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# Evaluation of Polyurethane Production Quality using Statistical Process Control Approach

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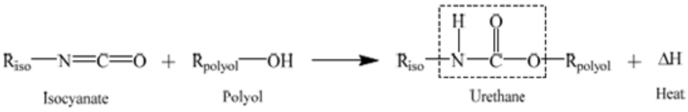
**ABSTRACT**
*Manufacturing processes in the recent times prioritizes competitiveness and continuous improvement. This study examined production data from an indigenous polyurethane firm to monitor controllable variables (i.e., density, tensile strength, hardness, compression and elongation) for quality and improve outcomes. Data was subjected to statistical process control (SPC) using control chart methods of analysis. In addition to raising an alarm when a process deviates from control, control charts are crucial for determining internal and natural control limits. An analysis of the data revealed that at the beginning of production, 35DC (27084), 22DC (26543), 18DC (21805), and 16DC (20666) consumed more production material than 14DC (3833). According to the mean value, the majority of the production material is either consumed during the early stages of production or preserved or minimized during the later stages of production. To counteract this irregularity, it is important to pay greater attention to identifying the material that suffocates other production components during the first stages of production. Therefore, for better health outcomes in terms of ergonomics and acceptability and/or comfort (the feel-good factor) during usage, an ideal blend of polyurethane under controlled manufacture is needed.*
**Keywords:** Polyurethane; Mixture; Optimization; Control; Density; Weight

## 1.0 INTRODUCTION

Materials with a solid phase and a gas phase include plastic foams, foamed plastics, cellular plastics, and polymeric foams. A variety of polymers, including polyurethane (PU), polystyrene (PS), polyisocyanurate (PIR), polyethylene (PE), polypropylene (PP), poly (ethylene-vinyl acetate) (EVA), nitrile rubber (NBR), poly (vinyl chloride) (PVC), and other polyolefins, can be used to create polymer foams, which can be rigid, flexible, or elastomeric (Gama et al., 2018; Matsumura et al., 2006).The term "polyurethane" refers to the urethane bond that results from the reaction of the OH (hydroxyl) groups of a polyol with the NCO (isocyanate functional group) (Gama et al., 2018).An exothermic reaction that leads to the production of urethane groups as shown in Equation 1(Molero et al., 2006).



(1)

A wide range of materials can be produced using polyurethane chemistry due to its adaptability, depending on the starting chemicals utilized in the synthesis (Suleman et al., 2014a; 2014b, 2014c). One of the most significant groups of cellular plastics is flexible polyurethane foam, which is used to create a variety of materials for a variety of applications, including furniture, beds, pillows, car cushions, and more. Polyurethane foams are highly adjustable and come in a variety of chemical compositions. Poly (isocyanate) and polyols are combined with a blowing agent to create the alveolar polyurethanes (Kaushik et al., 2015). One type of polymers called polyurethanes is often created when an isocyanate and a polyol react. These constituents react to generate a urethane group, and the polymer's backbone is formed by the repeating pattern of these urethane groups. The act of creating bubbles and keeping them stable inside a polymeric matrix is known as foaming. Generally speaking, bubble formation results from unstable phenomena or is an attempt to diffuse a "disturbance" in order to return to a stable condition.

To keep the created product in place when a system is agitated into an unstable condition, a way to stabilize the foam that forms must be used (Suleman et al., 2014a). Foams can be formed into either hard or flexible forms, depending on the right beginning material and how it is composed. By using blowing agents to create bubbles in a plastic mixture, these foams are created. Foams are produced in batches or laminates (slab stock) (using molds of different shapes and sizes). The final users of foam determine its properties. The uses for polyurethane foams are numerous. Flexible polyurethane foams are mostly used for furniture cushioning, car padding, appliances insulation, wall panels, shoe bottoms and heels and matrasses, among other applications. In cold storage appliances (such as refrigerators), insulator packing, lagging to stop heat loss, and other applications, rigid polyurethane foams are utilized as insulators (Suleman et al., 2014a).

