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Key Air Quality Pollutants from Bioethanol Production Using Cassava Peels: Reflections of the Industrial Society

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***Abstract*:** Air quality is essential for sustaining life on Earth and plays a critical role in various biological processes. However, the introduction of pollutants such as chemicals, particulate matter, and contaminants into the atmosphere from the use of fossil fuels compromises air quality, leading to severe health and environmental consequences. Approximately seven million deaths worldwide are attributed annually to air pollution-related illnesses, ranging from acute respiratory conditions to long-term diseases like lung cancer and neurological disorders. However, this study reveals that while bioethanol production offers a cleaner alternative to fossil fuels, the industrial processes involved also contribute to air pollution. This underscores the paradox of industrial societies: while technological advancements can drive progress, they simultaneously introduce new environmental and health risks, such as elevated levels of particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), and hydrocarbons (HC). In an industrial society, where mass production and consumption dominate, these byproducts of bioethanol production can exacerbate air quality concerns, particularly in countries like Nigeria with weaker environmental regulations. Bioethanol production from cassava peels represents a critical intersection between technological advancement, mass production, and environmental sustainability. Industrial society, characterized by mass production and technological innovation, significantly shapes energy consumption patterns, particularly in the transport and energy sectors. The shift towards biofuels, such as bioethanol, responds to the environmental challenges posed by fossil fuels, reflecting industrial society's capacity for technological solutions to pressing issues like climate change and air pollution. The emissions from bioethanol production highlight the tension between industrial expansion and environmental sustainability—an inherent feature of modern industrial societies. The findings of this study emphasize the dual role of industrial society in advancing cleaner energy alternatives and introducing new challenges related to air quality. This underlines the need for more sustainable practices and stronger regulatory frameworks, particularly in developing countries, to mitigate the environmental and public health risks associated with bioethanol production.

Keywords: Biofuel; Air Emissions; Bioethanol; Particulate Matter; Greenhouse Gases; Climate Change; Air Quality; Industrial Society.

1. Introduction

Air quality is essential for sustaining life on Earth, playing a crucial role in various life processes [1]. However, when pollutants such as chemicals, particulate matter, or contaminants are introduced into the atmosphere at levels that can cause harm to humans, other organisms, or the environment, air quality becomes compromised [2]. The detrimental effects of exposure to pollutant emissions are evident in the staggering statistic of approximately seven million deaths globally attributed to common air pollution-related illnesses annually [3]. These illnesses range from acute respiratory problems to long-term lung injuries, cancer, birth defects, neurological damage, and morbidity [4].

To combat air pollution and mitigate its adverse effects, the development and adoption of biofuels like bioethanol, biodiesel, and biogas have been identified as promising solutions. Biofuels offer the potential to improve urban air quality, enhance energy security, promote sustainability in the transport sector, and reduce greenhouse gas emissions [5]. Bioethanol, derived from starch-containing (e.g., cassava and corn), sugar-containing (e.g., sugarcane and beetroot), or cellulose-containing (e.g., cassava peels and wood) plants, has emerged as a cleaner alternative to petrol, thus benefiting both the environment and human health.

While the demand for bioethanol has seen significant growth in recent years, its combustion's impact on air quality depends on various factors such as vehicle type, combustion conditions, blend ratio, feedstock type, and engine performance [6][7][8][9]. Moreover, biofuel production generates air emissions at every stage of its lifecycle, including feedstock production, conversion processes, and combustion. However, emissions from feedstock conversion processes remain relatively understudied.

Recent research has highlighted the emissions associated with biofuel production, particularly from cellulosic ethanol refineries in the United States. These emissions include hazardous air pollutants (HAP) known to cause cancer, as well as carbon dioxide (CO_2), a greenhouse gas [9]. Compounds such as acetaldehyde, benzene, formaldehyde, and toluene are emitted during the production process, along with ammonia (NH3) and hydrogen sulfide (H2S) from certain biofuel refineries [9]. Wastewater treatment from biofuel production can also generate volatile organic compounds (VOCs), methane, CO, and H2S, contributing to air pollution [9].

In recent studies, particulate matter of 2.5 microns ($PM_{2.5}$) has become a preferred indicator of air pollution due to its significant health impacts [10]. $PM_{2.5}$ can penetrate deep into the lungs and bloodstream, causing inflammation, cardiovascular problems, and other serious health issues [11][12]. Diseases associated with continuous exposure to high levels of $PM_{2.5}$ include diabetes, prenatal disorders, and immune system disorders due to its mutagenic properties [12].

