Original Paper

Gob weight fluctuations due to a stirrer and to glass melting firing reversals

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It was difficult to adjust gob weights from a stirred, molten glass delivery system. The difficulty decreased when rotation of the gobbing stirrer was stopped. However, this was not a satisfactory solution as it left objectional striations in the glass items being produced. The weight changes were due to the superposition of several effects, each of which by itself would have been acceptable. Small temperature fluctuations and spontaneous changes in the stirrer's position and stroke were found but they were not the major causes of the weight fluctuations. Cyclic variations in weight with an amplitude of about 1% and a period of about 11 min were due to the stirrer's rotation. It became clear that close but approximate matching of the gobbing and rotational rates was inadequate and that synchronization of these two rates had to be perfect to eliminate this cyclic weight variation. The inevitable conclusion was that run-out associated with stirring was the cause of this problem. A second cyclic variation with a period of 20 min and an amplitude of about 0.4% was associated with tank reversals of the cross-fired melter with its regenerative checkers. This was the first time that weight changes due to tank reversals were noted.

A composite weight variation curve was synthesized, with one component representing an 11 min cycle and a second component representing a 20 min cycle formed by a ramp with a linear decay. A comparison of the synthesized and actual weight curves revealed many similarities and strengthened the conclusion that most of the actual weight run changes resulted from the stirrer and from tank reversals.

Schwankungen des Tropfengewichtes durch einen Rührer und durch Feuerwechsel beim Glasschmelzen

Die Schwierigkeiten bei der Einstellung der Tropfengewichte aus einem Rinnensystem mit gerührter Glasschmelze nahmen ab, wenn die Rotation des Rührers angehalten wurde. Dies war jedoch keine befriedigende Lösung, da sie störende Schlierenbildungen in den fertigen Gegenständen hinterließ. Grund für die Änderungen des Tropfengewichtes war die Überlagerung mehrerer Einflüsse, von denen jeder für sich durchaus akzeptabel wäre. Geringfügige Temperaturschwankungen sowie plötzliche Änderungen der Position und des Taktes des Rührers wurden festgestellt, sie waren aber nicht die entscheidenden Ursachen für die Gewichtsabweichungen. Zyklische Gewichtsveränderungen mit einer Amplitude von ungefähr 1 % und einer Dauer von etwa 11 min waren auf die Rührerrotation zurückzuführen. Es wurde klar, daß eine begrenzte, lediglich angenäherte Anpassung der Tropfenzuführungs- und Rotationsraten nicht ausreichend war und daß die Synchronisierung dieser beiden Geschwindigkeiten vollkommen sein mußte, um die zyklische Gewichtsveränderung auszuschließen. Die zwangsläufige Schlußfolgerung war, daß diese Abweichung in Verbindung mit dem Rühren der Grund für das Problem war. Eine zweite zyklische Änderung mit einer Dauer von 20 min und einer Amplitude von etwa 0,4% wurde in Verbindung gebracht mit dem Feuerwechsel der Querbrennerwanne mit ihrer Regenerativkammerausgitterung. Damit wurden erstmals Gewichtsveränderungen festgestellt, die durch Feuerwechsel verursacht waren.

Eine zusammengesetzte Gewichtsvariantenfunktion wurde erstellt, bei der eine Komponente den 11minütigen Zyklus repräsentiert und eine zweite Komponente den 20minütigen Zyklus darstellt, der sich aus einer linear ansteigenden Rampenfunktion ergibt. Ein Vergleich der theoretischen und der realen Gewichtskurven zeigt viele Ähnlichkeiten auf und stützt den Schluß, daß sich die meisten der auftretenden Gewichtsschwankungen auf den Rührer und auf die Flammenwechsel zurückführen lassen.

1. Introduction

Forming machine operators were complaining that it was difficult to decide when to adjust gob weights especially when the weights were changing spontaneously and other conditions appeared to be stable. The complaints were about a stirred system (figure 1) delivering 48.0 oz ((48.0/16) · 0.454 = 1.362 kg) gobs at 12.5 gobs/min. Over-weight gobs are objectionable as they often produce ware which is rejectable because of rim checks. On the other hand, gobs which are too light are also objectionable as they do not have enough glass to fill the molds and result in increased losses. Consequently, gob weights are often specified to within ±1 %.

