What is the ideal depth of a glass melter, with or without steps?

[1]H.P.H. Muijsenberg, Netherlands

[2]M. Muijsenberg, Netherlands

[3]J. Chmelar, Czech Republic

[1]Erik.Muijsenberg@gsbv.nl, [2]Marketa.Muijsenberg@gsbv.nl, [3]jch@gsl.cz

Keywords: Mathematical modeling, furnace design, furnace optimization, quality improvement.

Abstract. Mathematical modelling is reaching a high acceptance level within the glass industry. Today most new furnaces are being modelled before the final design is decided. It is clear that the modelling helps to optimise the furnace in respect to glass quality, energy efficiency and furnace life-time. The extra effort of the modelling is leading for sure to a quick pay-back of this extra investment and an increased profit over the furnace life-time. Even the furnace life-time can be extended with better insight on temperature distribution and glass speeds that corrode the refractory. Many glass produces are always asking us: "what is the optimal glass depth"? There is not just one answer to this, but the paper demonstrates how mathematical modelling can help to find the optimal furnace depth for a certain furnace design.

Introduction

With mathematical modelling we divide a furnace in small volume elements and calculate over these volumes the conservation equations for mass, energy and momentum. The result is that we obtain a flow and temperature distribution of the glass (and combustion gases) within the glass furnace. As a second step with post processing tools we can predict these days what will be relative trends with regard to the glass quality and production yield, next to furnace emissions and energy efficiency. We can estimate that more than 60% of furnaces being designed and constructed today have been optimised before with some mathematical modelling tool. Only Glass Service already executes about 40 of these optimisation studies per year in-house. Our customers using our license are estimated to make in total about 120-150 furnace design optimisation studies per year.

The Base Case

For the purpose of this study we used a non existing but very typical container glass furnace design. The glass is clear soda lime glass using 30% cullet. The furnace in this example is all the time melting 180 Tons per day on a surface of 74 m2, so 2.43 tpd/m2. The base case design glass depth is 1.4 meter. The total fuel input was 900 Nm3/hr. So specific energy use was about 4 MJ per kg of glass. The combustion is fired by 2 underport gas injectors injecting the natural gas into the regenerative preheated airstream.

The following figure 1 will show us a 3D view from the top looking to glass surface and the flame generated above. The colors show temperatures, from blue around 1000 °C till red 1800 °C.

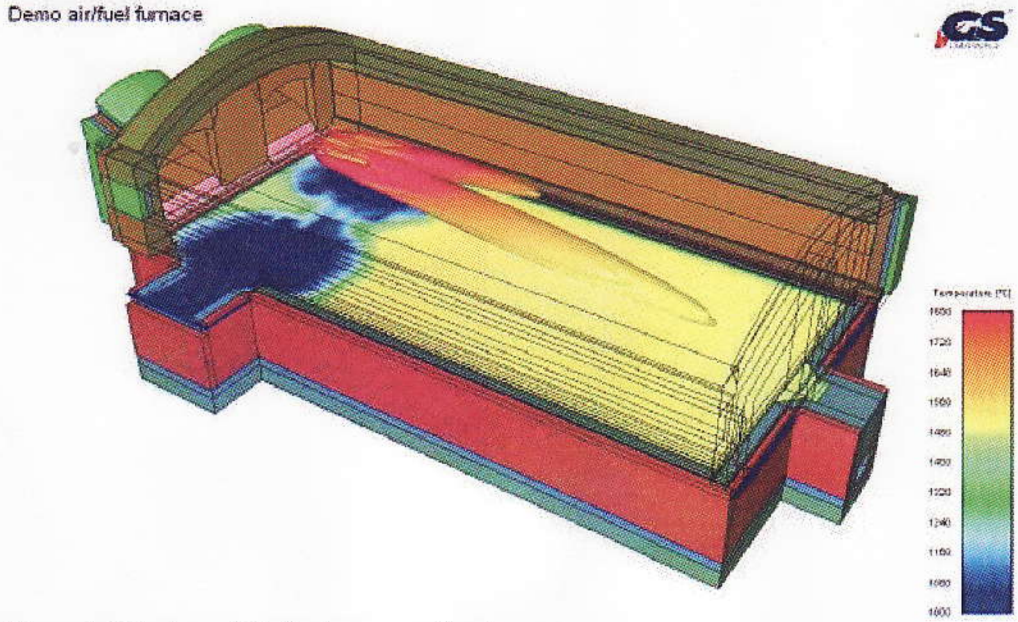


Figure 1. 3D view of air fired regenerative furnace.

