Sakarya University Journal of Science 25(5), 1129-1135, 2021

SAKARYA ÜNİVERSİTESİ

Impact of Dehumidification Devices on Production Efficiency in Plastic Injection

M. Tahir OKTAÇ [1], Mustafa TİMUR[2], Halil KILIÇ*[3]

Abstract

One of the many methods used in the production of plastic materials is plastic injection method. The plastic injection method needs equipment difficult to choose, and it is also costly. Many negativities could be experienced during production. One of them is the water droplet problems on the surfaces of the mold. Provision of insufficient cooling on molds, ambient temperature, non-homogenous humidity, mechanical and other stresses occurring during production, cracks on the product, warpage and thermal residual all cause some stress-like defects. In this study, the effect of water droplets problem on production efficiency in the molds of Polyethylene Terephthalate (PET) raw materials manufactured in a private enterprise was examined. The percentage productivity table has been created based on different months of the year, August July and August. In the enterprise, 8 dehumidifiers were placed to 17 injection machines to create a homogeneous production temperature in the environment. Humidity and heat values obtained during production were monitored daily and recorded. In this study, which was conducted over two years and three months, positive results were obtained suggesting that the water droplets formed in injection molds has decreased with the effect of dehumidification devices, and the efficiency of injection production has also increased by 8%.

Keywords: Plastic injection, dehumidifier, mold, temperature

1. INTRODUCTION

The injection molding technique is used to produce parts with complex geometries, as well as parts in various shapes and sizes. Plastic injection molding (PIM) is one of the most common methods used in the production of plastic parts. PIM is a cyclic process in which the mold is filled with hot melt under high pressure at high speeds. This is followed by cooling the resulting product in the mold and removing the product from the mold in the final stage [1]. This cycle is expected to typically last about 20 seconds [2]. Cooling the melt contributes to the 50-70% of the cycle time [3] when all the processes are considered.

Despite the many advantages of injection molding, many other factors need to be considered such as plastic melt temperature,

* Corresponding author: halil.kilic@klu.edu.tr
[1] Plas Plastik Ambalaj Sanayi ve Tic.Aş. Business Manager
E-Mail: tahir.oktac@plas.com.tr
ORCID: https://orcid.org/0000-0003-4952-0595
[2] Adnan Menderes University Eng. fac. Mechanical Eng.
E-Mail: mustafa.timur@adu.edu.tr
ORCID: https://orcid.org/0000-0002-4569-0450
[3] Kırklareli University TBMYO-Machinery Program
ORCID: https://orcid.org/0000-0001-6182-356X

injection pressure, mold temperature, coolant temperature and the method of demolding. For the most part, mold cooling is performed by creating cooling grooves into the mold or core with some straight holes on the surface. However, the process is good for the production of the parts with a simple design and flat surface. For complex components with curved surfaces, straight perforated canals are not sufficient to cool the mold homogeneously [4]. As the cooling of the mold is not a uniform process, it causes defects such as distortion, warpage marks and welding lines. These defects reduce the quality of the product. With proper cooling in the molds and prevention of water droplets, the errors that will occur in the final products are reduced, thus increasing the quality of the product [5].

Systematic identification and elimination of losses to reduce operating and production costs are the main factors affecting production efficiency. When the production efficiency matters, internal audit is an important management function. Processes and equipment must be continuously optimized to profitably maintain the production of quality parts and competitiveness in their production. In the plastics sector, where raw materials and material costs are of great importance, the cost of raw materials could go up to 50% of the total cost of the final product. Especially if the raw material is imported, much attention should be given to material efficiency as well as the efficiency of other resources used in the production. When the quality of the resulting product changes, production costs will also change accordingly, and therefore, cost-related changes will also affect productivity changes. Design, cost calculation and manufacturing of plastic injection molds are one of the most important stages in the industry of mass production. The design of plastic injection molds is expensive and complex. The most important parameters affecting the production of plastic injection companies are the selection of machines and molds in the parts to be produced in line with the set criteria. Selection of improper machines has a big impact on the mold, production errors and therefore production-related cost [6]. The temperature of the manufactured product changes during the cooling process. The design of the cooling system depends on the geometric structure of the injected plastic part. As the plastic melt material injected in the molding is hot, fast and smooth take-up must be ensured. The position of the cooling grooves should be designed in a position that can best transmit heat [7].

