AN ENVIRONMENTAL AUDIT OF METHYLENE CHLORIDE-BLOWN BATCH AND CONTINUOUS POLYURETHANE FOAM PRODUCTION PROCESSES: EMISSION QUALITATIVE DISTRIBUTION, AUXILIARY BLOWING AGENT TUNNEL CONCENTRATION AND DIFFUSION COEFFICIENT ESTIMATIONS[∗]

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Abstract. *In recent times, foam manufacturers have shifted from using dichloromethane (F-11/CFC-11/CCl$_3$F) as an auxiliary blowing agent (ABA) to methylene chloride (CH$_2$Cl$_2$) since CCl$_3$F was linked to global warming and depletion of stratospheric ozone. Hence, a proper environmental investigation of the behaviour of CH$_2$Cl$_2$ and its associated emissions during polyurethane foam production is necessary since CH$_2$Cl$_2$ is a known animal carcinogen and a suspected human carcinogen. Ambient air sampling of a batch and continuous system was done using activated charcoal as the absorbing medium. Extraction of the collected samples was done in Carbon disulphide (CS$_2$) and its analysis was carried out with an infrared spectrophotometer. A model was used in predicting the tunnel concentrations of CH$_2$Cl$_2$ as a function of formulation, tunnel length, conveyor speed and air flow. The diffusion coefficient of CH$_2$Cl$_2$ within the foaming tunnel was also estimated. An infrared analysis confirmed that the emissions from batch and continuous production processes are made up of CH$_2$Cl$_2$, amine and toluene diisocyanate (TDI) fumes. Also, with decreasing foam density and hardness, the CH$_2$Cl$_2$ feed rate, tunnel air flow and calculated CH$_2$Cl$_2$ concentration (ppm) increase. The diffusion coefficient of CH$_2$Cl$_2$ increases as its temperature within the foaming tunnel increases.*

Key words: *the production process, polyurethane foam, environmental protection*

1. INTRODUCTION

Nigeria's economy is highly dependent on the capital-intensive oil and gas industry. Crude oil accounted for 37% per cent of the GDP, agriculture (31.7%), sale and retail trade (14.7%) while manufacturing contributes as little as (2.6%) (APRM, 2008). Notwithstanding, the manufacturing sector is an important source of employment for a substantial fraction of the population. Hence, adoption of environmental friendly raw materials in its manufacturing sector is highly necessary for the adequate protection of its citizenry and ecosystem.

The growth of synthetic materials has been increasingly replacing those originating from natural sources in the last 80 years. They have led to the emergence of synthetic materials such as polyurethanes, rayon, nylon, glass, polystyrene, polyethylene, polyvinyl chloride (PVC), styrene butadiene resins (SBR). Polyurethane has a distinct application of importance including beddings in homes as well as furniture, automobiles and aircraft upholstery (Duck, 1971). Flexible polyurethane foams are divided into two groups; polyester-based foams and polyether-based foams. Polyester foam is widely manufactured in Nigerian Polyurethane industries (Makanjuola, 1999b). Table 1 below shows their comparative features.
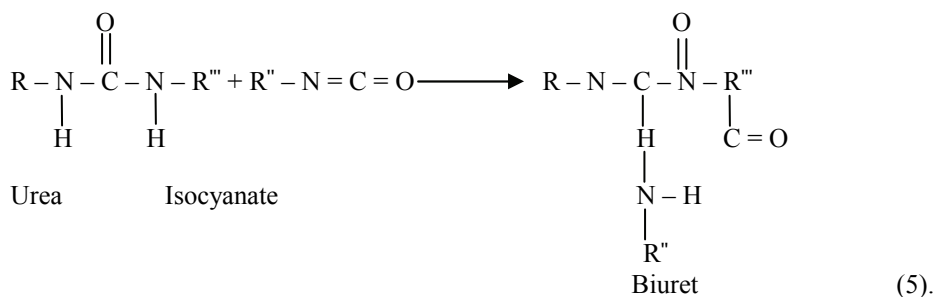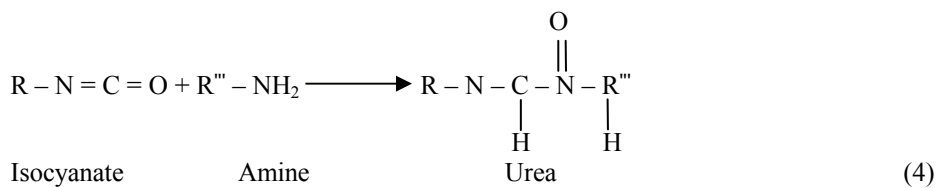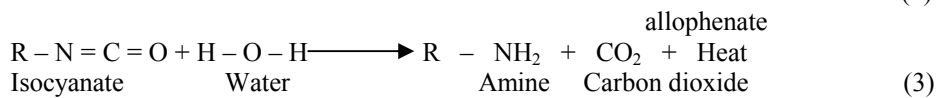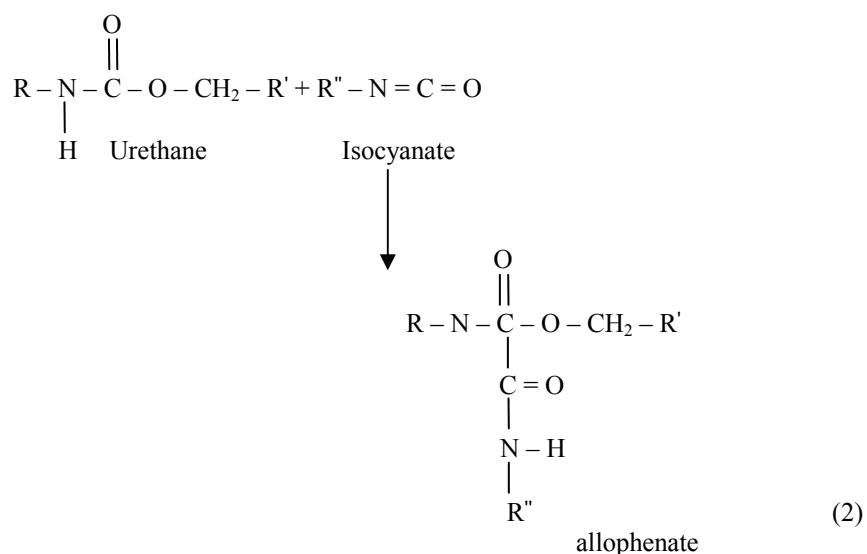
Table 1. Comparative Features of Polyether and Polyester Foams

