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Another task to accomplish regularly in the Batch-Furnace Dept. was the so-called imperfection control. There may exist voids in the bulk of glass caused by non-evacuated air, which are classified based on their sizes as:

• Seed: 0-1 mm • Bubble: 1-2 mm • Blister: > 2 mm

The maximum allowable amounts of these imperfections are standardized as 150 seeds, 4 bubbles, 0 blisters / 30 g glass. I made measurements of these using an optical machine with its appropriate software (SGCC Seedlab 3), taught me by my instructor. The produced series and their codes for all fourteen operating production lines are provided in weekly tables. The codes are entered to Seedlab where the sizes corresponding to the codes are recorded priorly. The specimen (flask or bottle) is then cleaned and loaded to the machine. The machine makes wavelength adjustments by rotating around its central axis and illuminating the specimen. I observed that the adjustment takes more time for amber products. After the adjustments are made, the process is executed and the machine counts the imperfections. The results are recorded and the products failing due to excessive number of imperfections are marked.

In the Batch-Furnace Department, I learned how the raw materials are provided and transferred, how the receipts are calculated and how the batch is prepared. I have been informed about the working principles of furnaces and their important parameters. From the raw material stage up to the end of the furnace, I observed the operation of all the main and auxiliary units on the line. I performed receipt calculations and imperfection control for various types of glass containers. Hence, I established a firm base for an extensive analysis of the fifth step of production in the Production Department.

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As mentioned, the processes beginning with the creation of a glass drop (gob) under the plunger at the far end of the forehearth are the concern of the production department. The primary scope of this department covers the processes following this point up to the end of hot surface covering. Although I observed the entire production line consisting of nine steps in the training program, my priority was surely the fifth step of production with IS machinery, which accounts for the very process of glass forming.

What I have accomplished in the production department is a thorough and stepwise analysis of all the units operating on this portion of the line. However, each and every unit of this production step was involving the operation of huge machinery and complex linkage systems as well as a series of considerations regarding dynamics and heat transfer. The significance of dynamics originates from the need of providing a synchronized distribution of gobs among the individual sections of the IS machines and a smooth operation of the numerous elements building these sections. Also, creation of perfect gobs depends on a synchronized motion of the plunger and the scissors, as will be discussed later in the section. Heat transfer is extremely important in this step as the glass forming process can be thought of as "non-metal casting". Proper cooling of various regions of glass during this process in the molds is obligatory in order to give the glass the desired shape. How narrow the tolerances are will be discussed in the following analysis.

My supervisor / instructor Savaş Saatçi, as well as the remaining

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coworkers in the department were all mechanical engineers. The first thing for my instructor to teach me was how the glass gobs (drops) are created and how they are transferred to the individual sections of the IS machines. He guided me to a clear viewpoint at the forehearth end of the furnace C and explained the dynamics of the system while I was observing the operation of the plunger.

The forehearth end creating the gobs is termed as the feeder. The main elements of the feeder are the plunger, the orifice ring and the tube. The number of gobs produced in each cycle of feeder operation equals the number of holes on the orifice ring, through which an equal number of plungers press down the glass gobs. The weight of a gob is adjusted by the height of the tube which allows glass to move under the plunger. The tube also rotates, homogenizing the glass. Molten glass pressed down by the plunger is cut by the scissors, producing a single gob. The timing of this cutting process is extremely important since it directly determines the weight of the gob, the loosest tolerance of which is about 30-40 g. The scissors operate synchronized with the plungers of the feeder, as their driving arms are connected via a mechanical linkage. The produced gob is received by a moving trough called the scoop, which, directed by a computer program according with some predetermined firing order, transfers the gob to one of the so-called deflectors. The deflectors are stationary and each deflector leads to one of the individual sections of the IS machinery. Briefly, the gob is taken by the moving scoop right after it is cut, travels down

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on it while the scoop is aligning itself with the appropriate deflector, and continues its way down to the blank mold on the curve established by the deflector. The final half a meter is free fall. Considering that an IS machine is composed of 8-10 individual sections, each having a precise working order of its elements, it is simple to observe the need for a computer program to determine and apply an adequate firing order for the gobs. One, two or three gobs can be produced and processed on the same section simultaneously in this factory.

There exist many details regarding the operation of the feeder and the delivery system, which I have learned from my instructor but prove to be beyond the scope of this discussion. For the sake of relating the gathered knowledge with the theory in class, however, I can mention that the height of the feeder tube as well as the level of molten glass on the feeder are adjusted utilizing PID control, as discussed in ME 335.

After getting informed about how the gob is produced and delivered to the sections, I was given an extensive briefing regarding the operation of the IS machines; in other words, the processes of glass forming. These are the very manufacturing techniques applied in this factory, the knowledge of which proves to be extremely important for a mechanical engineer.

