

## ORIGINAL ARTICLE

### Effects of Castor Oil on the Physical Properties of Polyether Based Flexible Polyurethane Foam

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#### ABSTRACT

A preliminary study was made on the effects of castor oil on the properties of polyether based polyurethane foam such as rising time, density, hardness, tensile strength, compression, elongation and heat ageing. The castor oil was introduced into the polyurethane foam by partially substituting it for silicone oil through seven experimental set up based on the laboratory mix formulation on 500g polyether based polyol with 0%, 20%, 40%, 50%, 60%, 80% and 100% castor oil substitutions. Incorporating castor oil significantly increased density from 21kg/m<sup>3</sup> for foam without castor oil up to 25.73kg/m<sup>3</sup> for 80% castor substitution and hardness index from 119kN up to 125kN. Improved compression set from 7.14% to 3.45% was also noticed while tensile strength and elongation decreased with increased castor oil. Also heat ageing did not significantly affect the properties of the foam samples. The rising time of foam also increased with the increased castor oil. Clear cut conclusions on 100% substitution of castor oil could not be made as the experimental sample collapsed totally.

**Key words:** Oleochemical, closed cell, hardness, polyether and polyurethane

#### Introduction

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. 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, D. 1999; Oertel, G. 1993; Uhlig, K. 1999). The short chain length compounds with tri- and trifunctional-alcohols are used to produce more rigid foams while longer chain length compounds with trifunctional-alcohols are used to generate more flexible foams (Oertel, G. 1993; Oertel, G. 1983; Reed, D. 1997). However, additional hydroxyl-containing compounds including glycerol, castor oil, raw sugar, sorbitol, isocyanate, and phenols can be incorporated to produce plastics with increased flexibility, increased rigidity, and increased heat resistance (Uhlig, K. 1999; Falbe, J. 1987; Gum, W.F., *et al.*, 1992). If a polyether alcohol is selected as the primary hydroxyl-containing group, the resulting foam may be referred to as polyether polyurethane foam.

Surfactants is a major raw materials used in the production of flexible polyurethane foam though in a very small quantity compared with TDI 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 defoaming effect of any solid added (Falbe, J. 1987; Heidbreder, A., *et al.*, 1999; Höfer, R. 1999). Of these functions, perhaps the most important is the stabilization of the cell walls, without which the foam would behave like a viscous boiling liquid.

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For developing economies whose productions are dominated by small and medium scale enterprises (SMES), ensuring quality at the minimum cost characterizes their operations. Likewise 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's. Fulfilling these goals prompted the quest to start looking inward for substitutes for most raw materials of the polyurethane industries in Nigeria that heavily dependent on importation for their supplies. This act of importation contributes to high product cost and again, the non-availability of some of these raw materials has sent some other SMES out of market.

This work is therefore centered on finding a partial or total substitute for silicone oil. Among many surfactants that are locally available is castor oil that shares very close chemical and physical properties with silicone oil. Castor oil is derived from the seed of *Ricinus Communis* L. and is essentially a tropical species that grows naturally over a wide range of geographical regions. In Nigeria, apart from some parts of the middle belt notably Kogi State (where it is cultivated), castor oil plant grows in the wild and is treated as weed (Vwioko, D.E. and Fashemi, D.S. 2005). This shows the ability of the plant to grow under variety of physical and climatic conditions and the viability of its commercialization. Castor beans contains about 30-35 percent oil (Akpan, U.G., *et al.*, 2006; Marter A.D. 1981; Weise E.A. 1983) which can be extracted by variety of processes.

The chemical structure of castor oil is of great interest because of the wide range of reactions it affords to the oleochemical industry and the unique chemical that can be derived from it. Castor oil is glycerol triester of 12-hydroxyoleic acid (ricinoleic acid) (Falbe, J. 1987; Heidbreder, A., *et al.*, Höfer, R., *et al.*, 1999).



The oil is essentially a pure triglyceride, and contains almost 90% of glyceryl tricinnoleate. With regard to product development based on triglycerides, the majority of reactions are carried out at the carboxylic group (>90%) whereas oleochemical reactions involving the alkyl chain or double bond represent less than 10%. When it acts as surfactants, the hydrophilic head and hydrophobic tail interpose themselves between water and water-insoluble substances. Characterizing properties of castor oil include a higher density, viscosity and reactivity than common triglycerides found in other vegetable oils (Heidbreder, A. *et al.*, 1999; Hill, K. 1998;).

