Josef Müller, Róbert Bódi and Frantisek Matustík* describe the advantages of using advanced control to achieve high-quality glass production.

A system for optimal glass furnace control

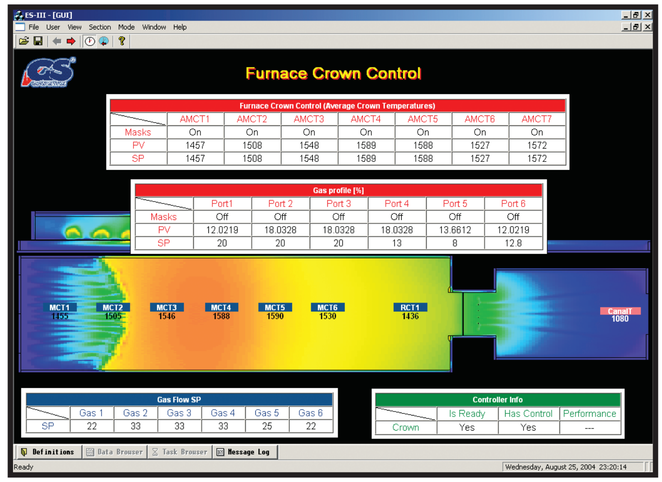
Glass quality depends on several factors, such as the type of control system used for glass production. For simple processes with one input and one output, it is sufficient to have well tuned PID control loops, but for more complicated processes with several inputs and outputs, it is difficult to reach a high-quality control aspect by manual or PID control. The main problem with manual control is that there are large amounts of information related to the process behaviour, such as the interdependence between all inputs and outputs, dynamics of those relationships and outside influences, etc.

These relationships can be different even for various types of glass product on the same furnace (small or big bottles, coloured glass, etc). Successful glass production also has technological requirements, such as restrictions on inputs and outputs etc, for corresponding glass production.

A different approach is used for a well-tuned PID loop. Although control actions are calculated automatically, these optimal control actions are only for the relationship between one input and one output. There is no technological approach to convince one PID loop that there are more inputs influencing its controlled output, and vice versa - one input influences more than one output. Furnace control by several PID loops is therefore not accurate due to the missing information between the respective PID loops about another PLC's behaviour.

Manual and PID control systems have advantages too; manual control means that it tries to control the whole process including disturbances – the influences that cannot be eliminated but can be considered for calculation. Simple and automatic step calculations are an advantage of PID loops as they are high precision.

Advanced control combines the advantages of manual and PID controls as well as eliminating their faults. Information about process relationships between inputs (including disturbances) and outputs are taken into account at the same time, so that all interactions are considered and optimal control actions are calculated and performed. These algorithms are independent of furnace operator strategies, as well as eliminating PID pairing problems, etc.



▲ *Fig 1. ESIII furnace crown control user's screen.*

The process is influenced by Manipulated Variables or MVs (eg heating, cooling, pressures, valves, etc) and Disturbance Variables or DVs (eg the entrance temperature into the forehearth). The measured outputs (Controlled Variables or CVs) show how the process was influenced by changes to the MV and DV variables.

Essentially, the process is characterised by the history of the inputs and outputs. However such information is not enough for a detailed process description, so a process model (which is a mathematical description of all of the relationships in the process) is implemented, based upon the historical data. This model should describe the process behaviour as accurately as possible, and in turn, the model should allow us to predict the future process behaviour.

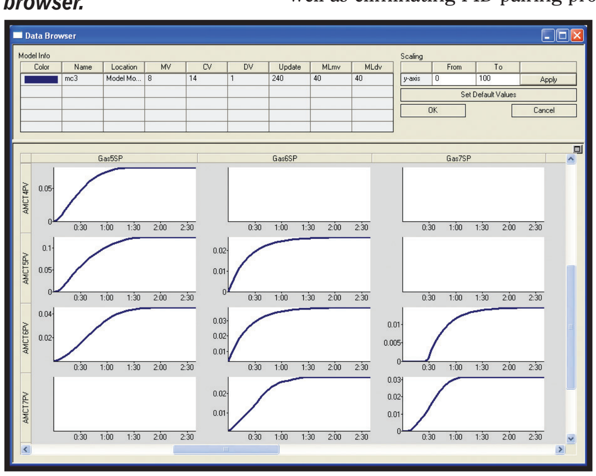
Together with the model knowledge and the past process behaviour including inputs and outputs, the history controller optimises the next control actions. When the suggested control actions are completed and the model has accurately described the process behaviour, then the calculated prediction would be the same as the actual process behaviour. This feedback is important in case the actual process behaviour differs from the predicted future process behaviour suggested by algorithm, so that the algorithm would be able to make a correction.

