Investigations on the Use of Biogas for Glass Melting

J. Leicher*[1], A. Giese[1], K. Görner[1], B. Fleischmann[2], H. Wuthnow[3]

[1]Gas- und Wärme-Institut Essen e.V., Essen, Germany
[2]Hüttentechnische Vereinigung der Deutschen Glasindustrie e.V., Offenbach, Germany
[3]Forschungsgemeinschaft Feuerfest e.V.,Höhr-Grenzhausen, Germany

Abstract

In many energy-intensive manufacturing processes, natural gas is the dominant fuel for providing process heat. However, there is increasing pressure to reduce both fuel costs and carbon dioxide (CO_2) emissions. One possible approach in this regard is the use of mostly untreated biogas from fermentation processes as a fuel, either to completely substitute natural gas, or for co-firing. But while the use of such biogas can decrease both natural gas consumption and overall CO_2 emissions (biogas is considered to be a CO_2-neutral fuel), there is concern how this change of fuel will impact on product quality, combustion behavior and the refractory material. Trace contaminations in the biogas are one aspect in this context which might have a negative impact on product quality of the glass or the life time of the refractory material of industrial furnaces.

Introduction

In glass production, the melting of glass from raw materials is the most energy-intensive process which consumes up to 80 % of the total energy use in mass glasses (container and flat glass) [1]. In addition to traditional air preheating, there are various other approaches to save energy and to reduce CO_2 emissions, e.g. using pure oxygen, improving the heat transfer through innovative combustion technologies or reducing of heat losses by selecting suitable refractory materials. Many of these options are exploited in modern plants. Another aspect for operators of glass melting furnaces and other technical combustion systems in Germany is the concern about the security of gas supply and the fluctuations or increasing energy prices in the years to come [2]. They have to contend with those rising energy prices and at the same time they have to contribute to the energy and climate policy goal of the German federal government. By 2020, 18% of total energy demand of Germany are to be provided from renewable sources and the CO_2 emissions should be reduced by 40% in comparison to 1990 [3].

While increase in efficiency is the most prominent approach to reduce CO_2 emissions, it is also possible to achieve this goal by choosing another, CO_2-neutral fuel, such as biogas. However, as product quality, efficiency and environmental concerns are paramount for the operation of industrial production processes, the impact of a different fuel has to be assessed in detail. In the course of a German research project [4], the applicability of raw, almost untreated biogas as a fuel for a glass melting furnace was therefore investigated. CFD studies of the use of biogas in a U-flame glass melting furnace were carried out while a mobile test rig was designed and built to investigate to effects of the combustion of untreated biogas on pollutant emissions, glass quality and refractory materials at different biogas production facilities.

Biogas in Industrial Applications

The main difference between biogas and more conventional fuels such as natural gas is the much larger content of inert species such as CO_2 or N_2 in the fuel gas, which leads to much lower calorific values. For the same reason, the densities of biogases are usually higher. Thus, in order to provide the same amount of energy, much higher mass flows of fuel gas have to be realized while at the same time, the amount of oxidizer changes as well due to the reduced specific air requirements of biogases which usually contain about 50 - 60 vol.-% of methane. All this leads to drastically different flow fields (and hence flame shapes, heat transfer characteristics, etc.) in a furnace if natural gas is completely substituted with biogas.

Another aspect is the possible existence of contaminants in the biogas. While natural gas is usually reasonably clean with regards to trace elements, biogas, especially if produced from bio wastes, can contain various trace elements which might impact glass quality but also lead to chemical interactions with the refractory materials. One aim of the research project was therefore to investigate the effects of the combustion of untreated biogas on both glass quality and refractory materials.

While these factors will in the end decide whether biogas is applicable in an industrial context or has to be upgraded to natural gas quality in order to be usable in industrial furnaces, thermal processing industries are definitely interested in this potential alternative fuel source, as the ongoing research activity for example in Germany and in France shows[4], [5]-

Investigations at Gas- und Wärme-Institut (GWI)

In a first step, the consequences of the utilization of biogas on the combustion process in glass melting furnaces were investigated both experimentally and by means of Computational Fluid Dynamics (CFD). Using various mixtures of natural gas and CO_2, various rates of biogas co-firing (or exclusive biogas firing) were

* Corresponding author: leicher@gwi-essen.de
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analyzed. Admixing of 25 % CO_2 would correspond to a biogas co-firing approach while a mixture of 50 vol.-% natural gas and 50 vol.-% CO_2 approximates the combustion of biogas only.