Part of the difficulty was due to changes in weight between successive gobs. This difficulty decreased when rotation of the gobbing stirrer was stopped. However, this was not a satisfactory solution as it left objectional striations in the glass items being produced [1]. Bruns [2] had also observed this type of problem. He was one of the first to conclude that rotation of stirrers was responsible for weight fluctuations between successive gobs obtained from a stirred glass delivery system. He concluded

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[1] Now retired.

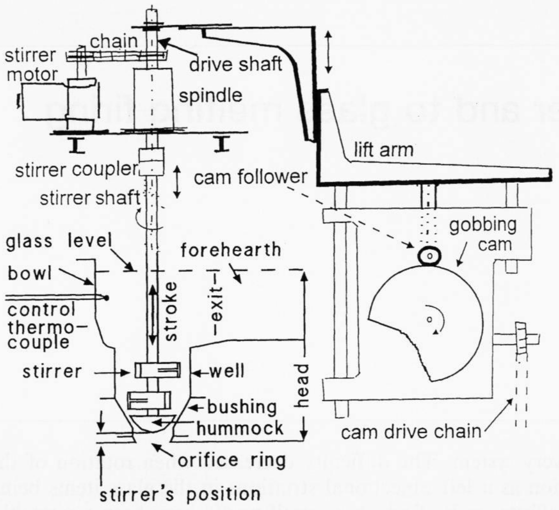


Figure 1. Sketch of a gobbing stirrer, its delivery system and its gobbing mechanism. The head (H) is the depth of the glass above the orifice.

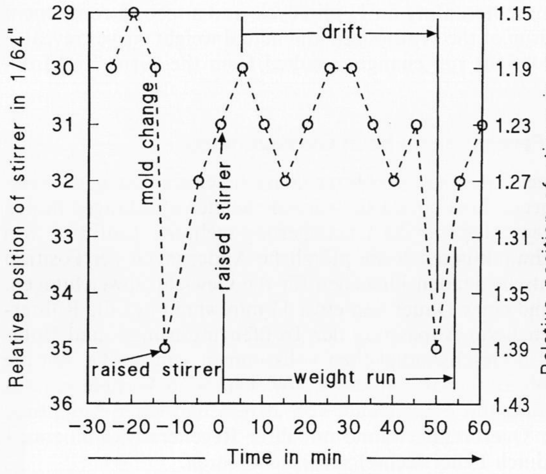


Figure 2. Position of the stirrer relative to the orifice.

that this weight fluctuation could be eliminated if the stirrer's rotational speed was made equal to the gobbing rate. In an attempt to synchronize these two rates, the stirrer's rotational speed was adjusted to equal the gobbing rate to within 0.15 %.

For this investigation two weight runs were made. A weight run consists of keeping track of the weight and other pertinent data associated with the ware being made. The data were obtained with the operator making no adjustments to the stirrer's position except as noted in figure 2. The delivery system was an outlet for a conventional, fossil fuel-heated, regenerative glass melter. During the first run, pieces were taken from the press at 1/2 min intervals. During the second run, consecutive pieces were kept in order, annealed, collected at the end of the line and then weighed.

2. First weight run

2.1 Hartford mechanical feeder

As the problem appeared to be due to gobbing, a (crude) attempt was made to get data on the position and stroke of the stirrer. These data were obtained at 5 min intervals. As it was hard to get reliable numbers and to gain some experience, the measurements were started before the weight run. After a mold change, the forming press machine operator found that the gob weight was unexpectedly quite low. He had to crank the weight-controlling screw twice to get the correct weight. He was then asked not to change the weight and the weight run was started. Gobbing appeared normal, but the data suggested a somewhat cycle change in stroke and near the end of the run showed an unexpected change in the position of the stirrer (figure 2). The change in position occurred because the weight screw vibrated loose from its set position.

As usual the vertical motion of the gobber was controlled by a cam follower mechanism. The cam follower is a roller which rides against a gobbing cam which converts the rotary motion of the driving motor into the desired vertical motion for the stroke (figure 1). Variation of the stroke was explained when it was observed that the gobbing cam follower did not remain in contact with the cam on the downstroke of the gobbing cycle. This meant, of course, that the resistance on the downstroke could vary from gob to gob. Variations of the stroke are undesirable as they can result in cyclic weight variations. These data showed that the feeder's performance had to be improved.