The next 2 figures show a vertical cut through the length of the furnace. Figure 2, shows a plane right at the center, showing the also the throat. The next figure 3 is shifted to the side showing the flame development on the firing side of this U-flame furnace.

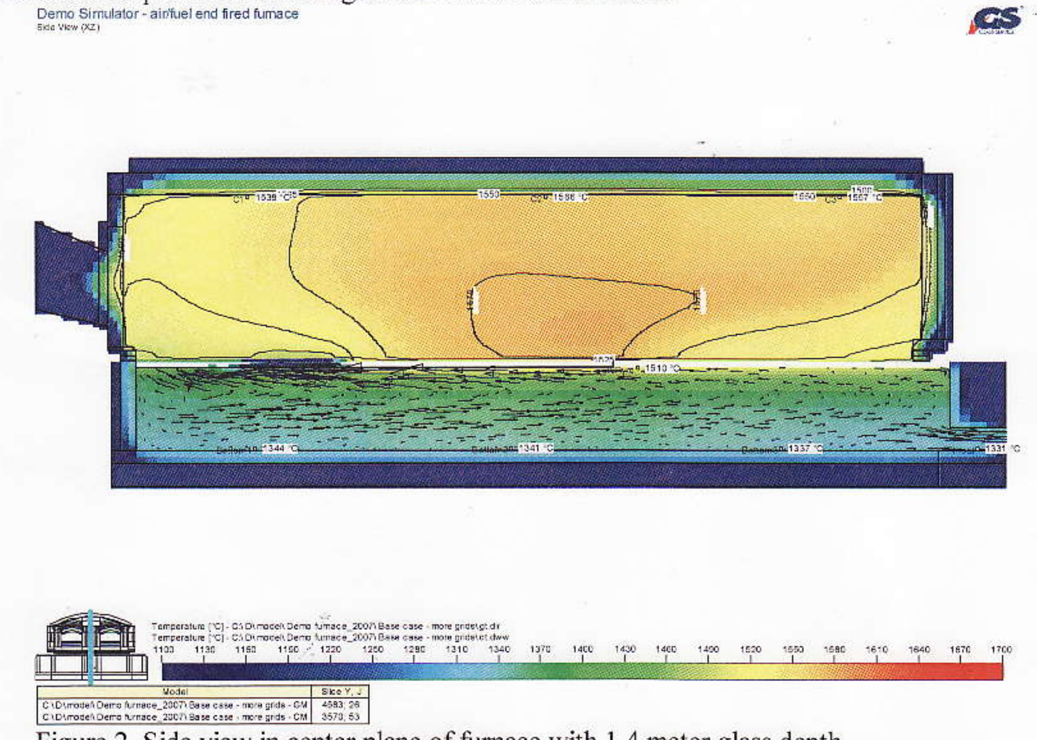


Figure 2. Side view in center plane of furnace with 1.4 meter glass depth.

