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# GOB TEMPERATURE CONTROL

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## ABSTRACT

Significant quality and throughput improvement to the glass container manufacturing process has been demonstrated by a new control method that directly controls the gob temperature. The new temperature control method combines ACSI's predictive-adaptive model based control system with BASF's Exactus® advanced high-speed optical gob temperature sensor. The gob temperature sensor provides an accurate and repeatable measurement of each sheared gob. The model based control system continuously adjusts the upstream process to ensure that the gob temperature is at the setpoint regardless of environmental conditions. The system has been field tested at the Saint-Gobain Containers, Inc. – Dunkirk, Indiana, USA plant, and has demonstrated the ability to improve gob temperature stability substantially as compared to conventional PID control. Results of implementing the new control method include improved manufacturing efficiency, product quality, and reduced gob temperature recovery time following a job change.

## INTRODUCTION

Conventional methods of controlling gob temperature do not include direct gob temperature measurements. The operator monitors the equalizing thermocouple measurements as a reference and adjusts individual forehearth zones in an attempt to maintain a stable glass temperature before it enters the forming process. The actual gob temperature can only be assumed or measured with a conventional optical pyrometer which is often unreliable and incapable of being used for closed-loop control.

To eliminate the uncertainty of the actual gob temperature, ACSI and BASF have developed a solution that accurately measures and controls the gob temperature. The system utilizes direct measurement of each gob through the use of the Exactus® advanced gob temperature sensor (GTS) produced by BASF. By combining the measurement from the GTS with ACSI's advanced model based control (BrainWave®), exceptional gob temperature stability and control is achieved at the point of entry to the forming process. This solution, described below, has provided significant benefits for Saint-Gobain Containers, Inc. including reduced variation in the production process and reduced gob temperature recovery time after a job change.

## THE ADVANCED GOB TEMPERATURE SENSOR

Conventional optical temperature sensors typically measure light energy using a photodiode sensitive to a range of infrared wavelengths. The signal from the photodiode is amplified with hard-wired amplifiers, providing a calibrated output of target temperature. These instruments usually suffer from a poor tradeoff between repeatability, speed, resolution, and data processing capabilities.

Recent advances in microelectronics circuits allow for amplification and measurement circuitry to be brought onto a single microprocessor, allowing for direct digital measurements which are faster, more accurate, and much less prone to drift over time. Additionally, the onboard microprocessor can automatically compensate for ambient temperature changes and provide sophisticated processing of measurement data. The result is an instrument that can process up to 1000 measurements per second with greater accuracy and nearly zero instrument drift.

The benefits of accuracy and very low drift are obvious for gob, or any other process temperature measurement. The benefits of high speed are essential for gob temperature measurements. Depending on the gob length and velocity, 1000 readings per second provide 25 to 40 temperature measurements of each gob. Each of these measurements can be output digitally and/or processed by the instrument and output as a single average temperature of the gob. Conventional IR temperature sensors, with their low speed, typically have to look up at the orifice when attempting to measure the gob temperature; the upward viewing angle leaves these sensors susceptible to contamination from shear spray and other contaminants. The GTS, with its much faster measurement rate, can be aimed to measure the gobs well below the shears. This allows for a downward viewing angle so the optics are much less likely to be contaminated.

Instrument optics are designed to provide a very small, concise measurement spot with 99% of the light energy within a circle 15 mm or less at a focal distance of 2 meters. The optics are coupled to the measurement electronics with high temperature rated fiber optic cables.

The optics are contained in a protective housing with plant instrument air providing a continuous flow of air over the optics and out the sight port, ensuring the optical components stay clean. The optics housing is installed in a heavy gauge metal adjustable mount which allows for side-to-side and vertical adjustment of aim. Bright green diode lasers are utilized to provide an exact image of optics alignment and focus quality. Figure 1 displays the GTS schematically.