Feature	Polyether	Polyester
Process	One-shot production	Premix before production
Machinery	Simple, less expensive, low pressure	Complicated, expensive, high-pressure
Properties	Good elasticity, soft to touch	Poor elasticity, slightly tougher
Uses	Cushions, matresses, toys, upholsteries	Carpet backings, laminations

1.1 Polyurethane Reactions

The chemistry of polyurethane foam can be divided into two categories; polymerization reaction and blowing/gas production reaction (Makanjuola, 1999a). Polymerization reaction is a reaction between toluene diisocyanate (TDI) and poly-functional alcohol (polyol), which in the primary reaction produces urethane, and later turns to allophanate during the curing stage (Onyenuforo, 1999). The reaction occurs in stages so as to form a familiar complex polymer structure (Makanjuola, 1999a). In the primary reaction, the di-functional isocynate (TDI) reacts with the poly-functional alcohol to form urethane. The reaction is catalyzed by a tin catalyst (Stannous Octoate). This reaction is very important during polymerization. The secondary reaction occurs during the curing stage. It is the reaction between hydrogen on the nitrogen atom of the urethane and another isocyanate molecule to form an allophenate group.
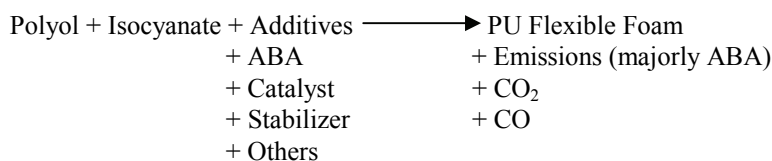
The blowing/Gas production reaction is the reaction between water and TDI. This produces quite a large amount of gas (Carbon Dioxide), which in turn blows up the foam cells created during the urethane-forming reaction (Makajuola, 1999a). Polyurethane reactions are summarized below:

$$R - N = C = O + R' - CH_2 - OH$$
$$\text{Isocyanate} \qquad\qquad \text{Polyol}$$

$$\downarrow$$

$$R - N - \overset{\overset{\displaystyle O}{\|}}{C} - O - CH_2 - R'$$
$$|$$
$$H \quad \text{Urethane} \tag{1}$$

$$R - N - \overset{\overset{\displaystyle O}{\|}}{C} - O - CH_2 - R' + R'' - N = C = O$$
$$|$$
$$H \qquad \text{Urethane} \qquad\qquad \text{Isocyanate}$$

$$\downarrow$$

$$R - N - \overset{\overset{\displaystyle O}{\|}}{C} - O - CH_2 - R'$$
$$|$$
$$C = O$$
$$|$$
$$N - H$$
$$|$$
$$R''$$
$$\text{allophenate} \tag{2}$$

