A Numerical Investigation of the Effect of Electric Boosting in an Oxy Fuel Fired Glass Fiber Furnace

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ABSTRACT

Glass fiber is used primarily as a polymer reinforcing agent. From the transportation to building and construction sector, the need for glass fiber for countless purposes is indisputable. The wide range of uses of glass fiber is mainly due to its characteristics such as low weight, excellent electrical resistance, and high strength. With the rising demand on glass fibers, energy-efficient glass fiber furnaces are crucial in today's world. Lately, there is an increase in number of fiber glass furnaces commissioned that utilize oxy-fuel firing systems that can significantly reduce levels of NOx and particulate emissions compared to traditional air-fired furnaces.

In this paper, it is aimed to evaluate the performance of an oxy-fuel unit melter type glass fiber furnace to meet the requirements of expected capacity of the furnace and product quality. Firstly, numerical simulations of oxy-fired glass fiber furnace are carried out for multiple cases that apply various amounts of electric boosting in a multi zone boosting system. After selecting the optimum boosting configuration, many trials with different bubbler configurations in accordance with a preferred number of bubblers are also accomplished within this framework. The glass quality estimated by calculation of residence time is also discussed. The study results explored the beneficial effects of electric boosting on convection currents, temperature homogeneity and residence times which all can improve energy efficiency as well as glass quality. It is discussed based on industrial economy in the forthcoming years that all-electric furnaces may be favored. Detailed results of the study will be presented in the paper.

1. INTRODUCTION

Glass fiber is a special type of glass having significant characteristics as high electrical resistance, mechanical and chemical durability. Production of this type of glass is highly challenging mainly due to its strongly corrosive interaction with most refractories at the required high temperature. Glass fibers applications determine the requirements of glass fiber production as well as certain properties of glass composition. The most significant aspect of glass fiber melting is excessive foam layer formed on glass surface during melting due to its composition. Additionally, oxy-fuel glass furnaces enhance formation of a layer of foam which has a great insulation on the molten glass surface as compared to air-fuel operation. Therefore, heat transfer from the combustion space to the glass bath is decreased as a result of foam formation. To overcome this difficulty, it is considered to supply some amount of energy by electrical boosting so energy is released directly in the melt. Electrical boosting is such a long-standing application to glass furnaces that is favored progressively because of restricted energy resources and environmental aspects.

Glass melt is heated from the bottom by direct Joule heating with most of the heat often being generated close the electrodes. In glass melters always alternating current is used and in this study three-phase transformers are used. Fiberglass fabrics are outstanding for electrical insulation purposes and has a low electrical conductivity compared to regular silicate glasses as a result of having less alkali metals in composition. Consequently, amount of current flow through the glass is low and this leads to low current density at the electrode surface.

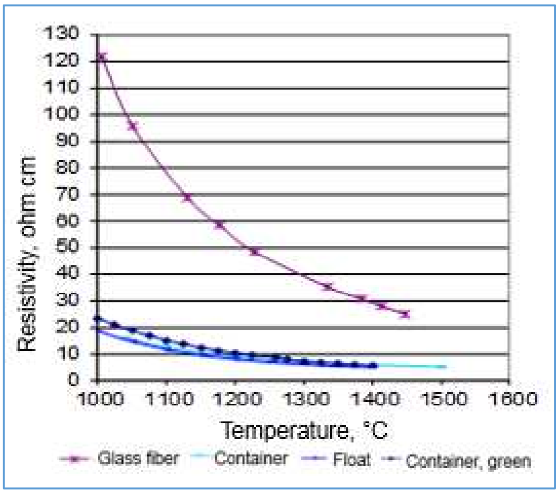


Figure 1: Electrical resistivity of different glass types

Main parameters investigated for the design of electrical boosting system are;

- Amount of electrical energy applied to the furnace,
- Distribution of electricity in the furnace, number of zones and amount of electrical energy per zone,
- Location, position and immersion of the electrodes,

2. OVERVIEW OF THE OXY-FUEL-FIRED UNIT-MELTER FURNACE DESIGNED WITH AN ELECTRIC BOOSTING SYSTEM

The furnace in this study is an oxygen-fired unit melter equipped with 9 flat flame burners In the beginning of this project, the design parameters of the furnace is optimized by the use of ŞİŞECAM mathematical model. Then it is decided to use electrical boosting to reach 28% increase in capacity by setting up ideal convective currents and temperature profile in the furnace and hence maintaining the glass quality,. This also helps for the flexibility of furnace pull rate during furnace lifetime. A general view of the furnace temperature and flow distribution can be seen in Figure 2.a and 2.b.