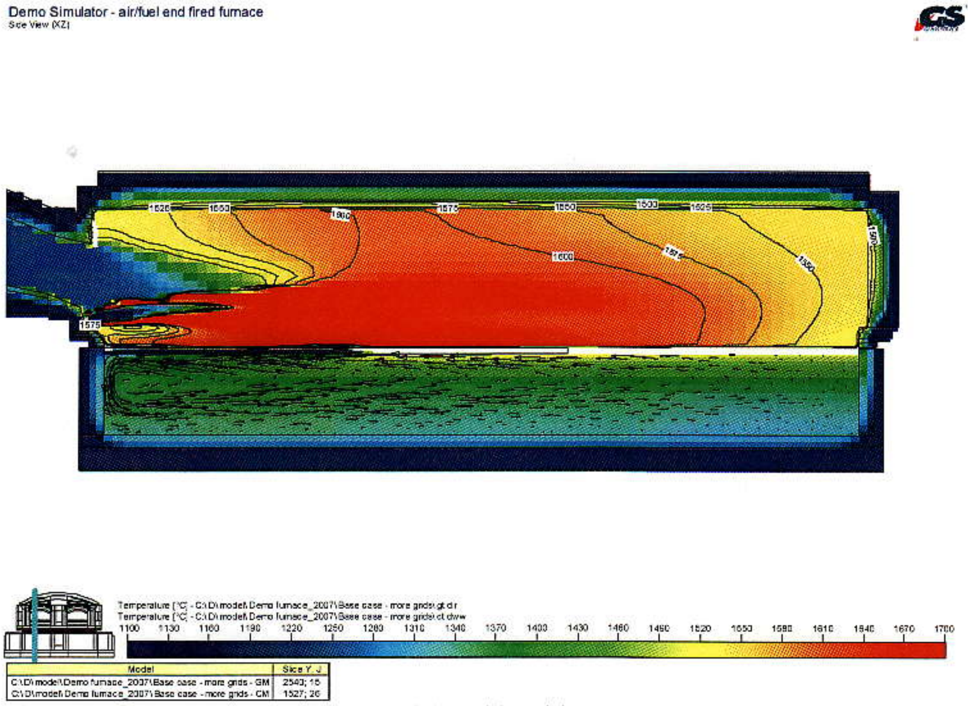


Figure 3. Side view to the side near firing side of furnace.

The variation cases

From this base case situation we calculated some variations to answer one of the most popular questions we hear repeatedly when we optimise the design of a new furnace:

"What is the optimal depth for this glass furnace?"

Now we have to say that of course the optimal depth depends on several factors. Most important here is the glass transmission, eg clear, green or amber. But there are several other variations here, an oxidized green glass does not have the same effective thermal conductivity as a reduced green glass will have.

Beside the glass type of course the ideal glass depth is also a variation of tonnage, firing principle, bubbling (or no bubbling), electric boosting, barriers etc etc. In this paper we just demonstrate for a basic U-flame furnace, melting clear glass what is the optimal depth for this design and tonnage. That means the conclusions are only valid for this furnace and this glass type and fuel rate etc. The conclusions might change completely when for instance doing the same study for green glass instead of clear glass.

We tested how the furnace would work when the glass depth is decreased or increased with steps of 20 and sometimes 10 centimeters. Note that for darker glass the effect will be stronger than for clear glass (the darker glass will have a higher temperature gradient)

Figure 4 shows the results of the glass bath temperature for five selected cases with 20 centimeters difference, starting from the most shallow on top and the deepest one on the bottom. We can clearly see that the more shallow furnace has higher bottom temperatures and less recirculation than the deeper ones. The colors represent the temperature. Dark blue is 1300 C and red is 1500 C.

We can see how the shallow furnace has the highest bottom temperature, on one side this is good as it is good for melting conditions, however the bottom refractory corrosion will be enhanced too. This will have a negative effect on lifetime of the furnace but also on glass quality (eg more stones). If we compare the temperatures also with the velocity profiles in figure 6 we can see how the recirculation is reduced in the shallow furnace. On the other hand in the deeper furnaces the last 20 till 40 centimeters actually are not participating much in the melting process. They just contain certain amount of "dead glass" that might spoil the good glass when having unstable conditions. Especially the doghouse corners in the most deep furnace are getting very quiet and so relatively very cold.

When you look at figure 5 you can see that the most shallow case starts to behave more as a heating pipe, the temperatures over the bottom increase. Also there is not enough free glass recirculation to heat the area underneath the batch. Also the deepest furnace starts to be more colder underneath the batch.

