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A Practical Study on the Increasing the Production Rate of a SBM Machine and Quality Optimization

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Abstract The stretch blow molding process is the main method for the mass production of PET, AN, PP containers. In the stretch blow molding process the preform is stretched in both the two direction as; axial direction and the hoop direction.In this study, some practical studies were carried out to increase the capacity of the stretch blow molding machine. For this reason, some constructive changes were made on the 2-liter liquid oil bottle production machine, methodologically and gradually. Firstly, the mold clamp-lock mechanism was renewed. Then the percentage of use of resistances and carrier speed were increased. Finally, the operation was completed by increasing the capacity of the air valves of the system. When all changes were completed, production increased from 900 Pcs/h to 1180 Pcs/h, resulting in a 31.1% increase in the number of appropriate products. On the other hand, in the original case of the machine, an average of 50 pieces of wastage was taken from 1000 bottles, and as a result of the modifying, this number decreased to an average of 10.

Keywords SBM, Preform, Clamp Mechanism, Process Control

Introduction

The idea of stretching a reheated thermoplastic material to improve its properties was first applied to extruded sheets in the 1930s. However, the first PET (polyethylene terephthalate) bottle from injection-molded preform was produced by Nathaniel Wyeth and his staff in the DuPont company in the 1970s [1]. The blow molding process is a molding process in which air pressure is used to inflate soft plastic into a mold cavity. In the blow moulding process, the material typically experiences a high speed, large strain biaxial deformation [2]. Blow molding includes three main thermoplastic processes: extrusion blow molding, stretch blow molding and injection blow molding. The stretch blow molding process is the main method for the mass production of PET, AN, PP containers. Furthermore, it can be said that the two stage stretch blow molding process is the most popular technique among PET bottle manufacturing techniques. Polyethylene terephthalate (PET) bottles firstly took their place on the market shelves in 1976. Nowadays many kind of soft drinks, edible oil, sauces, health care products, automotive fluids and house chemicals are packaged in PET bottles [3]. In the stretch blow molding process the preform is stretched in both the two direction as; axial direction and the hoop direction. In a first step a preform is injection molded. After the first operation the preforms are fed into the blow molding machine and then heated in an infrared oven above the glass transition temperature (~80^{0}C), followed by being simultaneously longitudinally stretched with a cylindrical rod and blown-up with high pressure air inside to create bottles of desired shapes. The last stage is solidification [4]. A schematic diagram of stretch blow molding is shown in Fig.1.

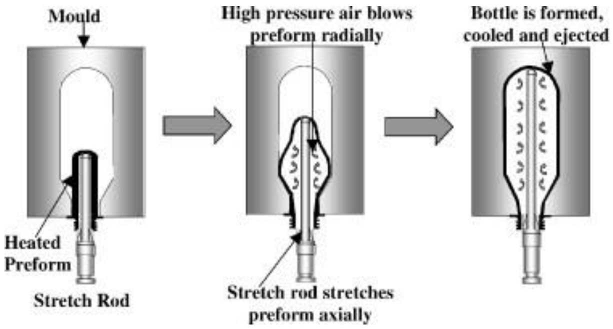

Figure 1: Stretch blow molding of PET bottles [5]

Relatively few papers have been dedicated to stretch blow molding. Both experimental study and numerical modelling have been employed to optimise the preform design and process parameters. Adams et al [6] found to be able to produce accurate simulations in terms of both free-blowing deformation and bottle thickness distribution. Yan et al [2] aimed to develop a new material characterization method providing new data for the deformation behaviour of PET relevant to the SBM process. Yang et al. [5] introduced a fully coupled temperature-displacement modelling of ISBM of PET bottles with a view to optimize process parameters. The model they proposed successfully predicted the wall thickness distribution in most parts of the bottle examined. They explained the reason for the difference between the estimated and measured results as the preform temperature was not recorded correctly. The optimum cooling time of the bottle preforms were determined by Daver [7]. In the mentioned study a series of PET juice bottles stretch blow molded at different preform cooling times and then they tested for burst strength and top load strength. Structural analysis was carried out by ANSYS in order to compare the test results with those obtained by finite element simulation predictions.