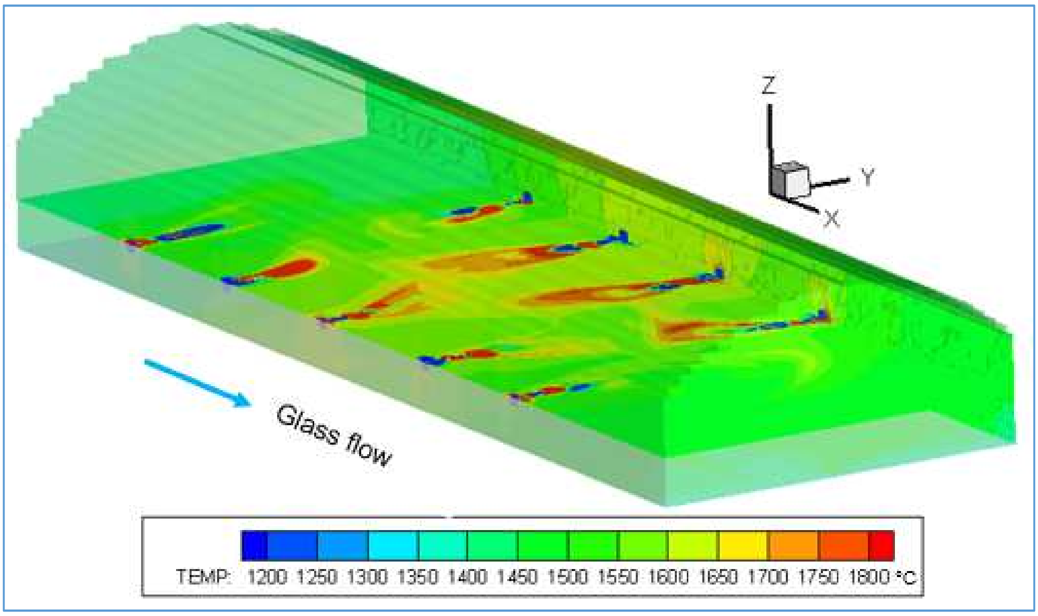


Figure 2.a: Combustion space of oxy fuel fired glass fiber furnace

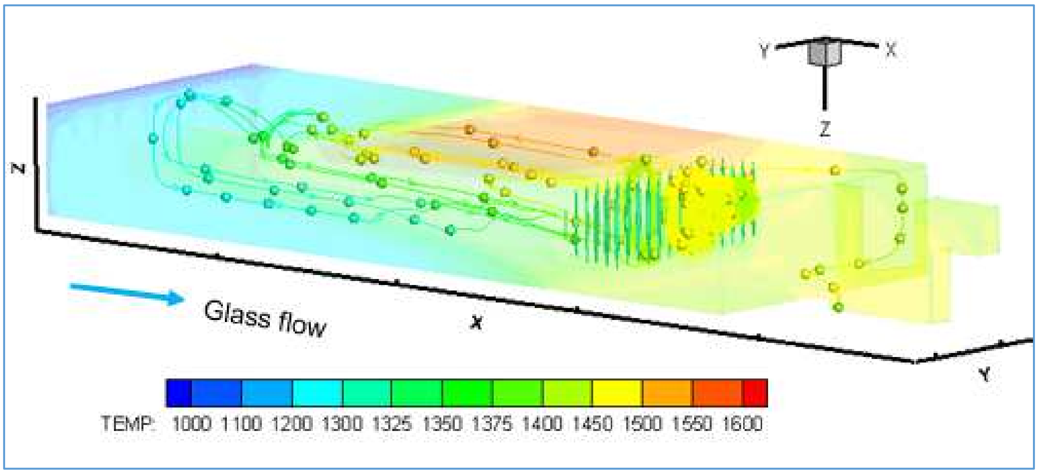


Figure 2.b: Glass bath of oxy-fuel fired glass fiber furnace

Then by examining the temperature distribution and glass flows obtained by mathematical modelling, different cases are decided to work with different amount of electricity and its distribution. The amount of supplementary electrical heating into oxy-fired glass fiber furnace also depends on economical optimization involving electricity and oxygen costs as well as efficiency of these two alternatives. Ratio of electricity in total energy given to the furnace for each case is seen from Figure 3.

