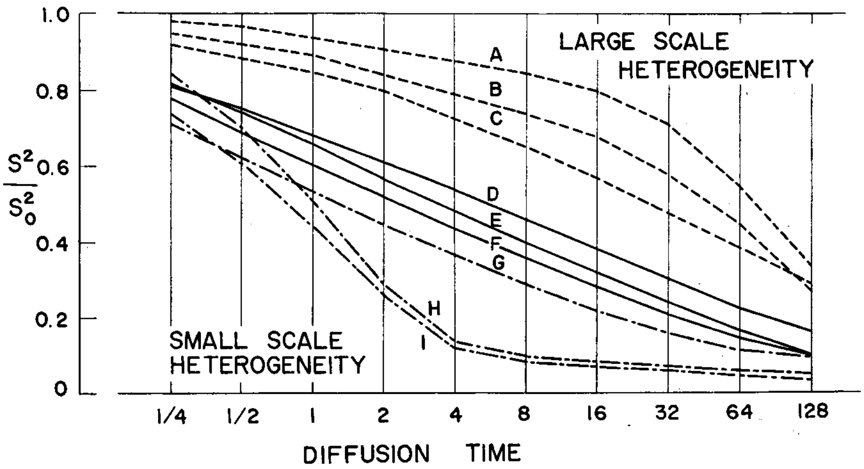

Fig. 5. Reducing of Variance for Complex Types of Distribution.

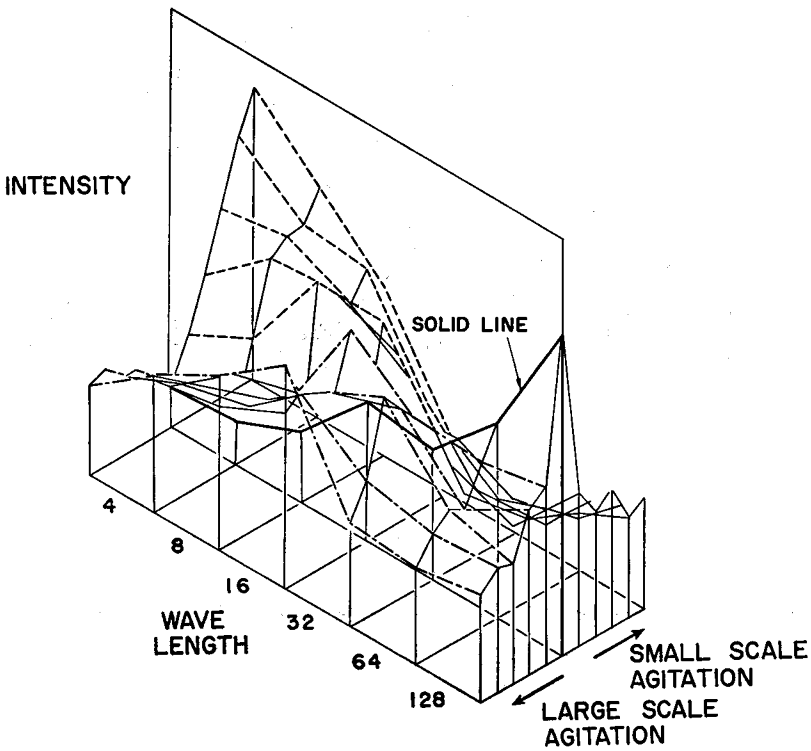

Fig. 6. Effect of Agitation on Large Scale Heterogeneity Represented by Use of Power Spectrum.

made by superposition of sinusoidal waves. Curve B, F and I correspond to the types of distribution made up by superposition of rectangular waves. Curve C, D and G represent the random distributions. Solid lines, dotted lines and broken lines represent the medium scale of heterogeneity, the larger scale of heterogeneity and the smaller ones respectively.

Agitation process was simulated by the division of the models into parts and the transposition of the parts. In other words, this is simulated by cuts and rearrangement as described by Dr. Cooper (1966)[1]. Repeating the agitation, the scale of the heterogeneity is reduced, but the intensity remains unchanged.

The effect of agitation is clearly represented by the use of power spectrum of the types of distribution in Fig. 6. The solid line in the figure represents the initial power spectrum of the distribution with large scale of heterogeneity. By agitation, the spectrum shifts to the shorter wave length. This agitation effect is more striking at the smaller scale of agitation.