Desiccant dehumidification technology is emerging as a technically viable alternative to comfort conditioning in many commercial and institutional areas. Dehumidification systems are gaining popularity due to their ability to remove moisture from outside vent air while allowing traditional air conditioning systems to deal primarily with control temperature [8]. Dehumidification is an approach to space conditioning that offers solutions to many of the current economic, environmental and regulatory issues facing facility managers. Conveniently integrated desiccant dehumidification systems become cost-effective additions such as reduced dehumidification cost, energy savings and more comfortable air availability. In some ambient conditions, it may be necessary to dehumidify rather than cool the outdoor air used for ventilation [9].

Dehumidifiers work on the physical principle that they cool the flowing air below the dew threshold and draw moisture from the air by condensation onto a cold surface. For this reason, they are called refrigerated dehumidifiers. As the ambient air temperature rises, more surfaces are formed on which the moisture condenses again. Humidity does not disappear by simply cooling the air [10]. In the injection production processes in the industry, moist surfaces (water droplets) are formed on the molds with the increase in the ambient temperature. This situation adversely affects the properties of the final product and thus the production process. In order to continuously absorb the moisture contained in the ambient air, the technical solution has been to dehumidify by condensation.

Many studies conducted on plastic injection molding have focused on minimizing cycle time by improving cooling to improve the production rate and reduce the possibility of producing faulty parts. Since the cooling of the injection mold takes up most of the cycle time, the literature reviewed is found to be mostly based on cooling systems. Sun et al. [3] conducted a study and proposed corrugated cooling grooves opened through the milling method. Using a sample door handle iron, they formed grooves opened with milling method in the core and mold. The cooling time for the milled grooves was shorter than for conventional straight-perforated grooves. It is stated that the cooling time can also be reduced by positioning the injection on the mold in the appropriate place [11]. Mercado et al.[12] developed a new algorithm for the automatic design of the cooling systems in injection molds based on the geometry of the plastic part. Li et al. [7] conducted a study on the optimal placement of cooling canals in plastic injection molds and developed a knowledge-based approach for the cooling system. Lin et al. [13] conducted research and created the optimal cooling system design for a free-form plastic product using the method of the neural network. Li et al. [14] conducted a study on the automatic placement of the cooling system in plastic injection molds. They created a computer-aided simulation of the cooling system of the TV panel mold.

These studies aimed to minimize the time losses during the production stage ensuring that the values regarding efficiency, temperature, humidity and mold parameters, etc. of the products made through plastic injection machines are in optimal conditions. Studies aiming to reduce the negative impacts of water droplets on injection molds under the influence of temperature are limited. In the literature review, different methods have been tried in the removal of water droplets in plastic injection molds, but the effect of dehumidifiers has not been directly observed. For this reason, studies examining the effect of dehumidifiers directly on plastic injection molds have not been found in literature research.

In this study, the effect of dehumidifiers on the production line was investigated as an innovative approach to reduce the negative effects of water droplets on plastic injection molds. For this purpose, dehumidifiers were placed in the injection molds in order to minimize the water droplets formed in the molds during the plastic injection process in a company that produces plastic bottles in Lüleburgaz. Values regarding humidity and heat measurements during the production were monitored and recorded daily. The effect of using a dehumidifier in the production line on the production efficiency of injection machines is reported. The data obtained from this study will be useful in terms of the possibility of using dehumidifiers for applications of reducing water droplets in plastic injection molds.

2. MATERIAL METHOD

2.1. Injection Line

Within the scope of the study, the layout plan of the injection machines on the production line are shown in Figure 1, and the physical characteristics of the injection department in the enterprise is presented in Table 1. There are a total of 17 plastic injection benches in the region where the works are carried out. Experimental studies are based on this area. While the 1st hol in this area has a height of 3m, the 2nd hol has a height of 4m. Due to this height difference in the production area, the sections has examined separately.

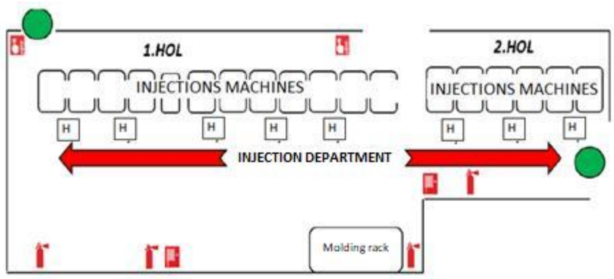

Figure 1 Layout plan of the injection department

Table 1 Physical properties of injection department

Area (m^2)	Volume (m^3)	Location	Height (m)	Machine (piece)
500	1750	1. Line	3	11
		2. Line	4	6

2.2. Dehumidification Device

Dehumidification is the process of removing water vapor from moist air. Too much water vapor in the air could cause many problems. These include deterioration of comfort conditions, acceleration in metal corrosion, reduced impact properties of its materials, premature chemical degradation, and worsening of surface finishing. These are the systems or mechanisms designed to remove heat from an environment using a cooling cycle, remove excess moisture and provide fresh air to the environment. For this reason, it is not enough to cool the air only through air conditioners, the humidity must also be adjusted. In this study, the technical specifications of the dehumidification devices used in the injection department are listed in Table 2. 8 dehumidifiers are placed in the injection area, taking into account the circulation conditions.