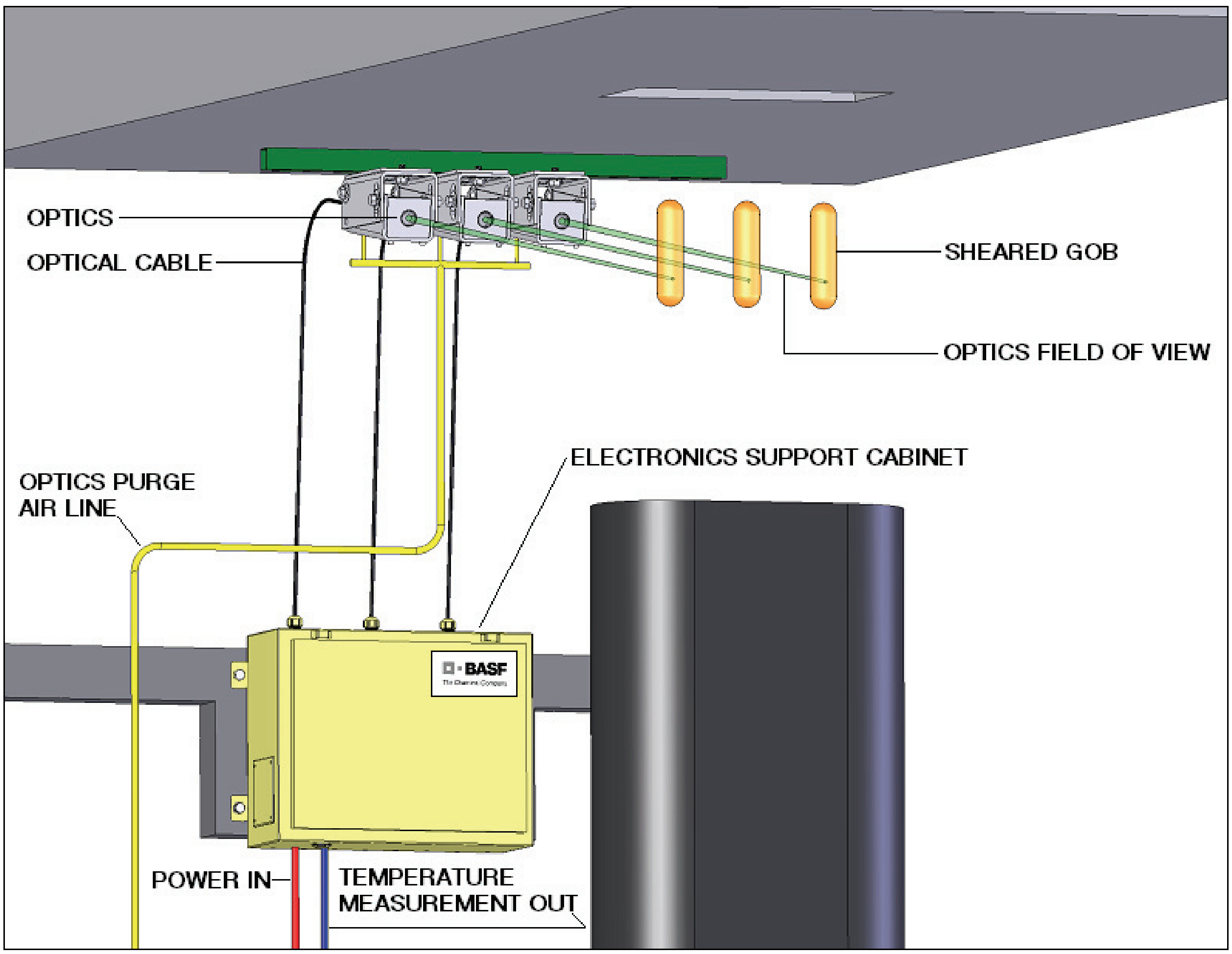


Figure 1: Schematic of gob temperature measurement system

## MEASUREMENT WAVELENGTHS

Two primary techniques exist for optical temperature measurement; single wavelength (sometimes called brightness measurements) which correlates the intensity of light at one wavelength to temperature, and dual wavelength (sometimes called two-color or ratio measurement) which measures the radiant intensity at two wavelengths and correlates the ratio of those intensities to temperature. The high-speed, dual wavelength technique as used by BASF's Exactus gob temperature sensor is essential for gob temperature measurement.

The transparency of container glasses varies widely with color, temperature, and wavelength of light. The transparency influences how deep the effective temperature measurement is into the glass. In the visible and near infrared, amber and green glass are partially transparent such that the radiation emitted by the gob originates over a depth of 0 to 10mm. Flint glass is much more transparent and radiation emitted in the visible to near infrared wavelengths originates from depths of 0 to 100mm. Outside the near infrared, container glass becomes fully opaque and longer wavelength optical measurements of gobs become surface temperature measurements which will vary with environmental conditions such as ambient air and shear spray temperature.

Beneath the air-glass boundary layer, the glass is quite isothermal for a particular horizontal section of the gob. For colored container glasses such as amber and green bottle glass, the measurement wavelength must be short enough that the interior of the gob is measured. Flint glass is highly transparent at near infrared wavelengths such that the emitted radiation originates from the entire depth and will depend on the diameter of the gob. The dual wavelength technique used by the GTS solves the concern of gob diameter dependence because the glass transparency is essentially equal at the two measurement wavelengths and any variation in gob thickness will not significantly affect the ratio.

Shear spray and smoke can also affect gob temperature measurements. Each of these will attenuate the light energy from the gob that reaches the instrument optics. Single wavelength measurements are strongly affected by shear spray and smoke. Dual wavelength measurements are usually unaffected by shear spray but intense smoke can cause a few degree measurement change; typically this change is short term and is averaged out in the data acquisition hardware.

## PEAK PICKING

After shearing, the gobs fall freely, accelerating as they approach the distributor. Gobs are typically measured below the drip pan where the gob velocity is usually greater than 13 ft/sec. At this speed, about 40 independent temperature measurements will be taken of a 6-inch long gob. Typical gob temperature profiles appear similar to what is shown in Figure 2.

In order to provide the gob temperature to the control system, a type of signal processing is necessary to isolate the gob temperature from the background measurement when a gob is not in the instrument's field of view. 'Peak picking' systems have been available in measurement systems for some time. When a high temperature occurs, the output will increase to a value indicating the maximum temperature measured by the instrument, commonly called the 'peak temperature'. Conventional peak picking instruments can only output the highest value measured; for gobs, the highest value measured is often not desirable. In both Figure 2 and Figure 3 the leading and trailing edge of the gob data stream show values significantly greater than is measured in the middle of the gob data. The high measurements are caused when the dual wavelength measurement views the hemisphere shaped top and bottom of the gob; these are optical effects and are not real glass temperature variations. Conventional peak picking systems will output these erroneous values causing false maximum readings to be processed as gob temperatures.

The Exactus gob temperature sensor by BASF has the ability to eliminate these values from the measurement by storing numerous measurement points and processing them as a group. The user configures the measurement with two pieces of information, the minimum possible gob temperature and the number of measurement points to ignore from both the leading and trailing edge of the gob. For gobs in a general container manufacturing operation, the minimum temperature might be 2010°F and nine data points ignored from each end of the gob measurement data stream. In the example shown in

Figure 3, there are 42 valid measurements above the 2010°F-threshold temperature. Removing nine measurements from each end of the measurement profile leaves 24 valid measurements of the gob. The user has the option of transmitting the maximum or average temperature in the region of interest. The average temperature is typically used because it provides a better indication of the amount of heat transferred to the forming machine from the gobs.


Figure 2: Gob temperature profiles

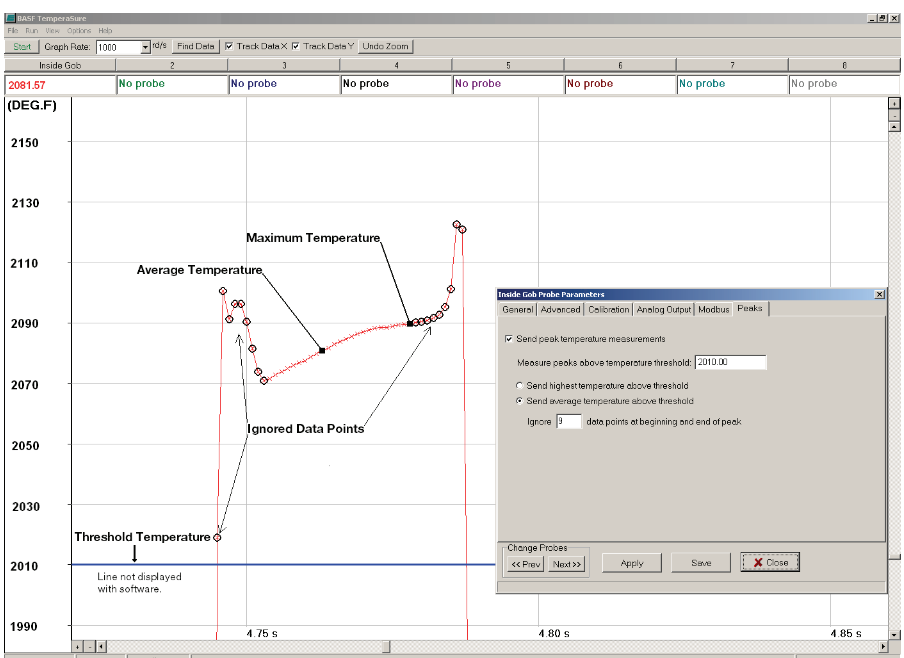


Figure 3: GTS ‘peak’ processing – measurement data from one gob displayed

**THE SIGNIFICANCE OF THE GOB TEMPERATURE**

Continuous monitoring and controlling of the gob temperature allows container manufacturers to remove thermal variation from the forming process. Because the gob temperature measurement is unaffected by the depth of glass in the forehearth as immersion thermocouples are, it is a better measurement to use when attempting to repeat process conditions.

