One of the conclusions reached at the United Nations Climate Convention in Kyoto in 1997 was the need for self-regulation as a method of reducing greenhouse gas emission levels within a decade.

By the year 2012 European Union (EU) countries will have to reduce their emissions by 8% from their 1990 level. EU authorities have defined their self-regulation programme so that EU countries will make individual contributions to the total amount of carbon dioxide reduction (or more precisely, the CO₂ equivalent of a number of different greenhouse gases).

The reduction programme will operate from 2008-2012. From 2005 onwards, emission monitoring and trading programmes will be established. During the first stage emissions will have to be registered nationally, in accordance with an ‘allocation plan’ to be drawn up by each EU country. Each procedure will be different for each country. Each company registered as an emission source must acquire certificates for their current emission level. In Germany, the National Environment Ministry has already stated that a limited number of certificates will be made available and that these will not equate with the total emission levels registered in the allocation plan.

Limiting emissions will have a major economic impact. The German Glass Industry Federation (HVG) is concerned and has discussed the matter with the Environment Ministry, placing emphasis on the special situation for the glass manufacturing industry where some basic aspects of melting technology mean that significant energy savings cannot be expected within the near future. No conclusion was reached during the discussions and the HVG has therefore called for further lobbying.

The basic energy balance of a glass melting furnace and the energy efficiency of modern furnaces are described below. This data is analysed in order to identify any possible way of optimising energy consumption.

### Energy balance in a glass furnace

A standard type of glass furnace will be used for comparison. The most common furnace type in use for container glass is end-fired and heated with gas or oil. A regenerator is used at the end of the furnace to recover waste gas energy, and the batch is charged from one or both sides near the back wall. The energy balance for an energy-consuming process can be shown in a Sankey diagram.

#### Heat content of the glass

The heat content of the molten glass consists of the chemical heat reached to convert the batch to glass, and the heat required to raise the glass to the target or exit temperature. The chemical heat needed to convert batch to glass is independent of the melting technology used. It can only be influenced by the cullet ratio or the batch moisture level.

Fig 3 shows how the chemical heat, the cullet ratio and the moisture content of the batch relate to each other. The extreme values shown are the result of a 25% reduction in energy consumption. The glass exit temperature depends on the individual furnace design and the glass produced. High quality glass requires a higher process temperature in order to ensure complete refining.

Special refining procedures and furnace designs, such as vacuum refining or the shallow refining bank, can help to reduce the average process temperature by releasing blisters without running the furnace at high temperatures. However, the potential energy savings need to be studied in relation to the energy balance of the entire system.

#### Heat flow through the walls

Heat loss through the bottom, tank side walls, furnace superstructure (the sides
walls of the combustion chamber) and crown has been significantly reduced in recent years by the development of new refractories with several layers with a higher insulating efficiency. A typical heat loss calculation for a 90m² melting area end-fired furnace is given in fig 4.

Total losses from furnace walls are less than half of the heat content of the glass so there is no significant potential for reducing wall heat loss, except by minimising uninsulated wall areas. Joints and areas that are kept free of insulation because of bracing can comprise up to 10% of the overall wall surface.

Wall heat loss is actually a function of the average process temperature and melter surface area for the furnace. Larger furnaces have a better ratio between pull and melter surface compared with smaller furnaces. Furnaces with several chambers (ie for melting and refining) will always have higher relative wall losses.

Regenerator efficiency

The third potential optimisation area is the regenerator efficiency. The temperature of the preheated air depends on the heat capacity and the surface of the checker packing, the flow speed of the gases and the temperature difference between gases and packing.

Efficient end-fired furnaces operate with a waste gas temperature of less than 450°C after the regenerator, and a preheat temperature of more than 1200°C. Further small increases in heat recovery are possible but if the combustion air temperature is to be increased further, the remaining temperature difference between the packing and the air will be very small.

Example of an energy balance

The efficiency of a furnace is closely related to the maximum pull for which the furnace is designed. A reduction in pull has an impact on the total energy balance of a furnace. The total energy balance for a 125 m² end-fired regenerative furnace is shown in fig 5. The data relates to a melting load of 350/24 h with a cutlet ratio of 50%. The furnace is heated with natural gas.

The total pull of a glass furnace with several production lines depends on the type of articles produced. The item weight and the cuts per minute have an influence on the furnace capacity. Market changes and customer requirements can alter the situation and reduce the efficiency of the entire melting furnace.

Specific improvements in efficiency

Lower furnace load causes a reduction in regenerator efficiency and increases wall losses, so the best possible specific energy consumption is only reached when the furnace is working at the optimum pull level.

Furnaces fired by fossil fuels can be made with a realistic melting capacity so that efficiency targets can be achieved. Additional melting capacity, which may sometimes be required, is provided by an electric boosting system usually applied to the furnace by electrodes installed through the bottom in the batch melting area. Typical operating data for a large end-fired regenerative furnace is given in fig 6.

Boosting helps to improve energy efficiency, but the electric power generation is linked with CO₂ emissions of about 400g CO₂ for 1kWh. The boosting raises the total amount of CO₂ to 5%. Converting an end-fired furnace into an oxy-fuel fired furnace reduces energy consumption and leads to increased CO₂ emission, because the oxygen plant consumes a large amount of electrical power. A comparison is given in fig 7.

Other concepts and outlook

Other developments to improve glass melting furnaces are in progress, particularly for the production of special glasses. In such cases the aim is to improve glass quality, whereas energy efficiency is not taken into consideration. Examples of this are vacuum refining and high frequency refining.

The US Glass Manufacturing Industry Council (GMIC) is funding a programme to identify the melting technology of the future. The results have been published(4) and an overall energy consumption figure given. The concept is a two-chamber furnace with a rapid melter, which is heated by oxygen burners and electric boosting, together with a refining chamber. The energy consumption is expected to be 0.94 kWh/kg of glass.

This energy consumption level is already being achieved with this end-fired furnace design. The energy balance shows that it is not possible to attain a specific energy consumption for this type of furnace much below 0.9 kWh/kg glass. Basic thermodynamic principles and technical limitations mean that no major improvement in energy consumption can be expected.

Furnace operation, which is the result of production requirements, can have a significant effect on efficiency. However, the conclusion is that the glass industry will not be able to make a significant contribution to the reduction of global emissions.

The programmes established by the authorities are based on a time frame which is not suitable for the glass manufacturing business. Furnaces built today must run for the next ten years in order to achieve a return on investment, and furnace ageing will cause energy consumption to rise during this time. No significant change in technology is possible during the tank campaign.

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