The MPC technique seems to be very suitable for advanced control, and in the case of a sufficiently precise model the future process behaviour is also predicted. This means the process behaviour is known in advance, so the user can look at the suggested next optimal steps.

However there are glass production processes where the MPC technique cannot be used. Unexplained or non-measured disturbances can cause the model to be unreliable, such as when the process behaviour predictions include imprecise measured variables, temperature oscillations around their desired values, or even frequent changes of a controller's control strategies that can cause an unstable situation. To avoid such an unwanted control behaviour there is an alternative - the FLC technique.

This is one of the rule-based control systems, and its size depends upon a lot of factors such as the number of observed variables, number of possible results, etc. For each combination of possible results of the variables (rules), there

▼ *Fig 2. ESIII data browser.*



Control algorithms

A good mathematical algorithm for process control is a basic part of each advanced control system. There are two such algorithms - a model predictive control (MPC) algorithm and a fuzzy logic control (FLC) algorithm.

A simplified explanation of the MPC technique can be given based upon a diagram.

is a control action that should be executed. According to logic based rules, there are only two values (true, false) at each scan time, with just one rule being valid with a corresponding control action then performed.

The use of fuzzy logic instead of the two-value logic approach brings more efficiency into making the decision. Compared to a rules-based system, the fuzzy logic controller is much more consistent. It means that very small changes of the initial conditions result in very small changes upon the control actions. It is not necessary to have any models of the process behaviour, and unknown disturbances can be eliminated by the FLC. However, FLC has no precise prediction of process behaviour; there can be only some raw estimation of the future process behaviour based upon some experiences.

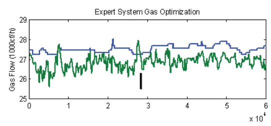
An absence of the prediction for the FLC controller means that the MPC controller is a leading method for advance control systems. The FLC technique will only be used following unsuccessful attempts to get reliable process behaviour models.

Implementation of an advanced control system

Some aspects of the system implementation should also be mentioned. The main purpose of these systems is to control the process and to calculate the optimal control actions requested by the user. If the control method used is the MPC, then the appropriate process model has to be available. There are several possible ways to know how to obtain this model. It can be imported from an external source, it can be generated automatically based on process knowledge, or it can be identified in accordance with tests performed upon the process, etc.

Process possibilities should also be monitored, so it is necessary to design user screens which allow the user to see requested data or values in the form of graphs, tables, etc. There are a lot of additional tasks that have to be done for successful advanced control system implementation, such as valid and stable communication connections between the advanced control system and the current furnace control system, database creation, user's rights, etc.

Generally, a good installation of the advanced control system is a very important stage of its implementation into the glass factory. Only a stable and well-tuned system can serve as a precise process control, bringing the following benefits to the user:



Gas (1000cf/h)	Port #1	Port #2	Port #3	Port #4	Port #5	Port #6	Total Gas	Cost per year
Operator	27.6	27.7	27.8	27.5	21.2	8.7	140.5	$4,923,120
ESII	27.0	27.0	27.1	26.7	20.6	8.3	136.7	$4,789,968
Savings	0.6	0.7	0.7	0.8	0.6	0.4	3.8	$133,152

Cost of 1000cf of natural gas: $4.00 — Saving of total gas in % 2.70

▲ ***Fig 3. ESIII gas fuel optimisation compared with manual operator's control.***

- More stable glass production - temperature stabilisation, increasing efficiency (forehearths), glass homogeneity
- Improved quality by reducing glass defects
- Reduced time for product changes - minimised production losses
- Energy savings and the effect on emissions - NOx reduction
- Increased furnace lifetime - stable temperature processes
- Almost no operator intervention - reduced disturbance, elimination of operating strategies
- Consistency and increased safety of the glass melting process.