Table 2 Technical specifications of the dehumidifier

Parameters	Value
Dehumidification capacity (L/D)	138
Voltage / frequency (V/Hz)	220/50
Air volume (m^3/h)	1200
Power input (W)	1850
Operating temperature (^oC)	5-35
Usable area (m^2)	120-160

2.3. Production Efficiency

Efficiency in the technical sense is defined as "the number of goods and services produced and the ratio between the inputs used in the production of the amount of service in the production of these goods". Production efficiency means achieving optimum product quality with minimal unit cost. If it is the aim to achieve this goal, it is not enough to concentrate only on energy efficiency and machine technology. Instead, the whole value chain and all variables and the best possible solution should be discovered individually. Various factors such as cycle time, mold cavity number, cooling quality, mold life and strength, mold assembly status and production time, discards and energy have a significant effect on efficiency. For instance, Eq. (1) is used to calculate the injection production efficiency as follows [15]:

$$\text{Efficiency (\%)} = \left(\frac{\text{Theoretical hourly quantity of product}}{\text{Actual hourly production of the machine}}\right).100 \qquad (1)$$

3. EXPERIMENTAL STUDY

The experimental research started with the relevant environmental measurements before the dehumidification devices were placed in the injection line. As of 2019, ambient temperature and humidity were measured in the injection line for 16 days. The data obtained from the measurements are listed in Table 3. The obtained results from 1. hol and 2. hol regarding the changes in temperature and humidity are presented in Figure 2.

Table 3 Temperature and humidity values measured in the injection department

Day	1. Hol		2. Hol		Chiller Set Value (^oC)	Water droplets	Environmental Air Cond.	
	Max Temp. (^oC)	Max Humid. (%)	Max Temp. (^oC)	Max Humid (%)			Temp. (^oC)	Humid (%)
1	36	57	38	29	24	No	27	48
2	35	57	37	28	24	No	28	49
3	35	57	38	28	12	Yes	27	50
4	33	53	35	30	15	No	27	51
5	Break							
6	33	52	38	28	15	No	27	57
7	35	55	39	27	14	No	27	55
8	37	43	38	26	13	No	30	59
9	32	46	36	27	12	Yes	28	60
10	34	48	37	29	14	No	31	65
11	34	57	37	32	14	No	33	69
12	Break							
13	34	58	36	30	14	No	30	65
14	34	59	40	27	13	Yes	32	64
15	34	58	41	26	15	No	31	64
16	34	55	42	25	15	No	32	63

During the production in the enterprise, 16-day ambient temperature and humidity values of the injection line was examined and it was found that; 1.hol the average temperature in the line was 34^{o}C and humidity was 53.2 %.The average temperature in the line was found to be 38^{o}C, and the humidity was found to be 28%.

It is predicted that the reason for the differences in the measurements performed in 1. hol and 2. hol in temperature and humidity could be the difference in machine capacities. As seen in Table 4, the changes in the measurements are affected by the changes in humidity and temperature in the air.

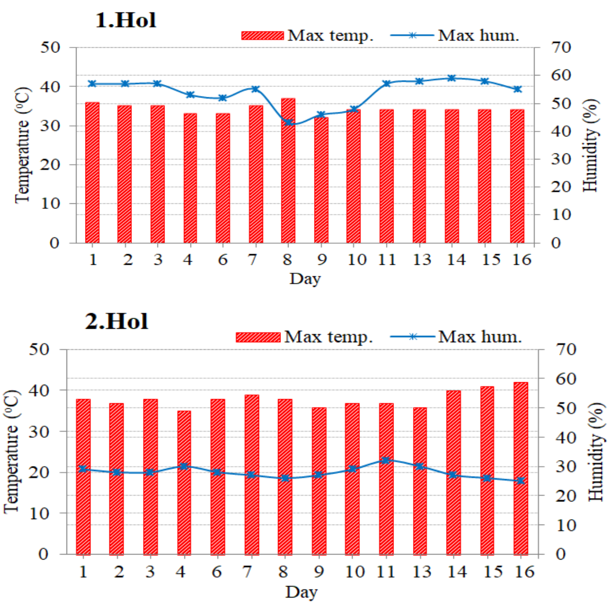

Figure 2 Temperature and humidity change in the injection environment

The amount of moisture in the environment decreases as the temperature increases. This is clearly seen in Figure 2. In an experimental study conducted with 8 dehumidifiers, it was found that the optimal temperature set value of the chiller cooling system was found to be 14°C.

