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Fuzzy Method for in Control Acetaldehyde Generation in Resin Pet in the Process of Packaging Pre-Forms of Plastic Injection

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Abstract—*In order to control the drying temperature of the PET resin in the silo of the plastic injection molding machine, during the plastic injection process in the industries producing preforms for the manufacture of beverage bottles, care is taken in the ideal temperature regulation for the better performance in controlling the generation of Acetaldehyde (AA), which alters the taste of carbonated or non-carbonated drinks, providing a citrus nuance to the palate and questioning the quality of the packaged products The objective of this work is to develop a tool based on Fuzzy logic to support the control of the drying temperature of PET resin, allowing specialists to make the ideal temperature control decisions necessary to control the generation of Acetaldehyde (AA). For the development of the proposed Fuzzy inference model, we used the Matlab Fuzzy toolbox tool, where the input variables, the fuzzyfication rules and the output variable were implemented based on the data collected from the preform injection process. From the inference model, we obtained a more precise management of the variables that influence the generation of AA, estimating a reduction of $ 240,044.00 in annual costs in the production of preforms.*

Keywords— Packaging, Fuzzy Logic, Inference Rules, Computational Intelligence, PET, Acetaldehyde.

I. INTRODUCTION

With the advent of modern life, the search for convenience and better quality of life, have enabled the increase of research and development of new technologies and raw materials generate new products.

In this context, processes that evolve the manufacture of plastic products have shown a considerable increase (PIRA, 2017).

Regarding the technology used glass as a raw material in the packaging of soft drinks and water. Polyethylene terephthalate (PET) in its bioriented form is the most popular plastic materials to replace glass containers of drinking water, mineral water and carbonated beverages. The resin properties and has some advantages, such as cheaper cost, packaging Lightweight, high mechanical and chemical resistance, versatility of shapes and colors, high barriers to gases, excellent transparency and gloss(ÖZLEM, 2008).

PET or poly (ethylene terephthalate) PET is known worldwide as classified chemically as a semi crystalline polyester polymer belonging to the family, suitable thermoplastic for many applications, particularly in the packaging industry, and particularly in bottles for carbonated beverages. The packaging for this type drinks require special properties, mainly carbon dioxide permeability, PET application come prove their acceptance by the market as a fully recyclable material, is aligned to global trends of economy, energy and environmental protection(GHISOLFI, 2009).

Recent research shows that PET packaging in the world market should reach levels of 21.2 million tons by 2021. In 2015 the PET bottles totaled 16.7 million tons, representing an increase of about 3, 8% compared with the previous year 2014. In the year 2016 the growth of packaging was around 17.5 million tons, achieved an increase of 4.8%. This growth was due to the development of new products for application in various areas of the canning industry, juices and other functional drinks, forecast the drop in PET resin prices will benefit the consumer market(PIRA, 2017).

The PET bottle is produced in the injection process originally in the preform of the bottle, and during this process the polymers soften with temperature, normally pass through several stages of heating the material, followed by mechanical forming, there are several methods that are used in production of plastic parts as extrusion, injection molding, blow molding, etc.(ROSATO, DONALD, & MATTHEWS, 2004).

They are produced through two processes, injection and blow, depending on the final part application during the process of injection molding, which consists essentially in heating and softening of the material grain in a heated cylinder and its subsequent injection at high pressure to the mold, where it cools and takes final shape(GHISOLFI, 2009).

The entire injection process for obtaining molded parts is divided into five stages: drying (bin), feed, plasticization, injection and extraction of the parts(GHISOLFI, 2009).

PET is a hygroscopic material absorbs environmental water during storage (storage), careful drying is controlled in the PET resin and is an essential operation prior to processing to obtain required levels of drying are required peripherals such as bin (store), drying with desiccants, typically with molecular sieves where the air used for drying of the resin is previously dehumidified, polymers and PET are no exception where the temperature range at the recommended drying, should be between 4 to 6 hours otherwise occurs excessive temperatures can damage the raw material, the temperature of the dry air used for drying should be between 160 ° C - 180 ° C (measured at the dryer outlet) when the dry air temperature must not exceed 190 ° C (GHISOLFI, 2009).

A problem came up and the formation of acetaldehyde during polymerization of the PET resin, typically a polymer produced by a polymerization process in liquid phase followed by solid phase polymerization to provide characteristics appropriate for use in the manufacture of blown containers for various applications. It is a colorless, volatile substance citrus odor is generated at high temperatures(ANJOS, 2007).

This problem is compounded during the injection process of the preform of PET, PET generated when the polymer is exposed to high temperatures normally used during the injection molding process. When the polymer is heated above the melting temperature, and may generate the AA altering the flavor of the carbonated drink packaged and not aerated (BACH, Dauchy, Chagnon, & Etienne, 2012).

But it is possible to keep the formation of acetaldehyde in PET bottles at low levels during the production process, controlling the critical steps of the injection process. The concern with the specifications required by the packaging quality control, processing conditions to have a bottle with low AA content during processing of PET resin are low-temperature molten resin, low shear rate, low time residence(ÖZLEM, 2008).

Artificial Intelligence (AI) techniques applied in the field of plastic injection process aimed at helping in the decision to select values for the process parameters deducted a qualitative inspection of injection defects. Also aiming at optimizing the process conditions to obtain a specific level of quality.

The development of systems for operations in the injection molding process suggests optimal conditions of control parameters based on IA which is a great degree of relationship in process conditions(CHAVES, Márquez, Pérez, Sánchez, & Vizan, 2018).

The AI in injection molding machines may have an important contribution in the production of plastic parts quality, due to the action of the sensors that monitor variations in the temperature of the grains subject to factors that may come to disqualify the results obtained in injection (LABATI et al., 2016).

This work has as main objective the use of a fuzzy inference model for control of acetaldehyde formation in the plastic injection process of the preform for the production of bottles.

II. LITERATURE REVISION

2.1 The Injection Mold

The injection molding is the most widely used method in the manufacture of plastic products, due to the high efficiency and manufacturability. The molding process includes three stages: filling, cooling and extraction. The first stage begins by filling the mold cavity with the molten polymer in an injection temperature, the polymer melt is packed into the cavity at a higher pressure to compensate for the anticipated shrinkage as the polymer cools (solidifies) in this cooling phase, when the part is sufficiently rigid to be extracted from the mold, care is redoubled because this phase directly affect and especially productivity and quality molding (CHEN, LAM, & LI, 2000).