As shown in Fig. 7, the agitation with a large scale have little effect on the

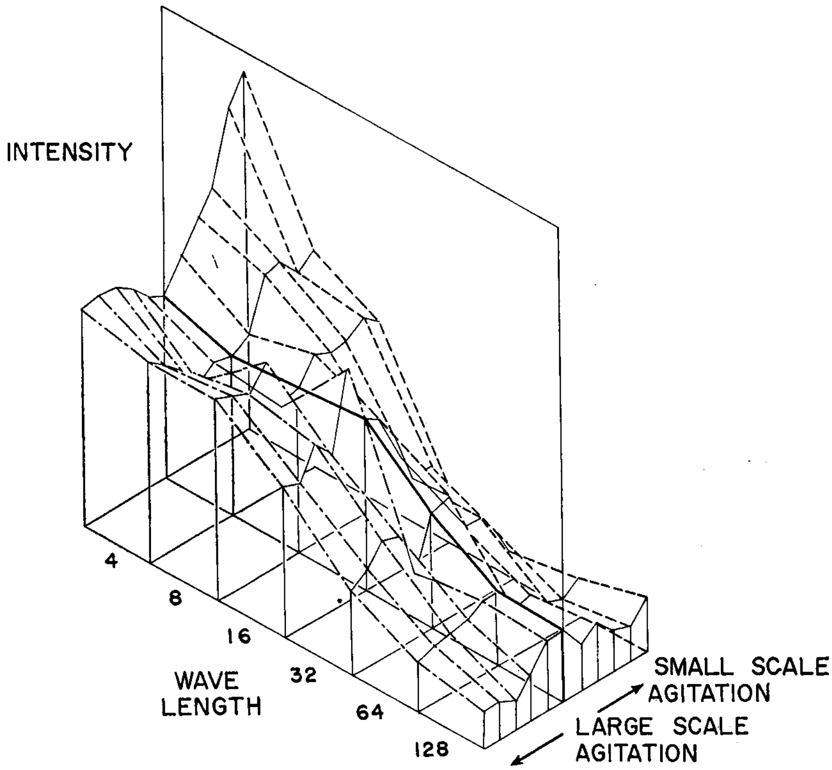

Fig. 7. Effect of Agitation on Small Scale Heterogeneity Represented by Use of Power Spectrum.

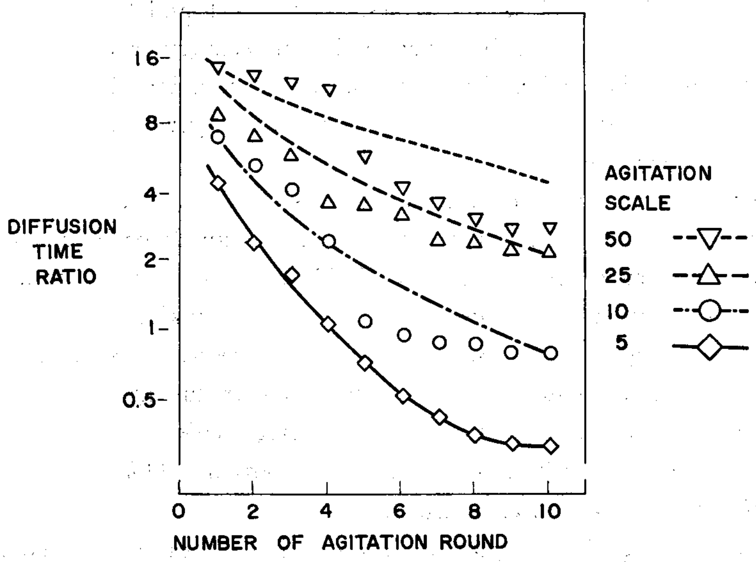

Fig. 8. Diffusion Time Required to Reduce Variance by 63% through Diffusion after a Repeating of Agitations.