**GOB TEMPERATURE VARIATION**

The GTS has monitored the gob temperature on several lines that have conventional PID control. The data has indicated that the gob temperature can fluctuate by as much as 16ºF while the equalizing zone thermocouples indicate stable behavior. It has also been realized that the mechanics in the feeder have a significant impact on the gob temperature. For example, adjustments to the shearing and gobbing process have shown to change the overall gob temperature and the temperature relationship amongst the gobs from the different orifices. It has also been observed that the gob temperature commonly oscillates at the tube rotation frequency.

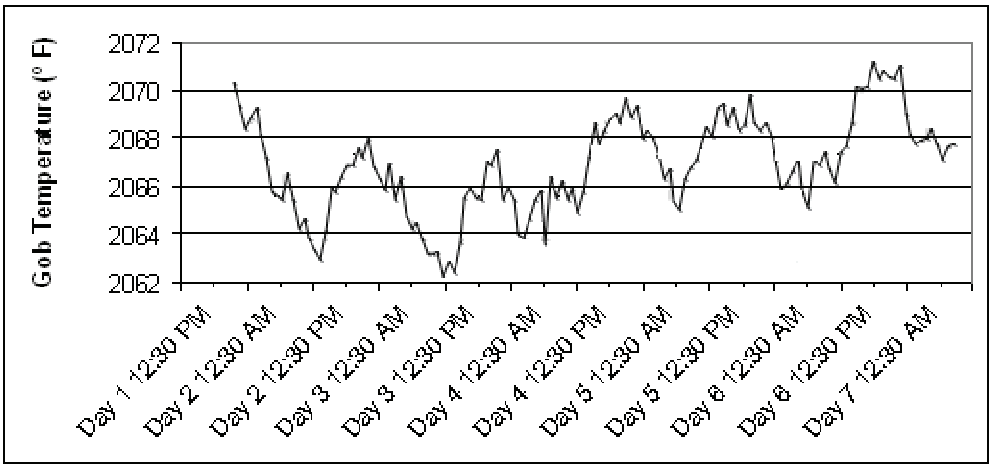

Figure 4: Gob temperature over several days

Figure 4 shows how the gob temperature can fluctuate day-to-night. While this data was acquired, the equalizing zone thermocouples indicated stable behavior.

**CONTAINER DEFECTS AND GOB TEMPERATURE**

The presence of container defects was compared to gob temperature on a continuous job, amber glass container line with PID control. It was observed that changes as small as a few degrees in gob temperature impacted the presence of seal surface and split finish defects. Figure 5 shows the normalized quantity of containers with either defect compared to the gob temperature. Because the forehearth was controlled with conventional PID, the gob temperature varied significantly as explained above. The gob temperatures were divided into three bins and tracked to the presence of container defects. As shown in Figure 5, an effective optimum gob temperature can be determined with the information from the GTS. The data shows that on this particular line, the quantity of containers with either defect is significantly reduced when the gob temperature is within ±2.5ºF of the optimum temperature.

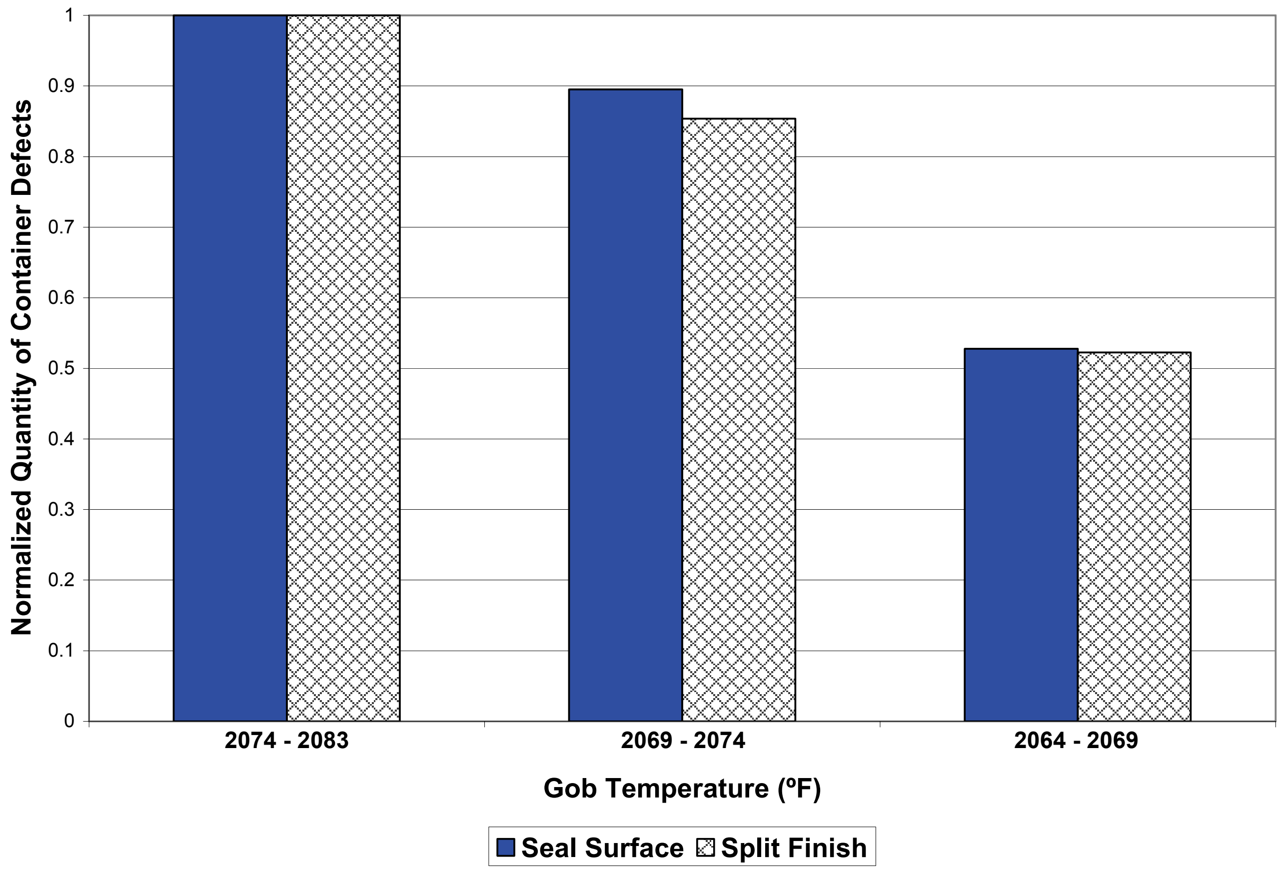


Figure 5: Container defects and gob temperature

**MODEL BASED CONTROL (MODEL BASED CONTROL VERSUS PID)**

Model based controllers (MBC) are outperforming PID control in glass applications and therefore have become a preferred installation by manufacturers. The MBC quickly responds to process disturbances and reacts quickly to stabilize temperature variations. A model based controller creates models for each control/process variable and feed forward input. The ideal model then anticipates changes needed to maintain consistent glass temperature. Once the optimum process is modeled, model based control

- Predicts control actions required to drive the glass temperature to setpoint quickly without overshoot.
- Continuously adapts to process and production changes automatically for better control without loop tuning.
- Models feed forward inputs and updates control actions to quickly stabilize temperature variation.

