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A Review on the Impact of Black Soot from Artisanal Crude Oil Refining and a Modified Artisanal Refining Process.

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ABSTRACT

This report presents a review of the health and economic implication of artisanal refining process in the Niger Delta region of Nigeria as a case study. It also is examines the overall implication for Nigeria as a sub-Saharan country in Africa and the world at large. The reviewed literatures reveal an overwhelming air pollution that has broght death and hardship to the inhaitants of the region mostly affected. The study in response to the seemly uneding challenge, presents a modified artisanal refining process as an immediate option to eliminate air pollution resulting from black soot generated from artisanal refining process, improve on product specification and maximize product yield in the absence of a political will and resources to introduce modular refining to replace the ongoing artisanal refining that produces soot with the attendant fatal consequences in the region. The modified process considering chemical engineering processes, principles consist of an enclosed system with a fume cupboard - chimney for the furnace, four optimized heat exchangers, a Counter Current Flow Packed Tower (CCFPT), a force draft fan, a flue gas tank and a black soot slurry tank. In the modified process the vent gas is collected and used as a fuel for heating the crude oil while the waste water from the soot slurry is collected for further separation and treatment in a water treatment plant. To enable efficient process and equipment control strategy instrumentation of the process with the inclusion of Pressure and temperature gauges.

KEYWORDS: Crude Oil, Nigeria, Kpo Fire, BlackSoot, Air Pollution, Refining, Artisanal Refinng.

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1. INTRODUCTION:

1.1 Brief History of Air Pollution

Air pollution as an age long environmental challenge occurs when harmful substances different from the natural composition of air are discharged into the environment at levels that is detrimental to – the health of humans and animals, plants and the atmosphere and natural environment (Natural Resources Defense Council, 2018). The air contaminants are classified either as natural contaminants – natural fog, volcanic eruption, particulates (aerosols) in the form of dust, smoke, fog, fumes, gases, heat, noise energy etc. (Whyte *et al*., 2020; Godish and Davis, 2015). Records of some past air pollution incidents show that in 1306 of our Common Era King Edward proclaimed a ban on burning sea-coal in London because of a major smoke and soot pollution, about 570 years after in 1873, air pollution caused by dense coal-smoke saturated fog caused the death of 268 person in London as. In 1909, 1000 persons died of smoke accumulation in Glasgow, Scotland and about 4000 person were killed by a severe Sulphur-laden fog in 1952. The United States of America has also been impacted on by air pollution. Records reveal that in 1953 a smog incident resulted in more than 170 deaths in New York and in 1963 trapped air pollutants resulted in the death of 405 persons (Center for Chemical Process Safety, 2006). Since the reported incidents there has been many of such environmental pollutions occurring in different parts of the world. Regrettably, air pollution has increased in countries where mining and artisanal activities that explore natural resources go on without regards to acceptable best practices (Efobi et al., 2019). While the challenge eventually ends up a global issue as currently conversed by the United Nations in the 2021 UN Assembly,

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the inhabitants of affected nations like Nigeria and its Niger Delta Region being one had hit by the environmental pollution are exposed to different health hazards and risks resulting from disproportionate and avoidable levels of air pollution.

1.2 Global Implication of Air Pollution

In a recent bombshell United Nations report code named "Code Red for Humanity" (BBC Report, 2021) a catastrophe of some sort is portrayed for planet earth and humans. In that report it is said that human activities which included air pollution, is causing an unprecedented warming of the atmosphere, land and oceans resulting in a gradual but steady rise in sea level with a prediction of the possibility of sea level rising up to 2 meters by the end of this century. Global warming is already predicted to rise up to 1.5 degrees by 2040, ten years earlier than the predicted 2050 year. A number of countries have been affected significantly from climate change leading to hundreds of deaths. This include the blistering heat wave that affected west coast of United States of America and Canada, with a disturbing 300 or more deaths and about 13 million people that were affected by massive floods that engulfed China, while countries like Germany, Belgium, Luxembourg, Switzerland and the Netherlands suffered what has been described as the worst flooding experience in decade after a heavy rain fall that claimed over 180 lives (Matt, 2021; Sam, 2021).