Numerical optimization methods for SBM have received more and more attention in the last two decades. Because of the complex material behaviour of polymers many studies have been performed for increasing the prediction accuracy of simulation models of the blow molded plastic bottles. CAE is mainly used for simulating the proses by means of the time, temperature distribution and the product performance. Researchers attempted to optimize all the elements within the stretch blow molding process to reduce the cost. Two different-sized bottles have been simulated and the thickness, axial strains, and intermediate blowing shapes have been compared with experimental results by McEvoy [9]. In the mentioned study solid elements were used in order to improve shell elements accuracy for prediction of the bottle thickness. Attar et al [9] attempted time reduction and part quality improvement for manufacturing in blow molding. In his study, Haddad [10] explained the combined use of both the B-SIM simulation software and the ANSYS finite element software to simulate the production process of PET bottles with ISBM. The authors firstly simulated the ISBM proses by using B-SIM simulation software and then transferred the results to ANSYS for testing the mechanical strength. Demirel [11] performed a study that optimizes the mould surface temperature and the time that the bottle remains in the mould. For this purpose, Demirel used a statistical analysis software program called ECHIP-7.Lee and Soh [12] presented a FE method to determine the optimal thickness profile of a preform, given the required wall thickness distribution for the blow molded part. Thibault et al [13] proposed an automatic optimization of the preform geometry (initial shape and thickness) and operating conditions. Bordival et al [4] presented a numerical modelling of the full SBM process. Bagherzadeh et al [14] studied the numerical modelling of the stretch low molding of PET bottles and compared the numerical results with the experiments by means of the thickness distribution. Lontos [15] dealed with numerical investigation of the effect of stretch rod velocity and the value of pre-blow pressure on the final bottle wall thickness distribution.

With the expansion of plastic bottle usage areas, advances in plastic bottle production technology have made it mandatory to produce more and better quality bottles at a certain time. For this reason, in this research, some practical studies were carried out to increase the production rate of the machine in a plastic bottle production facility. It is possible to list these studies as follows: 1) Modifying the mold clamp-lock mechanism, 2) Increasing the percentage of use of resistances and carrier speeds, 3) Adding escape funnel and snail fan to the machine, 4) Modifying the air valves of the machine. These modifications were integrated into the system step by step, and after each step, the improvements were recorded. Thanks to these modifications, both the opening and closing times of the mold were changed, and they ensured to obtain products with better quality and homogenous wall thickness. There were also significant increases in the number of products obtained in unit time and a decrease in the number of wastage calculated for every 1000 pieces.

Summary of the Current Situation and Problems

For the practical application of the presented work, the manufacturing process of 2-liter PET bottles, which has an important place in the production line of the company, was chosen. In the production line, preforms that produced in the injection molding machine is transferred into the receptacle of the stretch blow molding machine. The preforms, queued with the help of a belt, are placed on the conveyors. Thanks to the conveyors, the preforms, both going forward and turning around in circular motion (for homogeneous heating), move through the furnace and heat up. Once hot, the preforms, after coming out of the oven, go into the blowing mold. Entering into of blowing mold, preforms take the bottle form with the help of the 36 to 40 bar air pressure and also stretching rod. Mold is mounted to the machine's clamp and opens and closes as the clamp moves. The movement of the clamp in the present machine is provided by pistons. The mold, consisting of three pieces, is shown in Fig. 2. After the preform goes into the mold on the conveyor, the mold cavities move by clamp movement. Simultaneously the mold base descends down by piston movement. The two mold cavities approach to mold base and the mold closes [16].

Figure 2: A sample of multi cavity mold type used in the experiments

While the process continues, some problems occur from the related to the current machine, we can sort them as follows:

- Because it is difficult to control the speed of the pistons, in the production stage fast enough production is not possible. maximum 900 bottles per hour can be produced.
- The number of defective products when the air pressure is not balanced in the system is high.
- Blockages occur in the pneumatic sleeves of the pistons.
- Constructive difficulties are experienced when assembling the mold.
- Due to the noise of the pistons, a quality working environment is not provided.
- Some products show color differences caused by heat imbalance.
- Some products display folding in the base.
- The thickness of the wall of some products is disproportionate. (Hard surface and soft surface)
- Air valves are insufficient.
- Preforms are not heated quickly.