The injection molding process is a controllable process in the specified limits. The injection molding can be manufactured with a single cavity or a larger number

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of similar or dissimilar cavities, the cavities are interconnected through flow channels or runners, which direct the flow of molten plastic material into the cavities.

The manufacturing process of molded parts has five steps: drying, food, lamination, injection and extraction of the product. The cooling time in the manufacturing process, it is important that the injection cycle is from the start of injection until opening the mold for extracting the work piece, this time is associated with the solidification temperature (GHISOLFI, 2009).

The cycle of injection of the preform is performed as follows: mold closing; injection unit of advancement; Injection; Repression; Retreat (machine gun); Dosage; Opening the mold and extraction of the piece. Other processes for the production of PET containers can be made by three methods(GHISOLFI, 2009):

- Injection stretch blow: the preform produced is then reheated and stretched and molded into final packaging. This process is called ISBM (Injection Stretch Blow Molding) - Injection molding, stretching and blowing process of a stage;
- Injection blow: the preform is produced, then reheated and blown to stay in the shape of the final package. This process is called IBM (Injection Blow Molding) injection and blow-molding by.
- Injection: a preform is produced and stored and then forwarded to the area for blowing production of the package.

The injection molding machines meet different quality requirements for specific mold parts such as dry cycle, injection rate and injection pressure(ROSATO et al., 2004). The types of injection molding machines can be identified by their three most popular methods of operation are: hydraulic, electric and hybrid.

It is observed laminating two basic systems, the first is the molding of a single stage system (Figure 1) and the second of two stages (Figure 2). There are also molding units in three stages, etc. This is known as single-stage reciprocating screw injection molding machine. The double stage is the piggyback, which may partially be related more to a continuous extruder(ROSATO et al., 2004).

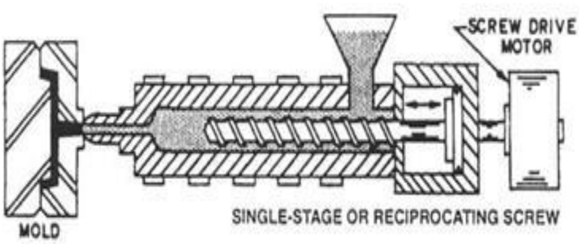

Fig.1: Cannon simple plasticizing injection molding machine.

Source:(ROSATO et al., 2004).

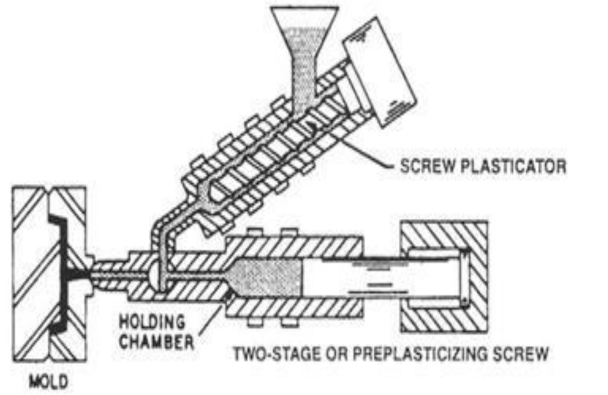

Fig.2: Cannon plasticizer double injection molding machine.

Source: (ROSATO et al., 2004).

One of the important and significant processes of this step is the drying of PET polymer. In solid form PET polymer to be hygroscopic, it absorbs moisture until the equilibrium value with the local relative humidity and high relative humidities in environments can reach up to 0.6% (w / w) by weight if exposed without any protection and weathering for long periods. In practice the polymer is stored indoors, properly packaged and for short periods of time, the humidity value is less may be less than 0.1% (w / w) or less of the weight before entering the polymer melt because it will hydrolyze, reducing the molecular weight and thus the physical properties, chemical and physico-chemical as(BACH et al., 2012).

If the resin is subjected to fusion with these levels of moisture, undergoes rapid degradation (hydrolysis), thereby reducing its molecular weight (Figure 3), which is reflected in the loss of intrinsic viscosity (IV) and consequent loss of its physical properties. To maintain the maximum performance of the PET polymers should reduce its moisture content to below 0.003% (30 ppm)(GHISOLFI, 2009).

The careful and controlled drying of PET resins is an essential operation before processing.

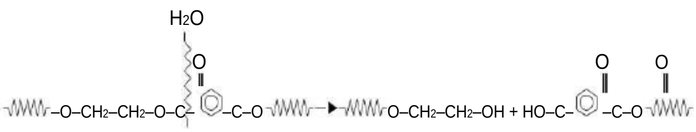

Fig.3: Reaction hydrolytic degradation (hydrolysis) of PET resins.

Source: (GHISOLFI, 2009).

2.2 Acetaldehyde

The (AA) is a colorless volatile liquid substance and pungent odor, non-toxic, with odor and taste typical of fruit, low limit of human perception. AA large quantities are found naturally in many foods such as fruits, butter,

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cheese, vegetables and beverages(EWENDER & WELLE, 2008).

The AA is miscible in water and various solvents, which being in diluted concentrations presents citrus fruit aroma. The most common synonyms are ethanol acetaldehyde, acetic aldehyde, acetaldehyde, etilaldeído, and diethyl 1,1 - dietioxiétano, whose molecular structure (Figure 4)(NIJSSEN, KAMPERMAN, & JETTEN, 1996).

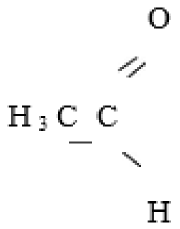

Fig.4: Structural formula of acetaldehyde. Source:(GHISOLFI, 2009).

2.3 Generation of acetaldehyde in manufacturing the resin

In the production of PET resin, AA is formed during the polymerization stage, which takes place in the melt phase. The amorphous grain obtained at this point may be between 50 ppm and 100 ppm AA as temperatures and residence times used in the process. This resin is post-condensed in the solid state up to a molecular weight suitable for manufacturing bottles. During this step, the AA diffuses out of the grain along with the glycol being driven by process N2. Thus, the AA in PET bottle out of the solid post-condensation step achieves lower residual AA levels of 3-4 ppm, depending on the desired specification for the beverage manufacturer and could reach levels below 1 ppm(GHISOLFI, 2009).