$$R - N = C = O + H - O - H \longrightarrow R - NH_2 + CO_2 + \text{Heat}$$
$$\text{Isocyanate} \qquad\qquad \text{Water} \qquad\qquad \text{Amine} \quad \text{Carbon dioxide} \tag{3}$$

$$R - N = C = O + R''' - NH_2 \longrightarrow R - N - \overset{\overset{\displaystyle O}{\|}}{C} - N - R'''$$
$$\qquad\qquad\qquad\qquad\qquad\qquad\qquad | \qquad\quad |$$
$$\qquad\qquad\qquad\qquad\qquad\qquad\qquad H \qquad\quad H$$
$$\text{Isocyanate} \qquad\qquad \text{Amine} \qquad\qquad\qquad \text{Urea} \tag{4}$$

$$R - N - \overset{\overset{\displaystyle O}{\|}}{C} - N - R''' + R'' - N = C = O \longrightarrow R - N - \overset{\overset{\displaystyle O}{\|}}{C} - N - R'''$$
$$| \qquad\quad | \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad | \qquad\quad |$$
$$H \qquad\quad H \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad H \qquad\quad C = O$$
$$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad |$$
$$\text{Urea} \qquad\qquad \text{Isocyanate} \qquad\qquad\qquad\qquad\qquad\qquad\qquad N - H$$
$$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad |$$
$$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad R''$$
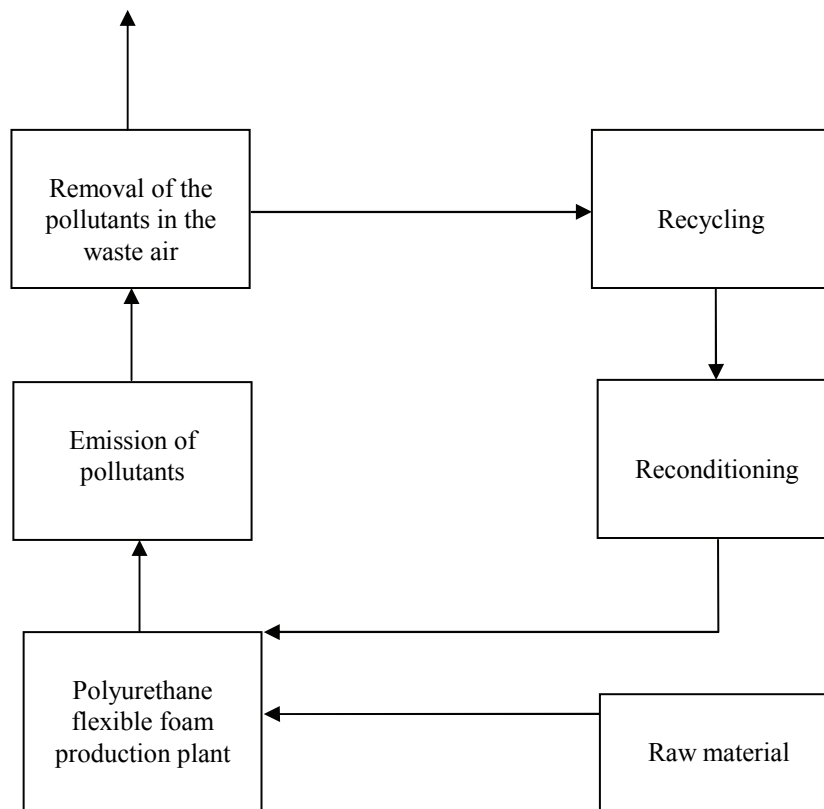$$\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \text{Biuret} \tag{5}$$
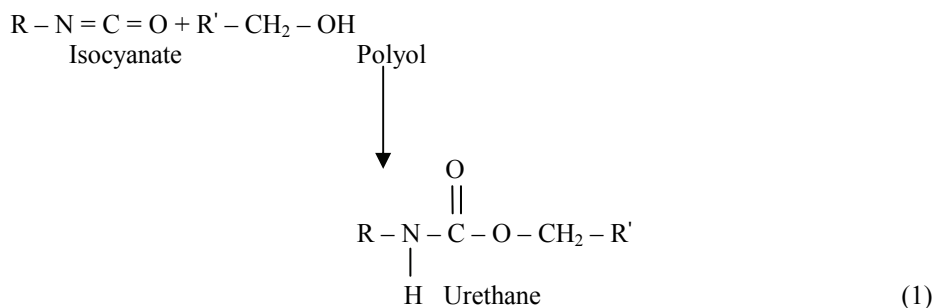
Reaction (1) is the primary reaction, (2) is the secondary reaction while (3), (4) and (5) are the blowing/gas producing reactions. Reaction (3) is being controlled by the level of the amine catalyst in the formulation. In polyurethane foam industries, the recycling of scrape polyurethane foam as finely ground powder is now being developed to help the environment by reducing the amount of generated waste, photochemicals consumed and the amount of auxiliary blowing agents used in the manufacturing processes (Kolajo, 2006). This process finally produces foam of good quality with a reduced cost of production. The need for maximising profit and environmental issues caused by fossil fuel exploration has necessitated sourcing for alternative of Silicone, the most expensive chemical in flexible foam synthesis (Olu-Arotiowa *et al*. 2008). Over the years, seeds have generally been regarded as a waste, except for a minute fraction that is used in agriculture for planting. The natural existence of oil in seeds at varying proportion together with the application of the knowledge of seed oil extraction techniques suggest that vegetable oil could possibly be extracted and used for industrial purposes in foam manufacturing (Olu-Arotiowa *et al*. 2007).