GWI's high-temperature burner test rig allows for burner investigations in a semi-industrial setting. For this campaign, the burner load was at 650 kW, with air ratios of about 1.05. Air pre-heat temperatures were about 1200 °C. Pre-heat temperatures, burner load and air ratios were kept constant for all experiments.

The burner was installed in a so-called underport configuration which is quite common on U-flame glass melting furnaces. The test rig is specifically designed for optimum access with measurement probes so that 2D field measurements of temperatures and species can be carried out, using thermocouples and suction probes respectively. Figure 1 shows an image of the furnace.

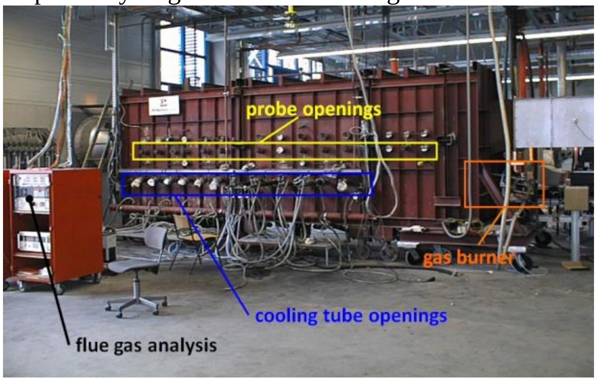

Figure 1: GWI's high-temperature burner test rig

Figure 2 shows a comparison of measured temperature distribution in the burner plane of the test rig for different natural gas (NG) and CO_2 mixtures.

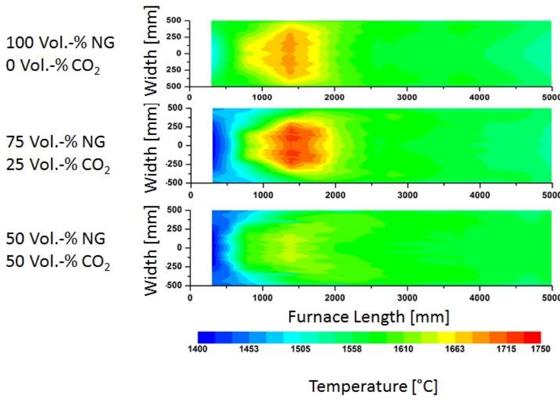

Figure 2: Temperature fields in the burner plane for different natural gas / CO_2 mixtures

It is interesting that although "pure" natural gas has the highest adiabatic temperature of the three investigated fuel mixtures, the mixture with 25 vol.-% CO_2 was found to have the highest furnace temperature in the measurement campaign. This result was corroborated by simulation results. This is most probably due to increased mixing efficiency in this case caused by different mass flows for both fuel and oxidizer. Burners for glass melting applications are generally designed for inefficient mixing in order to obtain long, highly luminous flames. Since the burner used in these experiments was originally designed for natural gas and not adapted for biogas utilization, the changing mass flows and hence momenta can very well have this effect. In the case of a 50/50 mixture, however, the amount of chemically inert CO_2 is too high to be compensated by improved mixing.

The measured NO_X emissions follow the trend of maximum temperatures, i.e. the mixture with 25 vol.-% CO_2 also showed the highest NO_X emissions. It should be pointed out though that in these experiments the biogas was generated synthetically which means that the only possible formation pathway for NO_X was the thermal Zeldovich mechanism. Real biogas may well contain nitrogen compounds in which case the fuel-NO_X pathway may become the dominant pathway. This was shown in a previous investigation [6].

The measurement campaign also served to validate simulation efforts to look into the use of biogas in industrial combustion processes. The comparison between numerical and experimental results showed a good agreement. Figure 3 shows a comparison of measured and calculated temperature fields in the test rig.

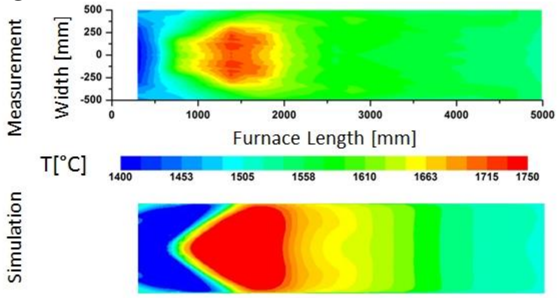

Figure 3: Comparison of measured and simulated temperature fields in the burner test rig

The effect of biogas utilization in a real glass melting furnace was also investigated using CFD. Figure 4 shows one result, a comparison of the temperature distributions in the burner plane for a typical horseshoe furnace. The image on the left hand side shows the result for the combustion of pure methane (as a substitute for natural gas), the image on the right hand side shows the result for the combustion with a biogas consisting of 65 vol.-% CH_4 and 35 vol.-% CO_2 which corresponds quite well to biogas from biowaste feedstock. In both simulations, the furnace was operated with a burner load of 11 MW, an air ratio of 1.07 and an air pre-heat temperature of 1400 °C, common operational conditions for such a furnace. The same burner geometry was used for both fuels.