The resin is intended for transformers, which is mainly subjected to injection blow molding process. In this process, the resin is remelted in the injection phase, then taking place again degradation of the resin, thus generating AA(NIJSSEN et al., 1996).

2.4 Generation of acetaldehyde in the molding process

In the resin molding process (PET) the melting temperature is a key control the generation of variable formation of acetaldehyde (AA) is in the process consisting essentially of softening the material in a heated cylinder (ROSATO et al., 2004).

In the production of PET resin for packaging can be produced with low levels of residual acetaldehyde (AA), this waste is generated during melting of the polymer in the injection molding of the preform. Therefore, it is important to control the injection process in which the polymer is subjected to high temperatures for prolonged periods fusion(EWENDER & WELLE, 2008).

Besides the residence of the fusion temperature, we have to consider other relevant factors which are responsible for acetaldehyde levels found in PET containers as type and formulation of the resin, type of equipment, thread profile design of the barrel of the injection machine and processing conditions(ANJOS, 2007).

Initially only the glass kept this property as required to properly package the carbonated and meet the manufacturer's requirements for packaging these products while maintaining the desired transparency. PET bottles obtained in injection and blowing process, allowed to gather optical properties, mechanical and permeability required for preparation of these carbonated beverages or non-(GHISOLFI, 2009).

The flavors and aromas in beverages groups may be altered by the presence of (AA) from the environment may be, the product itself and / or the packaging material used. From the point of environmental contamination arising view, can be diverse sources such as combustion of wood, coffee roasting, acetic acid and vinyl acetate production from ethylene, among others. The synthesis or the formation in the food itself comes also in different ways, mainly by oxidation of the primary alcohol ethanol or ethyl and fermentation processes for the production of foods and beverages(GHISOLFI, 2009).

Concern about the presence of acetaldehyde in PET packaging is due to the taste change that may cause the packaged product. For example, colas and mineral water in which its flavor is directly affected by the presence of AA. The non-carbonated mineral waters are more sensitive, resulting in a low perception threshold to the taste in the range of 20 ppm to 40 ppm AA, depending on the water composition(EWENDER & WELLE, 2008).

Acetaldehyde is a byproduct of PET degradation, formed when PET polymer is subjected to high temperatures, typically used in manufacturing and processing, when the polymer is heated above the melting temperature and maintained its high residence time(NIJSSEN et al., 1996).

Two mechanisms are proposed for AA formation by thermal decomposition of PET. The first is the thermal decomposition of hydroxyethyl end group (Figure 5), the second considers that degradation occurs preferably by random scission of the molecular chain of the PET with breaking of ester bonds. This degradation chains are formed with acids and vinyl terminal groups that can react in various ways, eliminating AA (Figure 5)(GHISOLFI, 2009).

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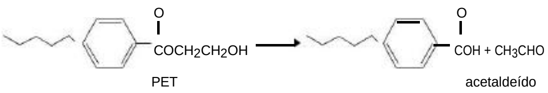

Fig.5: Thermal Degradation of hydroxyethyl end groups. Source:(GHISOLFI, 2009).

The thermal decomposition of PET (Figure 6) is significant when the polymer is melted (temperature above 245 ° C). Therefore, AA is formed so as to manufacture the resin during processing.

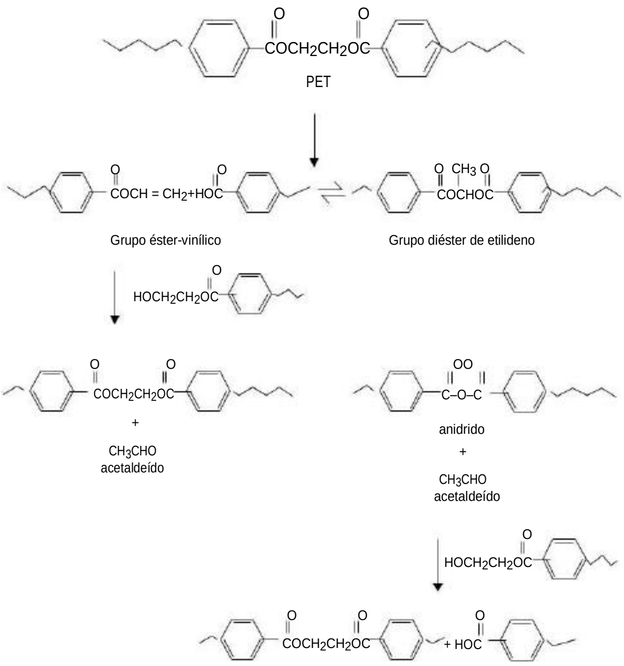

Fig.6: Mechanism of thermal degradation of PET. Source:(GHISOLFI, 2009).

AA Measurements made in various phases of the injection blow molding process for preforms of bottles, confirm that the major source of AA generation on PET resin transformation process occurs during injection of the preform due to reflow of resin (GHISOLFI, 2009).

AA generated during injection blow the PET is held in the bottle wall between the polymer molecules, spreading slowly to the contents thereof.(EWENDER & WELLE, 2008)

AA generation control in the manufacture of bottles, the AA formed in the bottle depends on(GHISOLFI, 2009):

- Resin Formulation - Aiming at the highest quality grade resins, formulations were developed and process conditions that result in lower residual AA content in the grains.
- Processing Conditions - The general processing conditions for a bottle with low AA content during the processing of PET are: Low temperature molten resin, low shear rates and short residence times (very long injection times corresponding to increased exposure heat).

AA is generated at significantly elevated temperatures. Thus, control of the injection process is critical to control the AA generation in the production of bottles. On the other hand, the blowing stage has virtually no effect on the formation of AA, since it works at warmer temperatures.

Thus, to reduce the generation of AA from the resin during the injection of the preform, it is advisable to keep the polymer melt in the lowest temperature possible for the minimum time, with minimum shear.