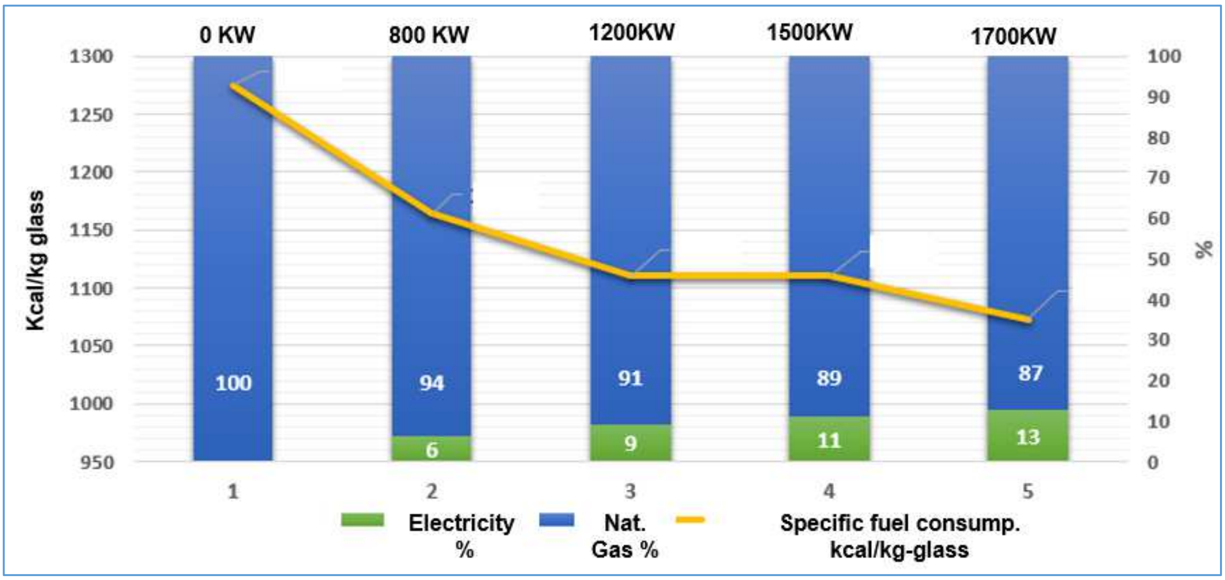
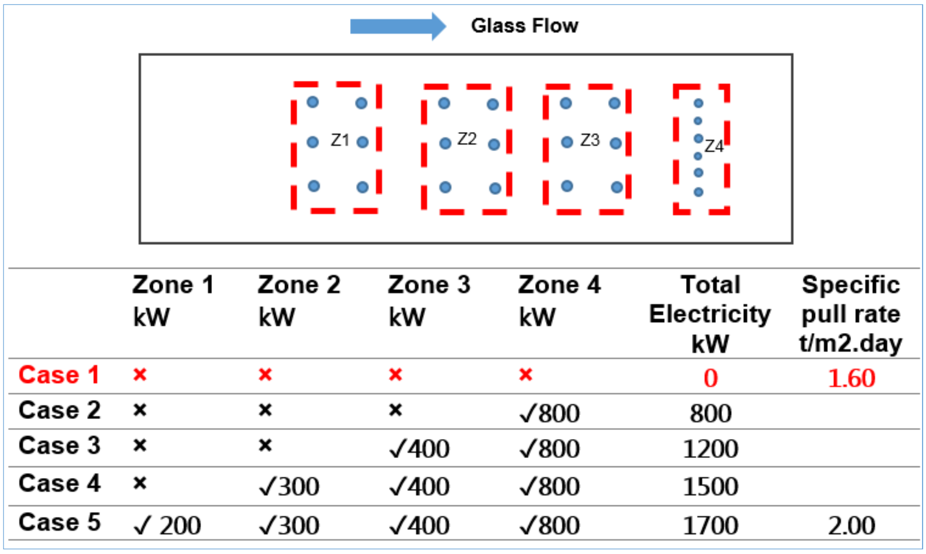


Figure 3: Ratio of electricity in total energy given to the furnace

Figure 3 highlights effect of electrical power contribution on specific fuel consumption. Substitution of natural gas for electric boost energy decreases specific fuel energy by %15.

2.1 EFFECT OF ELECTRICAL BOOSTING SYSTEM

Considering the factors mentioned above, total amount of electrical energy required to gradually increase specific pull rate from 1.60 t/m2.day to 2.0 t/m2.day is calculated and shown Figure 4.