2.2 Temperature

It is known that glasses in delivery systems have variable temperature distributions [3 and 4]. From past experience with the borosilicate glass for this investigation it was known that the core glass entering a bowl could be as much as 50 K hotter than the outer layers [5]. Rotation by stirring caused mixing of all the glass in the bowl and the temperature variations were further smoothed out by a recording temperature controller. This controller was activated by an under-glass bowl spout thermocouple assembly which projected into the bowl (figure 1). The controller had a 700 K span and a sensitivity of ±0.1 %. Thus, it could control temperatures to (700 K · ±0.001 =) ± 0.7 K. In other words, as the temperature at the control thermocouple reached either limit of the control range, power was automatically adjusted in the electrically heated bowl. Thus, the instrument kept the measured temperature in a ±0.7 K wide band about the control point. From previous experience [5], it was known that this "control band" could result in a weight variation of about ±0.7 %. With this recorder it was not possible to get adequate data. Therefore, a high-speed, more sensitive recorder was put in parallel with the controller. With this instrument temperatures were recorded in millivolts and were accurate to ±0.1 K. Remarkably, during this weight run the overall temperature varied by only 0.6 K. As a result the controller neither added nor decreased power.

The high-speed recorder disclosed a cyclic temperature variation which was too small to activate the controller. Even if power had been changed, the controller probably could not have altered the temperature as fast or with the observed cycles shown in figure 3. Thus, it was concluded that the cyclic temperature resulted from a different amount of core glass moving past the control thermocouple. It was assumed that the temperature cycle also occurred in the gobs as they left the orifice. As the control thermocouple was under-glass in the front of the bowl, this assumption caused the belief that the stroke influenced the temperature from the orifice and up and actually into the bowl. It was concluded that the cyclic temperature variations resulted from gobbing. In addition this meant that there was no (appreciable) time lag between gob weight and bowl nose temperature[2)].

It is remarkable that the in-glass bowl thermocouple was able to respond to such fast temperature changes. This is especially true when its structure is considered. Its two leads were separated by a double bore refractory tube which extended to the thermocouple's junction. This structure was inserted in a closed-end refractory tube which was sheathed in platinum. Without the sheath and insertion into the glass in the bowl, the couple could not have responded to the small and rapid temperature changes.

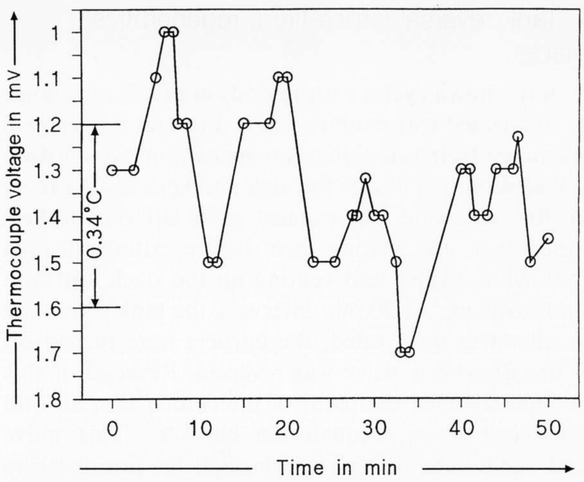


Figure 3. Voltage of the bowl's thermocouple versus time from the suppressed-range, high-speed recorded.

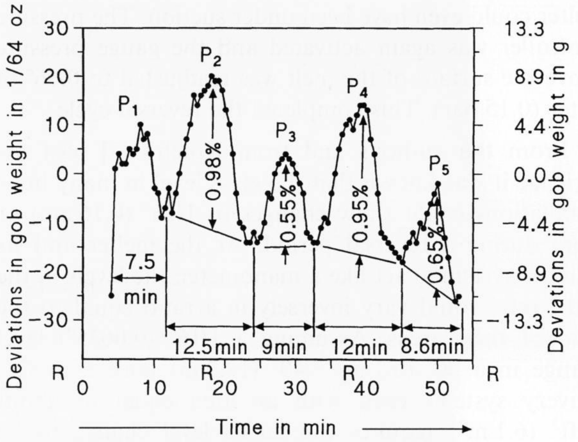


Figure 4. Gob weight deviations from the target value of 1.362 kg versus time. *R* indicates the tank reversal time.