The concentration of AA in the preform increases in proportion to the drying temperature, the barrel and the mold. But only adjust the barrel temperatures and mold channels does not guarantee that the temperature of the molten polyester go stay fit. The viscous melt is also heated by friction with the barrel, the screw and the distribution channels. This friction is much depending on the viscosity of the molten resin as the type and speed of the thread. Besides the heat generated by friction, shear mechanically break the polymer molecules, thereby forming more hydroxyethyl end groups, which, in turn, make more AA (Figure 5)(GHISOLFI, 2009).

Parameters to be controlled to minimize exposure to heat are:

a) cylinder temperature (decrease).
b) Temperatures of hot runner nozzles and manifold (lessen).
c) residence time in the barrel, and hot runner manifold (keep as short as possible).
d) Residence time of the polymer melt in the process.

A parameter of almost equal importance to the temperature of the molten polymer to minimize the formation of AA in the preform is the residence time thereof. Put simply note that the AA generated is almost directly proportional to the residence time of the melt in the process. Thus, it is a good rule to minimize the cycle time to decrease the generation of AA. Parameters that depend on the machine used: Dimensions of injection channels, the thread profile.

Since low AA concentrations already affecting the organoleptic properties of the mineral waters and colas manufacturing bottles with low AA is essential for the rigid packaging industry. Therefore, it is leading the AA analysis in quality control resins and bottles(EWENDER & WELLE, 2008).

2.5 Fuzzy theory

The fuzzy set theory was developed in 1965, with the work of Lotfi Zadeh, professor at the University of California at Berkeley(Nogueira & Nascimento, 2017).

The theory of fuzzy sets has emerged as a tool to address problems related to information vague, imprecise or ambiguous, often described in natural language - qualitative terms - to be transcribed into numerical language(Nogueira & Nascimento, 2017).

The use of fuzzy theory allows us to model mathematically variables vague and imprecise, provided by knowledgeable people of the study process(BOBILLO & STRACCIA, 2017).

Are many different applications of the theory of fuzzy sets, the further fuzzy control, has been applied in the automation of various areas of production in the industry.

A fuzzy set is a class of objects with a continuum of association notes. This set is characterized by a membership function (feature) that assigns each object a varying degree of association in a numerical range [0, 1](BOBILLO & STRACCIA, 2017).

The inclusion notions, union intersection, complement, relation, convexity, etc., are extended to these and various properties of these notions in the context of fuzzy sets and are established. In particular, a separation theorem for convex fuzzy sets is proved without requiring fuzzy sets are disjoint(ZADEH, 1965) (Nogueira & Nascimento, 2017).

2.5.1 System Mandami

In 1975, Mamdani represented one of the first fuzzy systems which applied a set of fuzzy rules provided by experienced human operators to control a combination of the steam engine and boiler(POURJAVAD & MAYORGA, 2017).

The main idea of Mamdani method is to describe the process of states through linguistic variables and use these variables as inputs to control rules; the rules connect the input variables to the output variables and are based on the description of the diffuse state which is obtained by definition of linguistic variables. It is expected that each crisp input (real or n-tuple of real numbers) do match a crisp output and overall system Fuzzy match the each input an output. In this case, a fuzzy system is a function Rn R, constructed by a method according to specify modules 3 (Figure 7)(MUÑOS & MIRANDA, 2016).

Fuzzification module: mathematically modeling the information of the input variables by means of fuzzy sets. It is the module that shows the great importance of the skilled process to be examined, every input variable must be assigned linguistic terms that represent the states of this variable and for each linguistic term relevance. The universe of discourse of each variable was determined by the linguistic components "Low", "Medium", "High" and "Low", "Medium", "High" for input and output. It is in this module that stores the variables and their language ratings(LEE, 1990);

Inference module: is which defines the logical connectives used to establish the relationship modeling fuzzy rules base. It is this module that depends on the success of the Fuzzy system as it will provide the output (control) to be adopted by the fuzzy controller from each fuzzy input(ROBLES, Vazquez, Castro, & Castillo, 2016);

Defuzzification module: which reflects the state of the fuzzy output variable to a numeric value.

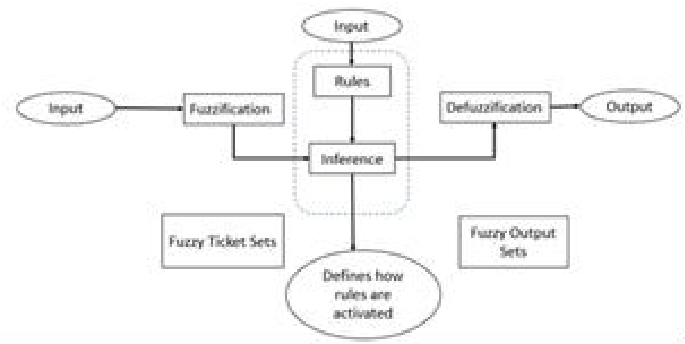

Fig.7: Structure of the fuzzy logic controller.
Source: Adapted from (Nogueira & Nascimento, 2017).

III. MATERIALS AND METHODS

3.1 Data

The data used for this study corresponds to information collected on an industrial hub company Manaus during production by injection preforms PET polymer to be used in its entirety for the manufacture of carbonated beverage containers or not, that process the preform is stored and then delivered to the beverage manufacturer, where the final package for the bottling of the beverage is produced by the blowing process.

All data relating to low linguistic terms, medium and high, fuzzy set and the universe of discourse, where the fuzzy rule-based system is generally derived from the knowledge possessed by an operator or an expert on the functioning of the system(ARIF, Anoraga, Handoyo, & Nasir, 2016).

Data were collected in the quality control sector in packaged preforms in lots of 500 pieces. The Intelligent System was developed as a solution of the injection molding process, which is a complex process with a high number of parameters and variables involved in the process. The only reference to set the appropriate parameters based on certain qualitative characteristics of the produced parts.

The software used to develop this intelligent system was MATLAB R2013a® by enabling management of variables and fuzzy operators, and adapt them to any application without restrictions (CHAVES et al., 2018).

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The work took place in two phases, the first characterized by the literature of computational intelligence applications industries processes, and the second occurred with the survey and analysis of control requirements to be used by the proposed fuzzy inference model.

3.2 Applied Methodology Fuzzy Model

The proposed fuzzy model (Figure 8) shows the representation scenery inference system Silo temperature control of the injection molding machine where the expert daily controls the resin drying process, process done manually, in accordance with the information and feedback from inspections of batches produced and analyzed by the quality control department.