As was to be expected, the impact of the fuel on the temperature distributions is quite profound. The size and shape of the hot region, crucial for heat transfer in glass melting furnaces, changes completely. A comparison of the energy balances for the two cases shows that about 10 % less energy were transferred to the glass melt, resulting in an inacceptable decrease of overall efficiency compared to the reference gas with natural gas. This means that for already existing furnaces, it appears to be more sensible to use biogas in an co-firing approach. If biogas is to be used exclusively, the burner geometries will have to be adapted accordingly.

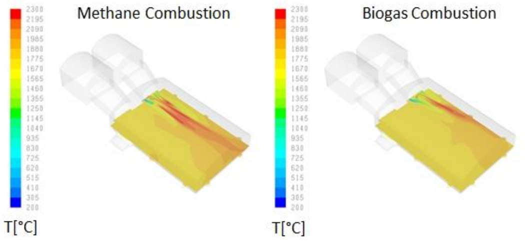

Figure 4: Temperature fields in the burner plane for combustion of pure methane and biogas in a horseshoe furnace

Mobile Test Rig Experiments

The experiments carried out at GWI gave important first insights into the effects of biogas utilization in industrial combustion processes. The "biogas" used in these experiments, however, was synthetically generated so that many questions pertaining to the application of biogas in industrial furnaces remained unanswered. Compared to natural gas, biogas -especially when produced from biowaste feedstock such as kitchen waste- is subject to significant variations in its composition and properties. Also, it may well contain trace elements which can interact with either the glass melt or the refractory material of the furnace, potentially causing decreased glass quality or reduced refractory lifetime.

In order to investigate the possible effects of biogas utilization on both glass quality and refractory properties, a mobile combustion chamber test rig with a flue gas duct was designed, built and equipped with the necessary safety and control technology which can be moved to different biogas plants and then use the locally available, only roughly de-sulphurized biogas for the experiments. During the research project, three measurement campaigns at different sites were carried out: one at a biogas plant which uses renewable resources; the second plant used bio and food waste with additional packaged foodstuff as feedstock, while the third campaign was a reference run at the GWI with natural gas.

A sketch of the test rig with the various measurement positions can be seen in Figure 5, while Figure 6 shows an image of the actual test rig installed at one of the biogas plants. One peculiarity of the test rig is that it was specifically designed to allow for the insertion of both glass and refractory material samples in various positions in furnace and flue gas duct without interrupting operations (cf. Figure 7). A 100kW burner was installed in the test rig while air ratios where controlled by a lambda probe in the exhaust gas duct. The furnace was operated at air ratios commonly found in glass melting furnaces ($\lambda \approx 1.05$). The biogas was directly drawn from the fermenter plant and only roughly de-sulphurized.

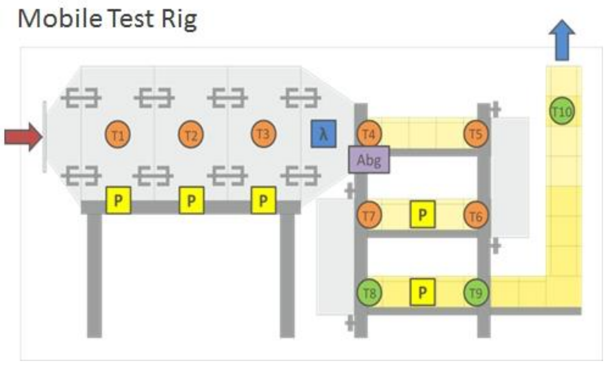

Figure 5: Sketch and measurement positions of the mobile test rig

Figure 6: Mobile test rig with measurement positions

Figure 8 shows the evolution of furnace temperatures, as measured by thermocouples, during one day of operations. The dips in the curves are due to the opening of access ports in order to introduce samples into the furnace.

Figure 7: A crucible containing a glass batch sample is inserted into the furnace

In addition to temperature measurements, relevant species in both the fuel and the exhaust gas are also continuously monitored (cf. Figure 9).