	Zone 1 kW	Zone 2 kW	Zone 3 kW	Zone 4 kW	Total Electricity kW	Specific pull rate t/m2.day
Case 1	×	×	×	×	0	1.60
Case 2	×	×	×	✓800	800	
Case 3	×	×	✓400	✓800	1200	
Case 4	×	✓300	✓400	✓800	1500	
Case 5	✓ 200	✓300	✓400	✓800	1700	2.00

Figure 4: Electrode zone array in each case

As it is seen in Figure 4, electrodes are decided to be placed in spread configuration on the basis of operational experiences. 4 zones, each designed with 6 electrodes to get a relatively even loading of the 3 phase electrical transformers. Electrodes are vertically installed at the bottom of the glass bath. 4 Zones are located from beginning of the melting end to the hot spot as can be seen on the above diagram. This configuration is studied to observe potential of electric boosting system which could influence overall furnace operation, energy consumption and glass quality, with increasing output. In this boosting system, only for Zone 4, 6 electrodes are installed as a single row to obtain a stronger hot spot so convective currents can enhance the glass circulation from the bottom to the surface. The power distribution in the glass melt, is arranged to use 53% of energy under the batch and the remaining 47% in the hot spot. It is the result of electrode placement shown in Figure 4.

A well placed boost system enhances convection currents that co-operate with desired effects of the top firing. For a comprehensive analysis, Şişecam Mathematical Model is used to carry out investigations with a series of 5 cases regarding incremental electrical power distribution. Temperature profile along the furnace length in each case is compared in Figure 5.

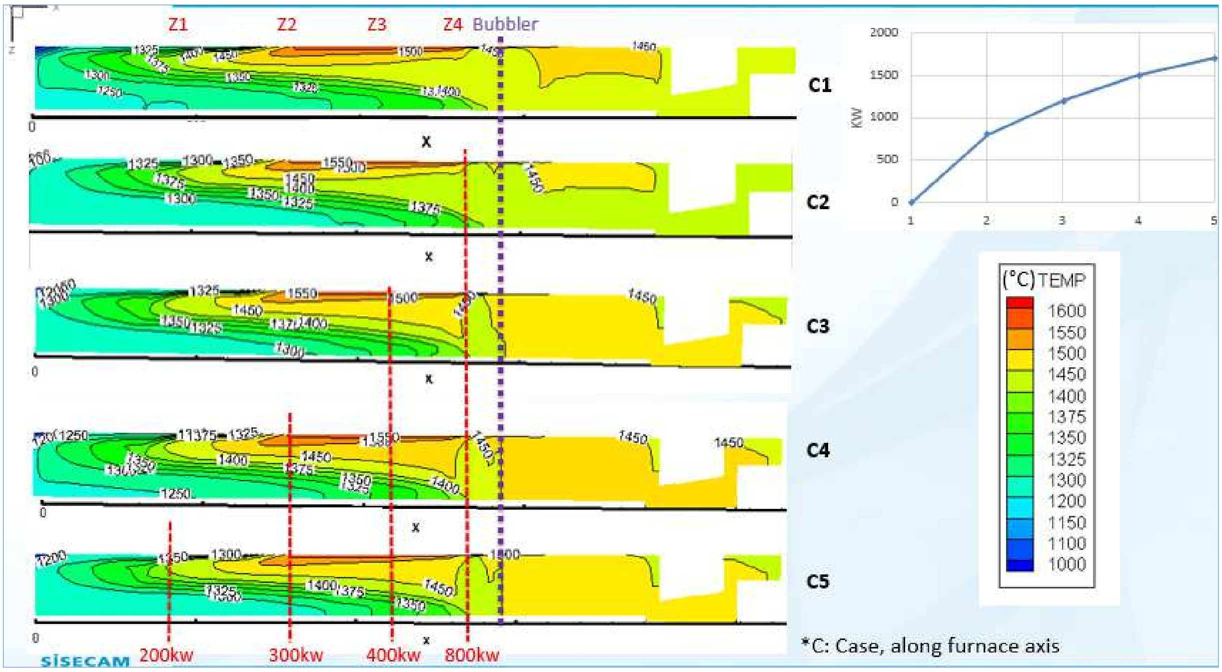


Figure 5: Temperature distributions obtained with different amount of electrical energy