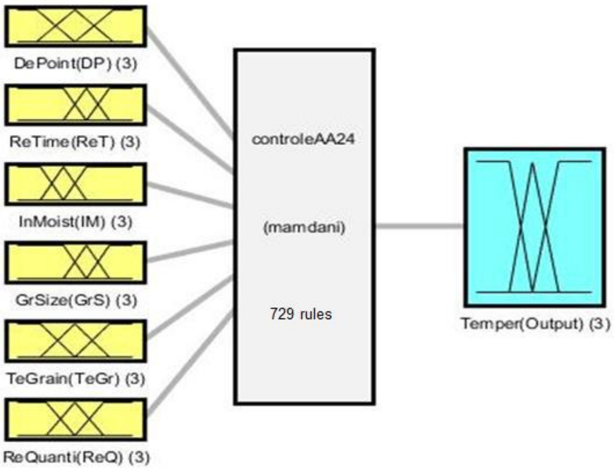

Fig.8: input and output variables of the proposed system.
Source: Authors (2017).

3.2.1 Misty Variables

The input and output data representing the schematic forms of the fuzzy system, through the amount of data in kilos PET polymer grains, dew point, air flow, residence time in the silo, initial moisture content, grain size, temperature grain and outlet temperature.

Table 1 presents the linguistic variables, as well as linguistic labels defined for all variables, the universe of discourse and its description.

Table.1: Description and results of the linguistic variables.

VARIABLE language		CLOUD Y SET	UNIVERSE OF SPEECH	DESCRIPTION
Input	Dew point	Low (B)	[10:50]	The lower the dew point of the higher speed air drying, where the drying air is greater absorption capacity.
		Medium(M)		
		High (A)		
	Residence Time	Low (B)	[12:10]	It is time that the PET bead is inside the dryer. To PET should be four to six hours. It depends on the size of the dryer and the resin consumption.
		Ideal (I)		
		High (A)		
	Initial moisture	Low (B)	[1000: 6000]	The absorption of water by the PET resin occurs until an equilibrium concentration depends on various factors such as time and storage temperature, relative humidity of atmosphere, crystallinity, grain size and shape.
		Ideal (I)		
		High (A)		
	Grain size	Low (B)	[12:10]	The smaller the grain size, the higher the equilibrium moisture of the resin. This effect is attributed to the greater surface area to adsorption (for a same amount of sample, the smaller the grain, the greater the total surface area).
		Ideal (I)		
		High (A)		

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	Temperature Grain	Low (B)	[12:45]	All polymers have a suggested drying temperature range. A long drying time and extreme temperatures can damage the material.
		Ideal (I)		
		High (A)		
	Resin Quantity	Low (B)	[450: 550]	PET polymer in the silo count should not exceed the consumer PET which the machine produces in 1 hour.
		Medium (M)		
		High (A)		
Output	**Temperature**	Low (B)	[155: 190]	Maintain the effective temperature of grains between 160 ° C - 180 ° C (measured at the dryer outlet);
		Ideal (I)		
		High (A)		

Source: Authors (2017).

Descriptions of the variables of the proposed system are: Low, Medium and High.

Variables Inputs:

The Amount of PET Resin - the amount of PET resin in the dryer silo consumption must not exceed the machine continuously produces in 1 hour, 500 Kg / h (Figure 9).

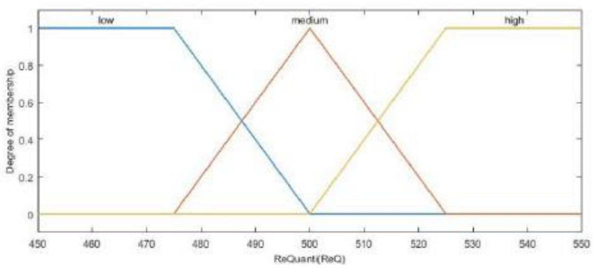

Figure 9: Changeable Amount of resin.
Source: Authors (2017).

Grain dew point - the lower the dew point of the air, the greater the rate of drying, where the drying air is greater absorption capacity (Figure 10).

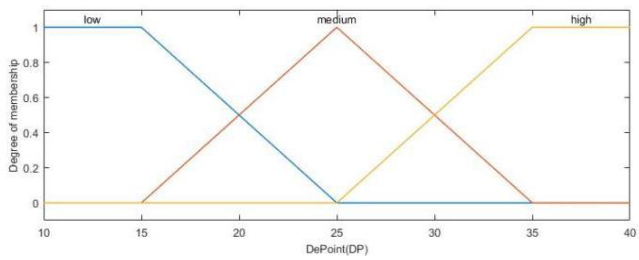

Fig.10: Variable Dew Point.
Source: Authors (2017).

Residence time of matter- the residence time of the raw material in the silo is the time that the PET resin is inside the dryer silo. For PET, must be four to six hours (Figure 11).

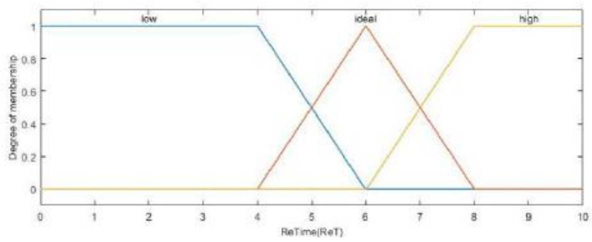

Fig.11: Variable Residence Time.
Source: Authors (2017).

The Initial Moisture of the grains- should not exceed 3.000ppm (0.3%) prior to fusion. PET resin by water absorption occurs until an equilibrium concentration depends on various factors such as storage temperature and time, so it is recommended careful storage in cool environments and covered (Figure 12).

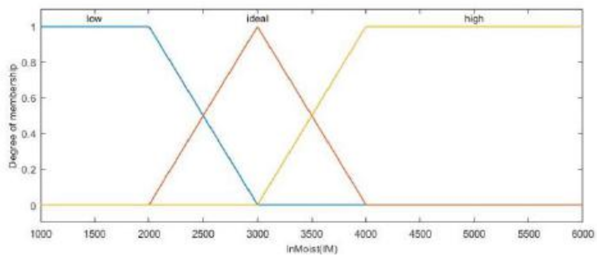

Fig.12: Changeable Initial moisture.
Source: Authors (2017).