As mentioned, there exist three different manufacturing techniques of glass forming: BB (blow & blow), PB (press & blow) and NNPB (narrow-neck press & blow). In all three processes, the gob firstly enters the so-called blank mold and obtains the predesigned shape of a "parison", which is then placed into the blow mold to obtain the final shape of the glass container. The structure of an IS machine is such that the blank molds of each section are placed in a row at one side of the machine and the blow molds are aligned on the other side.

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Blow & Blow Process:

While the gob travels through the scoop and the deflector, the halves of the blank mold are united such that the gob falls through a funnel into the blank mold. Right after this, the so-called baffle settles from upside onto the funnel. The blank mold is placed inverse, such that its upper section corresponds to the bottom of the parison. Through the baffle, the settle blow is applied to the inside of the blank mold, which pushes the gob down onto the "thimble". The thimble is the part which forms the top section of the bottle. Hence, the head of the bottle obtains its shape already in the blank mold. The thimble extends into the blank mold through an auxiliary part called as the neck ring. After the settle blow, the baffle is removed, it allows the funnel to move out, and resettles onto the top of the mold; its air tunnels being sealed. Now the counterblow is applied from downside such that the gob obtains the shape of the blank mold and the parison is ready. The halves of the blank mold are separated and the parison is transferred by the "invert mechanism" connected to the neck ring into the blow mold on the otherside of the IS machine. Because the blank mold was inversely placed, the parison settles properly into the blow mold after this 180° maneuver, and not inversely anymore.

The heat transfer analysis of the process is extremely important since temperature differences at different regions of glass are the primary cause for many defects and residual stresses. When the settle blow and the counter blow are applied in the blank mold, the inner surface of the parison cools due to convection heat transfer and its outer surface cools due to conduction via the cooler walls of the mold. There exist minor channels for air evacuation on the inner surface of the mold and many cooling channels parallel to the longitudinal axis of the mold which keep it always cooler than

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the gob and the parison. Hence, there exists an intermediate layer on the parison which has a higher temperature than the inner and outer surfaces. Such a temperature difference would cause critical problems if the invert maneuver did not account for a "reheat process" which homogenizes the temperature of the parison. Not only the conduction and convection heat transfer occuring during the process, but also the finned structure of the molds involves the stuff covered in ME 361.

When the parison is properly set into the blow mold, the blow head settles on it and applies the final blow. The parison obtains the final desired shape of the glass container. The thicker bottom portion of the bottle (which is generally two times thick as the side walls) is formed by the bottom plate. Now that the bottle is ready, the halves of the blow mold are separated, the take-out comes and grips the bottle from the head and drops ~~it~~ onto the so-called dead plate for cooling. The strength of the grip must be adjusted properly in order to avoid the deformation of the still hot head.

Press & Blow Process:

The blow mold part for all three processes is identical. The difference lies in the forming of the parison. In PB, there exists no such thing as the settle blow or counterblow. No funnel is used, the baffle directly settles in sealed position onto the blank mold after the gob is received. The critical part of this process is the plunger. It is a mobile part extending through the neck ring just like the thimble. During the delivery, the plunger is in its lowest position. It takes an intermediate position when the gob is received, and is fully pressed upward after the baffle is settled. The gob takes the shape of the parison dictated by the gap between the plunger and the inner wall of the blank mold. Surely, there exists a cooling unit inside the plunger. The remaining processes applied to the parison are the same as those in BB.

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Narrow-Neck Press & Blow Process:

Principally, this process is identical to PB. However, it utilizes plungers with extremely small radii, which barely allow the installation of the cooling unit inside the plunger. The main advantage of this process is that it enables a perfect surface finish, i.e. it minimizes undesired thickness variations on the surface of the parison. Hence, the bottles being produced have a uniform thickness all along their surface. The producer does not need to consider regions on the surface having lower thickness than demanded, rendering the product inacceptable. This asides the need for putting extra weight on the gob and for producing unnecessarily thick bottles in order to tolerate thickness variations. The result is light weights and cheap bottles.

The BB process is generally applied to usual drinking bottles and pharmaceuticals. Large jars and pots are made by PB process. The NNPB technique requires bottles with narrow necks for a proper application of the special plunger. Weight tolerances are extremely narrow for NNPB, being about 4-5 grams. They loosen for PB to about 10-20 grams and for BB to about 30-40 grams.

The schematics showing the BB and PB processes are provided in the Appendix.

Furnaces A and B have both four production lines extending from their forehearths and furnaces C and D have three each. The furnace D had four lines actually, one of which ceased production in the early days of my training. A total of 134 production sections operate in the factory, belonging to 14 IS machines.