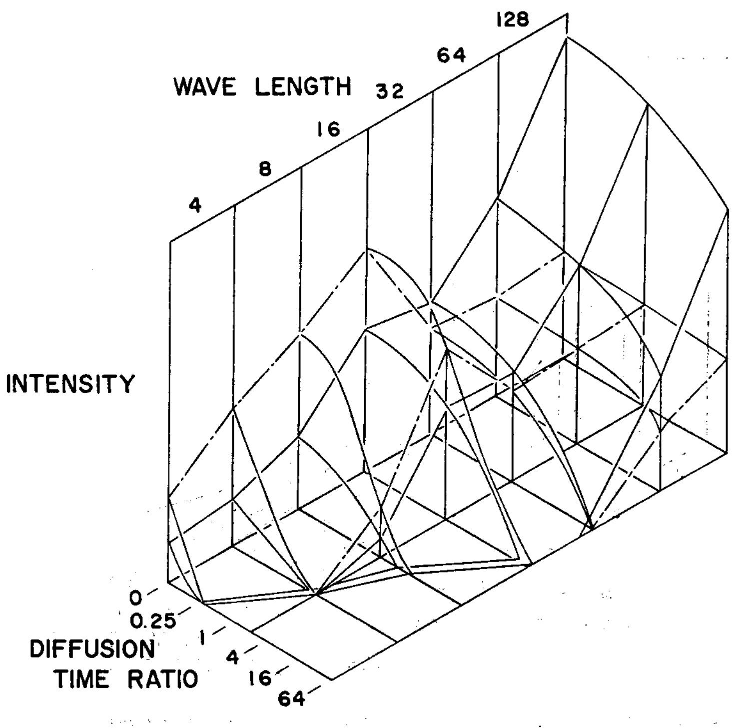

Fig. 9. Change in Power Spectrum (1).

distribution with a small scale of heterogeneity. As agitation reduces the scale of heterogeneity, the concentration gradients are increased, so that the diffusion is accelerated by agitation.

Reducing of the variances of random distribution with large scale of heterogeneity through diffusion after some repeating of agitation, particularly with small scale, are effective to accelerate the reducing of the intensity of heterogeneity. For the distribution with small scale of heterogeneity, agitations, particularly with large scale, are not so effective to accelerate the homogenisation by diffusion.

The time required to reduce the variance by 63% $(=1-e^{-1})$ through diffusion after a repeating of agitations is plotted against the number of repeating of agitations in Fig. 8. The more agitation is repeated, the less diffusion time is required. At a same diffusion time the number of repeatings was proportional to the scale of agitation.

Fig. 9 shows a change in power spectrum through diffusion for a large scale heterogeneity (solid lines), and a change in power spectrum through diffusion following a repetition of agitation with large scale (broken lines).

The dotted lines in Fig. 10 show a change in power spectrum through diffusion

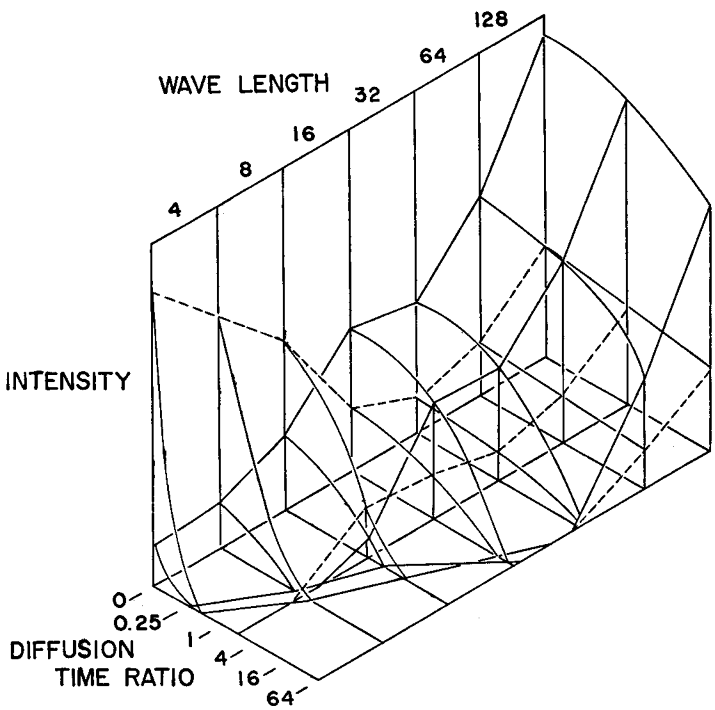

Fig. 10. Change in Power Spectrum (2).

