



FORMULATION OF POLYURETHANE FOAM USING CASTOR OIL AS A PARTIAL SUBSTITUTE FOR SILICONE OIL

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ABSTRACT

This study was aimed at the formulation and characterisation of polyurethane foam using castor oil as a substitute for silicone oil. In the study an alternative surfactant, "castor oil" was used for the formulation of flexible polyurethane foam. The castor oil and silicone oil were mixed at different ratio for the formulation. It was found that the maximum castor/silicone oil ratio for substitution was found to be 4:1 (80%:20%) and should be highly respected. The physical properties were determined and it showed increase in density (21.40-25.80 Kg/m³), hardness index (168-180 KN) and compression set (7.14-3.45%), while rise and fall was observed in tensile strength and elongation. However, no significant difference existed between tensile strength and elongation before and after heat ageing. This methodology allowed up to 80% substitution of silicone oil with castor oil for foam formulation. Exceeding this ratio will lead to total foam collapse as was observed in the sample of 90% and 100% silicone oil substitution. It was concluded that castor oil can only be used as partial substitute for silicone oil in foam production. Hence, this will help to reduce the cost of production which constitutes a major hurdle in small scale industries in the third world countries.

Keywords: Polyurethane foam, castor oil, silicone oil, partial substitute, formulation

INTRODUCTION

Urethane foams can be made in either flexible or rigid form depending on the nature of the polymer and the type of crosslinking produced. Their popularity have increased very rapidly, production rose from 35 million lb in 1958 to 500 million lb of flexible and 240 million lb of rigid foams in 1969 (Billmeyer, 1971). In the production of urethane foams, excess isocyanate groups in the polymer react with water or carboxylic acids to produce carbon dioxide, blowing the foam, at the same time that crosslinking is effected. Like polyurethane elastomers, urethane foams are made in several steps. The basic intermediate is bifunctional if flexible foams are desired and polyfunctional if rigid foams are to be made (D'Ancicco, 1969). However here we are concerned with the flexible polyurethane foam. Generally, the urethane linkage, which all polyurethanes have in common, involves the reaction of an isocyanate group with a hydroxyl-containing group. Common hydroxyl-bearing groups include polyether alcohols, polyester alcohols, carboxylic acids, and amines (Pigott, 1969). The chemical structure, such as the length and side branching, of the hydroxyl-bearing group plays an important role in the properties of the final foam product (Makanjuola, 1999, Oertel, 1993, Gum *et al.*, 1992). Surfactants is a major raw materials used in the production of flexible polyurethane foam though in a very small quantity compared with toluene diisocyanate and polyol but have a significant cost implication. In cost term, silicone oil which is the surfactant used is in the range of 0.5-2.5 parts per hundred polyol but have a cost implication of about 25% minimum of the unit cost of the product. Flexible polyurethane foam production relies greatly on the performance of non-

ionic, silicone based surfactants which are added to realize a variety of functions. Some of the main functions performed are reducing surface tension, emulsifying incompatible ingredients, promoting bubble nucleation during mixing, stabilization of the cell walls during foam expansion, and reducing the deforming effect of any solid added (Heidbreder *et al.*, 1999; Höfer, 1999; Falbe, 1987). Among these functions, perhaps the most important is the stabilization of the cell walls, without which the foam would behave like a viscous boiling liquid (Small, 1969).

Traditionally silicone oil is employed in foam production. An alternative surfactant 'castor oil' is being considered for the production of flexible foam. Castor oil is a vegetable oil obtained from the castor bean seed, which contains 50-55% of oil (Weiss, 1983). The castor bean plant, *Ricinus communis*, is a native of tropical Africa. Castor oil shares very close chemical and physical properties with silicone oil. It has better low temperature viscosity properties and high temperature lubrication than most vegetable oils, making it useful as a lubricant in jet, diesel, and race-car engines (McGuire and Nancy, 2004). Obviously castor oil and its derivatives have become important commodities and items of interest to chemical industries (Vignolo and Naughton, 1991).

The need to reduce importation of materials to encourage local production is at the heart of the economic reforms agenda of most developing economies like Nigeria. Fulfilling these goals prompted the quest to start looking inward for substitutes for most raw materials of the polyurethane industries in Nigeria that are heavily dependent on importation for their supplies.



This act of importation contributes to high production cost and again, the non availability of some of these raw materials has sent some other small and medium scale enterprises out of market. In view of this fact, this study is aimed to find a partial or total substitute for silicone oil in foam production. The successful substitution of silicone oils either partially or totally with castor oil in the production of flexible polyurethane will definitely reduce the cost of production thereby increasing profit.