**CONTROLLING THE FOREHEARTH AS A UNIT**

Typically, the 9-point grid is monitored to determine temperature stability in the forehearth. The operator assumes that there is a direct relationship between gob temperature and the 9-point grid. The operator adjusts the individual zone temperatures in an attempt to achieve the desired gob temperature. As explained above, data from direct gob temperature monitoring has shown this method of control to be unreliable from both an accuracy and stability standpoint.

This new control method allows the grid temperatures to be controlled directly using the model based system. This system understands the interrelationships among zones; therefore, it removes the complications that would normally be difficult for operators to resolve. The model based controller:

- Thinks of the forehearth as a unit, not as individual zones
- Prioritizes temperature readings to determine the most important temperatures
- Allows zones to work together rather than fight each other

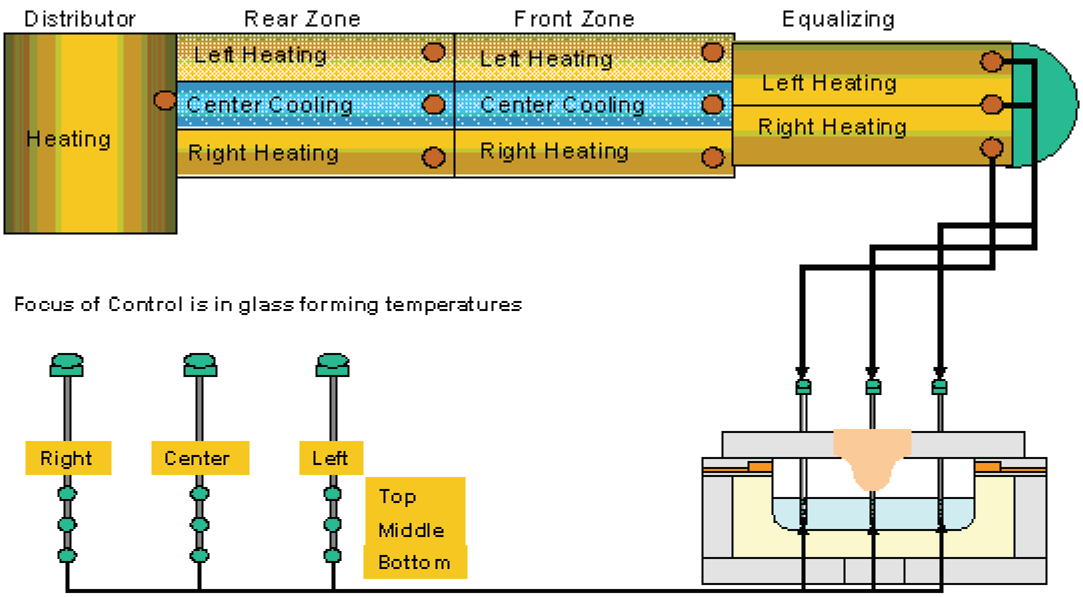


Figure 6: Typical forehearth and 9 point grid

**MASS FLOW TEMPERATURE CONTROL**

The mass flow temperature (MFT) is made up of an average of nine equalizer triplex temperature values. Each of these nine temperatures is given a priority, where some values are more important than others. The higher the priority, the more interest the model has in keeping the temperature at a desired setpoint. Lower priority temperatures can be slightly off setpoint without affecting the glass quality.

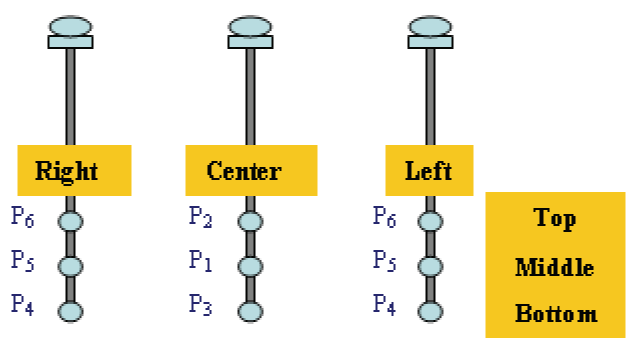


Figure 7: Nine equalizer triplex temperature values

In this new system rather than controlling temperatures by individual zones, the mass flow temperature is used to control the entire forehearth. Individual zone temperatures are no longer of interest, because the equalizer triplex temperatures are now controlled directly. The setpoint for the mass flow temperature is automatically adjusted by the gob temperature model.

## FEED FORWARD REAR ZONE DISTURBANCE REJECTION

The rear zone (and sometimes distributor) is used in this strategy to remove any incoming temperature disturbances and to position the glass temperature in a range that allows the front and equalizing zones to handle the final conditioning. The entrance forehearth temperatures are fed forward and used as an input to the forehearth model. The system is now aware of an upset before it reaches the forehearth entrance, and output adjustments can be made to eliminate the temperature upset before it enters the remaining forehearth zones. Ultimately, this prevents unstable glass from traveling through the forehearth.

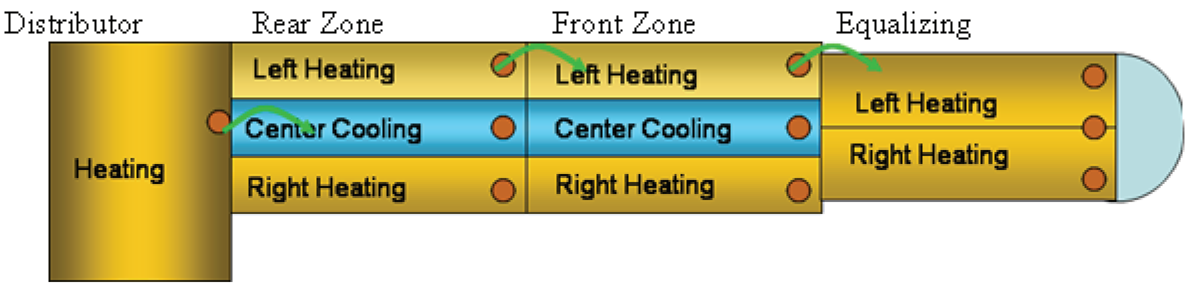


Figure 8: Feed forward

## GOB TEMPERATURE CONTROL

The gob temperature measurement from the GTS is used as the process variable for a model based control loop where an operator can enter a desired gob temperature setpoint. The output of this model determines a new setpoint for the mass flow temperature. The mass flow temperature is a composite of the nine triplex readings in the conditioning zone of the forehearth. The desired MFT is adjusted by the gob temperature control model. Model based controllers are used to adjust zone heating and cooling values to maintain the desired MFT therefore controlling the forehearth as one unit. To avoid process upsets and disturbances before they reach the conditioning zone, there is rear zone disturbance rejection (feed forward). Feed forward models are used to minimize incoming temperature disturbances. These models eliminate the effect of job changes on adjacent forehearth and melter upsets.