It is a known fact that during the filling of the plastic injection mold, the hottest molten plastic was found to be at gate, and the coldest molten plastic was found to be at the farthest point from the input point of the mold. The temperature of the cooling water (chiller) increases as it passes through these canals, so to ensure equal cooling at the production stage, it is necessary to provide cooling water inlet to the hot areas of the mold and cooling water outlet to the cold areas of the mold. Increasing the temperature of the chiller is a factor that prevents optimal values in the production stage.

When Table 4 was examined, it was observed that chiller operating temperature values fell by 4.3°C in the summer when humidifier devices were active in injection machines and the machine operated at an average of 14.3°C. At these temperatures, no water droplet was observed on the surfaces of the injection mold. This confirms that the molds cool better, thus energy and production efficiency is increased. Under these conditions, when the humidity values on dehumidifiers were examined, the machine was observed to have worked at an average 30% set value.

Table 4 Operating set values of chiller system regarding months June, July, August (°C)

2018	**June**	**July**	**August**	**Average**	**Decrease**
Injection machine (Inactive-dehumidifier)	18	19	19	18.6	-
2019	**June**	**July**	**August**	**Average**	**Decrease**
Injection machine (Active-dehumidifier)	15	14	14	14.3	4.3

In addition, efficiency results of injection production calculated based on the measurement data made in the months when the research was conducted are summarized in Table 5. It is possible to observe the average % efficiency of the machines in the injection line before and after the integration of dehumidifier into the system. Here, as a result of the effect of the dehumidifier on production, it is seen that the production efficiency has increased by ~ 8%. With the reduction of water droplets on the mold, a homogeneous temperature distribution occurs. Fault-free production is ensured by the fact that the temperature of the pet raw material at the injection point and the temperature value at the nozzle outlet end are the same. By adding dehumidifiers to the injection hall, the temperature balance on the mold was regulated and it was seen that it contributed positively to the production efficiency.

Table 5 Injection production efficiency obtained in June, July, August (%)

2018	**June**	**July**	**August**	**Average**	**Increase**
Injection machine (Inactive-dehumidifier)	79.02	77.44	78.11	78.19	-
2019	**June**	**July**	**August**	**Average**	**Increase**
Injection machine (Active-dehumidifier)	86.56	85.72	81	84.42	8

4. CONCLUSIONS

The fact that the temperature exceeds the operating conditions during production has a negative impact on the production efficiency of injection machines and the performance of molds. To increase product quality for better, the machines were accelerated, but no successful results were obtained. At the same time, the rising temperature in the environment made the operating conditions difficult and created an unsuitable operation environment. This is also not ergonomically appropriate. For this purpose, dehumidifiers were integrated into the operating area manufacturing plastic injection. Humidity and heat values generated during the production were monitored daily and recorded.

The results revealed that setting the injection line to a fixed temperature and operating degrees will help prevent water droplets on the molds and also help increase the production efficiency by 8%. The decrease in the operating temperature of the chiller cooling system, compared to the figure of the former year, and the formation of effective cooling are thought to have eliminated water droplets. Integration of a humidifier device into the system helped the operation of the machines realize based on needs. Thus, with the more efficient operation of the machines and the elimination of water droplets on mold, the workload on the cooling was reduced. The findings suggest greater obtained efficiency, productivity, machine availability and quality. Besides, the study revealed that additional cooling applications are required in the injection operating environment to achieve a higher level of efficiency, especially at higher temperatures.

Acknowledgments

Authors would like to extend acknowledgement to the Plaş Plastic Package Corporation for the opportunity to conduct experimental studies.

Funding

The authors has no received any financial support for the research, authorship or publication of this study.

The Declaration of Conflict of Interest/ Common Interest

No conflict of interest or common interest has been declared by the authors.

Authors' Contribution

All authors have contributed in experimental study and writing of the manuscript equally.

The Declaration of Ethics Committee Approval

The authors declare that this work does not require an ethics committee approval or any special permission.

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