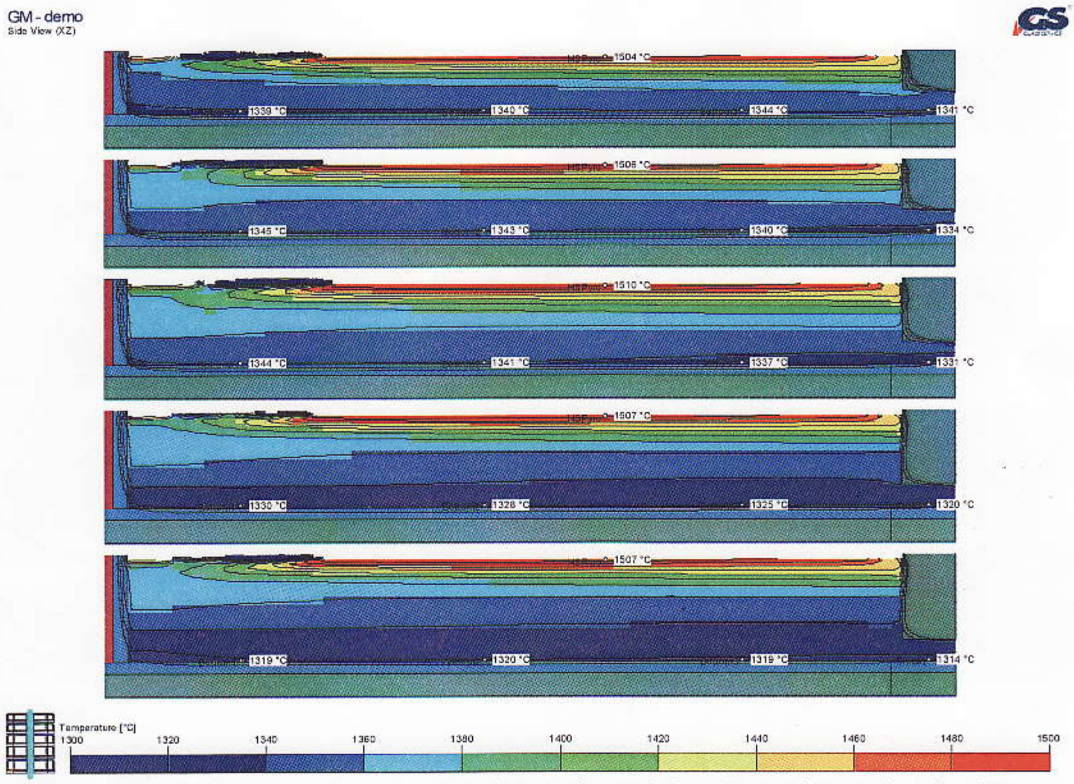


Figure 4. Comparing 5 cases below each other, each one being 20 cm deeper than the former one. The picture shows the vertical temperature distribution in the center of the furnace..

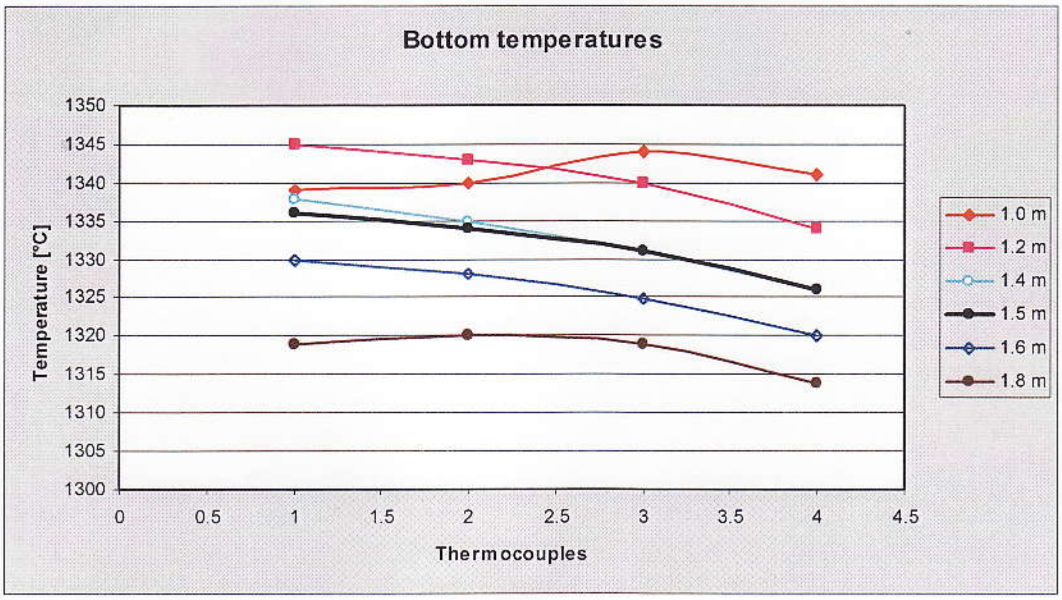


Figure 5. Shows the bottom temperatures of 6 cases.