1.3 Nigeria's Experience

Nigeria is battling with its sad share of climate change resulting partly from over 50 years of massive oil exploration and production activities and the rising population (Whyte *et al.,* 2020; Olowoporoku et al., 2012; Yakubu, 2018). Again, Nigeria suffers extensive environmental degradation occasioned by several factors including gas flaring (Brandt, 2020) and oil spills (UNEP, 2011a; Zabbey et al., 2017). Although Nigeria is signatory to the fight against climate change, not much success has been recorded in the effort to reduce or eliminate environmental pollution largely because the country's economy is driven by the huge revenue from oil and gas activities. While the effort to reduce gas flaring is commendable there is yet need for more to be done (Brandt, 2020). The need to eliminate gas flaring established and adopted since 1984 has not been achieved and the implication is rising air pollution from greenhouse gas emissions caused by the continuous burning of fossil fuel and deforestation (Akinola, 2017).

The Niger Delta region of Nigeria (Plate 1), the seat of oil and gas production activities in Nigeria and home to a vast mangrove forest (Okonkwo *et al.*, 2015) is faced with an increasing air pollution challenge because of the identified reasons adduced by Anejionu (2015) and in recent years the risk has doubled with increase in artisanal refining of crude oil in the region (Okhumode (2018) & Whyte, (2020)). Artisanal refining referred to as "Kpo Fire" - a localized unregulated distillation of crude oil hydrocarbons to produce petrol, diesel and kerosene in the creeks of Bayelsa, Rivers and other Crude Oil rich States has been established as destroying the regions of the country and the globe. This activity discharges particulate matter– soot, seen in Plates 2, 3, 4 and 5, rated as $PM_{2.5}$, carbon dioxide, methane and other gases into the atmosphere (Whyte, 2020; UNEP, 2011b). Air pollution in Nigeria and Rivers State in particular is not without the dangerous effects and the increased risk of motality among those exposed to it (Okhumode 2018) .

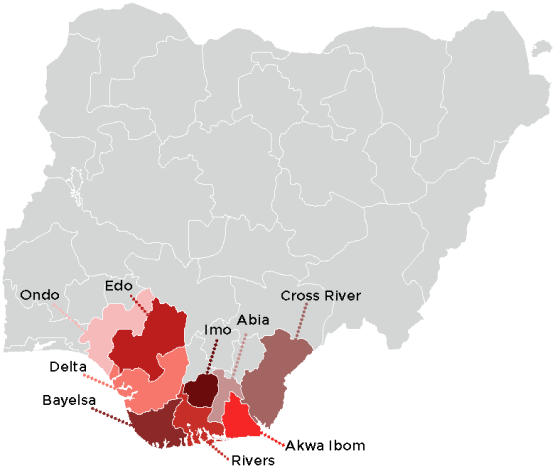

Plate 1: Niger Delta States of Nigeria (SDN, 2020)

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Plate 2: Up in smoke: illegal refining in Bayelsa state (Reuters - Financial Times, 2015)

However, the search for air pollution solution should start with availability of data, sadly Africa is in want of data on the effect of air pollution on Africans and Nigerians. Coker and Kizito in a research in 2018 identified a paucity of ambient air pollution epidemiologic data in sub-Saharan Africa as major challenge. Petkova, *et al* in a report published in 2013 had identifed that there is lack of data on air pollution studies in Africa. Petkova *et al.*, (2013) reported that available evidence from short- and long-term air monitoring studies when collected and analyzed reveal a level of pollution that is higher than international guidelines while Amegah and Agyei-Mensah (2017) in an effort to bridge the gap created by lack of data reported on exposure of sub-Saharan Africa dwellers to ambient air pollution as a major treat that has led to the death of some 176,000 persons and another 626,000 suffering from Disability Adjusted Life Years (DALY's).

This report is in agreement with the report of World Health Organization (WHO) that identified environmental pollution as having catastrophic effect on inhabitants of poor economies of the world like Nigeria. The estimate according to WHO is that Nigeria and other countries in this category has 91% of all 4.2 million recorded deaths linked to atmospheric pollution (Whyte, 2020). This sickening report is substantiated by a 2015 World Bank Environmental monitoring data (World Bank, 2015) showing Nigeria had 94% of its population exposed to air pollution beyond the WHO acceptable limits of air quality (Whyte *et al* 2020; WHO, 2016). This situation has not improved as seen in World Bank Group report (2016).

