Introduction

During industrial activities, air pollutants are produced and emitted to the immediate environment. These air pollutants are hazardous to humans, animals, vegetation and materials, consequently causing serious damage over time. The commonest industrial air pollutant is smoke produced from factory chimneys which consists predominantly of carbon particles and other combustible materials. Other industrial air pollutants include carbon (ii) oxide from automobile exhausts, hydrocarbons, organic acids and some oxides of sulphur and nitrogen which result from large power plants and low heat burners and furnaces. The effects produced by these pollutants include; tarnishing of building surfaces and clothing, corrosion of metal surfaces, collapse of leaf tissue (necrosis), bleaching or other colour changes (chlorosis) and alterations in growth of vegetation .It also causes fluorosis in livestock and affects weather as it reduces visibility, a situation that affects the operations of aeroplanes and automobiles and also reduces the amount of solar radiation reaching the earth, (Tsor, 2003). The most alarming of all is its health effects which include cancer of the skin and lungs, respiratory and cardiovascular illnesses such as bronchitis, asthma and tuberculosis, instant death etc.

The Gaussian plume model is based on the approximation that the concentration downwind of a point source in the atmospheric boundary layer is Gaussian, but with unequal dispersion coefficients in the horizontal and vertical directions. It describes the atmospheric dispersion of a puff in three dimensions, or a steady–state plume from a continuous source in two dimensions. Deriving the Gaussian dispersion equation
requires the assumption of constant conditions for the entire plume travel distance from the emission source point to the downwind ground-level receptor. For a simple model, assuming that a plume traveling horizontally (in the x-direction) at a mean speed

\[ \frac{Q}{\pi u_0 \delta_y \delta_z} \exp \left( -\frac{y^2}{2\sigma_y^2} \right) \exp \left( -\frac{H_s^2}{2\sigma_z^2} \right) \]  

(1)

where, \( C_{(x,y,z)} \) Pollutant concentration (kg/m\(^3\)) at the receptor located at \((x,y,z)\), \( Q \) is the source emission rate, \( \delta_y \) and \( \delta_z \) are dispersion coefficients in the y and z directions respectively and are functions of the downwind distances \( x \) from the source, \( u \) (m/s) is the mean wind speed through the layer in which diffusion takes place while \( H_s \) (m) is the effective stack height.

The dispersion models are used to estimate or to predict the downwind concentration of air pollutants emitted from emission sources such as industrial plants and vehicular traffic (Briggs, 1976). The model is an important tool in the design of effective control strategies to reduce emissions of harmful air pollutants and serves governmental agencies in United States and similar ones in other nations such as NESREA in Nigeria tasked with regulations of the ambient air quality standards. In this work, we have employed the model to determine whether existing or proposed new industrial facilities at the Benue State Industrial Layout that produce gaseous effluent have stacks which are in compliance with the National Ambient Air Quality Standards (NAAQS). The result and analysis obtained from this work will be useful to the state ministry of environment, NESREA and investors intending to build new industries at the layout. The work will also serve as a reference

Figure 1: Illustration of plume centerline at height \( H_s \) as emitted from an elevated point source.
Materials and Methods

This research was conducted at the industrial layout, Makurdi which is located 5 km on the out skirt of Makurdi town along Makurdi-Naka road in Benue State. It covers about 4 square kilometres of land. At the time of this research, the industries found at the industrial layout were: Lobi Cassava Flour Mills, Benkims Plastics Nig Ltd, Benfruits Nig Ltd, Benue Fertilizer and Chemical Company Ltd, Bashy Ventures Rice Mill Factory, Ahtell Industrial Products Ltd and Lobi Fresh Table Water. A few of these industries are owned by Private individuals and the others by the Government of Benue State. It is hoped that the industrial layout Makurdi, if fully developed, will house up to 100 small and large scale industries. At the time of this research, only five industries were operational; they include Lobi Cassava Flour Mills which was on full production was chosen for the pre-survey. Lobi Cassava Flour Mill has only one stack constructed on a relatively low flat terrain. The stack emission flow rate is continuous and constant and allows for a steady state analysis. The industry was operating for 24 hours a day.

As it is the case for most plume dispersion models, the work is in two phases, the input data acquisition phase and the simulation stage. The input phase was carried out by measuring and/or retrieving data on the industrial layout site. This data includes metrological conditions such as wind speed \( u \) and direction, the stability classes which represent the amount of atmospheric turbulence, the ambient air temperature \( T_a \) and the height to the bottom of any temperature inversion. The point source Gaussian plume model also requires the use of emission parameters such as, the stack height \( H \), stack diameter \( D \), effluent exit velocity \( V \), effluent exit temperature \( T_e \), source emission rate \( Q \) obtained from the company’s installation manual.

The parameters obtainable from the industry's installation manual through the technical department of the industry include; \( V = 0.92 \text{ m/s}, T_e = 60^\circ \text{C}, H = 20 \text{m}, D = 0.5 \text{ m}, Q = 9.17 \text{ m}^3/\text{s} \). The \( T_a \) of 28 \(^\circ\text{C}\) and \( u \), of 0.27 m/s were measured.

Stability class F among the three stability classes A, D and F (Very Unstable, Neutral and very Stable respectively) considered in this research reflect the most prevalent atmospheric condition of the layout.