## RESULTS OF MODEL BASED CONTROL OF THE GOB TEMPERATURE

The following presents the results of the gob temperature model based control system installed on a dual-gob flint glass container line.

Table I. Expected benefits and results of gob temperature control system

| Expected Benefits | Results of Field Trial |
|---|---|
| Reduced variability of gob temperature | 7x reduction in gob temperature variation (95% confidence) |
| Faster compliance to setpoint changes | Reduced gob temperature stabilization time after a job change from 5-7hrs to 0.5-4 hrs |
| Faster recovery from disturbances | Significant reduction in lost production volume caused by job changes |
| Improved process quality | 50% less time required to achieve stability |
| Improved performance after a job change | |
| Improved gob weight consistency | |

**Gob Temperature Stability**

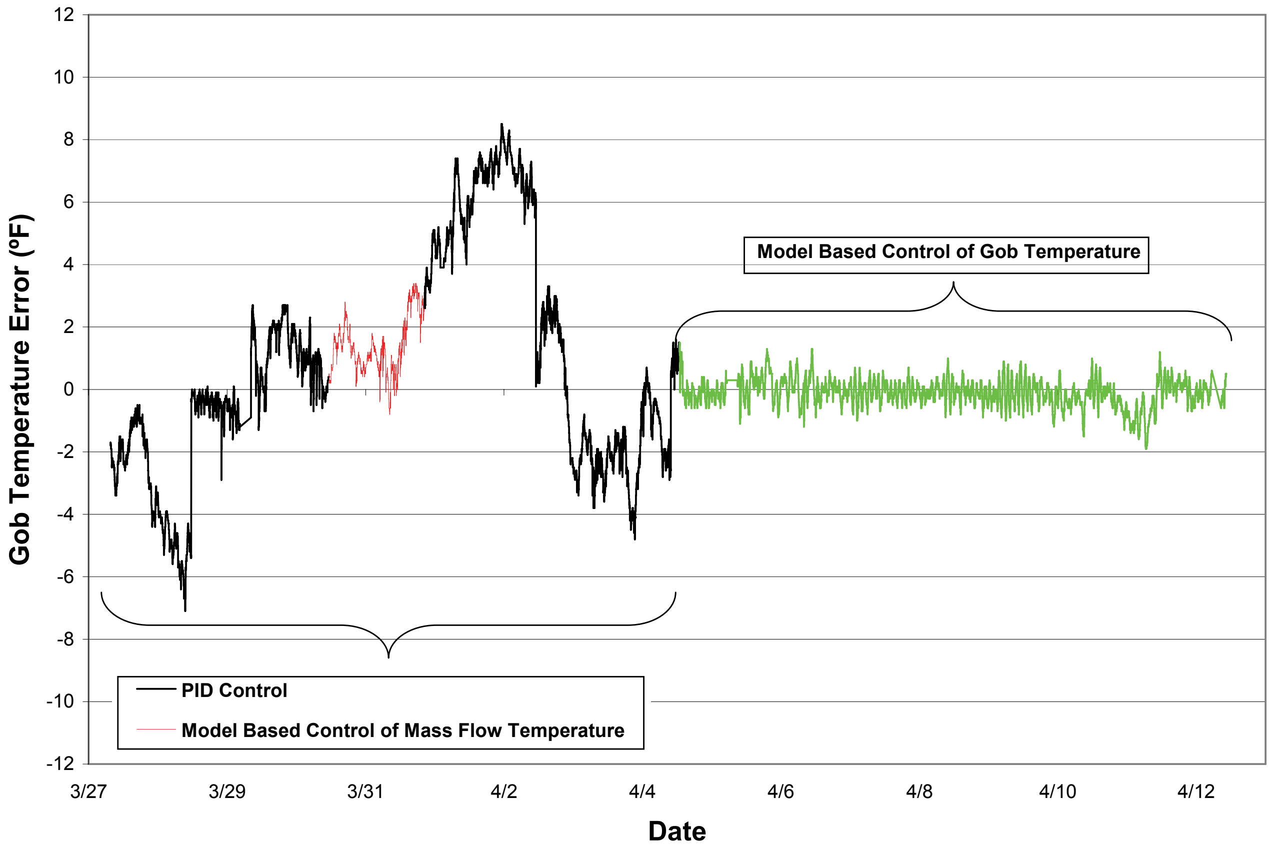


Figure 9: Gob temperature variation for different control methods

Figure 9 displays the gob temperature error on one container line during a 16-day period with the following configurations:

1) PID control
2) Model based control with the mass flow temperature as the process variable
3) Model based control with the gob temperature as the process variable

The gob temperature error is defined as the difference between the desired and actual gob temperature. In the case of the MBC system using the gob temperature measurement as the process variable, the error is the difference between the measured and the setpoint.

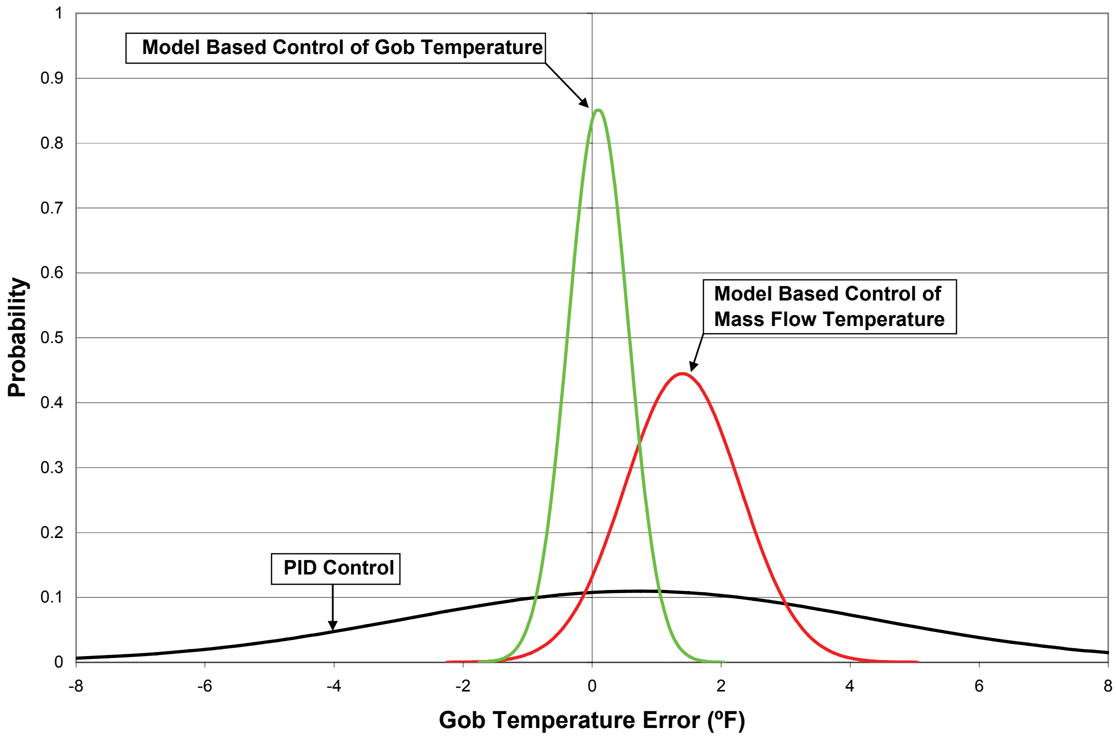


Figure 10: Normal probability distribution of the gob temperature error under different control methods