Statistical process control (SPC) is a primary instrument used for continuous process improvement. It is frequently used to track and enhance production procedures. But it's also frequently applied to raise the calibre of services. SPC, for example, could be used to raise the calibre of the grading procedure. In order to understand SPC methodology, we must realize that the variations we observe in quality characteristics are caused by various factors. These factors include equipment, materials, people, methods and procedures, the environment, etc (Bogo et al., 2023). Rabago (2013) asserts that common cause variation can be quite significant. A process that is poorly planned, outdated or improperly maintained equipment, and insufficient instructions are a few common causes that can have a big impact on process output. Together, the important and unimportant common causes of variation determine the usual process variability. That is, these causes determine the amount of variation that exists when the process is operating routinely. We can reduce the amount of common cause variation by removing some of the important common causes.

There are two categories of input variables that impact every chemical process. Factors that are uncontrollable are referred to as noise factors or common causes (e.g., fluctuations in environmental factors like temperature and humidity throughout the year). The second types of input variables are controllable and are called assignable or special causes (e.g., person, material, unit operation and machine). They are intermittent or permanent changes in the process that are not common to all process observations and that may cause important process variation. Assignable causes are usually of short duration, but they can be persistent or recurring conditions (Epa, 2016).One of the instruments deployed for SPC is control charts which focuses the attention towards the special cause of variation when they appear or reflect the variation magnitude due to common causes. The central line (CL) shows the characteristics of the measured mean value of the quality. Two horizontal exists and namely, upper control limit (UCL) and the lower control limits (LCL) $\overline{X}$ is the mean value of n of observation and $\overline{R}$ is the range which signifies the difference between the maximum and the minimum observation of the sample while $A_2$ is the sample size (Bogo et al., 2023; Rabago, 2013) (Equations 1-3).

$$UCL = \bar{X} + A_2\bar{R} \quad (2)$$
$$CL = \bar{X} \quad (3)$$
$$LCL = \bar{X} - A_2\bar{R} \quad (4)$$

Plotting the process data points on the proper statistical control chart could achieve prompt and online notice of an irregularity (or an outlier) in the foam process (Taylor, 2017). Charts are statistical tools that track a process and notify when the process has been disrupted to the point that it is out of control, according to Taylan & Darrab (2012). This signal identifies the disturbance's source and address it. For monitoring needs, a variety of control charts are offered. The choice of control chart for a particular process is contingent upon two factors: the initial stage of the process improvement, and the nature of the available data and its logical sub-division. Therefore, the purpose of this study is to apply this methodology to data that was provided by a foam manufacturing company, APACO Foam Nigeria Ltd, Agbor, Delta State to evaluate the quality of polyurethane based on the density of formulation, ergonomics and safety of the foams. This research is of significant importance in ensuring high performing product quality that complies with the standardized requirements, desired density, comfort, and reliability.

## 2.0 MATERIAL AND METHODS

Sample was tested at different densities of 35DC, 22DC, 18DC, 16DC, and 14DC4 of 22DC, as indicated in Table 1, using the same mold dimension of 77×88×35.The composition of the sample include; polyol, silicone, water, calcium, methylen chloride, amine, and toluene diisocyanate. Essentially, density is a structural property, defined as mass per unit volume; $\rho = {}^{m}/_{v}\ ({}^{kg}/_{m^3})$. The apparent density of polyurethanes can be used to determine their various physical characteristics. Density was determined for simple-shaped samples by weighing them and then determining their volume using linear measurements; however, DIN 53479 was followed when calculating density for complex-shaped materials, such as polyurethane and elastomers. After the sample was dried and dipped into the test liquid, it was weighed again (water). Here, the density was determined by applying Equation 5:

$$Q_{PK} = \frac{m_1 Q_v}{m_2 - m_1} \quad (5)$$

Where; $Q_{PK}$ is the density of test sample, $Q_v$ is the density of test liquid, $m_1$ is the weight of dry specimen, $m_2$ is the weight of wet specimen. The time interval at which the mixture becomes creamy and begins to expand is represented by the density values for each batch of the foam time. Using a timer, the bench time for mixing was calculated in seconds. Furthermore, the gel time also referred to as the duration at which a mixture becomes a gel foam was measured. When a spatula was used to touch the foaming mixture to test the gel, a thread was seen between the foam and the spatula, suggesting a strong gel structure. It should be noted that the gel time typically exceeds the cream time. The rise time, or the amount of time that the mixture takes to begin rising, is another crucial component. Each of these characteristics were examined for densities of 35DC, 22DC, 18DC, 16DC, and 14DC4 of 22DC respectively.