Grain Size- the smaller the grain size, the higher the equilibrium moisture of the resin. This effect is attributed to the greater surface area to adsorption (for a same amount of sample, the smaller the grain, the greater the total surface area), this hypothesis is supported by the equilibrium moisture results obtained by PET resin (Figure 13).

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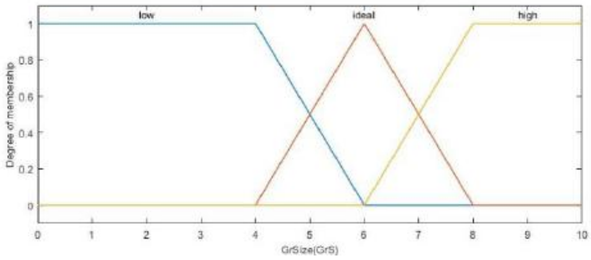

Fig.13: Variable Size grains.
Source: Authors (2017).

Temperature Grain- water absorption resin, should keep in storage the resin at 25 ° C ambient temperature, with temperatures controlled in the manufacturing areas. (Figure 14).

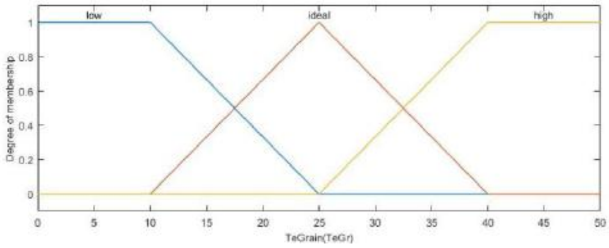

Fig.14: Variable Temperature Grain.
Source: Authors (2017).

Output:
Temperature Control in bin - corresponds to the effective temperature of grains between 160 ° C - 180 ° C (measured at the dryer outlet), if correct change in acetaldehyde content (Figure 15).

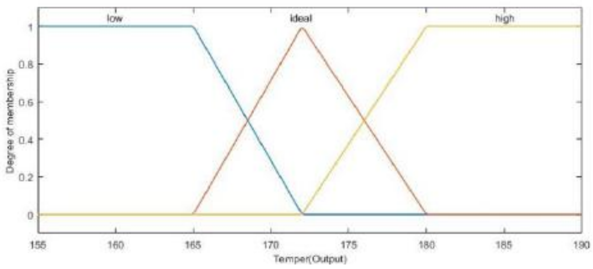

Fig.15: Variable Temperature out.
Source: Authors (2017).

3.2.2 Rule Base

Through the knowledge of experts were obtained the information necessary to create the consistency of the rule base.

To answer the problem posed were created major Inference Rules Bases of linguistic variables resulting in 729 combinations, applied in this fuzzy solution, where part of it is shown in Figure 16, the construction of a fuzzy rule system also should check out no unnecessary rules and which can be removed from the system.

1. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is low) and (GrSize(GrS) is low) and (TeGrain(TeGr) is low) a
2. If (DePoint(DP) is low) and (ReTime(ReT) is ideal) and (InMoist(IM) is ideal) and (GrSize(GrS) is ideal) and (TeGrain(TeGr) is idea
3. If (DePoint(DP) is low) and (ReTime(ReT) is high) and (InMoist(IM) is high) and (GrSize(GrS) is high) and (TeGrain(TeGr) is high)
4. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is ideal) and (GrSize(GrS) is low) and (TeGrain(TeGr) is ideal)
5. If (DePoint(DP) is low) and (ReTime(ReT) is ideal) and (InMoist(IM) is low) and (GrSize(GrS) is ideal) and (TeGrain(TeGr) is low)
6. If (DePoint(DP) is low) and (ReTime(ReT) is high) and (InMoist(IM) is low) and (GrSize(GrS) is high) and (TeGrain(TeGr) is low)
7. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is ideal) and (GrSize(GrS) is high) and (TeGrain(TeGr) is low)
8. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is high) and (GrSize(GrS) is low) and (TeGrain(TeGr) is high)
9. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is low) and (GrSize(GrS) is ideal) and (TeGrain(TeGr) is low)
10. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is low) and (GrSize(GrS) is low) and (TeGrain(TeGr) is ideal)
11. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is low) and (GrSize(GrS) is low) and (TeGrain(TeGr) is low)
12. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is ideal) and (GrSize(GrS) is ideal) and (TeGrain(TeGr) is idea
13. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is high) and (GrSize(GrS) is high) and (TeGrain(TeGr) is high)
14. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is low) and (GrSize(GrS) is high) and (TeGrain(TeGr) is high)
15. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is low) and (GrSize(GrS) is low) and (TeGrain(TeGr) is high)
16. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is low) and (GrSize(GrS) is low) and (TeGrain(TeGr) is low)
17. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is ideal) and (GrSize(GrS) is low) and (TeGrain(TeGr) is low)
18. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is low) and (GrSize(GrS) is ideal) and (TeGrain(TeGr) is low)
19. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is low) and (GrSize(GrS) is low) and (TeGrain(TeGr) is ideal)
20. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is low) and (GrSize(GrS) is low) and (TeGrain(TeGr) is low)
21. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is high) and (GrSize(GrS) is ideal) and (TeGrain(TeGr) is low)
22. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is high) and (GrSize(GrS) is low) and (TeGrain(TeGr) is low)
23. If (DePoint(DP) is low) and (ReTime(ReT) is ideal) and (InMoist(IM) is high) and (GrSize(GrS) is low) and (TeGrain(TeGr) is ideal
24. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is low) and (GrSize(GrS) is ideal) and (TeGrain(TeGr) is ideal)
25. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is low) and (GrSize(GrS) is high) and (TeGrain(TeGr) is high)
26. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is low) and (GrSize(GrS) is low) and (TeGrain(TeGr) is ideal)
27. If (DePoint(DP) is low) and (ReTime(ReT) is low) and (InMoist(IM) is low) and (GrSize(GrS) is low) and (TeGrain(TeGr) is high)

Fig.16. Inference rules of linguistic variables.
Source: Authors (2017)

3.2.3 System Parameters

To perform system controls was used R2013a® MATLAB tool that used the Fuzzy Logic Toolbox and Table 2 shows the summary of system parameters on the use of this tool.