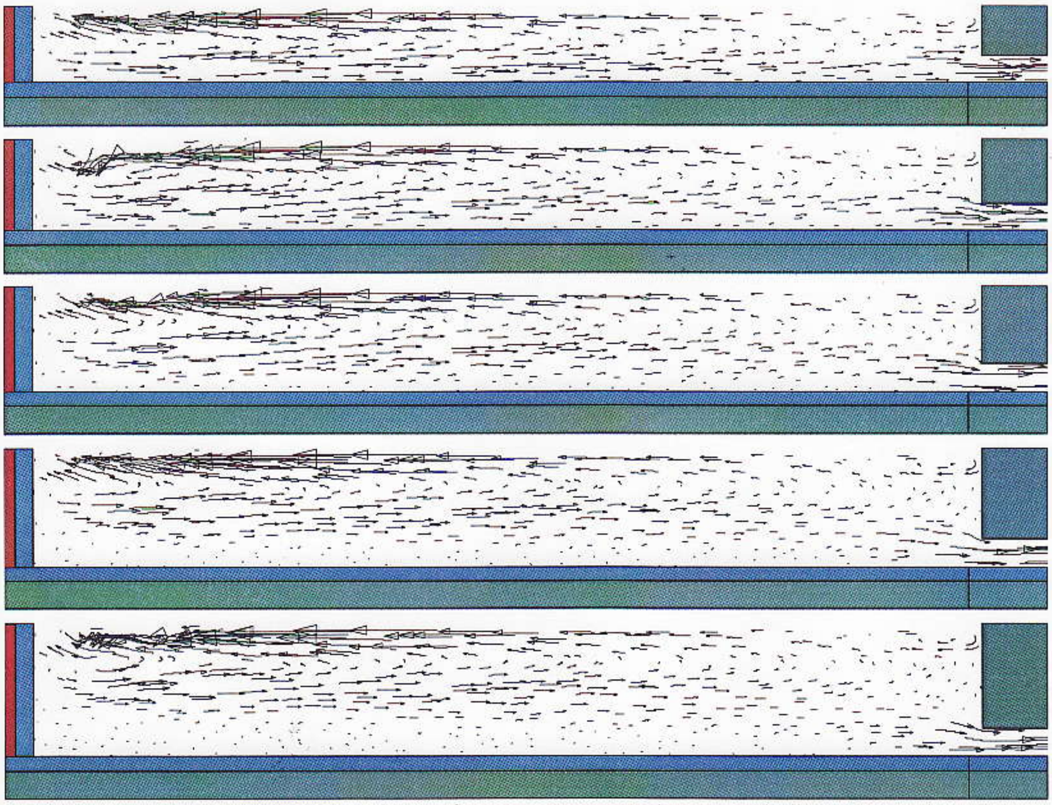
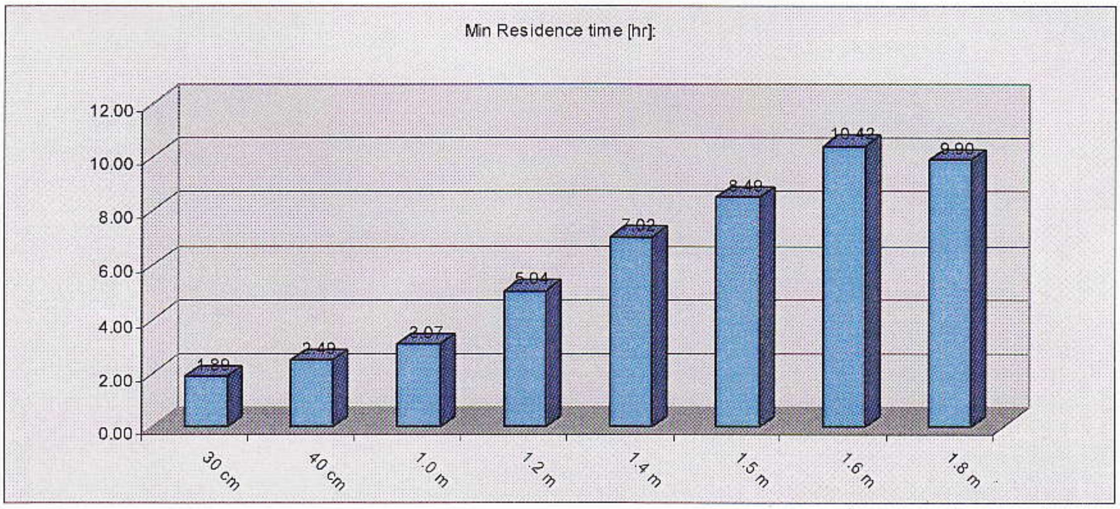