According to Taylan & Darrab (2012) and Taylor (2017), each formulation was subjected to statistical process control (SPC) methodologies for performance evaluation utilizing control charts. Over the course of manufacturing, samples were divided into subgroups. The subgroups were shown against time after production data analysis. Plots that are produced are frequently referred to as "graphs of process performance." The upper control limit (UCL) and the lower control limit (CL) are the two control limits on a control chart (LCL). When the process is in a state of statistical control, its average performance is represented by the centre line. That is, when variation has just a common cause. When the process is under control, nearly all of the plot points will fall between the upper and lower bounds suggesting that the set targets of quality variables are within established control boundaries (Molero et al., 2006).

These graphs are used to set and maintain an acceptable quality level for a process, allowing the process's output to be quantitatively assessed or its dimensions verified. Process output samples were routinely gathered, their means calculated, and plotted in order to verify earlier results. Furthermore, the control charts were employed to illustrate the changes in the process's mean output over time and to compare the nominal and actual process means. In order to ascertain which points failed each test and whether the process mean or variation is under control, control charts were employed.

## 3.0 RESULTS AND DISCUSSION

Table 1 displays the findings of the several formulations, which are compared according to their densities. It is important to remember that each formulation's density and material composition affect the final result. On the other hand, it has been demonstrated that specific compositions affect how soft or firm the PU is created (Gama et al., 2018; Kaushik et al., 2015; Matsumura et al., 2006; Singh & Jain, 2009; S. Suleman et al., 2014a). A well-chosen blend of polyurethane constituent materials and densities has the ability to yield the best ergonomic and comfort outcomes for individuals (the feel-good factor).

Table 1: Polyurethane Formulations

| Formulation Dimension (Inches) | 35DC | 22DC | 18DC | 16DC | 14DC |
|---|---|---|---|---|---|
| | 77×88×35 | 77×88×35 | 77×88×35 | 77×88×35 | 77×88×35 |
| Composition | Qty used (kg) | Qty used (kg) | Qty used (kg) | Qty used (kg) | Qty used (kg) |
| Polyol | 65 | 60 | 45 | 58 | 42 |
| Silicon | 0.6 | 0.6 | 0.7 | 0.67 | 0.74 |
| Amine | 0.06 | 0.06 | 0.05 | 0.056 | 0.042 |
| Stannous | 0.156 | 0.156 | 0.16 | 0.16 | 0.174 |
| Methylene Chloride | 0 | | 3 | 1 | 5 |
| Toluene Diisocyanate | 31.5 | 34.3 | 30 | 33.5 | 30 |
| Calcium | 20 | 18 | 15 | 16.8 | 12.6 |
| Water | 2.6 | 2.7 | 2.8 | 2.5 | 2.6 |

As illustrated in Figure 1, quality control thus encompasses the following activities: specification, design, production or installation, inspection, and usage review. According to Taylor (2017), quality control refers to all inspection techniques used during the manufacturing process that are appropriate for providing information about the process's status and enabling process intervention with the goal of maintaining the product's quality characteristic within the designated tolerance limit.