1.2 Emissions During Polyurethane Foam Production

Essentially, methylene chloride (an auxiliary blowing agent), carbon dioxide and traces of toluene diisocyanate (TDI) are emitted in the production of flexible polyurethane foam (Wolfgang and Peter, 1986). Attempts are now being made to reduce these pollutant emissions by simultaneous recycling in the foaming process. Polyurethane foam insulation currently used in refrigerators and freezers in the United States is blown primarily with Chlorofluorocarbon type HCFC – 141b, because of its potential for depleting the ozone layer, the Montreal Protocol mandated that the domestic production of HCFC – 141b should be ceased by the end of 2002 (Wilke *et al*. 2000). During polyurethane foam production, sources of gases during foaming include auxiliary blowing agents, carbon dioxide (CO_2) produced by reactants, dissolved gases in liquid reactants and gases from thermally decomposable additives (Makanjuola, 1999a). Of all these sources of gases, methylene chloride (an ABA) was found to be a major pollutant. In fact, it is a confirmed animal carcinogen and a suspected human carcinogen. Hence uncontrollable emissions of methylene chloride into the air during the production of polyurethane foam needs to be reduced and properly monitored.

Polyol + Isocyanate + Additives ⟶ PU Flexible Foam
　　　　　　　　　　　+ ABA　　　　　　+ Emissions (majorly ABA)
　　　　　　　　　　　+ Catalyst　　　　+ CO_2
　　　　　　　　　　　+ Stabilizer　　　 + CO
　　　　　　　　　　　+ Others

Fig. 1. Emission During Flexible Polyurethane Foam Production

Fig. 2. Recycling of Pollutants in Polyurethane Flexible Foam Production.

1.3 The tunnel concentration and diffusion coefficient of Auxiliary Blowing Agent (ABA)

In order to offset runaway heat generation and build-up in high water containing formulation, and at the same time produce low density foam ($< 20kg/m^3$) and soft heavy foams, ABA is sometimes introduced into the foam formulation to give an additional blowing effect (Makanjuola, 1999b). Before now, trichlorofluoromethane (CFC11/Freon11/F11), low boiling halogenated alkanes were used as ABA. However it was discouraged due to its role in depleting the ozone layer in the stratosphere (Ajayi, 1999). Alternatives like methylene chloride (MC), liquid carbon dioxide (LCD), dichlorofluoro methane (HCFC) have been introduced. Methylene chloride is now extensively used in many countries due to its applicability to conventional formulations and low costs. However, it requires higher amine concentration to compensate for its delayed action due to its higher boiling point. It is also subject to future restrictions due to its uncertain toxicological status. Recently, it has been shown that it is carcinogenic to plants and animals, although not yet confirmed on human beings (Susu, 1998).

The tunnel concentration and diffusion coefficient of CH_2Cl_2 during foam production becomes environmentally important since CH_2Cl_2, a known animal carcinogen and a suspected human carcinogen, is released into the air when polyurethane foams are blown. However, the Occupational Safety and Health Act (OSHA) standard do not ask for complete phasing out of methylene chloride but provides a regulatory framework to reduce the problem over time through cleaner process technologies. The steady tunnel concentrations (molar ppm) of CH_2Cl_2 were predicted (Kaufman and Overcash, 1993) using the model equation

$$ppm CH_2Cl_2 = 954.8 \times (CH_2Cl_2 \text{ feed rate}) \times \frac{\text{tunnel residence time}}{\text{tunnel air flow}} \qquad (6)$$

Where CH_2Cl_2 feed rate is in kg/mins, tunnel residence time is in mins and tunnel air flow is in thousand ft^3/min.