The point source Gaussian plume model is being used in this research. The point source Gaussian plume model for determining the ground level concentration of equation 1 can be written as considering the image source:

\[
C_{(x,y,z)} = \frac{Q}{2\pi H_{e} u} \exp\left(-\frac{z}{H_{e}}\right) \left[\exp\left(-\frac{1}{2\delta^2}\right)\exp\left(-\frac{1}{2\delta^2}\right)\right] \]

where \( Q \) is the plume rise and \( H_{e} \) is the actual stack height. Stability classes A, D and F (Very Unstable, Neutral and very Stable respectively) are related by the equation 7, where \( \Delta H \) is the plume rise and \( H_s \) is the actual stack height.

\[
\Delta H = \Delta H + H_s \]  

\[
H_s = \Delta H + H_e \]  

\[
\Delta H \text{ for stable atmosphere is calculated from equation 7 (Briggs 1972), we have} \]  

\[
\Delta H = 2.6 \left(\frac{F}{\delta_s}\right)^{1/3} \]  

where \( F \) and \( S \) are the initial buoyancy flux of the emitted plume and stability factor respectively and are defined by the equations (9) and (10) respectively (Houl et. al., 1969, 1972).
Dop, 1992):

\[ F = g \left( \frac{T_s-T_A}{T_s} \right) v \left( \frac{D}{2} \right)^2 \]

\[ S = \frac{g}{f} \left( \frac{\Delta \rho + 0.01 \nu}{v} \right) \]

For unstable atmosphere where plume theoretically would never stop rising as a result of ambient air entrainment, and the plume rise equation changes to equation 11 (Dop, 1992)

\[ \Delta H = \frac{1.6 \rho \sqrt{2} \Delta T}{u} \]

Equation 7 is used to compute values of \( H \), i.e.

\[ H_s = H_c - \Delta H \]

\( \Delta H \) was calculated for stability classes A, D and F as presented in table 2.

Table Calculated \( \Delta H \) for stability class A, D and F

<table>
<thead>
<tr>
<th>Stability class</th>
<th>A</th>
<th>D</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>( H ) (m)</td>
<td>0.42</td>
<td>1.53</td>
<td>-1.55</td>
</tr>
</tbody>
</table>

Table 2: Values for four of the stability dependent constants (a, c, d and f)

<table>
<thead>
<tr>
<th>Stability class</th>
<th>( x \leq 1 \text{km} )</th>
<th>( x &gt; 1 \text{km} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( a )</td>
<td>( c )</td>
</tr>
<tr>
<td>A</td>
<td>213.00</td>
<td>440.80</td>
</tr>
<tr>
<td>B</td>
<td>156.00</td>
<td>106.60</td>
</tr>
<tr>
<td>C</td>
<td>104.00</td>
<td>61.00</td>
</tr>
<tr>
<td>D</td>
<td>68.00</td>
<td>33.20</td>
</tr>
<tr>
<td>E</td>
<td>50.50</td>
<td>22.80</td>
</tr>
<tr>
<td>F</td>
<td>34.00</td>
<td>14.35</td>
</tr>
</tbody>
</table>

Source: (Pontiggia et al., 2009)
Figure 2: $\delta_y$ as a function of downwind distance $x$ in km computed for stability classes A, D and F.

Figure 2: $\delta_z$ as a function of downwind distance $x$ in km computed for stability classes A, D and F.
Results and analysis

After obtaining the preliminary data presented above the maximum ground level concentration of pollutant downwind along the plume centreline from the effluent source was calculated for stability classes A, D and F for downwind distances of 500m and 2x10^3m respectively from the source point. C was calculated for various estimated effective stack height. The calculation is based on equation 6, however, the values were computed using the AJ Atmospheric Dispersion software (Raymond, 2002). The software is more of a calculator and computes both the $H_e$ and $C$. The computed values for maximum ground level concentration at 500m and 2x10^3m downwind, along the plume centreline are presented in figures 4 and 5.

Figure 4: Computed maximum ground level concentration of pollutants at 500m receptor point from source.

Figure 5: Computed maximum ground level concentration of pollutants at 2x10^3m receptor point from source.
In figure 4, it is observed that the ground level concentration at 500m from source decreases as the stack height increases for stability class D and F while remaining fairly constant for stability class A. Since the atmospheric stability changes from time to time, it is always useful to estimate an appropriate stack height that will be suitable for other prevailing atmospheric conditions too. The average minimum ground level concentration for the three stability classes studied here is at an effective stack height of 40.42m. At 2km from source, C decreases for all stability classes as H increases. Even though the decrease for the three stability classes converges at ~40m (same as obtained for 500m), further extrapolation thus reveal that minimal effluents concentration are obtained as H increases. It can be concluded that for minimal C, within the industrial layout and its environs the, the stack height should be at least 40m. Considering the average settlement distances of the two nearest communities, Tionsha and Agbough villages which are slightly beyond 1km, industries at the layout need to ensure that more specific investigation is carried out to ascertain an appropriate stack height for their site. In order to minimise the enormous problems of health and environment posed by the release of pollutants by industries at the industrial layout, it is recommended that the most appropriate stack height for industrial layout Makurdi is 40.0 m.

References