Figure 10 displays the normal probability distribution of the three control methods during the 16-day period. It can be seen how the model based control system controlling the mass flow temperature achieves greater stabilization of the gob temperature as compared to PID. When the gob temperature is used as the process variable, the model based control system is able to further stabilize the gob temperature and keep it much closer to the desired value.

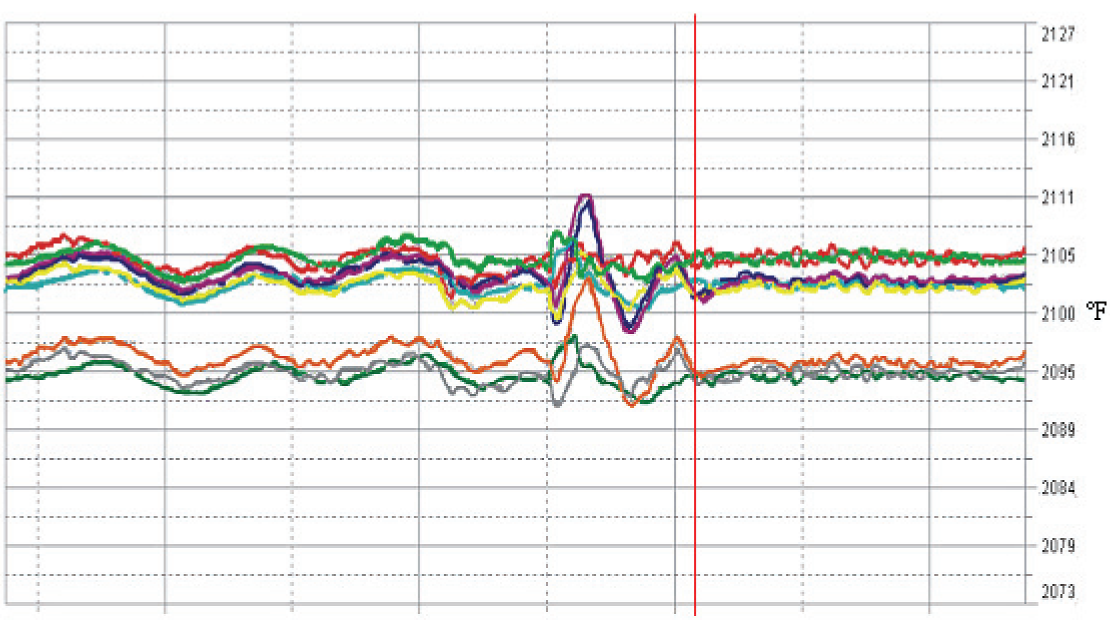


Figure 11: Nine point grid before and after model based control

**Job Change Performance**

The two figures below show the 9-point grid temperatures during job changes. These two forehearths are essentially equal to one another in size, tonnage, and pull rate, and the same setpoint changes have been made. The results are dramatic and show the ability of model based control to quickly stabilize the temperature during job change, thereby minimizing the time it takes to return to steady operation.

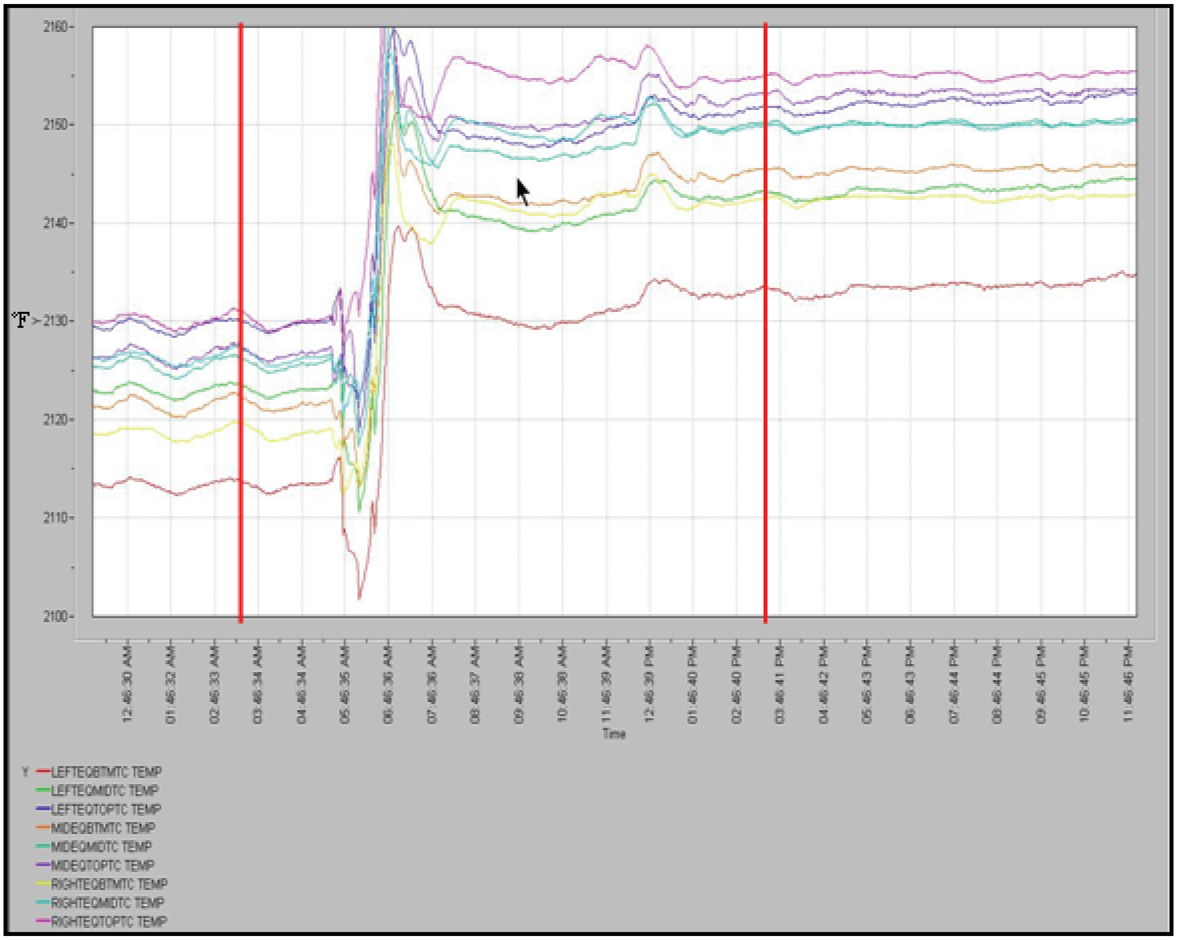


Figure 12: Job change with optimized PID tuning

Figure 12 represents optimized PID tuning, which was tuned as well as possible prior to the change. The total time from setpoint change to stabilization is approximately 8 hours.