Table.2: Summary of system parameters.

TYPE	"Mamdani "	The response of the process is a fuzzy set for each rule.
METHOD	'Min'	Used to be the connector system rules.
DEFUZZYMET HOD	'Centroid'	Being adherent and computationally simple.
INPUT:	[Strut 1x6]	6 input variables
OUTPUT:	[Strut 1x1]	One output variable
RULE	[Strut 36]	729 rules in total

Source: Authors (2017).

In the literature appear several Fuzzy numbers, the most common are triangular, trapezoidal and bell-shaped. Among them, the best fit to the proposed model was the triangular and trapezoidal, since it works the averages centered on a given range, whose extreme values are related to the mean and standard deviation functions.

IV. RESULTS AND DISCUSSIONS

After inspection of a sample of the produced batches are considered failed lots whose Acetaldehyde indices have up to 4 ppm values as specified in the standard for the

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beverage manufacturer, this information is passed on to technical production which thereafter alter the adjusting the polymer drying silo temperature.

A simulation with use of real situations of arguments where the model can evaluate the linguistic variables of predefined input generating information to support the expert decision in controlling the optimum temperature of the silo during the manufacturing process of the preform was held. Table 3 shows an example of results of the proposed fuzzy inference model.

Table.3: Simulation of the proposed fuzzy inference model.

D.P.	R.T.	I.M.	G.S.	Te.Gr.	Qt.Rs.	Output
10	3	1000	1	9.5	450	161
45	9	4500	9.0	40	545	161
50	10	5000	10.0	45	550	161
15	4.5	1500	2.5	10	470	162
40	8	4000	8.5	35	540	167
20	4.0	1700	3	15	490	168
35	6	2500	6	25	520	172
25	5.5	2000	4	20	510	173
30	5	3500	5	22.5	500	173
35.5	7	3000	7.5	30	530	173

Source: Authors (2017).

In Table 3, it is seen that the output values are within the limits silo temperature tolerance for non-generation of acetaldehyde in order to evaluate the appropriate values of the input variables, which result in the drying process of PET resin. And allowing the specialista on better regulation of temperature.

By varying the input values is possible to assess the outputs by the proposed system, obtaining a value that allows support in decision-making with respect to the silo temperature control, there is the following situation for example, if the dew point is -35 ° C, the residence time is 6 hours, initial moisture content is 2500ppm (0.25%), 6mm² the grain size, grain temperature is 25 ° C and the amount of resin is 520kg / h., then the result will be the 172 ° C temperature, as shown in simulation performed and observed in Figure 17.

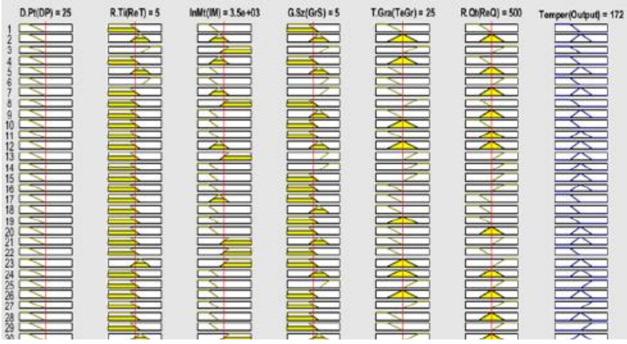

Fig.17: Results shown from inferences.
Source: Authors (2017).

In the graph of Figure 18 has the development performance of the outlet temperatures from the values of the input linguistic variables, where the optimal temperature for the non-generation of acetaldehyde, and not affect the degree of crystallization of the packaging, no loss the intrinsic viscosity of the resin and loss of physicochemical and mechanical functions, that are on average 172 ° C

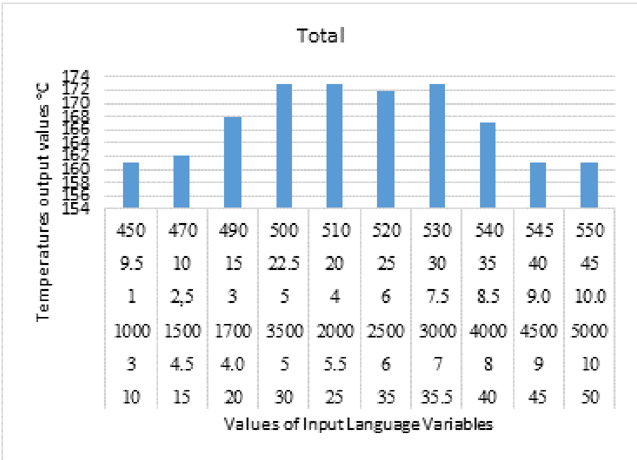

Fig.18: Evolution of the temperature performance.
Source: Authors (2017).

In Figure 19, we note that the residence time of the resin in the injection molding machine-drying silo must not exceed 6 hours and the amount of resin should not exceed 480 kg, approximately.

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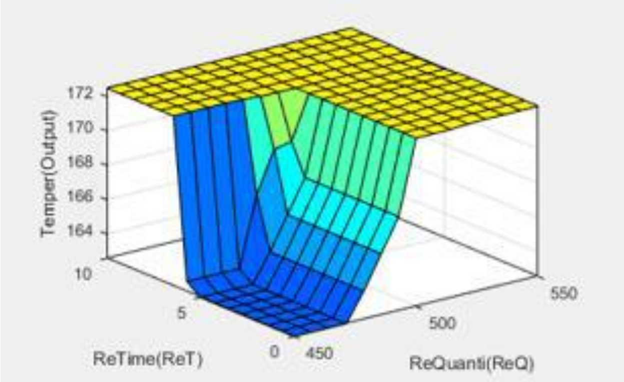

Fig.19: Graph of linguistic variable residence time.
Source: Authors (2017).

Figure 20 shows the optimum temperature of the grain should be maintained between 20 to 25 ° C for a resin amount not exceeding 480 kg, approximately.