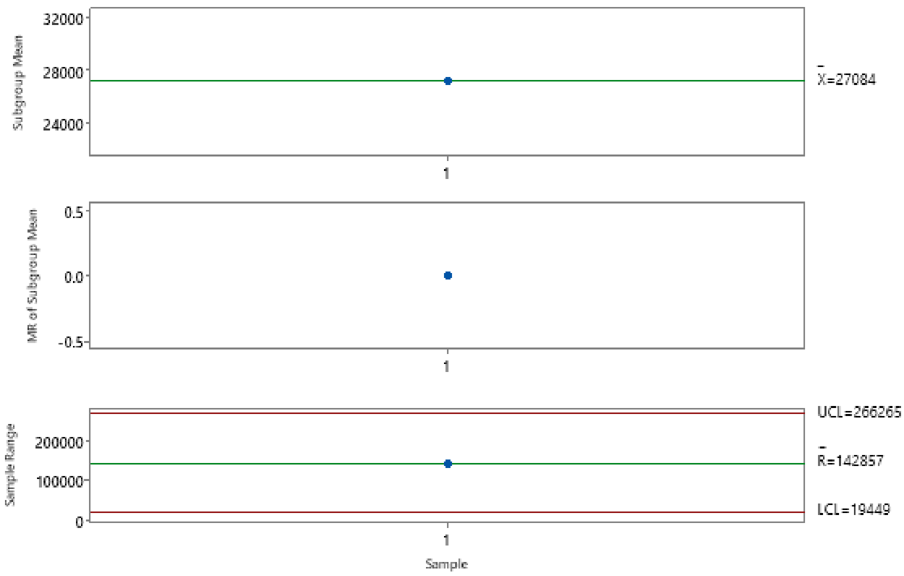



**Figure 1:** 35DC

The production data's subgroup mean, *X*, is 27084, whereas the Lower Control Limit (LCL) is 19449 and the Upper Limit Control (ULC) is 266265. According to Jiang et al. (2009), the goal of the quality control process is to create an environment in which standards violations are identified early on rather than after they have already happened. The complete rise time, gel factor, and cream factor are all implied by this result.
As seen in Figure 2, the ULC is 257390, the LCL is 18801, and the mean value of, *X*. is 26543.

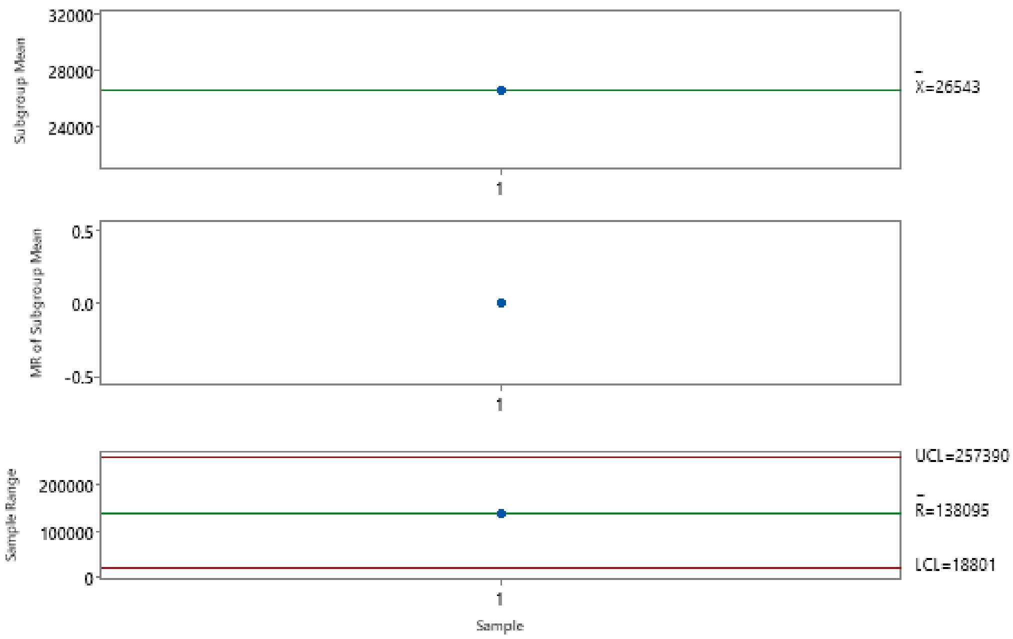



**Figure 2:** 22DC

Control of quality is monitoring the deviations from these criteria that are seen in real units of the product or service, with an emphasis on the intended quality level as a target. As a result, Figure 3 shows that the observed mean was 3833, with corresponding ULC and LCL values of 18639 and 1361, and that there were only minor variations in the complete rise time.