Redesign and Assembly of the Clamp Lock Mechanism

The molding clamping unit is one of the most important parts of the injection molding machine as it affects the quality and dimensional accuracy of the product. The clamping force greatly affects the molding and product quality, especially in the production of thin-walled plastic parts. Optimizing the clamping force and distributing uniform load to the four tie bars are an important parameter to evaluate the performance of the injection molding machine. For this reason, it is possible to find some studies on the clamping mechanism and clamping forces in the literature. Huang and Lin [17] were developed a new search algorithm based on information about tie-bar elongation with various clamping force settings to determine the appropriate clamping force value. In this study, it has been shown experimentally that the clamping force determined by the method suggested by the authors improved the injection molding quality. Chiang et al. [18] developed a new parallel control system that provides clamping force and energy-saving in hydraulic injection molding machines (HIMMs) to simultaneously control load and achieve high energy efficiency. Huang et al. [19] experimentally investigated the effect of clamping force on quality of injection molding in terms of part thickness. The authors also developed a system that measures mold separation and tie-bar elongation at every corner of the machine and mold during the injection molding. Altinbalik and Kahraman [16] redesigned a clamp lock mechanism for a SBM and obtained an increase of approximately %16 in production rate.

At the SBM selected for presented study, the top plate of the clamp driven by pistons in its current form is presented in Fig. 3. Firstly, servo motor is planned to replace pistons which provide clamp movement. The servo motor which will be selected should be able to hold the weight of the differential spider and perform this movement faster than the pistons. The movement of the clamp will be provided by a servo shaft going through the differential spider. Also designing a rail system that will facilitate the movement of the clamp is planned. Instead of the piston which provides the movement of the mold base, a system of roll bearings and cams will be installed. Finally installing the sensors to follow the movement of the servo motor is planned. The place on the plate where the servo motor is to be installed has been determined and after modelling, it was manufactured. Detailed information and pictures can be found in [16].

Figure 3: Initial mechanism of the top plate of the clamp driven by pistons

Then, the pistons and the upper plate in the machine had been removed. After the differential spider was removed, screw shaft of the servo motor was assembled to the system. A roll bearing was put in place on the bottom plate for the assembling of the servo motor's screw shaft. Then the differential spider was mounted in its place. This shaft will transfer the motor's movement to the differential spider and provide the up and down movement of the differential spider. With this movement, the mold will open and close. To make sure that no unnecessary load is placed on the servo motor and it moves freely, a rail system was assembled to the clamp. Detailed information and pictures can also be found in [16].

After the top plate has been mounted, the servo shaft and servo motor were assembled, actuator sensors were added to the starting and ending points of the motor's movement. These sensors, blocking the extra movement of the servo motor, in a sense protect the machine. The working principles of the new system and also its picture in open position is shown in Fig.4.a and 4.b. respectively.

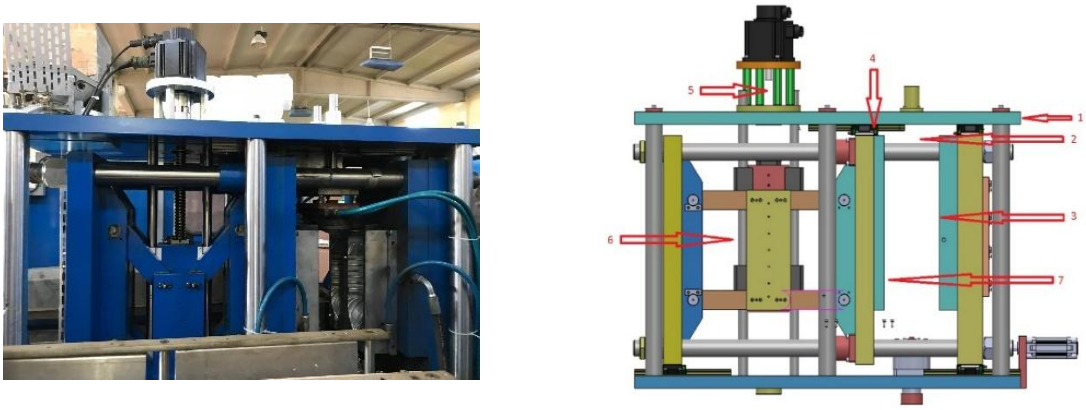

Figure 4: The photo and representation of the working principles of the clamp mechanism after the new design

1- *The upper plate produced in accordance with the servo motor*
2- *The cam and roll bearing system which moves the base of the mold upside-down*
3- *The stabl mold part*
4- *The guides which move on the rails and facilitate the movement of the clamp*
5- *The area where the servo shaft is installed*
6- *The mechanism which opens and closes the mold as the servo shaft moves the differential spider*
7- *The plate where the moving part of the mold will be assembled*

The most important positive result of all these arrangements is the decrease in the opening and closing times of the mold. According to this, mold opening and closing times, each lasting 0.8 sec, decreased to 0.25 sec depending on servo motor capacity, and an acceleration of 69% in opening/closing times was gained. This is also shown in Figure 5. Because there was no change in time of blowing, the total time saving was approximately 14%.