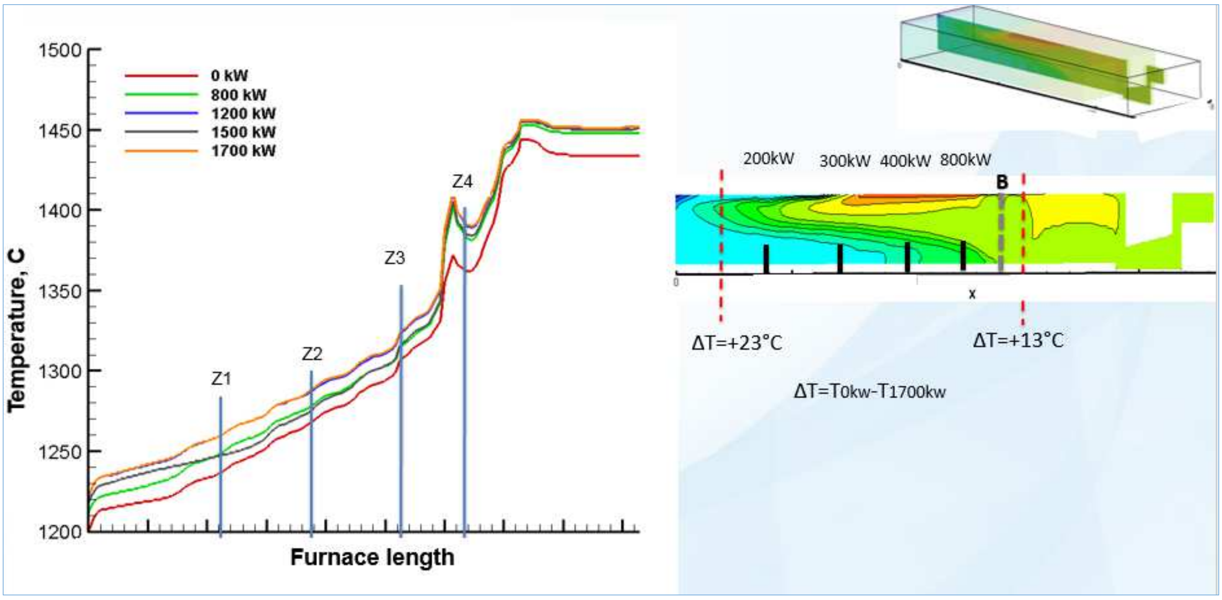


Figure 6: Glass *bottom* temperatures with/without electric boosting

As it is seen from Figure 6, there is a significant difference in the furnace bottom temperatures of Case 1 (0 KW) and Case 5 (1700 KW). With an increase in the total electrical power, glass convection currents are enhanced and temperature of the glass melt, flowing from the doghouse area towards the throat increases. Generally, refining zone temperature increases as hotter glass from the hot spot flows into the refining zone. Consequently, it is expected to see higher riser temperature with increased total electrical power. Comparing Case 2 and Case 3, it is clearly seen that zone 3, installed just before hot spot has great impact on defining riser temperature in the furnace. It is also obvious that bubbling improves the overall heat transfer in the glass tank by bringing the relatively colder glass melt from the bottom to the surface of the melt.

With an increase in the total electrical power, an improved heat transfer into batch blanket is observed in Case5. The main temperature difference obtained by the use of different amount of electrical boosting is noticeable at the hot spot region. In all cases with electrical boosting, temperature profile stays similar in the refining zone. At this point, increasing the energy input in the hot spot does not contribute as much difference as expected in the glass temperatures. Figure 6.a shows bottom glass temperatures along the furnace for all cases. While bottom glass temperature difference between Case 1 and Case 5 is 23°C under the batch blanket, temperature difference drops down to 13°C in the refining zone as seen in Figure 6.