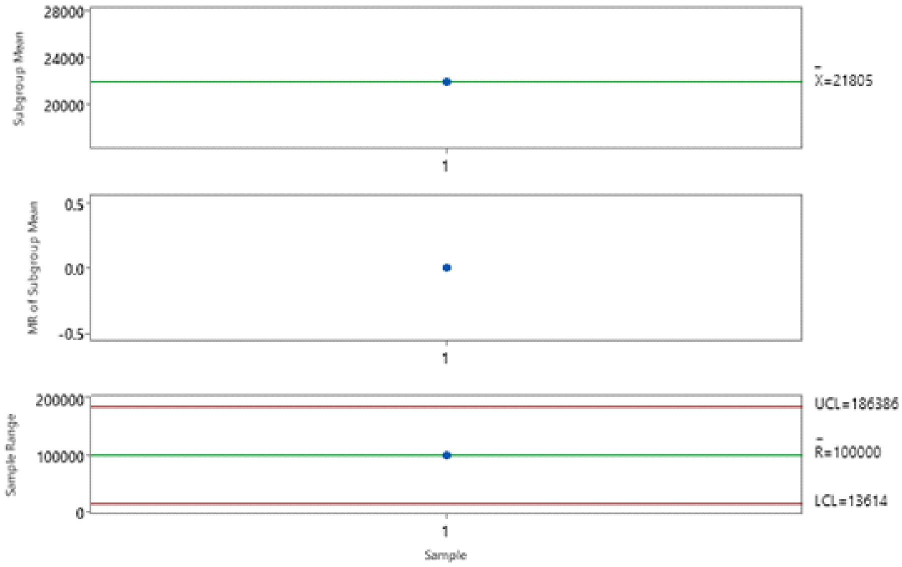



**Figure 3:** 18DC

Similarly, as Figure 3 illustrates, *X.* is 21805, the ULC is 186386, and the LCL is 13614. To put it simply, the control chart is a graphical tool used to help maintain acceptable standards of quality by conducting periodic significance tests (Bogo et al., 2023; Taylan & Darrab, 2012).

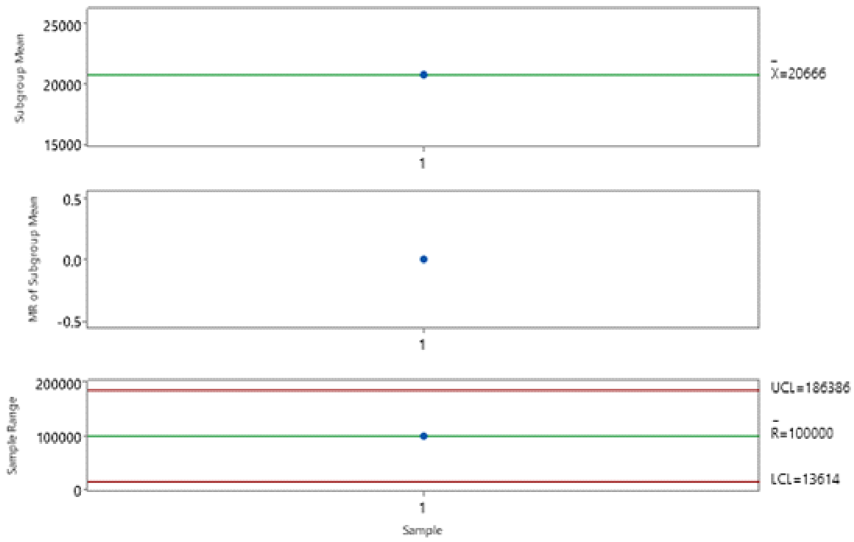



**Figure 4:** 16DC

$\overline{X}$ is 20666whereas the LCL is 13614 and the ULC is 186386. (see Figure 4). Thus, it is possible to describe the control chart as a tool that is mostly used for analysing discrete or continuous data that are produced over a period of time (Epa, 2016; Jiang et al., 2009).