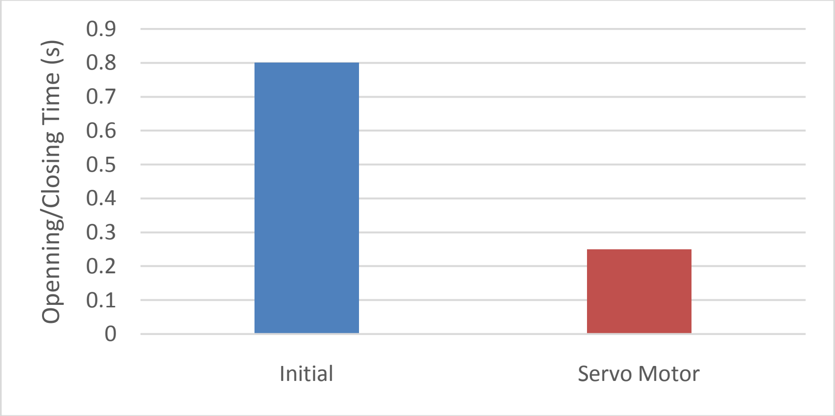

Figure 5: Decrease in opening/closing time of the mold by using servo motor

Accelerating the opening times of the mold increased the number of products produced in unit time and since the vise movement was fixed, an average of 50 faulty products was produced in 1000 bottles in the previous construction, while this number was decreased from 50% to 25%. As a result of both the increase of production rate and the decrease in the quantity of wastage, the number of ready-to-use bottles, which were previously 900 per hour, increased to 1042/h with these arrangements, as can be seen in Figure 6. That means a 16% increase. Additionally;

- When the pistons disappeared, the problem of the blockage was solved because there was no pneumatic sleeve.
- The structural difficulties that occur when inserting the mold were eliminated.
- Air and electricity savings were ensured.
- Electronic sensors of the base piston were canceled.
- Noise pollution was decreased.
- The crowd and bad image on the machine disappeared.

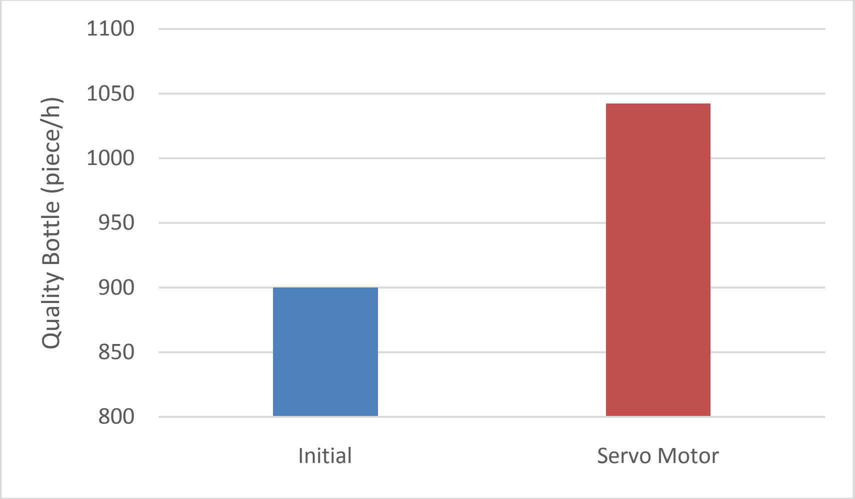

Figure 6: Increase in number of quality final products by using servo motor

However, this arrangement did not solve all of the problems encountered during production. The heterogeneity of the wall thickness, color differences (burning), and folding in the product bases, caused by heat imbalances, shown in Figure X, are still ongoing. To eliminate these errors and speed up the production a little more, it was thought to more heat up the preforms in the next step and thus reduce the time of blowing.