Considering Nigeria's reliance on bioethanol production from cassava, it becomes imperative to assess the air quality impact of this process, especially given the weak environmental standards in the country. Failure to consider environmental factors in biofuel production may exacerbate existing environmental problems in Nigeria, posing risks to public health, particularly for individuals living and working near production plants.

2. Conceptual Clarifications and Origins of Industrial Society

For the avoidance of academic ambiguity and enhancement of proper understanding of the problem, in question, it is of utmost importance for us to provide some conceptual clarifications and the attributes, of Industrial societies, as they evolve over time.

b) What is Industrial Society?

The question as to what attributes do we use in defining what constitutes an industrial society has been debated among numerous scholars, from different fields of human interests, particularly from the fields of Agriculture and Industry. Crossman observes that:

> …*industrial society is the one in which technologies of mass production are used to make vast amounts of goods in factories and in which this is the dominant mode of production and organizer of social life* (Crossman, 2023:01).

By implications, for any human *society* to be termed as *industrial*, it has to exhibit elements of mass production of processed factory goods and that *modern social structure* that dictates on the tempo indigenous economic growth and development.

Similarly, some scholars within the domain of Industrial Sociology have echoed this angle of vision, by referring to industrial society as the one driven, not only by technological advancement, but also by instances of mass production of goods and services, capacity to accommodate population density with high propensity for division of labour and high consumption of some finished goods (Ashok, 2012).

b) History of Industrial Society

From the historical point of view, many industrial societies, especially in the West, are known to be product of the Great *Industrial Revolution.* Thinkers like Karl Marx, Emile Durkheim and Max Webber, among other evolutionary scholars of societies, have tried providing comprehensive explanations of the evolution of human society from the simplest (Hunting and gathering/ Agrarian Societies) to the most complex (Industrial Society).

Marx, having studied the Industrial societies of Europe and Britain, has used the method of historical and dialectical materialism, to account for the evolution of human society from the simplest (Communal) to the most complex (Capitalist/Industrial society). That's as a result of the exploitative power relation between those occupying the positions of authorities (The exploiter class) and these occupying those of subordinations (exploited class), every industrial society undergoes stages of historical evolution, from the communal, to slave, Feudal and Capital (Industrial) stages. It is against this background that Marx concludes that, economic structure of every industrial society does serve as the base of its super structure (social and political).

Durkheim, another evolutionary scholar of society, focuses on how division of labour and social cohesion do serve as the engine wheel for evolutionary process, leading to urbanization and industrialization in every human society.

Weber, having based his theory and research on the roles that individual actors play in setting the pace for the emergence of technology and social change, asserts that every individual of any given society is an actor capable of kick-starting the process of social change that brings about Industrialization and, ultimately, to industrial society. By implication, the individual scientists, of the industrial societies, must have exercised their free will, or personal choices, for them to have made scientific discoveries and inventions, capable of transforming the agrarian societies into the industrial ones.

3. Materials and Methods

Preparing cassava peels for fermentation involved the removal of the brown outer covering. The peels were thereafter washed and oven dried to a constant weight at 50°C. The dried cassava peels were subsequently crushed manually using a mortar and pestle and stored in a desiccator. Air sampling was done in the course of ethanol production in the laboratory at a sampling interval of two days, for a sampling period of one month. Air sampling of air quality parameters was done using a hand-held gas analyser (EPAM 500 model).

The air quality assessment was aimed at quantifying emissions from the cassava peel to ethanol production process. Consequently, air quality prediction variables such as temperature, humidity and wind speed/direction were not considered. Similarly, the prediction of pollutant levels in the broader environment will not be addressed by this study. The parameters measured are noise, sulphur dioxide (SO_2), oxides of nitrogen (NO_X), carbon monoxide (CO), carbon dioxide (CO_2), Hydrogen Sulphide (H_2S) and Hydrocarbons (HC). Respirable and inhalable particulates ($PM_{2.5}$ and PM_{10}) were also measured. Noise emission from the aforementioned sections of the plant was carried out with the aid of a calibrated smart sensor digital sound level meter (AR824 model), placed at a height of 1.2 meters.

Analysis of Variance (ANOVA) was used to examine the variations in the levels of monitored parameters during production.