2.3 Gob weight and cycle times

Data for a weight run of about 50 min disclosed a bicyclic variation in gob weights with a maximum deviation of about 1 % from the desired weight of 1362 g (figure 4). If the excursion at P_1 in figure 4 represented a complete cycle, its time would have been 7.5 min. The time intervals for the other cycles P_2, P_3, P_4 and P_5 were 12.5, 9.0, 12.0, and 8.6 min, respectively. Including P_1 the average for these five cycles was about 10 min. Thus, on the average, the number of gobs cut between adjacent peaks was (10 min) (12.5 gobs/min) ≈ 125 gobs.

Thus, if only one type of cycle were present, weights would repeat approximately every 125 gobs. The time between peaks P_1 and P_3 ($7.5/2 + 12.5 + 9/2 = 20.75$) was about 21 min, that between peaks P_2 and P_4 ($12.5/2 + 9.0 + 12.0/2 = 21.25$) was also approximately 21 min while that between peaks P_3 and P_5 was ($9.0/2 + 12.0 + 8.6/2 = 20.8$) approximately the same. With a 21 min period, weights would be approximately the same every (21 min) (12.5 gobs/min =) 263 gobs.

From figure 4 the deviations of the gob weights at peaks P_1 to P_5 were 3.99, 8.87, 1.77, 6.21 and −0.89 g, respectively. The absolute or positive differences between the gob weights for the adjacent peaks were 4.88, 7.10, 4.44 and 7.10 g, respectively. Division of these numbers by 1362 g and multiplication by 100 % yielded 0.36, 0.52, 0.33 and 0.52 %, respectively. The average of these four percentages is 0.4 % which is the average percent weight variation between the adjacent peaks.

It was concluded that two cyclic events would explain the variation in peaks. The more rapid cycles were due to the stirrer's rotation. The longer period cycle was effective in either increasing or decreasing the apparent amplitude of the faster cycle.

[2)] This was an important conclusion [6]. In a subsequent experiment carried out at Corning Inc. the peak temperature of individual gobs was determined with an optical pyrometer. The lens was cleaned and then focused on a gob as it was being formed. After each reading the lens was recleaned and the temperature of another gob taken. In this way it was possible to determine the temperature of alternate gobs. Twenty temperature determinations were made. The values were compared with the corresponding gob weights. One value did not agree, the other nineteen correlated.

2.4 Tank reversal (cross-fired, regenerative furnace)

The only known cycles with periods in the 20 min range were associated with tank reversals. In normal operation fuel entered from one side of the melter and combustion air, heated on its passage through checkers, also entered from the same side. The exhaust gases left via checkers on the other side heating them before exiting through the Blowknox valve and venting up the stack and into the atmosphere. At 20 min intervals, the tank's pressure controller was inactivated, the burners were turned off and the Blowknox valve was reversed. Reversal of this valve interchanged the paths of the combustion air and the exhaust gases through the checkers. This move forced "cold" combustion air through the hot checkers on the other side of the melter. Fuel was then admitted through burners on this same side and the exhaust gases exited through the opposite, cooler checkers. Possibly this whole procedure required less than 1 min. Changes in the direction of air flow had to be accompanied by surges in pressure and during part of this cycle the melter could even have been under suction. The pressure controller was again activated and the gauge pressure above the surface of the melt was readjusted to 0.06″ of water (0.15 bar). This completed the reversal cycle.

From the author's and from Kotch's [7] past experience it was known that the glass level in many bowl installations could show changes of 1/16″ (0.16 cm) or more during a reversal period. As the melter and its delivery system(s) act like a manometer, the levels in the two zones would vary inversely in a ratio equal to the ratio of their areas. Assuming a 1/16″ (0.0625″) level change in a 20′ (6.1 m) · 40′ (12.2 m) tank with five delivery systems each with an area equal to about 20 ft^2 (6.1 m^2) requires the tank's level change to be [(0.0625″) (5 · 20 ft^2)/(20 · 40 ft^2) =] 0.008″ (0.02 cm). This small change in the melter's level was not measurable even though water in an inclined glass tube is used to measure gauge pressure. To raise the bowl's level by 1/16″ requires a pressure on the surface of the melt end of the tank also to 1/16″ of molten glass. As the glass melt has a density 2.25 times that of water, the equivalent gauge pressure would have to be (0.0625 · 2.25 =) 0.14″ (0.36 cm) of water. A surge in the pressure of this magnitude during the actual reversal time interval does not seem to be unreasonable.