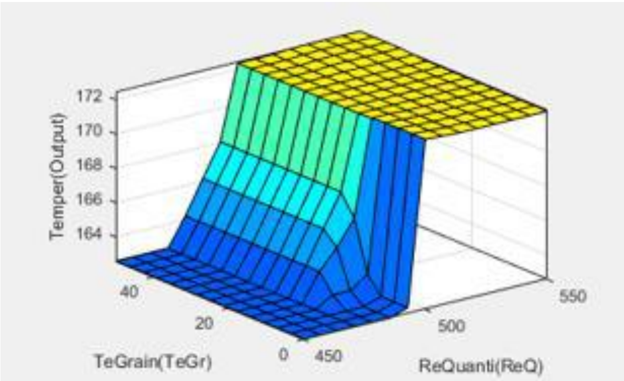

Fig.20: Graph of linguistic variable temperature.
Source: Authors (2017).

V. CONCLUSION

This study presented a method for application of fuzzy drying silo temperature control of the injection molding machine PET polymer. The used model input parameters preset by the resin manufacturers.

The results showed that, in general, the proposed inference model enabled, from the input information, determine ideal temperature of the silo for the production of preforms is carried out within the quality standards required by the beverage manufacturer, ie, with acetaldehyde content below 4ppm. Based on these results, it can be said that the fuzzy inference model proposed, can be considered as an important classification tool temperature control, showing that the Fuzzy method is a promising tool for this classification, it is suggested search Fuzzy an interconnection system controls the injection molding machine so that a synchronized control is carried out with temperature control sensors, being a fully automatic system,

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REFERENCES

[1] ANJOS, C. A. R. (2007). INFLUENCE OF THE PROCESS IN THE GENERATION OF ACETALDEHYDE AND RESIDUAL LEVELS IN POLY (ETHYLENE TEREPHTHALATE) (PET) PACKAGING AND DRINKS. *Revista Brasileira de engenharia de Biossistemas, 3*, 277 - 290.

[2] ARIF, M. F., Anoraga, B., Handoyo, S., & Nasir, H. (2016). Algorithm Apriori Association Rule in Determination of Fuzzy Rule Based on Comparison of Fuzzy Inference System (FIS) Mamdani Method and Sugeno Method. *Business Management and Strategy, 7*.

[3] BACH, C., Dauchy, X., Chagnon, M.-C., & Etienne, S. (2012). Chemical compounds and toxicological assessments of drinking water stored in polyethylene terephthalate (PET) bottles: A source of controversy reviewed. *Water Research, 46*(3), 571-583. doi: https://doi.org/10.1016/j.watres.2011.11.062

[4] BOBILLO, F., & STRACCIA, U. (2017). Generalizing type-2 fuzzy ontologies and type-2 fuzzy description logics. *International Journal of Approximate Reasoning, 87*(Supplement C), 40-66. doi: https://doi.org/10.1016/j.ijar.2017.04.012

[5] CHAVES, M. L., Márquez, J. J., Pérez, H., Sánchez, L., & Vizan, A. (2018). Intelligent Decision System Based on Fuzzy Logic Expert System to Improve Plastic Injection Molding Process. In H. Pérez García, J. Alfonso-Cendón, L. Sánchez González, H. Quintián & E. Corchado (Eds.), *International Joint Conference SOCO'17-CISIS'17-ICEUTE'17 León, Spain, September 6–8, 2017, Proceeding* (pp. 57-67). Cham: Springer International Publishing.

[6] CHEN, X., LAM, Y. C., & LI, D. Q. (2000). Analysis of thermal residual stress in plastic injection molding. *Journal of Materials Processing Technology*.

[7] EWENDER, J., & WELLE, F. (2008). Determination of the Migration of Acetaldehyde from PET Bottles into Noncarbonated and Carbonated Mineral Water. *Fraunhofer Institute for Process Engineering and Packaging (IVV), Giggenhauser Straße 35, 85354 Freising, Germany,*.

[8] GHISOLFI, M. E. (2009). M&G - Manual Técnico Resina PET. *M&G Polímeros Brasil S.A.*

[9] LABATI, R. D., Genovese, A., Munoz, E., Piuri, V., Scotti, F., & Sforza, G. (2016). Computational Intelligence for Industrial and Environmental

Applications. *IEEE 8th International Conference on Intelligent Systems*.

[10] LEE, C. C. (1990). Fuzzy Logic in Control Systems: Fuzzy Logic Controller. *IEEE International Conference on Fuzzy Systems (FUZZ)*.

[11] MUÑOS, M., & MIRANDA, E. (2016). A Fuzzy System for Estimating Premium Cost of Option Exchange Using Mamdani Inference. *IEEE International Conference on Fuzzy Systems (FUZZ)*.

[12] NIJSSEN, B., KAMPERMAN, T., & JETTEN, J. (1996). Acetaldehyde in Mineral Water Stored in Polyethylene Terephthalate (PET) Bottles: Odour Threshold and Quantification. *PACKAGING TECHNOLOGY AND SCIENCE*.

[13] NOGUEIRA, E. L., & NASCIMENTO, M. H. R. (2017). Inventory control applying sales demand prevision based on fuzzy inference system. *Journal of Engineering and Technology for Industrial Applications (JETIA), Vol: 03*.

[14] ÖZLEM, K. E. (2008). Acetaldehyde migration from polyethylene terephthalate bottles into carbonated beverages in Türkiye. *International Journal of Food Science & Technology, 43*(2), 333-338. doi: 10.1111/j.1365-2621.2006.01443.x

[15] PIRA, S. (2017). Sustainability and lightweighting are key areas in the developing PET packaging market. *https://www.smitherspira.com/resources/2017/april/key-areas-in-pet-packaging*.

[16] POURJAVAD, E., & MAYORGA, R. V. (2017). A comparative study and measuring performance of manufacturing systems with Mamdani fuzzy inference system. *Journal of Intelligent Manufacturing*.

[17] ROBLES, E. O., Vazquez, J. L. G., Castro, J. R., & Castillo, O. (2016). A hardware architecture for real-time edge detection based on interval type-2 fuzzy logic. *IEEE*.

[18] ROSATO, D. V., DONALD, V., & MATTHEWS, V. (2004). **Plastic Product Material and Process Selection Handbook.** 2. *Ed. Elsieveier Science & Tecnology Books, 2004*.

[19] ZADEH, L. A. (1965). Fuzzy sets. *Information and Control, 8*(3), 338-353. doi: https://doi.org/10.1016/S0019-9958(65)90241-X