Heating Preforms and Vacuum System

The preforms, which move forward and around themselves in a circular rotation, are heated by passing through the resistances and reflectors of the furnace. The heating process is provided with glass rod resistances. The rod resistances were placed on one side of the furnace and a metal reflector was placed across it to reflect the heat. The reason why the preforms rotating around themselves is to provide homogeneous heating of all sides of the preform. If one side of the preform is more heated than the other side, it causes a hard part of the bottle to become soft. As a result, a defective product is obtained. The heated preforms enter into the blowing mold immediately after exiting the furnace.

There are a total of 7-rod resistances in the furnace where practical work is carried out. The operating capacities of these resistances can be adjusted and instant capacity values can be read from the screen as shown in Figure 7.a. The number and capacity of resistance are adjusted depending on the height and weight of the preform. They heat the 2nd, 3rd, and 4th regions of the preform shown in Figure 7.b.

Figure 7: a) Heating resistance of performance screen
b) Heating zones of the bottle
c) Regions of the preform that need better heating

Before revision work was carried out on heating the preforms, the capacity to work of the performs was as follows:

Resistance 1	%38
Resistance 2	%34
Resistance 3	%28
Resistance 4	%28
Resistance 5	%28
Resistance 6	%28
Resistance 7	%32

The red-marked regions of the preform shown in Figure 7.c are thicker than in other regions. There is also a high probability of puncture as the stretching rod presses on the base part of the preform. So it needs to be heated better. The amount of raw material accumulated in the jaw area (region 2) should be heated well to be distributed suitable with the stretching rod. However, using the resistances at their full potential causes the preforms to burn (becoming white after blowing) because of heating too much. Without a change in the way preforms are heated, it is inevitable that the errors shown in Figure 8 will occur when the machine is run as determined by the producer firm.

At this stage of the study, it was aimed to increase the capacity of the blowing by heating the preforms faster and leaving them from the furnace earlier. The resistance values set for the PET bottle in question are as given above. When these values were increased, burning occurred as seen in Figure 8. When carrier speeds were increased to prevent these burns, the preforms were not heated enough and the product was not properly produced. In this case, it is clear that simply increasing the resistance capacity or changing the carrier speeds without any constructive arrangement in the design cannot be the solution unfortunately.

Figure 8: Burnt and wasted preforms

To eliminate this negative situation, a chimney, whose technical drawing, solid model, and dimensions are given below, was designed to evacuate the excess heat in the furnace when both the usage percentage of the resistances and the carrier speeds increase. The chimney was manufactured and placed on the furnace as shown in Figure 9 and both resistance capacity and carrier speed were increased. As a result, there was a noticeable improvement in the preforms, but there were still slight burns in the resulting products.

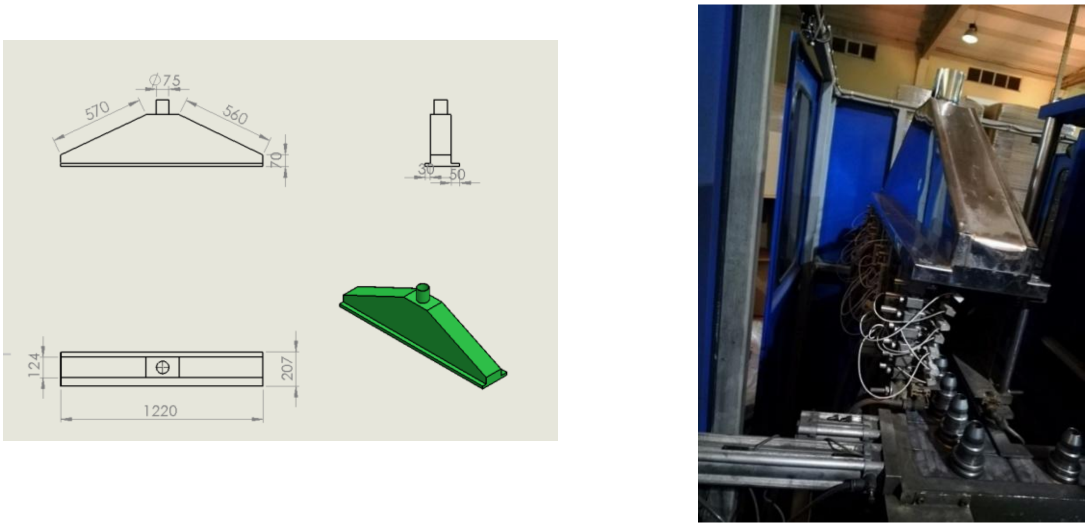

Figure 9: a) Technical drawing, solid model, and dimensions of newly designed chimney
b) Photo of the chimney assembled its own place

To prevent the slight burns, a design change was also considered and a snail fan was added to the chimney, which would evacuate the air inside. This new version of the machine is shown in Figure 10 a. With this added fan, it was aimed to have air circulation in the furnace and to heat the preforms homogenously. Moreover, it was aimed to prevent regional burns. With the installation of the snail fan, the capacities of the resistances were updated and their values were increased.