## Materials and discussion

### Materials

The following are the equipment and materials required for the experiment: Polyol, Toluene di isocyanate, Amine, Stannous Octaoate, Water, Silicone Oil, Stirrer (wooden), 28cm by 22 by 7cm volume box with inner nylon lining, 5 litre volume bowl, Weighing balance (graduated in gramme), Methylene Chloride, 2 litre volume bowl. Industrial grade castor oil with viscosity of 900psi and specific gravity of 0.94.

### Methods

#### Foam Preparation

Each of the ten different mixing ratio of silicone oil and castor oil as shown on Table 1 was added to a mixture containing a laboratory mix formulation based on 500g polyether based polyol (i.e Surfactant being 1part to 100 part of polyol (Makanjuola, D. 1999; Uhlig, K. 1999; Simpson, R. 2004). The control experiment was 21kg/m<sup>3</sup> density foam formulation without castor oil. When homogeneity in mixing has been achieved, the mixture was quickly poured into the mould. After 5-10 minutes, depending on how fast is the rising time, it was removed from the mould and the mould was then prepared for the next experiment.

#### Physical Testing

Physical tests carried out on the foam samples to ascertain their quality are as outlined in ASTM-D3574 (Simpson, R. 2004; Woods, G. 1990; Ogunleye, O.O., *et al.*, 2006; UT 2000). These properties are:

- Density test
- Indentation test
- Compression Set test
- Tensile Strength and Elongation tests
- Heat Ageing



Table 1: Mixing ratio of Silicone oil and Castor Oil

Set Up	Amount of Silicone Oil (g)	Amount of Castor Oil(g)
Control	5.00	0.00
Experiment 1	4.50	0.50
Experiment 2	4.00	1.00
Experiment 3	3.50	1.50
Experiment 4	3.00	2.00
Experiment 5	2.50	2.50
Experiment 6	2.00	3.00
Experiment 7	1.50	3.50
Experiment 8	1.00	4.00
Experiment 9	0.50	4.50
Experiment 10	0.00	5.00

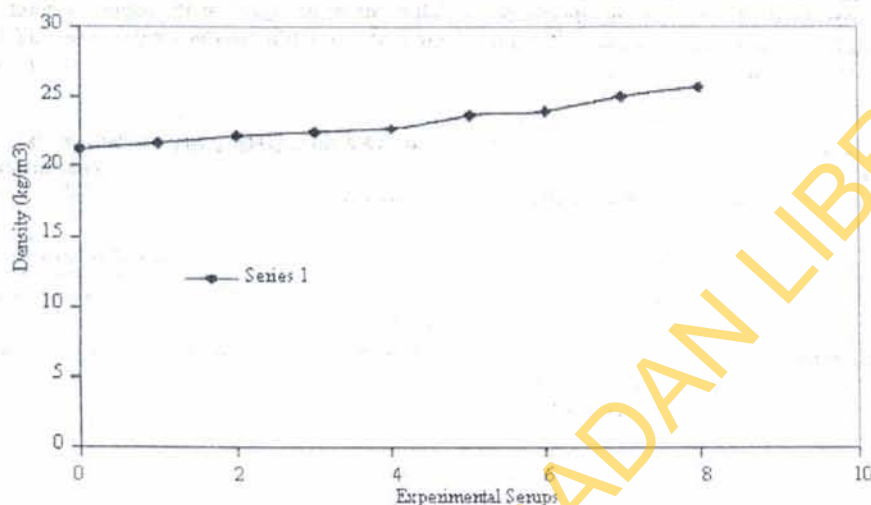


Fig. 1: Effect of Castor Oil on Density

## Results and discussion

### Effect of Castor Oil on the Foam Rising Time

Table 2 shows the observation made on the samples during experimentation. It could be seen that the rising time of experiments 1 and 4 were lower than that of the control experiment but increased with increased castor oil quantity. Foam formulation from experiment 5 had to be altered by reducing stannous octoate by 20% (i.e. 0.75gm to 0.6gm). This is because of the close cell foam (dead foam) experienced as a result of excess stannous octoate. There was increased rising time from experiment 5 with increased castor oil quantity used after the formulation was changed. This same phenomenon was also true of the height of the foam samples. The ten experiments were subjected to the same curing time of 24 hours. It was observed that experiments 9 and 10 (i.e. 90% and 100% castor oil) gave a total foam collapse. 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. Considering foam formulation used, all other chemicals were kept constant except silicone oil but on getting to experiment 5 (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 become too viscous resulting in slow rising and hence the reason for the observed rising time.