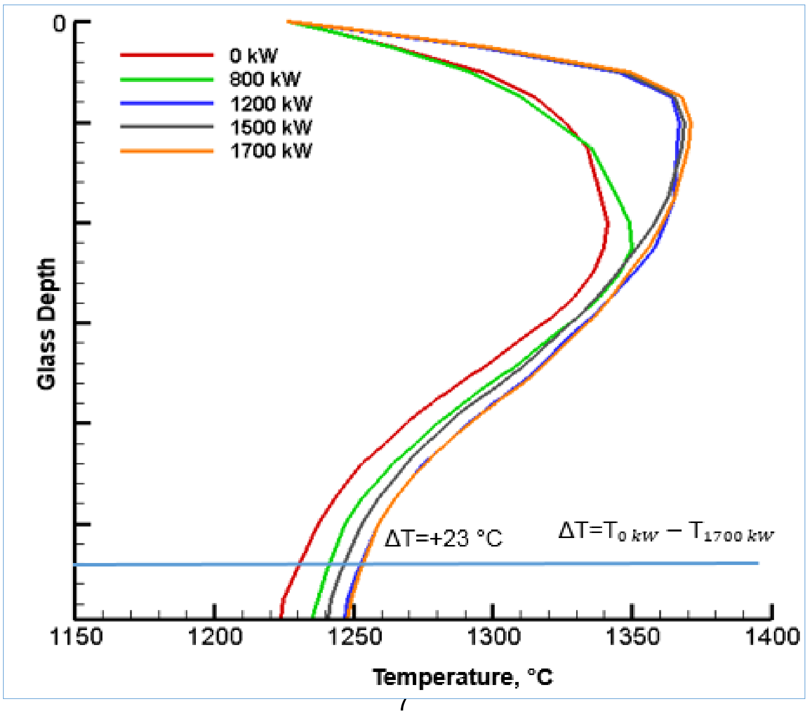


Figure 7: Glass bottom temperatures along glass depth with/without electric boosting at *batch side*

In Figure 7, temperature difference along glass depth at the batch side for each case is examined in more detail. Calculated temperature difference allows for an increase in specific pull rate of 2.0 t/m^2.d. It is seen that hot spot boosting does not have contribution on glass surface temperature on batch side. However, switching on zone 3 enforces upper convection currents which flow under the batch blanket and a noticeable temperature escalation is recorded in this region of the glass melt. Convection currents flow downward along the back wall of the furnace under the first circulation loop and these convective currents increase bottom glass temperatures.

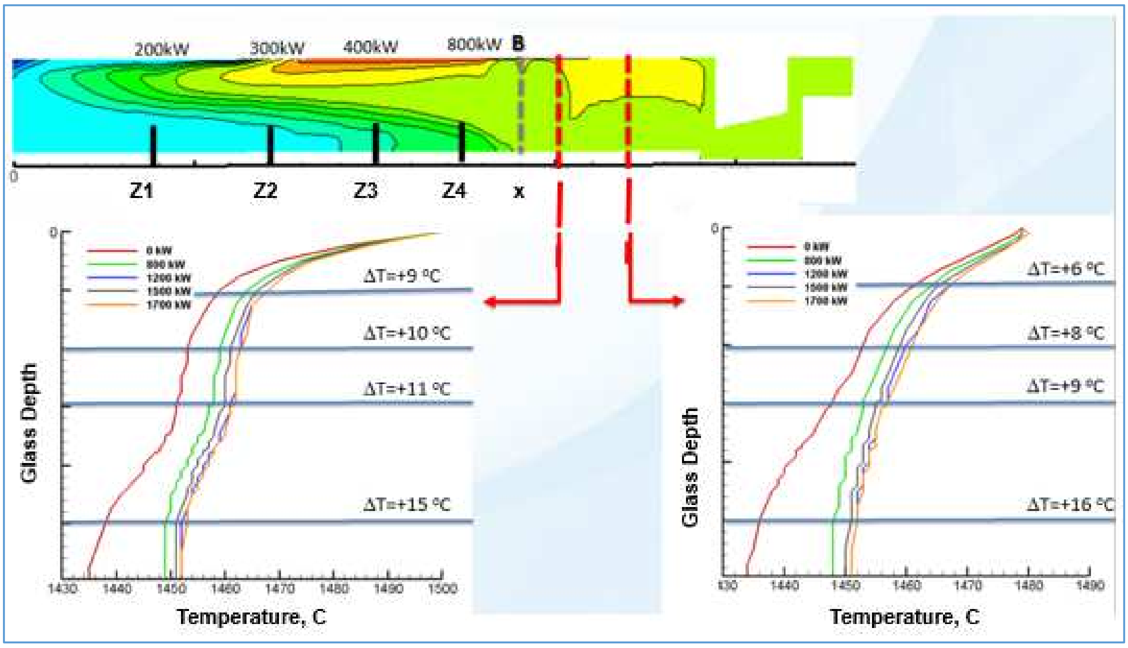


Figure 8: Glass bottom temperatures along glass depth with/without electric boosting at *refining* section

Foam on the surface of glass melt generated in E-glass reduce energy efficiency and can lead to poor glass quality. Therefore it is highly important to obtain desirable temperature profile in the refining zone. It is justified that electrical boosting improves glass flow pattern so refining time to remove possible bubbles or seeds which would affect the properties of the final product. Therefore the glass should pass through certain temperature areas in the refining zone. As can be seen from Figure 8, temperature difference along the glass depth increases by the increase in amount of electrical boosting.