The machine was operated in this form and it was determined that the preforms came out of the furnace without burning as seen in Figure 10.

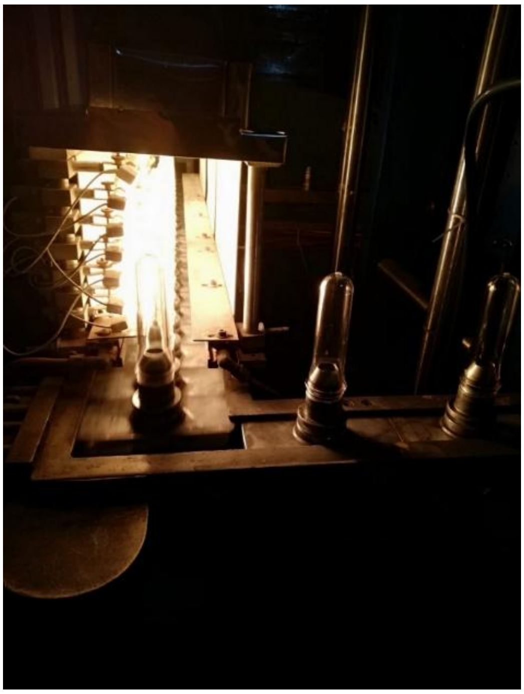

Figure 10: Qualified preforms

After all these arrangements, the effect of the modifying was observed when the machine was operated at full capacity. The first positive change was seen at the time of blowing the preforms. As the carriers accelerated and the preforms heated up better, the time of blowing of the preforms decreased from 6.4 seconds to 5.9 seconds, resulting in an improvement of approximately 8%. This is shown in Figure 11 and the time-saving –through the positive change in opening and closing times- increased to 20% in total compared to the original state of the machine.

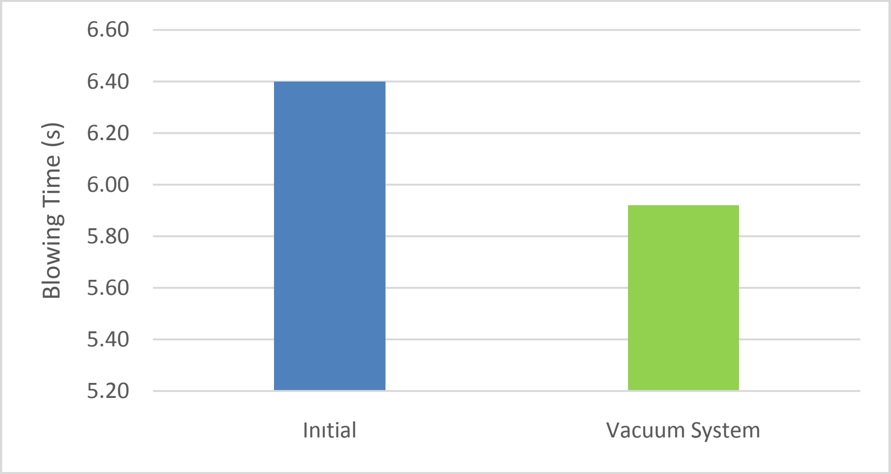

Figure 11: Decrease in blowing time by increasing heating performance

In addition, heterogeneities in product wall thickness improved greatly and burns caused by superheating were almost completely eliminated. With the change of the previous servo motor, the average number of wastages in 1000 bottles fell to 25 was further reduced to 15 with the change of the heating characteristic. Thus, as can be seen from Figure 12, the number of bottles obtained in 1 hour and suitable for use increased to 1120 as a result of both the speeding of the mold and the decrease in the number of wastages. Thus, the number of quality products obtained from the machine in 1 hour and suitable for use increased by 24.5% compared to the original state of the machine and by 7.5% compared to the condition of mold locking by servo motor.