Similarly, according to Kaufman and Overcash (1993), the behaviour of the ABA (CH_2Cl_2) within the foaming tunnel was calculated using the formula:

$$Diffusion\ Coeficient\ of\ CH_2Cl_2 = \frac{(10^{-3})(T^{1.75})(M_t)^{0.5}}{P[V_{air}^{0.33} + V_{CH_2Cl_2}^{0.33}]} \qquad (7)$$

Where   T = Temperature (K)
         P = Pressure (atmospheres)
         V_{air} = Molar volume of air = $20.1 cm^3$/mole
         $V_{CH_2Cl_2}$ = Molar Volume of CH_2Cl_2 = $71.4 cm^3$/mole

$$M_t = \left[\frac{MW_{air} + MW_{CH_2Cl_2}}{MW_{air} \times MW_{CH_2Cl_2}} \right]$$

$$Diffusion\ Coeficient\ of\ CH_2Cl_2 = \frac{10^{-3} \left[\dfrac{MW_{air} + MW_{CH_2Cl_2}}{MW_{air} \times MW_{CH_2Cl_2}} \right]^{0.5} T^{1.75}}{P(V_{air}^{0.33} + V_{CH_2Cl_2}^{0.33})} \qquad (8)$$

2. MATERIAL AND METHOD

2.1 Experimental set-up

Laboratory foam of a known formulation (density $18 kg/m^3$) was prepared inside a $0.3m \times 0.3m \times 0.15m$ mould. A clean stirrer was used to mix each reactant (i.e. each chemical) while a tared mechanical stirrer was used to mix the mixture before finally poured into the mould. Clean beakers were used to store each weighed chemical in the recipe. Clean syringes were used to measure those ingredients that were extremely small. Similarly, a continuous plant producing foam of the same density (density $18 kg/m^3$) was used for the continuous foam production.

2.2 Experimental procedures

This experiment was aimed at determining the emission profile from a batch and continuous foam plant using methylene chloride as ABA. It involves ambient air sampling of

batch and continuous systems using activated charcoal as the absorbing medium. This was then followed by the extraction of the collected samples using carbon disulphide (CS_2) and ended with its analysis using an infrared spectrophotometer.

Experiments were also carried on a continuous foam plant to estimate tunnel concentration of methylene chloride (ppm) using a developed model in order to evaluate the CH_2Cl_2 feed rate, tunnel air flow and calculated (CH_2Cl_2) in parts per million (ppm) with varying foam density and hardness. The diffusion coefficient (cm^2/s) of methylene chloride within the foaming tunnel was also calculated to appreciate its sensitivity to the temperature of the auxiliary blowing agent within the foaming tunnel.

2.2.1 The sampling system

This was made up of a low-volume air sampler, adsorption column, adsorbent (pre-treated activated charcoal), a rotameter flow meter and re-chargeable battery. The continuous plant operation showing the sampling sites is as shown in Fig. 3. About 15 – 25g pre-treated activated charcoal (the adsorbent) was packed in the adsorption column. Glass wool was used as the packing material at the tapered end of the column so as to prevent the escape of the adsorbent. The top of the column was connected to a rotameter which was then connected to a battery-powered sampler. With the known volumetric flow rate (measured with a rotameter) and measured time of sampling, the volume of the sampled air was determined. After the sample collection operation, the collected samples were preserved in an ice-block in a cooler before being taken to the refrigerator where they were kept until extraction time and analysis.

The batch foam emission sample was first taken 10 minutes after pouring the reactants into the mould. The exercise was repeated 25 minutes after pouring. For the continuous plant, sampling was done after 5 minutes of pouring close to the flexible tubes of the trough as indicated in Fig. 3. The procedure was repeated just before the cut-off saw. After this, samples were taken in the storage area where the freshly-produced naked foam blocks are stored for curing. The portable air sampler used was operated with a re-chargeable battery, hence, sampling in both the batch and continuous plants could go on uninterrupted by the fluctuation of a national grid electricity supply.

2.2.2 Extraction procedure

The solvent extraction was carried out in a soxhlet extractor. The sample to be extracted was placed in the thimble which was housed in the extractor that was filled to the 50ml round bottom flask containing carbon disulphide (CS_2) as the extraction solvent. The extractor was placed on the heating mantle with a thermostat for the regulation of temperature. The reflux condenser was connected to a CHURCHILL Hiller Thermo Circulator as the source of the cooling fluid. In order to attain the desired very low temperature, a mixture of glycerol and water (in ratio 1:1) was used as coolant for the chiller. It was never operated without first checking that there was sufficient coolant in it. For about an hour before the commencement of the extraction, the chiller must have been switched on so as to make sure that the desired low temperature will be attained. The operating temperature was between -5^0C and 0^0C. The heating mantle was switched on and regulated to a convenient point in order to attain this temperature.