### Effect of Castor Oil on the Density

The general summary of the physical tests carried out on the samples are as presented in Table 3. It was observed that the Density increase as the castor oil increases from experiment 1 to 8 as shown on Figure 1. A formulation of 21 kg/m<sup>3</sup> (density) foam was used to prepare the entire Laboratory mixing yet it was

Table 2: Observation during experimentation

Experiment	Control	1	2	3	4	5	6	7	8	9	10
Rising Time	1min 18sec	1min 10sec	1min 10sec	1min 12sec	1min 15sec	1min 18sec	1min 25sec	1min 25sec	1min 26sec	*	*
Height (cm)	26.50	26.60	27.20	27.20	27.30	25.20	26.60	27.10	27.40	0	0
Curing Time(hours)	24	24	24	24	24	24	24	24	24	24	24

\* Total Collapse

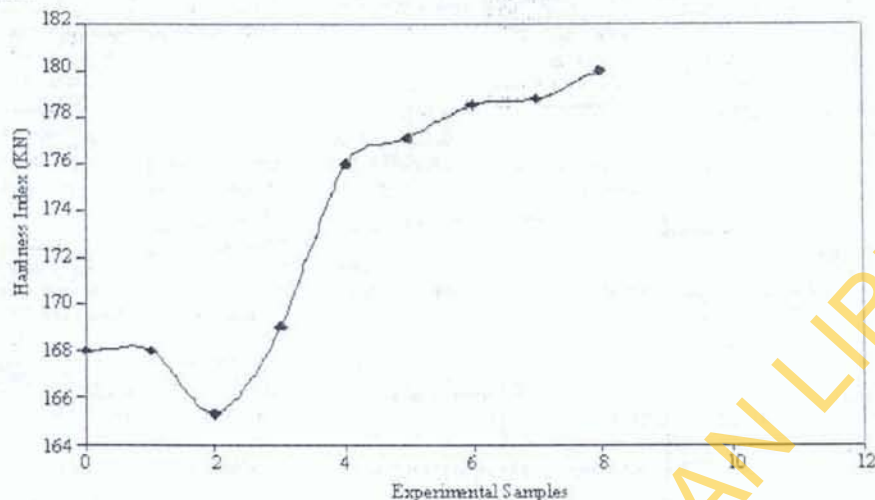


Fig. 2: Effects of Castor Oil on Hardness Index

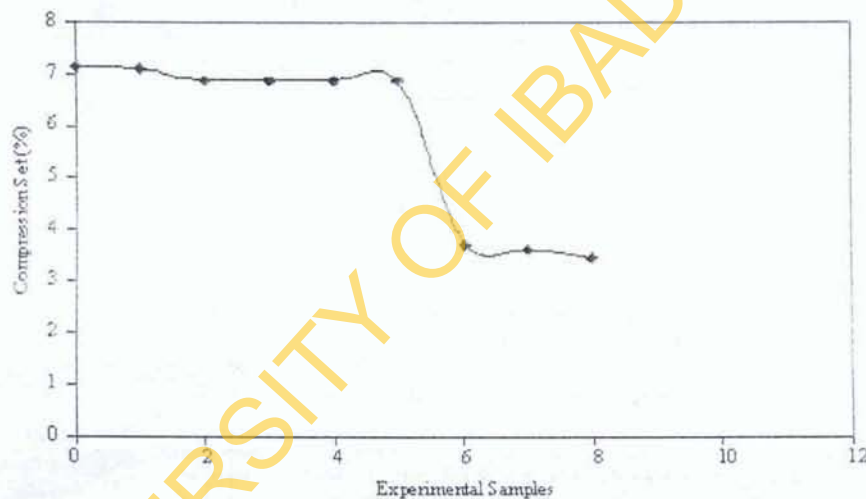


Fig. 3: Effects of Castor Oil on Compression Set

discovered that the density increases as the quantity of castor oil was increased and silicone oil reduce. Increase in the densities of samples with increased castor oil can be explained by possibly the high viscosity caused by castor oil presence which improved the homogeneity of the mixture because of its oleochemical binding nature. This improved emulsification and binding actions improves the foam's fine structures and cross linkages of foam cells. Hence the increased densities.

*Effect of Castor Oil on the Hardness Index*

It was observed that the hardness increased with increased castor oil as shown on Figure 2. Hardness index increased from 119kN for control experiment to 125 kN for experiment 8 (80% castor oil). Hardness index increased with increased castor oil. The load bearing capacity of the foam depends on the hardness of the foam. Yet the TDI index which is responsible for foam hardness was also kept constant. With the rapid and

Table 3: Result of the Physical Tests on Samples.