MATERIALS AND METHODS

The materials employed in this work include among others, castor oil, silicone oil, polyol, toluene diisocyanate, amine, stannous octoate, chloride, mould, beakers and bowls. All chemicals used were of analytical grade. The experimental work was performed in Research Laboratory, Department of Chemical Engineering, Federal University of Technology, Minna, Nigeria. The complete methodology of the conventional mixing technique was employed in this experiment. Each of the eleven different mixing ratios of silicone oil and castor oil as shown in Table 1, were laboratory mix formulation based on 500g polyether base polyol that is surfactant being one part to hundred parts of polyol (Makanjuola, 1999; Simpson, 2004). The experiments have been run for eleven times, with the foam sample of 100% silicone oil used as a reference.

Five hundred grams of polyol was weighed into a beaker and kept aside. Twenty grams of tap water was weighed out in the 500 cm³ glass beaker and 0.6 grams of amine was then added to the water. Five grams of silicone oil was also added to the mixture of water and amine, 0.1 cm³ of methylene chloride was then added and mixture was stirred for about 15 sec. The mixture was stirred thoroughly and then poured into the beaker containing polyol. Stannous octoate (1g) was measured in the 25 cm³ glass cup and then poured into the beaker containing the other mixture. The content of the beaker was thoroughly mixed and kept to the already prepared box. 200 grams of toluene diisocyanate was then measured out in a separate beaker. The mixture containing polyol and the foaming catalyst was again stirred thoroughly; the toluene diisocyanate was then poured into the beaker containing the polyol mixture and thoroughly stirred for about twelve seconds before it was poured quickly into the box for moulding. After 5-10 mins, depending on how fast is the rising time, it was removed from the mould and the foam sample ready. This procedure was repeated for the various mix formulation ratio of silicone oil and castor oil for the remaining samples. Using standard procedures and that of America society for testing materials, physical properties such as density, hardness index, elongation test, ageing test, compression set and tensile strength were determined as outlined in (ASTM D 3489-81, ASTM D 3574,

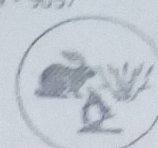
Simpson, 2004., Woods, 1990., Ogunleye *et al.*, 2006., UT, 2000).

RESULTS

The mix formulation ratio of silicone oil and castor oil are given in Table 1. Sample one (control sample) was 100% silicone oil and sample eleven was 100% castor oil. While the remaining samples are mix formulations ranging from 10 – 90% castor oil respectively. The effects of castor oil on foam rising time and height of foam after curing for 24 hrs are presented in Table 1. There was a decrease in rising time from sample 1 to 5. While an increase in rising time was recorded from sample 6 to 9. The height of foam samples after 24 hrs curing followed the same trend as rising time of foam samples (Table 1). The physical characterization carried out on samples such as: densities, hardness indices, compression set, tensile strength before and after heat ageing, elongation before and after heat ageing, are presented in Table 2.

DISCUSSION

It can be seen from Table 1 and 2 that samples 10 and 11 gave characteristics that were totally different from other samples. It was observed that the two samples 10 (90% castor oil) and 11 (100% castor oil) which were subjected to the same treatment gave a total foam collapse (Ogunleye *et al.*, 2006). This may be as a result of perceived hindered blowing reaction caused by less availability of water that was to react with isocyanate to form amines and carbon (IV) oxide that were to do the blowing. Shortage of water would have been caused by the presence of castor oil that reacts with water due to its chemical nature (Ogunleye *et al.*, 2008). Considering foam formulation used, all other chemicals were kept constant except silicone oil but on getting to sample 6 (i.e. 50% silicone and 50% castor oil) there was a close cell foam (Dead foam) which signifies excess stannous octoate which warranted its reduction by 20%. The excess stannous octoate can be traced to the rapid and vigorous reactions of castor oil with isocyanate groups where the polymers sets quickly and branching points were formed by the biuret linkages. The mixture also became too viscous resulting in slow rising and hence the reason for the observed rising time (Ogunniyi *et al.*, 1996). The densities of foam samples were in the range of 21.40 – 25.80 Kg/m³ and increased in the order from sample 1 to 9. It was observed that increase in the amount of castor oil and decrease in amount of silicone oil resulted to increase in densities of foam sample. Except for samples 10 & 11 in which a total foam collapse was recorded (Ogunleye *et al.*, 2008). Table 2 shows the increase in the density of the foam samples produced. The increase in the densities of samples with increase in castor oil could be attributed to the high viscosity caused by castor oil present which improved the homogeneity of the mixture because of its oleochemical binding nature (Höfer, 1999).