The set up was run in a fume chamber fitted with an extraction fan and a run was allowed to last for about 4 hours (for complete extraction) after which the extract was collected in a volumetric flask with a glass topper and placed in the refrigerator for preservation. Before further use, the extractor and flask were cleaned and the process repeated for every other sample. For every sample, a new thimble was used to avoid contamination. To avoid analysis being done in dilute state, the collected samples were concentrated at a temperature of about 40^0C in a fume chamber. Before any operation, the level of the coolant was checked to be sure that it was at the desired level so as to prevent the chiller from overheating. On completion of the extraction, the heating mantle was switched off first before the chiller to prevent the temperature of the condensers environment from being increased.

2.2.3 Analysis

The infrared type that was used in the analysis is the Model 500 infra-red spectrophotometer. It consists of a single beam, micro-processed ratio recording spectrometer. Pre-sample chopping and stepper motor-controlled wavelength drive gave results unattainable from a conventional double beam and optical ruling system. The clean single beam design and microprocessor control make the operation simple and maintenance cost low for the system.

The instrument was firstly set for either 115 or 230V.A. C; 50/60 Hz. This can be altered if it becomes necessary. Then, the power cord was connected to the instrument. The instrument was turned on to make sure that it initialized after which it was then allowed to stabilize for about 1 hour. The setting of low energy loss samples as 3-minute scan time, gain 0 and pen response 1 second was done. The scan button was pushed so as to store reference data into the instrument memory. After reset, the instrument was changed to the ratio mode. This was used to a true % of transmittance or absorbance reading. The % of transmittance was set on the strip chart recorder.

A polystyrene test film was used to test for the abscissa accuracy of the instrument. This confirmed that the infrared spectrophotometer was in order. The sample was put in the instrument and the scan button was pushed. The recorder drew the spectrum and the index to the next chart. The remaining 4 samples were then run, just like it was done for the first one. The results are summarised in Table 2.

2.2.4 Tunnel concentration estimation and diffusion coefficient calculation of CH_2Cl_2

In order to estimate the steady tunnel concentration of methylene chloride (ppm), formulations were done for two grades of foams, A (density 18kg/m^3 and hardness 100 Newtons) and B (density 16kg/m^3 and hardness 80 Newtons). This enhanced the knowledge of the CH_2Cl_2 feed rate (kg/min) in the formulations. Then, the continuous foam plant was started and tunnel air flow (cm^3/min), conveyor speed (m/s) and tunnel length (m) were recorded as indicated on the panel. Batch run time of the plant was measured with an accurate stop clock. The record for the production of foam type A was done first while type B was produced and readings recorded on the next production day. The batch run time of the first production (Run A) was 48 minutes while run B production lasted for 42 minutes.

For the diffusion coefficient calculation, a continuous foam plant was operated and the temperature (^{0}C) and the pressure (bar) of CH_2Cl_2 as indicated on the panel were recorded when production was going on. The recordings were repeated for the other, but now in the afternoon so as to calculate the value of diffusion coefficient of CH_2Cl_2 (cm^2/s) and hence evaluate the behaviour of the auxiliary blowing agent (CH_2Cl_2) within the foaming tunnel at two different times of the day (morning and afternoon).

3. RESULT AND DISCUSSIONS

3.1 Results from the infrared analysis

From the literature values of the infra-red spectrum of Carbon disulphide (CS_2), the solvent used for the extraction, the spectrum shows strong absorption in the region $2700 cm^{-1}$ (3.76μ), $2900 cm^{-1}$ (3.52μ), $1500 cm^{-1}$ (6.67μ) and $850 cm^{-1}$ (11.88μ). Table 2 below shows the characteristic peak absorptions from the various samples and the remarks and inferences that were drawn from the absorptions after their infra-red analysis.