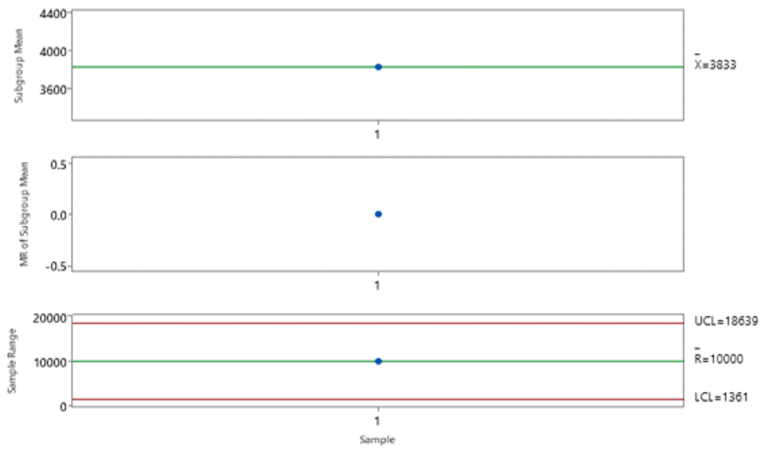



**Figure 5:** 14DC

Figure 5 shows the mean to be 3833 with upper control limit of 18639 and lower control limit of 1361 respectively. Certain variations in quality are due to causes over which we have some degree of control, such as different quality of raw materials or new or unskilled workers; we call these assignable causes of variation. The random variation is the result of each cause being slight; by and large nothing can be done about this cause of variation except to modify the process (Kaushik et al., 2015; Kaya & Kahraman, 2011). Similarly, this has implication on the gel factor, cream factor and the full rise time of the form.
Results of comparison of the formulations based on their densities is as shown in Figure 6.

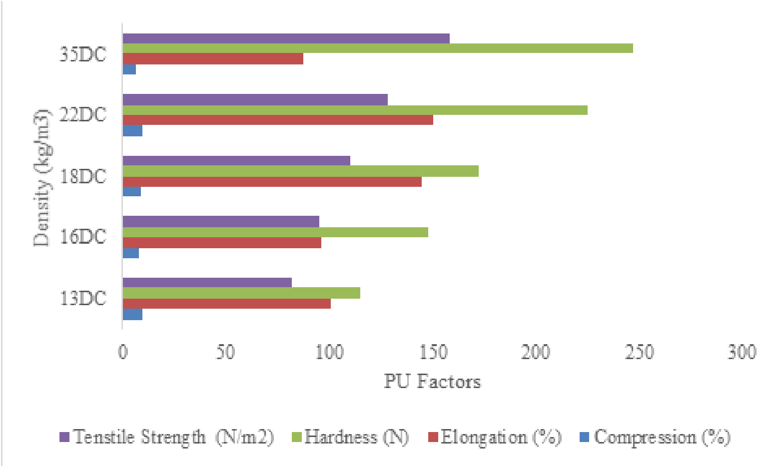



**Figure 6:** Comparison of Polyurethane (PU) Densities

The desired characteristic of each of the mixtures is to obtain an appropriate tensile strength, hardness, elongation and compression. Essentially, 35DC have the hardest formation followed by 22DC, 18DC, 16DC and 13DC respectively. Similarly, 35DC have the highest value in terms of the tensile strength, followed by 22DC, 18DC, 16DC and the least 14DC. In other words, the higher the density, the higher the hardness and the tensile strength (Bogo et al., 2023; Rabago, 2013)(Kaushik et al., 2015). The elongation was not consistent with the densities and this was the same for the compression factor.

## 4.0 CONCLUSION

Process control chart has been used to monitor and control production process. In essence, the variations recorded between each of the materials used for foam production is the residuals of improper fits. i.e. error of production. In other words, the control variables were used in stabilizing the production process over time in order to achieve the best quality. Formulations based on densities include; 35DC, 22DC, 18DC, 16DC and 14DC respectively show distinctive variance in terms of tensile strength, hardness, compression and elongation. Whether the majority of the production material is consumed during the early stages of production or preserved or minimized at the latter stages of production is shown by the mean value. The 35DC, 22DC, 18DC and 16DC was observed to have consumed more of the production material at the initial stage of production than 14DC. In order to mitigate against this irregularity, it is vital that greater attention be paid at the earliest stage of manufacturing to identify the material that suffocates other production components. Furthermore, the range of the charts also brings to bear that mixtures of constituent are fine and not coarse and indicates that machine usage is controlled and hence, no outliers at the upper control and lower control limit.