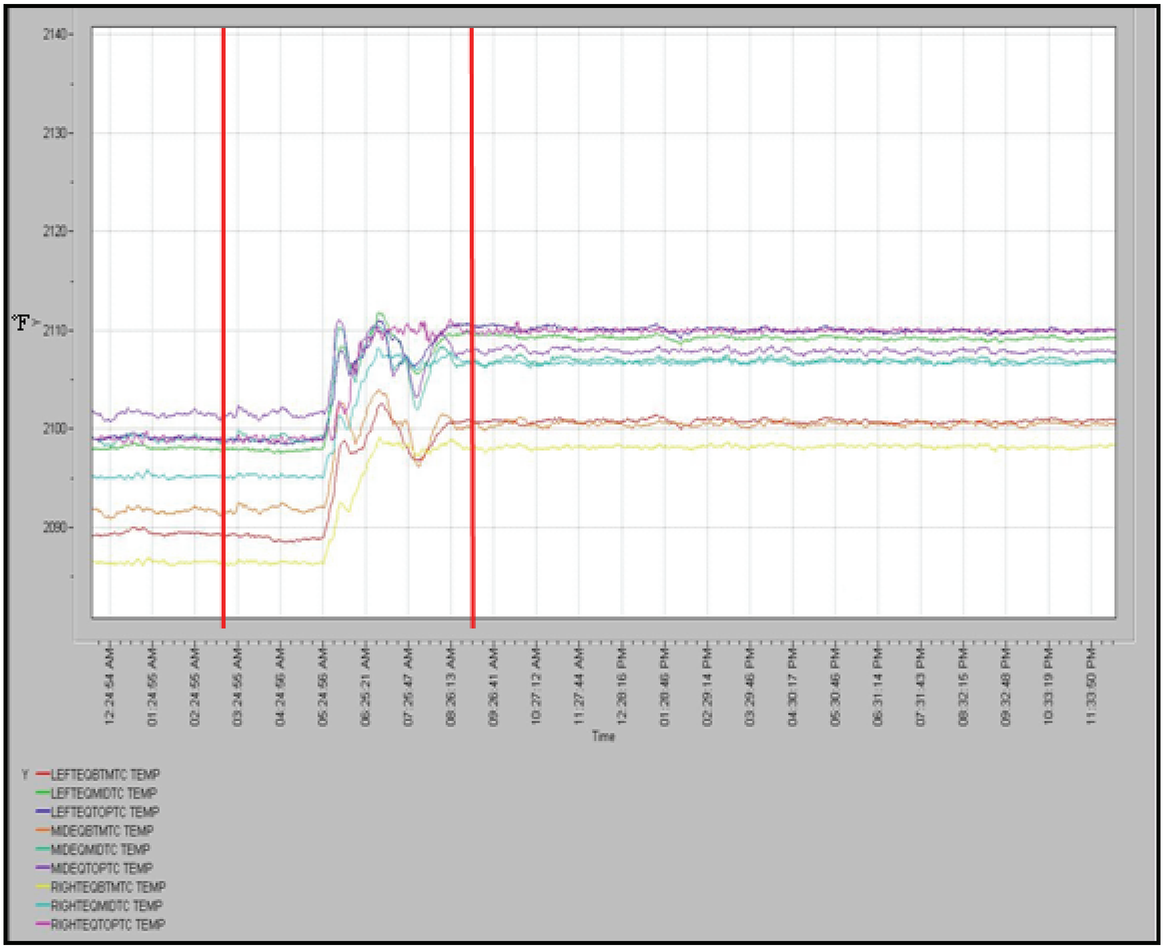


Figure 13: Job change with model based control

Figure 13 represents a job change on a forehearth using model based control. The total time from setpoint change to stabilization is approximately 3 hours, only 25% of the time it took for PID to stabilize.