**Table 1: Formulation Ratio of Silicone Oil and Castor Oil**

Samples	1	2	3	4	5	6	7	8	9	10	11
Amount of silicone oil (g)	5.00	4.50	4.00	3.50	3.00	2.50	2.00	1.50	1.00	0.50	0.00
Amount of castor oil (g)	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00	4.50	5.00
Rising time (secs)	78.00	70.00	70.00	72.00	75.00	78.00	85.00	85.00	86.00	-- --	-- --
Height of sample After Curing (24hr)	25.00	26.50	27.20	27.20	27.30	25.20	26.60	27.10	27.40	-- --	-- --

Table 2: Physical Characteristics of Samples

Samples	Density (Kg/m ³)	Hardness Index(KN)	Compression Set Test (%)	Tensile Strength Before Heat Ageing (KN)	Tensile Strength After Heat Ageing (KN)	Elongation Before Ageing (%)	Elongation After Ageing (%)
1	21.40	168.00	7.14	119.00	118.60	189.50	187.00
2	21.80	169.00	7.10	118.00	116.00	190.00	188.00
3	22.30	169.80	6.89	115.90	115.40	192.80	191.00
4	22.50	171.50	6.80	119.00	118.00	194.00	192.80
5	22.80	176.00	6.50	127.50	126.40	196.60	190.90
6	23.70	177.00	5.90	131.90	129.70	154.80	152.60
7	24.20	178.00	3.82	128.20	126.90	165.20	162.80
8	25.00	178.00	3.60	126.00	125.60	156.20	154.30
9	25.80	180.00	3.45	125.00	124.20	145.00	141.80
10	-- --	-- --	-- --	-- --	-- --	-- --	-- --
11	-- --	-- --	-- --	-- --	-- --	-- --	-- --

This improved emulsification and binding actions improves the foam's fine structures and cross linkages of foam cells as a result increased the density.

Table 2 shows that increase in hardness index was observed in the foam samples. The effect of variation in the amount of silicone and castor oil in the samples showed an increase in hardness index from 168 to 180 KN. The load bearing capacity of the foam depends on the hardness of the foam (Ogunniyi *et al.*, 1996). Yet the toluene diisocyanate index which is responsible for foam hardness was also kept constant. With the rapid and vigorous reactions of castor oil with water and isocyanate groups, the polymers set quickly and the branching points were formed by the biuret linkages. This may be the reason for the hardness trend. The hardness indices obtained are higher than that of the control sample 1 which is an indication of improvement. However, hardness index increased with increase in castor oil.

The result of the performance test carried out in this study with the foam sample are discussed below and shown in Table 2. The ability of foam samples to recover after compression was observed, measured and recorded. Results obtained showed a decrease in thickness with increase in ratios of castor oil to silicone oil. The percentage values represent the loss in thickness after the test was performed. The control sample had 7.14 % loss in thickness after the test and this reduced with increased castor oil till sample 9 with 80% castor oil substitution that has 3.45% loss in thickness after the test (Ogunleye *et al.*, 2006) as shown in Table 2. This is an indication of

better ability to recover after compression with increased castor oil. This may be due to the fine structure nature of the foam cells formed as a result of the oleochemical activities of castor oil in the mixture (Höfer, 1999). The voidage fraction is reduced and hence the improved recovery ability. These characteristics indicated the improvement in the ability of foam to recover after compression.

The tensile strength of samples before and after heat ageing were determined and presented in Table 2. Table 2 shows clearly that sample 6 which has the composition of equal amount (50%: 50%) castor and silicone oil recorded the highest tensile strength value for both before and after heat ageing. While the lowest value was recorded by sample 3. This implied that equal ratio content of silicone and castor oil gave the highest strength. Heat ageing test are usually carried out to ascertain the stability of the foam sample under very harsh condition of heating for hours. It is generally assumed that this will indicate the foam stability with time. Comparing the strength before and after heat ageing, shows that no significant differences were observed in their strength (Ogunleye *et al.*, 2008). Generally, as the castor oil increased the strength of foam under tension fluctuated but were still within the acceptable limit of standard. This trend can be attributed to the hardness of the foam which ordinarily has a define relationship with castor oil ratio formulation. The elongation test carried out on the samples before and after heat ageing was performed to ascertain not only the elasticity but also the stability of the foam sample.



It can be observed that as castor oil increased, the elongation value increased from sample 1 to 5, and suddenly drop to sample 6, it then rise to sample 7 and decreased to sample 9. Comparatively, the results do not show significant difference between the elongation before and after heat ageing (Ogunniyi *et al.*, 1996). The results obtained in this study conform with the Standard Organisation of Nigeria (SON).

CONCLUSION

The comparative study of the results with the control sample concluded that the properties of the produced foams were within the recommended standards. From these results it is evident that the substitution of



silicone oil with castor oil indicated increase in density, hardness index and compression set respectively. These properties are still within standard range recommended for foam formulation. It was also found that the maximum castor/silicone oil ratio for substitution was 4:1 (80%:20%) and should be highly respected. Exceeding this ratio will lead to total foam collapse as were observed in the samples of 90% and 100% castor oil substitution in all the physical tests performed. Apparently, from this investigation castor oil may only be used as partial substitute for silicone oil in flexible foam production.

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