From figure 4 the percent difference in peak values between adjacent cycles was calculated earlier to be about 0.4 %. If this difference is due to a change in the head of glass, it can be used to estimate it. From figure 1 it is clear that head is the pressure at the orifice due to the level of the glass in the bowl. Assume that gob weight is proportional to head and keep all the other variables constant, then, logarithmic differentiation yields

$$\Delta W/W = \Delta H/H\,.$$

In this equation $\Delta W/W$ is the fractional change in gob weight and is equal to 0.004 while H is the head of glass above the orifice and ΔH is its change. Drawdown (this means the loss in glass level between the furnace and the surface of the glass in the bowl spout) was 1″ (2.54 cm) so the actual head was 15−3/8″ (39.1 cm). Substituting these values in the above equation yields 0.06″ or about 1/16″ (0.16 cm) for ΔH. This agrees with the difference sometimes observed at combustion reversals.

3. Second weight run (data not shown)

For the second run, variations in the position of the weight control screw and drift of the stroke remained smaller than those found earlier. Control temperature was even better than in the first run as it held within 0.3 K. The bicyclic weight variation again was evident and the period appeared to remain unchanged with the peaks between the highs and the lows repeating about every 140 gobs. The cycles now appeared very broad as more data were plotted for the same time interval. The amplitudes were 1.03 and 0.62 for a difference equal to 0.4 %, in agreement with the value found earlier. The total weight variation was 1.2 %. Thus, the second weight run confirmed the earlier data but did not yield any new results.

4. Stirrer's weight cycle

With a fixed design the pumping action of a stirrer depends on its position, direction and speed of rotation (rpm). The position controls the coupling or the influence of the vertical and radial gaps between the stirrer's blades and the stirring well. If the rotational speed of a stirrer that pumps down is increased, then, for the same gob weight with the same stroke, the stirrer must be raised in its normally tapered stirring well. This decreases the coupling by increasing the size of the gaps between the blades and the wall and thus decreases weight variation. As long as the other variables are kept constant, gob weights repeat when a stirrer is in the exact same angular position at the bottom of its down-stroke. The number of pieces required to complete a weight cycle and return to the original weight can be calculated as follows provided the actual gobbing and rpm rates are known. Experimentally it was known that the number of gobs per second was: 100 gobs/480.0 s = 0.20833 gobs/s or 12.50 gobs/min. This number was in agreement with the setting of the press operator. In addition by actual measurements the rotations per second were determined to be 100 revolutions/482.75 s = 0.20715 rotations/s or 12.429 rpm.

Thus,
(gobs/s)/(rotations/s) = 0.20833/0.20715 = 1.0057 gobs per rotation.

When the ratio (gobs/s/rotations/s) is (or almost is) equal to unity, means that gobs are cut when the stirrer is (or almost is) in the same angular position and the

gob weights will (or almost will) repeat. Thus, this last equation can be used to find the integral number of gobs for a weight cycle. In equation form
(integral number of gobs)/(integral number of rotations) = 1.0057.

By trial and error, that is by trying various combinations of integers, it was shown that
(integral number of gobs)/(integral number of rotations) = 140/139 = 1.0072. This was the closest approximation of integers to the desired ratio of 1.0057. Therefore, the weight should almost repeat every 140 gobs in agreement with section 3. The error in the above ratios is (1.0072−1.0057)/1.0057 = 0.0015 or 0.15% as mentioned in section 1. Thus, even though the rotational speed was almost synchronized with the gobbing rate, the small difference between their rates still resulted in a comparatively fast (140 gobs/12.5 gobs/min =) 11.2 min weight variation cycle and the weight nearly repeated every 140 gobs. These numbers agree with those from the first weight run. This agrees with the statement that synchronization must be perfect to eliminate this type of weight variation.