## REFERENCES

Bogo, A. B., Henning, E., & Kalbusch, A. (2023). Statistical parametric and non-parametric control charts for monitoring residential water consumption. Scientific Reports, 13(1). https://doi.org/10.1038/s41598-023-40584-w

Epa, U. (2016). Control Chart Methodology for Detecting Under-reported Emissions.

Gama, N. V., Ferreira, A., & Barros-Timmons, A. (2018). Polyurethane foams: Past, present, and future. In Materials (Vol. 11, Issue 10). MDPI AG. https://doi.org/10.3390/ma11101841

Jiang, P., Liu, D., & Zeng, Z. (2009). Recognizing control chart patterns with neural network and numerical fitting. Journal of Intelligent Manufacturing, 20(6), 625–635. https://doi.org/10.1007/s10845-008-0152-y

Kaushik, C. N., Achutha, M. V, & Prakash, K. R. (2015). Design and Development of Automation System for Polyurethane Foaming Machine. In Online) International Journal of Research Studies in Science, Engineering and Technology (Vol. 2, Issue 6).

Kaya, H., & Kahraman, C. (2011). Process capability analyses based on fuzzy measurements and fuzzy control charts. Expert Systems wit Applications, 38(4), 3172–3184. https://doi.org/10.1016/j.eswa.2010.09.004

Matsumura, S., Soeda, Y., & Toshima, K. (2006). Perspectives for synthesis and production of polyurethanes and related polymers by enzymes directed toward green and sustainable chemistry. In Applied Microbiology and Biotechnology (Vol. 70, Issue 1, pp. 12–20). https://doi.org/10.1007/s00253-005-0269-2

Molero, C., De Lucas, A., & Rodríguez, J. F. (2006). Recovery of polyols from flexible polyurethane foam by "split- phase" glycolysis: Glycol influence. Polymer Degradation and Stability, 91(2), 221–228. https://doi.org/10.1016/j.polymdegradstab.2005.05.008

Rabago, D. M. (2013). Statistical Quality Control and Process Capability Analysis for Variability Reduction of the Tomato Paste Filling Process. Industrial Engineering & Management, 03(04). https://doi.org/10.4172/2169-0316.1000137

Singh, H., & Jain, A. K. (2009). Ignition, combustion, toxicity, and fire retardancy of polyurethane foams: A comprehensive review. Journal of Applied Polymer Science, 111(2), 1115–1143. https://doi.org/10.1002/app.29131

Suleman, S., Khan, S. M., Gull, N., Aleem, W., Shafiq, M., & Jamil, T. (2014a). A Comprehensive Short Review on Polyurethane Foam. In International Journal of Innovation and Scientific Research (Vol. 12, Issue 1). http://www.ijisr.issr-journals.org/

Suleman, S., Khan, S. M., Gull, N., Aleem, W., Shafiq, M., & Jamil, T. (2014b). Synthesis and Characterization of Visco-Elastic (VE) Polyurethane Foam. In International Journal of Innovation and Applied Studies (Vol. 9, Issue 4). http://www.ijias.issr-journals.org/

Suleman, S., Khan, S. M., Gull, N., Aleem, W., Shafiq, M., & Jamil, T. (2014c). Synthesis and Characterization of Visco-Elastic (VE) Polyurethane Foam. In International Journal of Innovation and Applied Studies (Vol. 9, Issue 4). http://www.ijias.issr-journals.org/

Taylan, O., & Darrab, I. A. (2012). Fuzzy control charts for process quality improvement and product assessment in tip shear carpet industry. Journal of Manufacturing Technology Management, 23(3), 402–420. https://doi.org/10.1108/17410381211217434

Taylor, W. A. (2017). Normalized Individuals (I N ) Control Chart.