Experiment	Control	1	2	3	4	5	6	7	8	9	10
Density kg/m <sup>3</sup>	21.20	21.60	22.20	22.40	22.71	23.73	24.00	25.00	25.73	ID	ID
Hardness Index (kN)	168.00	168.00	165.30	169.00	176.00	177.10	178.50	178.80	180.00	ID	ID
Compression set Test (%)	7.14	7.10	6.89	6.89	6.89	6.89	3.70	3.60	3.45	ID	ID
Tensile Strength (kN/m <sup>2</sup> )	119.00	118.00	115.90	119.00	127.50	131.90	128.20	128.00	125.00	ID	ID
Elongation (%)	189.50	190.00	192.80	194.00	196.60	154.80	165.20	156.20	145.00	ID	ID
Tensile Strength After Heat Ageing (kN/m <sup>2</sup> )	118.60	116.00	115.40	118.00	126.40	128.70	126.90	125.60	124.20	ID	ID
Elongation After Heat Ageing (%)	188.40	188.00	191.60	192.80	194.90	154.60	164.80	154.30	144.80	ID	ID

ID: Indeterminate

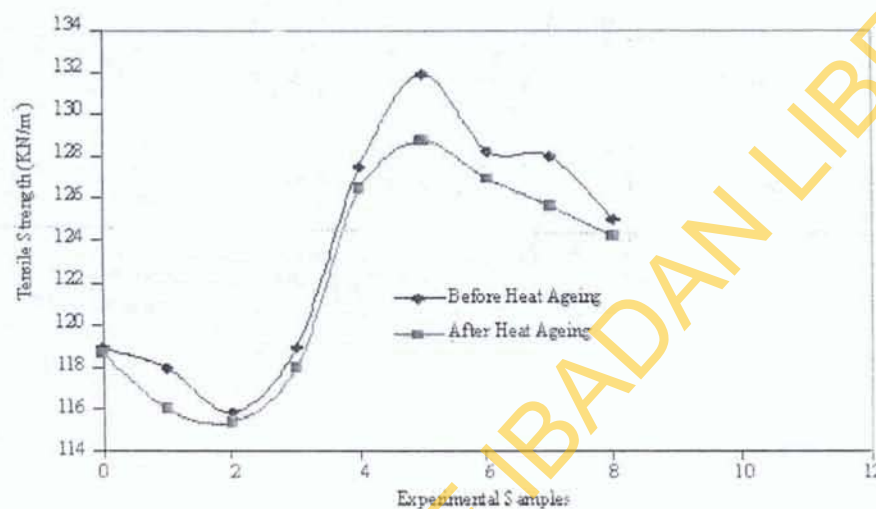


Fig. 4: Effects of Castor Oil on Tensile strength

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 explains the reason for the hardness trend. The hardness indices obtained are higher than that of the control experiment 1 which is an indication of improvement.

#### Effect of Castor Oil on the Compression Set

The measurement of foam's ability to recover after compression was also observed. Whatever value of percentage gotten shows the loss in thickness after the test was performed. The control experiment has 7.14% loss in thickness after the test while this reduced with increased castor oil till experiment 8 with 80% castor oil substitution that has 3.45% loss in thickness after the test as shown on Figure 3. 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. The voidage fraction is reduced and hence the improved recovery ability.

#### Effect of Castor Oil on Tensile Strength and Elongation

The strength and elasticity of foam under tension also compared favourably with the control experiment. Figure 4 shows the tensile strength for before and after heat ageing. Heat ageing test normally come up to ascertain the stability of the foam sample under very harsh condition heating for hours. It is generally taken that this will indicate the foam stability with time. Broadly speaking, as the castor oil increases the strength and elasticity of foam under tension declined but still within the acceptable limit of standard. This trend can be attributed to the hardness of the foam which ordinarily has an inverse relationship with the elongation and the tensile strength.



### Conclusion

This preliminary study shows that the physical test carried out on most of the samples are acceptable and hence castor oil can be said to be a viable substitute for silicone oil. Castor oil can be use as a partial substitute of silicone oil up to 80% substitution. These substitutions also have effect on the quantity of stannous octoate used as indicated from experiment 5. Polyol, isocyanates and water reacts to form polyurethane foam of different qualities. Making a partial substitution of silicone oil by castor oil up to 80% significantly increased density from 21kg/m<sup>3</sup> for foam without castor oil up to 25.73kg/m<sup>3</sup> for 80% castor substitution and hardness index from 119kN up to 125kN. The tensile strength and elongation of samples declined with increased castor oil but however compared favourably with the control experiment.

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