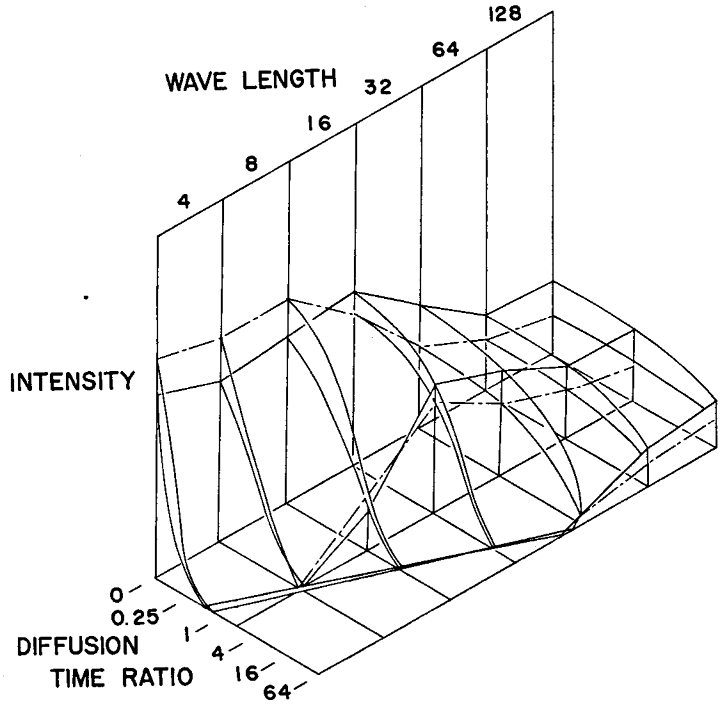

Fig. 11. Change in Power Spectrum (3).

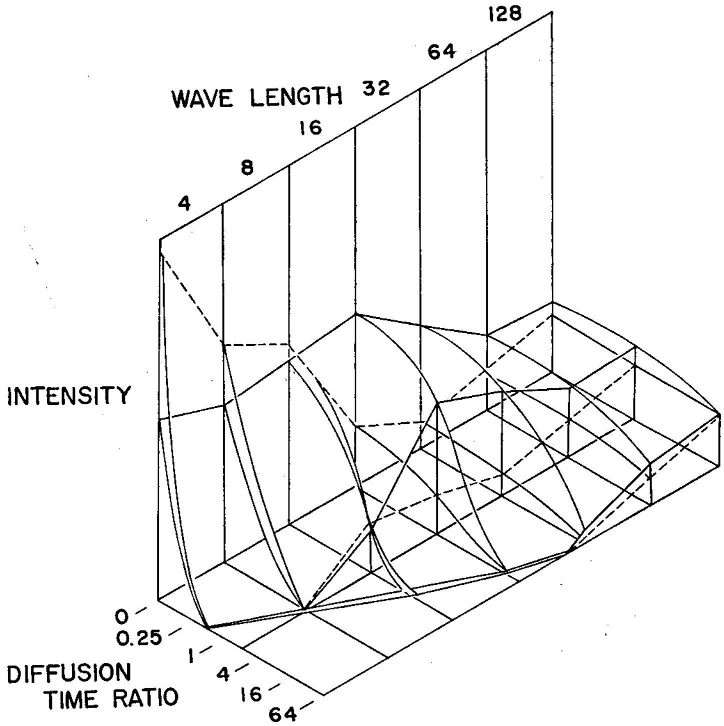

Fig. 12. Change in Power Spectrum (4).

after a small scale agitation. The intensities are rapidly reduced as the spectrum is shifted to shorter wave lengths. It can be seen that the agitation effect is more notable in the middle of diffusion time.

Fig. 11 indicates the change in power spectrum through diffusion for a small scale heterogeneity (solid lines), and through diffusion following after a large scale agitation (broken lines). Very little effect by agitation is shown as we expected. However, the small scale agitation is still effective for a distribution with small scale heterogeneity, as shown in Fig. 12.

At the end of diffusion time in this diagram, both spectra nearly agreed with each other. It means that the agitation has no effect for such a long diffusion time. But, in the middle of the diffusion time, the effect of the agitation was remarkable.

Summary

To sum up, by agitation we can reduce the large scale heterogeneity and the intensity spectrum shifts to the shorter wave length. Some repeating of small scale agitation is effective to accelerate the homogenisation by diffusion, that is, the agitation with appropriate scale is effective to reduce the diffusion time for homogenisation of glass melts. When the levels of intensity and scale of heterogeneity in the glass melt and in finished product are given, there must be a suitable combination of diffusion and agitation processes for a desired homogenisation.

References

1) A.R. Cooper, Jr.: Glass Tech., **7** (1) 2–11 (1966)