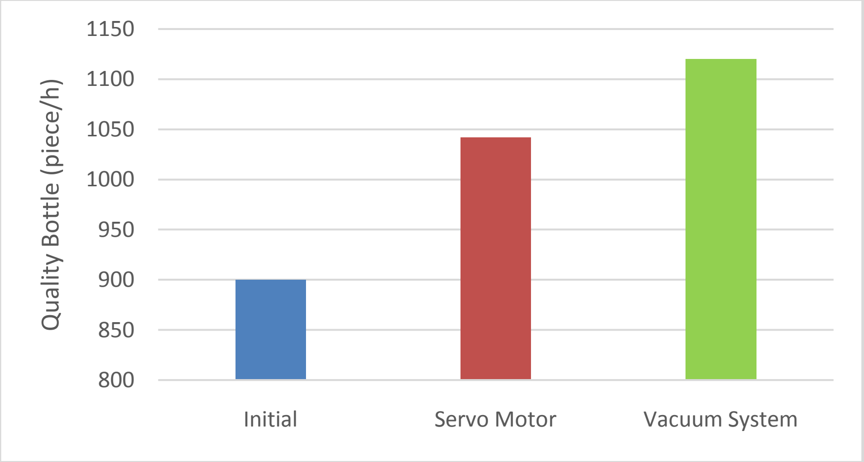

Figure 12: Increase in number of qualified final products by increasing heating performance

In spite of all these changes, it is possible to reduce the time of blowing a little more and reduce the number of faulty products in the unit time. That is why there are still bottles in the machine that are not fully blowed or crooked. The reason for this was understood to be the lack of inefficacy of air valves. Thus the final step of the study was planned to be the replacement of the air valves.

Replacement of the Air Valves

As a result of the constructivist changes listed above, a 24.5% increase in the number of bottles in unit time was achieved. The air valves capacity installed on the machine are relatively low. If this flow rate is increased, it may be possible to increase the number of products. In this respect, a new air valve was installed on the system. This valve is shown in Figure 13. Care has been taken to install the air valve close to the mold. Since the newly installed air valve is both close to the mold and has a higher capacity, air can be given faster to the mold, also can be discharged faster.

Figure 13: New air valve

After the air valve was replaced, the time of blowing of the preforms decreased to 5.6 seconds and the total change is shown in Figure 14. Thus, the time of the machine's opening, closing, and blowing, which was a total of 8 seconds in its original state, reduced to 6.1 sec., saving 24% time. The higher quality blowing of preforms was reflected in the number of wastages, and with the furnace vacuum system, the average number of wastages in 1000 bottles was decreased from 15 to 10 at this last stage. Thus, the number of bottles produced and ready to use in 1 hour with the final form of the machine was determined to be 1180. The change in the total number of bottles is presented in Figure 15, including all revision steps.