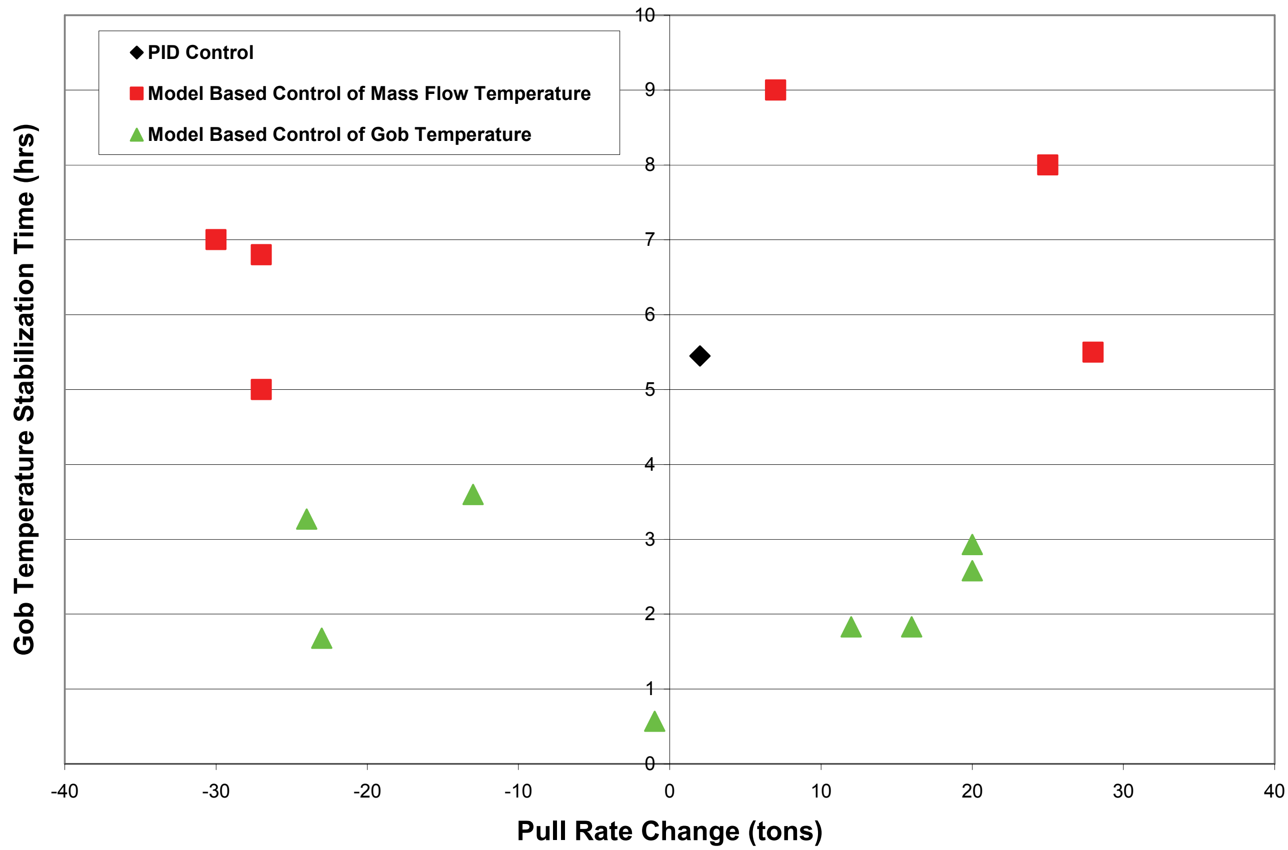


Figure 14: Gob temperature stabilization time after a job change

Figure 14 contains data from fifteen different job changes given different control methods. Both the pull rate change and time required to achieve stable gob temperature conditions are plotted. Stable conditions were defined as ±1ºF for the MBC. PID control could not achieve ±1ºF so the time required to reach typical gob temperature stability was recorded.

In order to equalize the data displayed in Figure 14, the ratios of tons changed to time required for gob temperature stabilization were calculated. Figure 15 displays the averages of the calculated ratios defined as the gob temperature recovery rate for the different control methods.

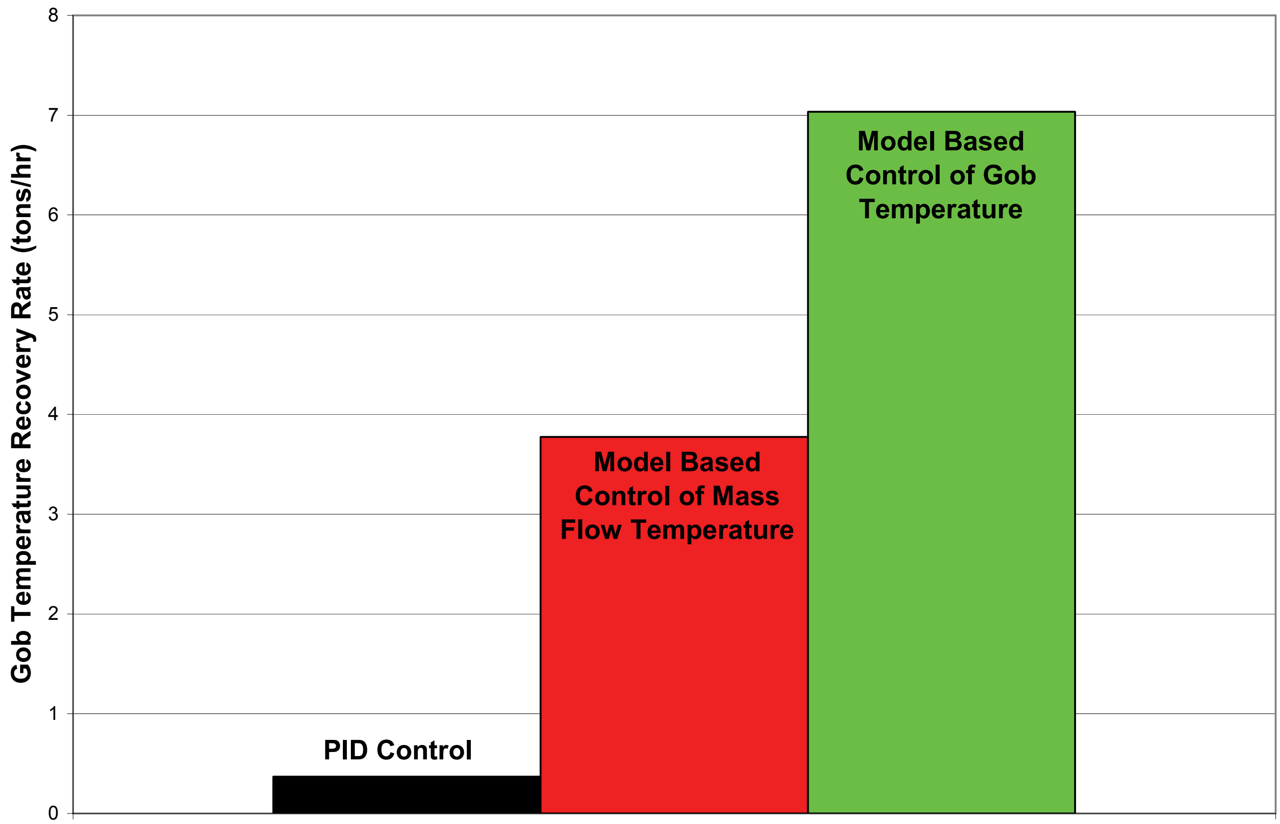


Figure 15: Gob temperature recovery rate after a job change

**CONCLUSION**

BASF's Exactus advanced gob temperature sensor is capable of providing an accurate and repeatable temperature measurement of each sheared gob. The sensor has demonstrated that with conventional PID control, the gob temperature can vary significantly even though the equalizing thermocouples indicate stable behavior. At the Saint-Gobain Containers, Inc. – Dunkirk, Indiana, USA plant, it was found that if the gob temperature could be maintained to within ±2.5ºF of the optimum temperature, the presence of seal surface and split finish defects could be significantly reduced.

The ACSI model based control system (BrainWave®) possesses the ability to tightly control the gob temperature to better than ±1ºF. The BrainWave system treats the forehearth as a single unit rather than several zones and continuously adjusts the upstream process in order to maintain the setpoint. The BrainWave system quickly reacts to process disturbances and significantly reduces the time required for the gob temperature to return to a stable condition after a job change.

By combining the advanced technologies of BrainWave and Exactus, ACSI and BASF are able to offer container manufacturers a solution that tightly controls the glass temperature at the point of entry into the forming process. This new type of control allows the plant to minimize container defects, improve production efficiency, and significantly reduce the gob temperature recovery time after a job change.

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## About BASF Catalysts

BASF's Catalysts division is the world's leading supplier of environmental and process catalysts. The group offers exceptional expertise in the development of technologies that protect the air we breathe, produce the fuels that power our world and ensure efficient production of a wide variety of chemicals, plastics and other products, including advanced battery materials. By leveraging our industry-leading R&D platforms, passion for innovation and deep knowledge of precious and base metals, BASF's Catalysts division develops unique, proprietary solutions that drive customer success.