2.2 EFFECT OF BUBBLER

Convection of the glass in the furnace is affected by implementing bubblers which are important for a well-defined hotspot and heat distribution. As a result of bubbling, colder glass rises to glass surface and heat transfer from combustion space to the glass bath increases. Placing electrodes in the vicinity of the hot spot, this advantage could be influenced adversely.

Bubblers increase the amount of energy transferred into the glass from the combustion space by enhancing convective motions. If the power above a certain level is supplied at the hot spot, the heat transferred from the combustion space will decrease because of the higher glass surface temperature. That means, when the electrodes just before the hot spot are placed closer to the bubblers, some energy transferred from the combustion space into glass bath is replaced with electrical energy, by reducing furnace efficiency. Therefore, the distance between bubbler and hot spot electrodes is a crucial parameter in furnace design.

The bubbler system in this study comprises two rows of bubblers, reasonably closely spaced, arranged across the width of the furnace.

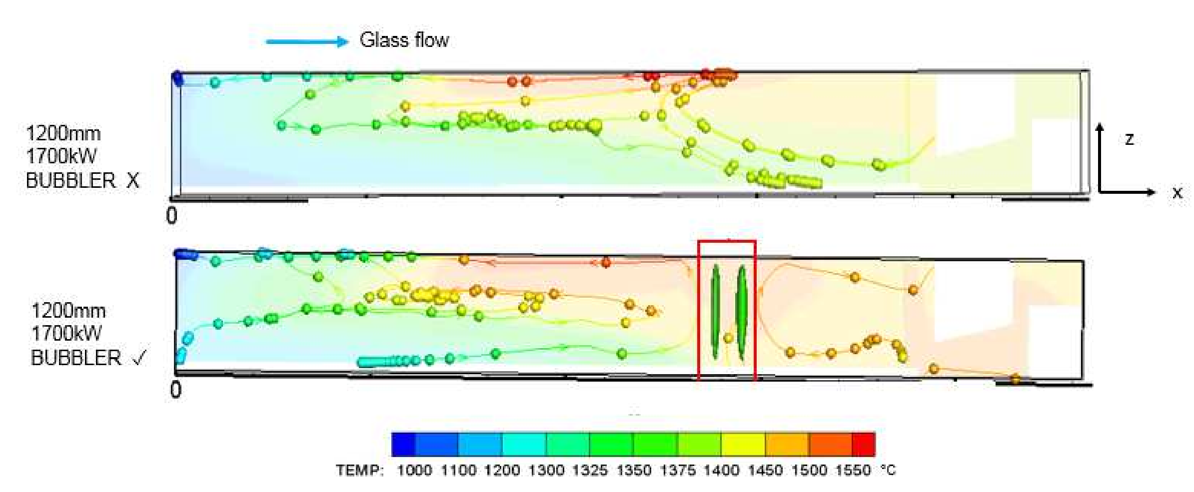


Figure 9: Temperature and flow distribution in the longitudinal cross section of the glass bath with and without bubbling

Figure 9 justifies that bubbler systems are significant to regulate glass flow pattern. As seen, the bubbling system establishes a thermal barrier and promotes two main glass convection loops. The benefits of bubbler system are not only decreased fuel consumption but also a notable increase in quality promoted by the improved homogeneity. Besides, when the bubbler is switched on in the case of applying 1700 kW of electrical power, the average temperature of the furnace increases by ~35°C. This shows that the mixing action of bubblers are very effective and economical way to increase average glass temperature in the furnace.

In Figure 10, effect of bubbler installed across the furnace at hot spot on bottom temperature is shown. Bubbling through the glass significantly improves the heat exchange both between the glass melt and the flame and also inside the glass itself as explained above. Therefore, it is expected to see higher bottom temperatures when the bubbler system is introduced. Besides, the homogenizing action of bubblers can significantly speed up color or composition changes.