Table 2. Characteristic Absorption of Various Samples

Sample	Characteristic Absorptions (wave numbers)	Remarks/Inference
1. Sample I. 10 minute batch foam emission sampling after pouring	$3200 cm^{-1}$, $2850 cm^{-1}$, $2640 cm^{-1}$, $1708 - 1700 cm^{-1}$, $1592 cm^{-1}$, $1528 cm^{-1}$, $1500 cm^{-1}$, $848 cm^{-1}$. Sample absorptions - Solvent absorptions $= 3200 cm^{-1}$, $1708 - 1700 cm^{-1}$, $1592 cm^{-1}$ and $1528 cm^{-1}$.	Amine emission, aldehyde $C = O$ stretch from TDI emission, conjugated benzene ring from TDI emission.
2. Sample II, Subsequent 15 minutes batch foam emission sampling	$3140 cm^{-1}$, $2880 cm^{-1}$, $2640 cm^{-1}$, $1712 cm^{-1}$, $1580 cm^{-1}$, $1500 cm^{-1}$, $1474 cm^{-1}$, $844 cm^{-1}$. Sample absorptions – Solvent absorptions $= 3140 cm^{-1}$, $1712 cm^{-1}$, $1580 cm^{-1}$, and $1474 cm^{-1}$.	Amine emission, aldehyde $C= O$ stretch from TDI emission, conjugated benzene ring from TDI emission, methylene C- H bend from CH_2Cl_2 emission.
3. Sample III, 10 minutes continuous foam emission Sampling after pouring	$3180 cm^{-1}$, $2810 cm^{-1}$, $2630 cm^{-1}$, $1720 cm^{-1}$, $1720 cm^{-1}$, $1556 - 1544 cm^{-1}$, $1460 cm^{-1}$ and $836 cm^{-1}$ Sample absorptions – Solvent absorptions $= 3180 cm^{-1}$, $1720 cm^{-1}$, $1556 - 1544 cm^{-1}$ and $1460 cm^{-1}$	Amine emission, aldehyde $C= O$ stretch from TDI emission, conjugated benzene ring from TDI emission, methylene chloride emission.
4. Sample IV, 10 minutes continuous foam emission sampling before cut-off saw	$2930 cm^{-1}$, $2630 cm^{-1}$, $1728 cm^{-1}$, $1572 cm^{-1}$, $1504 cm^{-1}$, $1464 cm^{-1}$, $840 cm^{-1}$. Sample absorptions - Solvent absorptions $= 1728 cm^{-1}$, $1527 cm^{-1}$ and $1464 cm^{-1}$.	Amine emission, aldehyde $C=O$ stretch from TDI emission, conjugated benzene ring from TDI emission, methylene C-H bend from methylene chloride emission
5. Sample V, 10 minutes continuous foam emission sampling at storage area	$2930 cm^{-1}$, $2610 cm^{-1}$, $1592 cm^{-1}$, $1460 cm^{-1}$, $844 cm^{-1}$. Sample absorptions + Solvent absorptions $= 1460 cm^{-1}$	Methylene C-H bend from methylene chloride emission

From Table 2 above, it can be inferred that the two samplings in the batch process emissions consist of amine emission and the emission from TDI fumes. The first sampling does not show the presence of methylene chloride emission while the second sampling shows conspicuous methylene chloride emission as a result of the presence of methylene C-H bond in the sample. In the continuous foam production process, the sample taken just after pouring consists of a methylene chloride emission, amine emission from TDI fumes. The sample taken just before the cut-off saw consists of methylene chloride emission, emission from TDI fumes while amines were conspicously absent. The sample taken at the storage area/curing hall consists of methylene chloride emission only.

3.2 Results from calculated tunnel concentration of CH_2Cl_2

The steady state tunnel concentrations (molar ppm) of CH_2Cl_2 were predicted and calculated as shown in Table 4 below:

Table 3. Formulations of type A and type B foams showing machine output (kg/min)

Raw Material Feed (kg/min)	Type A	Type B
	Density: $18kg/m^3$ Hardness: 100 Newtons Output Factor: 0.49	Density: $16kg/m^3$ Hardness: 80 Newtons Output Factor: 0.42
Polyol	49.00	42.00
Water	2.28	2.01
Time	0.10	0.08
CH_2Cl_2	2.94	5.04
Silicone surfactant	0.53	0.45
Stannous Octoate	0.15	0.13
TDI	28.95	24.81
Total	83.95kg/mins	74.52kg/mins

Table 4. Calculated steady state tunnel concentration of CH_2Cl_2 for varying density foams

Foam Formulation	CH_2Cl_2 Feed Rate (kg/min)	Tunnel Air Flow (cm^3/min)	Tunnel Residence Time (seconds)	CH_2Cl_2 (ppm)
Density: $18kg/m^3$ Hardness: 100 N	2.94	800	70	1.45×10^{-6}
Density: $16kg/m^3$ Hardness: 80N	5.04	900	70	2.20×10^{-6}