3. Results

The emissions data from bioethanol production using cassava peels show significant levels of various air pollutants, which are summarized in Table 1. The particulate matter concentrations were 49.8 ± 2.34 µg/m³ for $PM_{2.5}$ and 22.4 ± 1.43 µg/m³ for PM_{10}. Both values exceed the World Health Organization (WHO) recommended limits for air quality (PM2.5 < 15 µg/m³ and PM10 < 45 µg/m³ for 24-hour exposure). These levels are significantly higher ($p < 0.05$) than safe thresholds, indicating a considerable risk of respiratory and cardiovascular diseases due to the inhalation of fine particulate matter.

Carbon monoxide (CO) emissions were recorded at 2.8 ± 1.12%, which is significantly high ($p < 0.05$) when compared to safe ambient air quality levels. CO impairs oxygen transport in the bloodstream, posing serious health risks, particularly for people with cardiovascular conditions. Carbon dioxide (CO_2) levels were measured at 15.8 ± 1.70%, reflecting considerable emissions from fossil fuel combustion in the bioethanol production process. Although CO_2 is not immediately harmful in these concentrations, it contributes significantly to global warming and climate change, warranting concern.

Nitrogen oxides (NOx) were detected at 0.2 ± 0.10 mg/m³, which is within acceptable limits and considered low. The absence of sulfur oxides (SOx), with recorded levels at 0.0 ± 0.00 mg/m³, is a positive result, as SOx is a known contributor to acid rain and respiratory irritation. These pollutants were not detected at statistically significant levels ($p > 0.05$), suggesting that SOx and NOx emissions are not a major concern in this bioethanol production process.

Hydrocarbons (HC) were detected at 65.3 ± 1.48 mg/m³, which is significantly high ($p < 0.05$) and poses a major environmental threat. Hydrocarbons contribute to ground-level ozone and smog formation, which are associated with respiratory illnesses. Finally, hydrogen sulfide (H_2S) emissions were measured at 0.4 ± 0.01 mg/m³. Although this concentration is relatively low, it is still significant ($p < 0.05$) and can cause discomfort, such as eye irritation and respiratory problems, particularly for sensitive individuals.

4. Discussion of the Findings

The emissions data highlight significant levels of pollutants associated with bioethanol production, particularly fine particulate matter ($PM_{2.5}$), PM_{10}, carbon monoxide (CO), carbon dioxide (CO_2), and hydrocarbons (HC). These pollutants pose serious risks to human health and the environment. The concentration of $PM_{2.5}$, at 49.8 µg/m³, exceeds the World Health Organization (WHO) recommended threshold, which is concerning because $PM_{2.5}$ particles can penetrate deep into the lungs and enter the bloodstream, contributing to respiratory and cardiovascular diseases. Similarly, PM_{10} levels (22.4 µg/m³) surpass WHO guidelines, increasing the risk of respiratory illnesses and premature mortality, especially in vulnerable populations such as children and the elderly.

Carbon monoxide (CO) emissions, at 2.8%, also represent a health concern, as prolonged exposure to CO can impair oxygen transport in the body, leading to symptoms like dizziness, fatigue, and, in severe cases, life-threatening complications. The U.S. Environmental Protection Agency (EPA) emphasizes that CO is a significant pollutant that requires control, particularly from industrial processes and motor vehicles. The CO_2 concentration was reported at 15.8%, which, though not directly harmful in typical outdoor settings, contributes significantly to global climate change by enhancing the greenhouse effect, as highlighted by the Intergovernmental Panel on Climate Change (IPCC).

On a positive note, nitrogen oxides (NOx) and sulfur oxides (SOx) were measured at relatively low levels, with NOx at 0.2 mg/m³ and no detectable SOx. NOx, however, can still contribute to the formation of ground-level ozone and smog, exacerbating respiratory conditions such as asthma. Long-term exposure to NOx can also lead to decreased lung function and increased vulnerability to lung infections, according to the European Environment Agency (EEA). The absence of SOx is encouraging, as sulfur oxides contribute to acid rain, which can harm ecosystems and infrastructure.

Hydrocarbons (HC) were recorded at 65.3 mg/m³, which is concerning due to their role as volatile organic compounds (VOCs) that contribute to the formation of ground-level ozone, leading to respiratory issues. The EPA classifies many VOCs as hazardous air pollutants due to their potential carcinogenic effects. Additionally, hydrogen sulfide (H2S) was detected at 0.4 mg/m³, a concentration that, although low, can cause eye irritation, headaches, and respiratory issues with prolonged exposure, as noted by the Centers for Disease Control and Prevention (CDC).