The glass containers being newly formed on the IS machines and delivered to the extending conveyors are transferred to the hot surface coating unit, where they are coated with tin oxide while their surface temperature is still above 650°C. The purpose

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of this coating unit is to avoid the propagation of the microcracks present on the glass surface. That would probably occur on the numerous conveyors extending up to packaging units because the bottles steadily contact each other during motion. In order to keep the tin oxide at gaseous state, the ambient temperature must be above 100 °C in this unit.

The bottles arrive at the entrance of the stress relieving tunnel with a surface temperature of about 650 °C. The tunnel extends for about 26 m in direction of the remaining units of the Cold End Department. Stress relieving is extremely important since the residual stresses present on the glass container surfaces would cause them to break during any rigid contact in service use if not relieved. The tunnel consists of ten zones which gradually cool the bottles moving through. The ambient temperature at the entrance is 560 °C, which diminishes only about 50 °C in the first five zones. The bottles leave the tunnel with a surface temperature just above 100 °C. How long it takes for one bottle to move through the entire tunnel depends on its color and thickness, but varies usually around 45 minutes.

Each and every unit following the exit of the stress relieving tunnel is under the concern of the Cold End Department, the first of which being cold surface coating. Quality control dictates that the produced glass containers must have a surface temperature above 100 °C while being coated with polyethylene here, which accounts for the shiny and slippery surface of the bottles in service.

After cold surface coating, glass containers are transferred in large amounts to the so-called row-sort unit, where they are forced into unary or binary rows for the following processes. At the row-sort unit, manual quality checks are implemented each 15 minutes, and the confronted defects are recorded along with the mold number, which informs the controller about the corresponding IS section on the line. The purpose of this is obvious; whenever some defect repeatedly occurs on the bottles having the same mold number, the individual section responsible for that defect can be stopped and checked.

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There exist 117 types of defects which may occur on a glass container. The controller determines exactly which of these defects are present, and records their numbers on a card, which is then copied to special templates on computer. Following checks are made in manual control: Height, top & bottom diameter, wall thickness, ovalness.

Surely, a manual control of all the glass containers produced in the factory is impossible. Mounted on each production line are several automatic inspection machines, which eliminate defective products before they are packed. There exist 77 inspection machines in the factory. Following checks are accomplished in the inspection machines: Dimensional intolerances, view defects, ovalness, diameter, body and head straightness, bubbles, blisters, dirt, wall thickness, all kinds of cracks, height, leakproofness.

Defective bottles are discarded after they pass through the inspection machine by striking them with air jets on their side wall such that they fall apart from the conveyor and are transferred up to the silos to reparticipate in the production in form of glass fragments. Surely, an extremely accurate optical sensor network is needed for such a separation process.

The automatic control process is exceedingly swift, and all the machines send their data regarding the number of confronted defects (which determine the efficiency) to a central control panel, where all the data concerning the production line, defect type, mold number, efficiency etc. can be observed.

In the first part of my worktime in the Cold End Department, which followed my work in the Production Department, I analyzed the process of stress relieving from both materials science and dynamics perspectives. My instructor here, Ülkü Zengin, informed me about the provision of

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gradual decrease in the surface temperature of the glass containers. She explained me how and why cold surface coating is implemented. Several times, we toured the units under the scope of the Cold End Department, where I gathered knowledge regarding the row-sort mechanism, the manual separation process accomplished at the row-sort unit and the complicated working principles of the automatic inspection machines. I learned how to work with the cards where the defects confronted during manual checks are recorded and with the templates on computer to which these data are copied.

As the first function of the Cold End Department is to eliminate the glass containers which exhibit one or more attributes beyond the dictated tolerances and hence to accomplish the objective of Quality Assurance; its second function is to implement a proper packaging process before storing and delivering the products.

The entire packaging process is accomplished by automatic machines. After the quality control through the inspection machines, unary or binary rows of glass containers are transferred by conveyors to the entrance of the so-called palletizers, where they are sorted into one of three special arrangement types. Generally, they are arranged as 10x10 squares and then move to the palletizer, which is a computer-controlled machine used to place such squares on top of each other and to construct a tower of glass containers packed in the most compact way. I analyzed the mechanism behind the accuracy in lifting about a hundred bottles simultaneously and placing them right on top of another group, separated by a carton board. My instructor explained me that this is done in two ways. Glass containers of uniform horizontal cross-section are lifted by squeezing them between pneumatic airbags. That is, when a 10x10 group is on its place, an 11x11 grid of empty bags connected to the lift is driven down onto the group such that the bags penetrate into the holes between the necks of the jars. Afterwards, pressurized air inflates these bags just like the airbag of an automobile, squeezing the