The ESIII advanced control system

The ESIII expert system was developed to create a universal system primarily configured for advanced control, so all of the tools available are fully configurable by the end user. Tracking of ESIII project phases is done by a tree–folder structure.

Firstly, communication between the ESIII system and the current hardware has to be established, then the user can continue with the variables registration and with configuration of the built-in database for process data gathering.

All data from the initial tests of the process behaviour can be imported, analysed and identified in order to obtain a first estimation of the model. Based on this model, the design of a PRBNS test can be configured, followed by its execution and simultaneous process identification. If there are sufficiently reliable models from previous versions, previously obtained models can be imported into the ESIII structure.

These models allow the user to configure the controller. The MPC controller configuration can respond to requests on outputs, the retention of fuel distribution profiles, the possibility of reaching the ideal values for inputs, and choosing the control strategy.

The ESIII has user screens which enable the user to see either a graph, a table or both. For instance, to see a furnace and the place of the thermocouples and the related temperatures, the user can view the picture of the furnace and all of the necessary information placed upon the picture wherever the user wants to see it.

The ESIII System can also simulate process behaviour if there is missing process data. The same model can be used for the controller as well as for the simulator, or different ones can be used to see how the advanced control works when the model or controller does not correspond with the process behaviour.

Improvements

The ESIII has the following attributes:

- Furnace operation consistency with a low level of operator actions needed
- Furnace and sensor fault detection
- Furnace stability
- Stable crown and bottom glass temperatures, less risk of corrosion
- Stable temperature for glass delivery to the forming machinery
- Increased homogeneity and consistency to the forming process
- Reduced time and production losses for product changes
- Continuous optimised heat input distribution
- Less glass defects from melting and forming
- Increased throughput and tighter control of the whole process.

Glass Service has seen energy savings of up to 2-3%, and improved yield up to about 8% from installed furnace applications.

Conclusion

The concept and benefits of advanced control have been explained. Advanced control brings a new level of process optimisation in the whole furnace technology, from batch charging to conditioning. The system has been applied in TV, fibre, float and special furnaces including air-fuel and oxy-fuel technology. G

* *Josef Müller, Róbert Bódi, Frantisek Matustík, Glass Service Inc, Vsetín, Czech Republic. Tel: +420 571 498 511. Fax: +420 571 498 599. Email: glass@gsl.cz*

Significant increase in melting productivity

Linde AG's Linde Gas Division, together with the BOC Group, has reached a licensing agreement on the marketing of the Connective Glass Melting (CGM) technology developed by BOC. Under the agreement, Linde will now offer CGM technology under the name Corox-CGM to glassmakers worldwide.

Corox-CGM is a melting technology that uses oxy-fuel burners located in the crown of a glass furnace. Thereby a convective heat transfer is generated in addition to the normal radiant heat transfer, which means that more energy is transferred into the glass melt.

This leads to a significantly increased melting capacity which can be used to extend furnace life. Another advantage is an improved glass quality.

The CGM technology has been implemented successfully in 20 furnaces making float, container and speciality glass. Air-fuel furnaces, as well as oxy-fuel furnaces, can be optimised further using the Corox-CGM system by which Linde Gas offers another solution to glassmakers in their daily challenge to enhance production, improve quality and meet emissions regulations.

Linde Gas Division is one of the leading gas suppliers worldwide and is now Linde Group's largest division, employing 17,500 people. Linde Gas supplies 1.5 million customers in more than 50 countries with very comprehensive know-how in different applications, extensive services and the surrounding hardware.

Contact Dipl-Ing Hans Mahrenholtz, product manager glass, Linde AG, Linde Gas Division, Unterschleissheim, Germany. Tel: +49 89 31001 696. Fax: +49 89 31001 699. Email: hans.mahrenholtz@linde-gas.com; Website: www.linde-gas.com