Specifically, the high PM_{10} concentrations observed during the distillation phase of bioethanol production can be attributed to the presence of cooling towers, which tend to emit higher concentrations of particulate matter. This suggests that workers in the distillation area may be at greater risk of respiratory diseases from long-term exposure to these pollutants. Similarly, the significantly high $PM_{2.5}$ levels observed in the power generation area may be due to the use of natural gas in electricity generation. Natural gas-fired turbines have been associated with the emission of photochemical smog, acid rain, greenhouse gases, and high levels of $PM_{2.5}$.

This study indicates that promoting ethanol production from cassava may lead to increased particulate matter and CO_2 emissions in production areas, raising concerns about air quality. Comparisons with other studies are challenging due to variations in production location, pollutants measured, and feedstock used. However, studies from other contexts underscore the potential trade-offs. For example, a U.S. study found that health costs from corn-based ethanol production exceeded those from gasoline due to emissions during production. Another study in the U.S. suggested that switching to E85 (an ethanol-gasoline blend) could increase mortality rates due to ozone emissions. Conversely, research in São Paulo, Brazil, found that bioethanol use could improve public health, although the study did not account for lighter vehicles.

Further research has shown that ethanol expansion can increase $PM_{2.5}$ concentrations in many regions compared to fossil fuel use. Moreover, scientific studies have established that increased combustion temperatures in diesel engines, especially in early combustion phases, can lead to higher NOx emissions.

These findings underscore the importance of weighing the environmental and health costs of bioethanol production, particularly in the context of air quality and public health risks.

Table 1: Mean concentrations of Air Pollutants from the Production of Ethanol from cassava peels

Parameter	Emissions
$_{2.5}$ (µg/m^3)	49.8 ±2.34
$_{10}$ (µg/m^3)	22.4 ±1.43
(%)	2.8 ±1.12
$_2$ (%)	15.8 ±1.70
$_x$ (mg/m^3)	0.2 ± 0.10
$_x$ (mg/m^3)	0.0 ± 0.00
(mg/m^3)	65.3 ± 1.48
S (mg/m^3)	0.4 ± 0.01

5. Conclusions

The study highlights the significant environmental and health risks associated with bioethanol production from cassava peels, despite its potential as a cleaner and non-food alternative to fossil fuels. Emissions of particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), hydrocarbons (HC), and carbon dioxide (CO_2) observed in the production process present clear challenges to air quality, particularly in industrial societies where mass production and energy consumption are high. This paradox, where technological advancement contributes to both progress and environmental degradation, underscores the complex relationship between industrial growth and sustainability. The findings call attention to the need for more effective environmental regulations and practices, especially in developing countries like Nigeria, where bioethanol production is expanding without adequate regulatory oversight. Industrial society, with its focus on large-scale production and economic growth, must also consider the localized environmental impacts and long-term public health risks posed by such industrial processes. Without strong regulatory frameworks, the potential benefits of bioethanol, such as reduced greenhouse gas emissions and improved energy security, may be outweighed by the negative consequences of air pollution, particularly for communities near production facilities.

In light of these findings, several key recommendations emerge. First, developing nations, particularly Nigeria, should establish and enforce stricter air quality regulations for bioethanol production facilities, including regular monitoring of emissions, adherence to international air quality standards, and penalties for non-compliance. Second, bioethanol production processes should incorporate cleaner technologies, such as advanced filtration systems and closed-loop processes, to minimize harmful emissions and reduce the release of pollutants into the atmosphere. Additionally, governments and industries must invest in research and development to explore more sustainable methods of bioethanol production, with a focus on reducing emissions at every stage of the production lifecycle, from feedstock cultivation to fermentation and distillation. Regular environmental and public health assessments should also be conducted in areas surrounding bioethanol production plants to track the impact of air emissions on local communities, providing essential data for future policy decisions. Lastly, public awareness and community engagement are crucial, and governments and industries should involve local communities in discussions about bioethanol production, raising awareness of both its benefits and potential risks to encourage informed decision-making and greater public support for environmental policies. By implementing these measures, industrial society can strike a balance between reaping the benefits of bioethanol production and protecting public health and the environment, ultimately ensuring a more sustainable future.

Conflicts of Interest: The authors declare no conflict of interest.

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