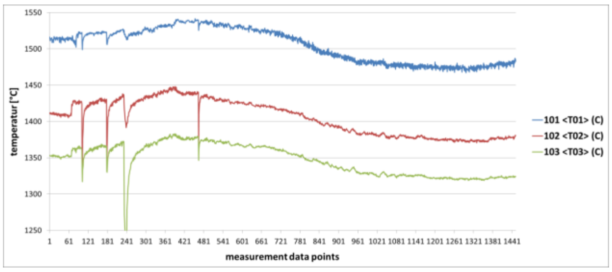

Figure 8: Typical temperature measurements in the test rig

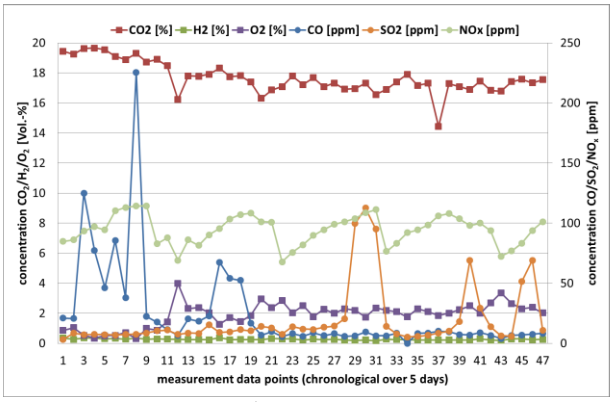

Figure 9: Flue gas analysis for a 5-day interval

Using this mobile test rig, it was possible to investigate the impact of untreated biogases of various sources on furnace operation, pollutant emissions, glass quality and refractory material. One aspect of concern may be the sulphur content in the biogas. While the SO_2 emissions due to biogas combustion are relatively small compared to other SO_2 emission sources in the glass manufacturing process such as refining, the overall increase of SO_2 emissions however may make the installation of a desulphurization plant necessary, putting the overall economic feasibility of biogas utilization in question.

The detailed analysis of glass and refractory samples which were exposed to biogas combustion flue gases, however, showed that neither glass nor refractory did suffer from prohibitive negative effects due to the use of biogas.

Conclusions

In the course of the AiF-funded research project "Biogas Glas (AiF-Grant No. 397 ZN)", the applicability of untreated biogas for the combustion in industrial furnaces (glass melting furnaces in this case) was investigated. In addition to experiments with synthesized biogas which were carried out to analyze the impact of the fuel change on furnace operations, the focus of this project was also on the interaction between trace elements in the untreated biogas and samples of glass batch and refractory material in order to see if the untreated fuel will cause unacceptable losses with regards to glass quality or refractory properties. The results of the two-year project show that even untreated biogas can be in fact used to produce glass without compromising the glass quality or negative impact on the refractory material. If biogas is to be used exclusively, modifications of both the furnace and the burner systems should be modified in order to compensate for the different properties of biogases and natural gas, especially with regards to densities and calorific values.

Both experiments and simulations show that a co-firing approach is probably the most suitable strategy for using biogas in existing furnaces with a minimum of modifications.

In the context of pollutant emissions, the different composition of biogas, especially with regards to nitrogen-containing compounds and sulphur, has to be taken into account. If fuel-bound nitrogen is present in the fuel, it may drastically increase overall NO_X emissions. Sulphur in the fuel has also be considered, especially since natural gas is generally taken to be sulphur-free, at least in Germany.

Acknowledgments

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References

[1] Hassan, A., "Möglichkeiten, Potenziale, Hemmnisse und Instrumente zur Senkung des Energieverbrauchs und der CO_2-Emissionen von industriellen Branchentechnologien", IREES Expertenworkshop, Frankfurt a.M., 2010.

[2] Beerkens, R.G.C., van Limpt, H.A.C., Jacobs, G., "Energy efficiency benchmarking of glass furnaces", *Glass Science and Technology*, vol. 77, no. 2, pp. 47–57, 2004.

[3] N.N., "Wirtschaftliche Energie trotz verringerter Einspeisevergütung", *Gas*, vol. 61, no. 2, pp. 19–22–, 2010.

[4] Märtin, M., Giese, A., Fleischmann, B., Wuthnow, H., "Biogasbefeuerung in der Glasproduktion zur Reduzierung der CO_2-Emissionen - Untersuchungen der Auswirkungen auf die Glasqualität, das Feuerfestmaterial und die Schadstoffemissionen (BG-G)", Final Report, AiF-Forschungsprojekt IGF-Nr. 397 ZN, Essen,2014.

[5] Duclos, J., Marchand, B., Buchet, P., Perrin, M., Guerrini, O., "Towards green gases solutions for industry", International Gas Union Research Conference (IGRC), Copenhagen, Denmark, 2014.

[6] MacLean, S., Leicher, J., Tali, E., Giese, A., "Biogas Utilization in Small Decentralized CHP Applications", IFRF 17th Member Conference, Maffliers, France, 2012.