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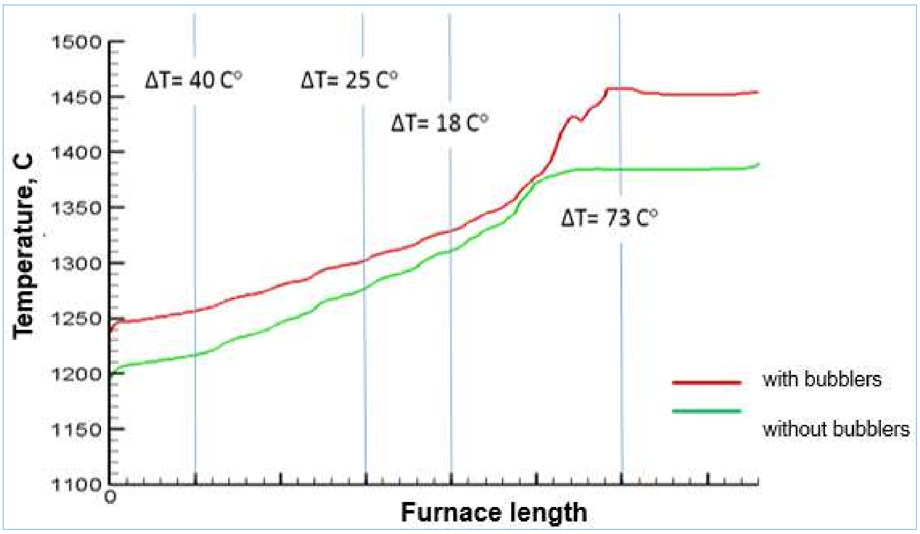

Figure 10: Glass bottom temperatures profile with/without bubbling

Figure 11 examines three cases which are equipped with only bubblers, only electrical boosting and combination of bubblers and electrical boosting. In the melting and refining sections temperature profiles across the glass depth are compared and it is seen that bubbling is much more effective on temperature distribution in glass bath.

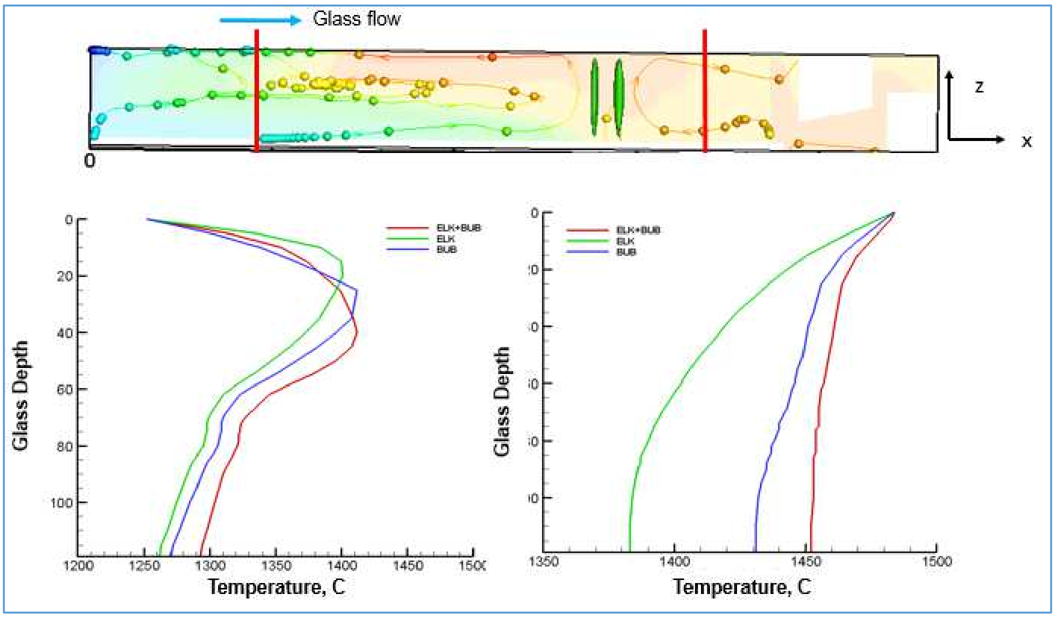

Figure 11: Glass temperatures along glass depth for melting and refining sections

The study concluded that the system established in the glass tank enforces convection currents in the melt, enabling increased pull rates, better fining, and glass quality improvements.

3. CONCLUSION

The furnace in this study is an oxygen-fired unit melter equipped with 9 flat flame burners. This study aims to increase pull rate of the oxy-fuel fiber glass furnace by 28% by supplementary heating. Within the context of this study, amount of electrical energy transferred by electrodes into the glass melt is determined based on targeted furnace pull rate and market prices of oxygen and electricity. A multi zone boosting system is placed in the furnace and a bubbler system is located 70% of the furnace length as double rows. A series of cases are investigated by Şişecam mathematical model with different amount of electrical boosting for a specific oxy-fuel fiber glass furnace.

The boosting system enhances convection currents formed by the temperature distribution obtained with the heat transfer from combustion space. So average furnace temperature increases maintaining glass flow pattern. Given electrical power has minor impact on convection currents since these currents are regulated by the bubbler system. However, the boosting system is still essential to regulate furnace temperature distribution.

4. REFERENCES

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