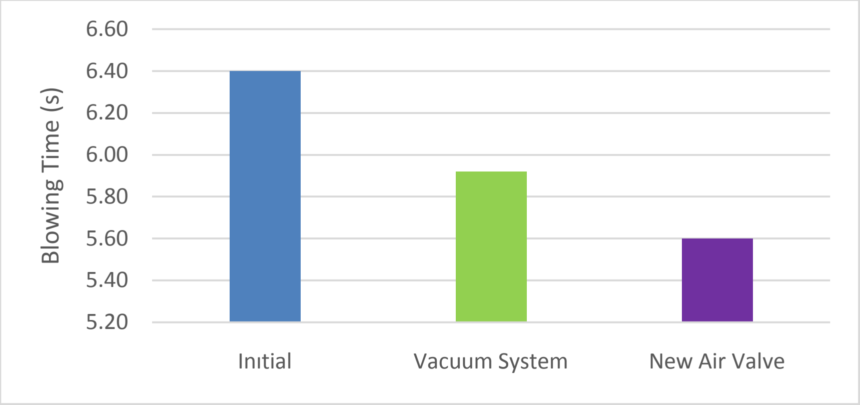

Figure 14: Decrease in blowing time by increasing air valve capacity

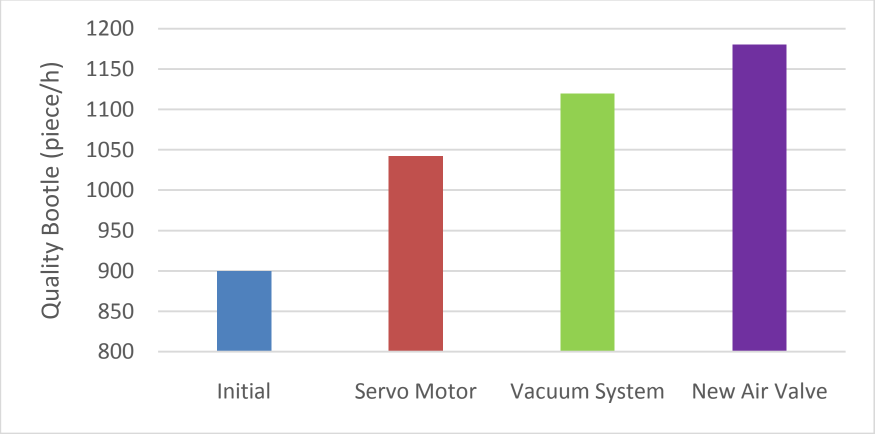

Figure 15: Increase in number of qualified final products by using new air valve

Conclusion

In this study, some constructive changes were made on the 2-liter liquid oil bottle production machine, methodologically and gradually. The main objective was to increase the number of quality products produced in 1 hour. First, the mold locking system was renewed. The Servo motor system was used instead of a clamp system. Then initial studies were done to heat the part quickly and homogenously in the furnace. Finally, the operation was completed by increasing the capacity of the air valves of the system. When all changes were completed, production increased from 900 Pcs/h to 1180 Pcs/h, resulting in a 31.1% increase in the number of appropriate products. On a number basis, 280 more bottles were produced per hour than the original state of the machine. About 40 of this excess was achieved by reducing the number of wastages, while 240 products were obtained as a result of increasing the speed of the machine. The change in the number of wastages proportionately is quite striking, although it may seem to be few in number. In the original case of the machine, an average of 50 pieces of wastage was taken from 1000 bottles, and as a result of the modifying, this number decreased to an average of 10. The graph of the decrease in the number of wastage based on all the changes made in the machine is given in Figure 16. As can be seen there, the reduction in the average number of wastages is 80%.

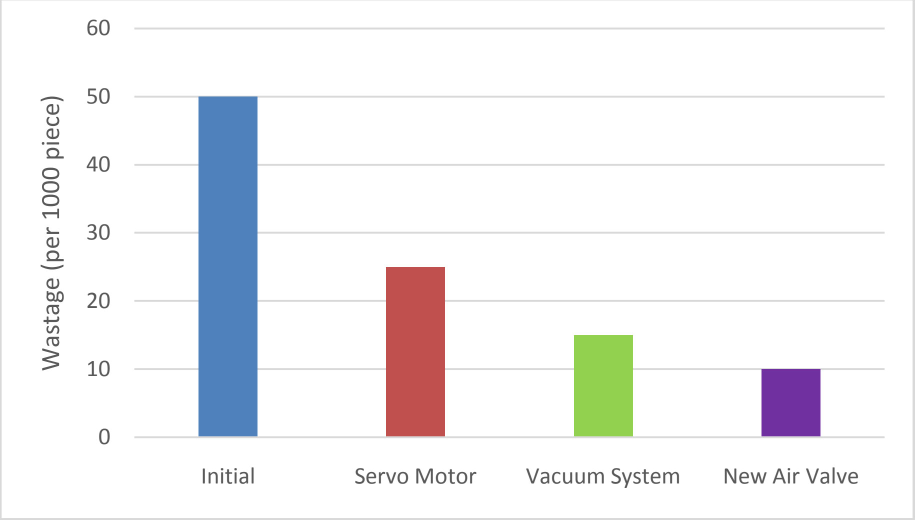

Figure 16:Decrease in number of waste product in each 1000 bottle

It is possible to produce an extra 6720 bottles in only 1 day, given that the machine works 8 hours a day continuously and that this type of PET bottle is produced in a total of 3 machines in the production line. Considering the monthly working period, the economic size of the changes can be understood more clearly.

Also, as a result of all these arrangements;

- The image and noise pollution generated by the machine was reduced.
- The better quality working environment was provided for the machine operator.
- Mold disassembly and assembly on the machine were made easy.
- Air and electricity save were realized.

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