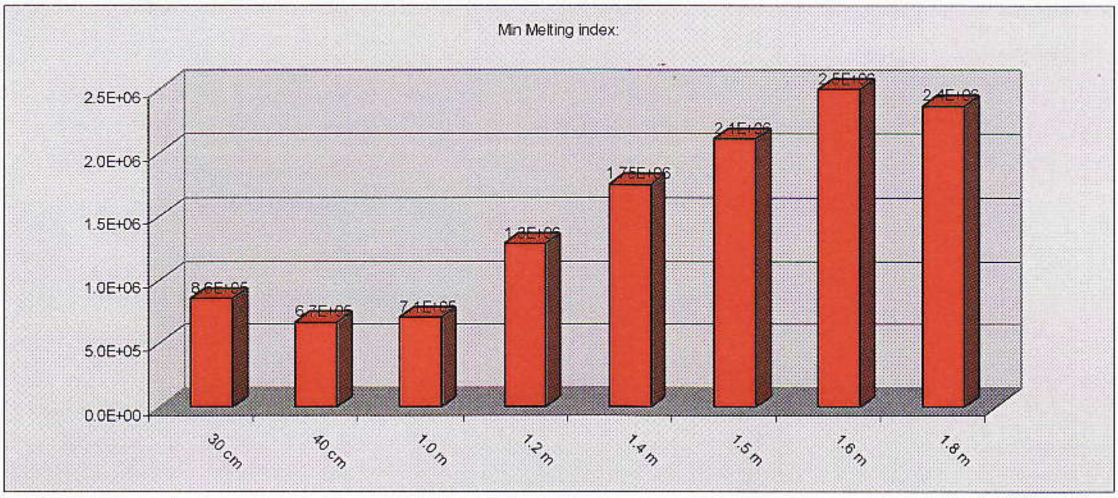
Figure 6. Velocity profile comparison of 5 cases, on top the most shallow one and on bottom the deepest furnace

Results

Using mass less particle tracing and tracing bubbles who really can fine in the model (reach glass level) helps us to evaluate what are the good and what are the less good cases.

The following figures show us the relative changes of minimum residence time, melting index, fining index and the mixing index. For all of them how higher the value is how better the conditions for melting and quality are. In these results we even show results of very undeep furnaces (30 cm), almost channels to give you some idea what will be the result of a very undeep furnace.