From Table 4, it can be observed that as the foam became less denser and less harder ($18kg/m^3$; 100N to $16kg/m^3$, 80N), CH_2Cl_2 the feed rate and tunnel air flow increased (from 2.94kg/min, 800cm^3/min to 5.04kg/min, 900cm^3/min). Also, the concentration of the calculated methylene chloride (ppm) increased as the foam became less dense and less hard. Thus, foam density of $18kg/m^3$, hardness of 100N gave a CH_2Cl_2 concentration of 1.45×10^{-6} ppm while less hard foam density of $16kg/m^3$, hardness of 80N gave a methylene chloride concentration of 2.20×10^{-6} ppm. Hence, as the density of the foam decreased (from $18kg/m^3$ to $16kg/m^3$) and the hardness decreased (from 100N to 80N); then the CH_2Cl_2 concentration (ppm) increases by about 35 percent.

3.3 Results from the estimated diffusion coefficient of CH_2Cl_2

The diffusion coefficients (cm^2/sec) of CH_2Cl_2 were calculated for the two foaming times (in the morning and in the afternoon) in order to determine the difference in the emissive losses of CH_2Cl_2 within the foaming tunnel. The results were tabulated below:

Table 5. Calculated diffusion coefficient of CH_2Cl_2 ($cm^{2/}$s) for varying foaming times

Foaming Time	Temperature of CH_2Cl_2 on the Panel (^{0}C)	Pressure of CH_2Cl_2 on the Panel (bar)	Diffusion Coefficient of CH_2Cl_2 (cm^2/sec)
Foam production in the morning	24	5	0.135
Foam production in the afternoon	28	5	0.138

The substitution of the values in Table 5 above into equation (8) yield 0.135 cm^2/sec for foaming in the morning and 0.138cm^2/sec for afternoon foaming. Hence, it can be deduced that the diffusion coefficient increased as the temperature of the auxiliary blowing agent (CH_2Cl_2) within the foaming tunnel increased. This implies that the toxicity effect of CH_2Cl_2 emission will be felt more when foaming in the afternoon than in the morning.

4. CONCLUSION

The infrared spectrophotometer analysis confirmed that the evolved gases from polyurethane foam production processes are made up of methylene chloride, amines and TDI fumes. These emissions are continuous from the foaming tunnels to the curing hall where hot foam blocks are stored to cure overnight. Hence, polyurethane foam workers should wear face masks capable of filtering out fine particles, chemical fumes and emissions from the production processes. These are masks with combination of filter cartridges and a respiratory apparatus.

With decreasing foam density and hardness, the CH_2Cl_2 feed rate, tunnel air flow cm^3/mm and calculated CH_2Cl_2 concentration (ppm) increases. The diffusion coefficient of CH_2Cl_2 (an auxiliary blowing agent) increases as the temperature of the ABA within the foaming tunnel increases. Therefore, polyurethane foam workers should be more safety conscious when producing lower density and less hard foams.

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ANALIZA PROIZVODNIH PROCESA STIROPORA IZ UGLA ZAŠTITE ZIVOTNE SREDINE

L.A. Jimoda

U novije vreme, proizvodnja stiropora je prešla sa upotrebe dichloromethane (F-11/CFC-11/CCl$_3$F) i agenta (ABA) na metilen hlorid (CH$_2$Cl$_2$). Dakle, pravilna istraga o ponašanju CH$_2$Cl$_2$ i njegovim emisijama tokom proizvodnju poliuretanske pene je neophodna jer CH$_2$Cl$_2$ je poznati karcinogen u životinjskom svetu a postoji sumnja da ima kancerogeno dejstvo na ljude. Uzroci ambijentalnog vazduha uzeti su pomoću aktivnog uglja koji apsorbuje. Prikupljane uzoraka je urađeno uz pomoć Karbon disulfida (CS$_2$) i analiza je sprovedena sa infracrvenim spektrofotometrom. Model je korišćen u predviđanju tunelskih koncentracije CH$_2$Cl$_2$ u funkciji formulisanja dužine tunela, transportne brzine i protoka vazduha. Koeficijent difuzije od CH$_2$Cl$_2$ u tunelu takođe je procenjen. Infracrvena analiza potvrdila je da su emisije CH$_2$Cl$_2$ isparenja amino i toluen diizocijanata (TDI). Takođe, sa opadanjem gustine pene i njene tvrdoće, izračunava se povećanje CH$_2$Cl$_2$ koncentracije (ppm). Koeficijent difuzije CH$_2$Cl$_2$ raste u skladu sa porastom temperature unutar tunela.

Ključne reči: *proizvodni proces, stiropor, zaštita životne sredina*