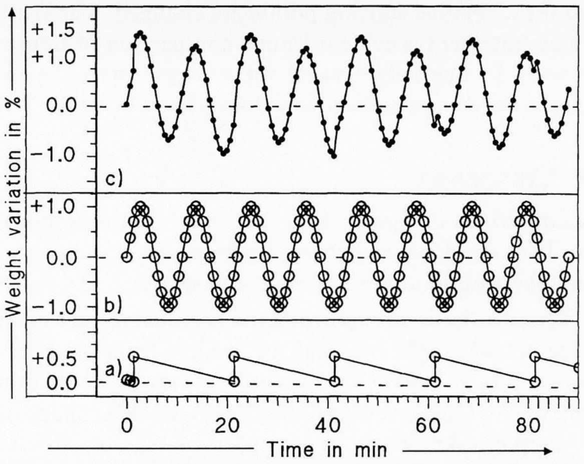
5. Discussion

5.1 Gobbing and friction

The failure of the cam follower to remain in contact with the gobbing cam indicated that the driving force needed to eject gobs was insufficient to overcome the opposing forces. (This defect can be overcome by changes in the gobbing assembly.) The driving force was the weight of the stirrer and its associated reciprocating parts. The opposing forces were due to the shearing forces occurring while the molten glass was being extruded and to friction in the gobbing assembly. The cyclic nature of the gob weights and temperature showed that the opposing forces had to be sensitive to the angular position of the stirrer when gobs were cut. The inevitable conclusion was that the stirrer wobbled while rotating. Thus, synchronization of the gobbing and rotational rates would eliminate much of the weight problem. In addition, the cyclic problem led to the speculation that the friction in the gobbing assembly might be sensitive to the different radial forces associated with any run out of the stirrer. If this was true then this friction could help explain why the cam follower did not always remain in contact with its cam.

5.2 Synchronization

At synchronization all gobs would be cut when the stirrer had exactly the same angular position, so no weight variations would occur. It was also postulated that gobs would have almost the same weight provided they were cut then the stirrer was close to any chosen angular position. This meant (and it was observed) that turning off and restarting the stirrer at a different angular position relative to the stroke would result in a different gob weight. If the stirrer's runout or wobble was the only variable influencing gob weights, then the weight cycles be completely symmetrical with equal positive and negative amplitudes. The cycles could be interpreted as part of a symmetrical wave with a fixed amplitude and period.



Figures 5a to c. Synthesized percent weight variation versus time curves, a) for a 20 min period, linear ramp; b) for a symmetrical 11 min period with a sinus-shaped cycle; c) for the combined action of the 11 and 20 min cycles.

5.3 Tank reversal

At tank reversal a positive surge in the melter's pressure would also result in a surge of glass into the bowl. This inrush would increase the head and be accompanied by a slight increase in the temperature of the incoming surge of glass. Both of these changes would increase gob weights which would return back to normal as the surge decayed. The net result would be a 20 min repetitive cycle starting with a surge. Thus, weight changes due to reversals could also be considered to be a wave whose shape is unknown. Weight variation due to tank reversals will always occur in any regenerative melter unless pressure surges are negligible.

5.4 Synthesis of a weight variation curve

From optics [8] it is known that two waves interact to form a final wave. For the present case this is a weight variation wave or curve. It is also known that the shape of the composite wave (curve) depends on the amplitudes, the periods and the relative starting points (phase angles) of the two waves. To be definite a ramp starting with a 0.5% step and a 20 min linear decay will be assumed to be due to tank reversals (figure 5a). It is also assumed that a symmetrical wave with a 1% amplitude and with an 11 min period represents weight variation due to stirrer wobble (figure 5b). The starting point for figure 5b is assumed to be near the tail end of a ramp. Point by point algebraic addition of corresponding ordinates of these two waves results in the composite weight variation curve (figure 5c). (It is now also emphasized that many "generally similar" curves will result if differently shaped ramps are used and also if the relative starting points are changed. The truth of this statement is evident from a comparison of figures 5b with 5a mentally revised for different step-like increases and decays and starting points.)

5.5 Comparison

A comparison of figures 4 and 5c reveals many similarities. They both have alternate high and low peaks, irregular shapes and jumps in weight and spikes.

This synthesis strengthened the conclusion that most of the actual weight run changes resulted from the interaction of an 11 min cycle due to the stirrer and a 20 min ramp due to tank reversals even though the exact shape of the ramp is unknown.

5.6 Results

This investigation resulted in five programs whose final outcomes were

a) The temperature control for the delivery systems was improved.

b) Tank reversal was upgraded.

c) Drift in position and stroke of the stirrers were eliminated.

d) Runout or wobble of stirrers was decreased.

e) Improvements in the gobbing assembly and synchronization eliminated weight variations due to stirring.

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These programs resulted in minimizing the total weight variations to less than 1 %.

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