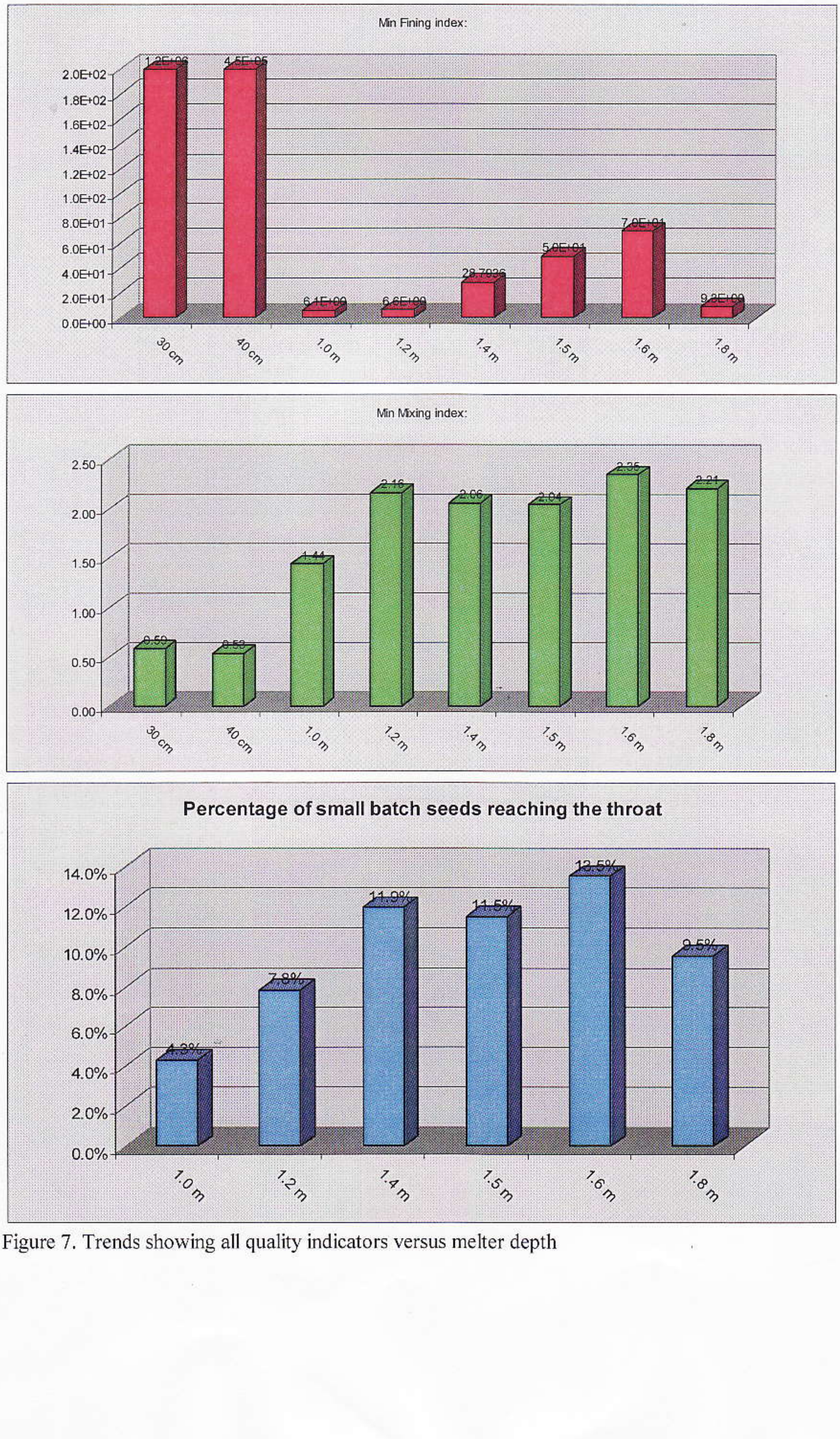


Figure 7. Trends showing all quality indicators versus melter depth

From the quality indicators we can see that the minimum residence time increases with a deeper glass melt, due to the higher volume. The most shallow furnace has only a minimum residence time of 1 hour, which is much too low to have good glass quality (See also the fining index for melters around 1 meter is very low). However for the very undeep channel melter all the glass is warm and this would lead to very good fining, but on the other hand very bad homogeneity (mixing) and high refractory corrosion. The barrier in the glass melter has often a similar effect like this. For the deepest furnace the minimum residence time does not increase further as the lower layers are behaving as dead zones.

The batch seed tracing, combined with the fining, melting and mixing index show us the optimum depth for this (clear) glass type and tonnage (with no bubbling or boosting) is about 1.5 meter.

Conclusions and Summary

Let us remark again that this is just a demonstration furnace and these results are valid only for this case melting clear glass. When evaluating the results from the calculation and visaulise in the figures above, we may conclude the following:

Comparing all quality indicators we can conclude that the optimum is somewhere between 1.4 and 1.6 meter deep furnace.

So for this furnace design, clear glass and this tonnage the best glass quality will be probably be produced with a furnace that is around 1.5 meter deep. At the same moment the lower bottom temperatures will also help the furnace life time and reduce defects potential from the bottom.

One must not forget that such optimisation is furnace design and case dependent and might give different results under different conditions.

There are of course also other options to consider, such as a multi level furnace with steps along the length (or even barriers), this already has been common for some float furnaces (being less deep towards the end) or container furnace with having deeper refiners than the main melting part.

References

[1] P. Cincibusova, L. Nemec, M. Jebava: The Influence of Glass Flow Character on Bubble Removal in Horizontal Channels, proceedings of 9th International Seminar Mathematical Modeling of Furnace Design and Operation.