Rivers State the hub of oil and gas exploration in the Niger Delta region lacks empirical data which the government in power made effort to solve by setting up a team of expert to empirically generate base line data on air pollution for the state. (Whyte *et al, 2020).* This indigenous oil rich state has been faced with deadly air pollution challenges which include acid rain and soot pollution (Whyte *et al*, 2020). Soot particulate matter is classified as $PM_{2.5}$ and contains carbonaceous particles with attached polycyclic aromatic hydrocarbons (PAHs) (Boffetta, Jourenkova & Gustavsson, 1997). Research shows that a number of fatal diseases result from exposure to soot and its associated volatile organic compounds (VOC's) (Okhumode, 2018). Prominent among these diseases are respiratory problems such as Chronic Obstructive Pulmonary Disease (COPD) and asthma. Others are bronchiolitis, lung cancer and cardiovascular events. A dysfunction of the central nervous system when inhaled soot penetrates deep into bronchiolar tissue, and cutaneous diseases are all part of the challenge (Ioannis *et al*, 2020; Subramaniam, 2014). These have been previously classified as being either cancer that are localized and systemic in nature, mild to possibly severe respiratory disorder and cardiovascular dysfunctions. Niranjan and Thakur (2017) who reported these also reported on the possibility of soot causing damage to deoxyribonucleic acid (DNA), a life squinter in human and that there are short-term effects which include irritation of the eyes, nose and throat, cough and chest tightness.

The events of the past two centuries continues to plague African, and Nigeria and the Niger Delta in particular in the past 5 decades since the commencement of crude oil exploration. Residents of Rivers and Bayelsa states in the Niger Delta have reported increased rates of difficulty in breathing, cough, frequent and deadly asthma attacks from its sufferers and skin maladies (Whyte *et al.*, 2020).

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No doubt that Soot is a major hazard to the population in the two states put together.

To manage the rampaging effect of air pollution Nigerian government have set up different agencies driven by laws to mitigate or eliminate the sources of soot. These include environmental laws and regulations such as the Constitution of the Federal Republic of Nigeria, the National Oil Spill Detection and Response Agency (NOSDRA) Act (2006), Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN), National Environment Standards and Regulation Enforcement Agency (NESREA) Act of 2007 and very recently the 2021 Petroleum Industry Bill (PIB) that was newly signed into law as the Petroleum Industry Act (PIA). Whyte (2017) posits that despite the presence of these regulatory agencies not much has been achieved giving rise to recent heightened concerns over air pollution in Rivers State as soot continues to pollute the air in many areas of the state.

Incessant soot pollution indicates a lack of efficient monitoring and regulation of the oil industry and the will power to eliminate the threat (Sam et al., 2017). This implies a lack of empirical data on the extent of pollution in the region. To address this fundamental challenge the Rivers State government set up a team of experts to generate empirically preliminary air quality data. The expert report revealed artisanal refining, emissions from asphalt factories and improper burning of mixed waste as major causes of soot pollution in the State. Other possible causes identified include the burning of used and expired tyres and emissions from vehicular (Rivers State Government, 2019).

1.4 Why the Challenge Persist

It seems that the environmental hazard occasioned by soot seem difficult to control because of the economic advantage of the activities that produce it. As captured in the expert report one of the major activities that stands out in soot generation is artisanal refining of crude oil. It was reported that from 2009 to 2013 Nigeria lost 109 billion dollars to oil theft. In another report, the Nigerian Extractive Industry Transparency Initiative (NEITI) stated that Nigeria lost 105 billion dollars due to the activities of oil thieves in the downstream sector (Nigeria's Oil & Gas monthly, 2013).

These loses are closely related with the feelings of the indigenous people of the Niger Delta that their oil was taken away without much for them and so the youths of the region see artisanal crude oil refining as a way of recuperating lost wealth. Government agencies saddled with the responsibility to protect national resources have responded to prevent the continuous oil theft. The response of government agencies to deter and stop the artisanal activities is usually to burn storage tankers and illegal local refineries as seen in Plate 3, and these burning activities essentially increase air pollution and its associated health hazards in the region as seen in Plates 4 and 5.

Plate 3: Burning Artisanal Refinery (The Atlantic, 2013)

Plate 4: Soot in the environment in Port Harcourt Sky (Legit.ng, 2017)

More than ten years after artisanal refining of crude oil began in the region, records show that rather than being curtailed there has been increase

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in the number of artisanal refining. Camp profitability is said to have increased from 17% in 2012 to 60% and 62% in 2017 in Bayelsa and Rivers State respectively with increase in refining capacity from 45% to 88% within the period.

Plate 5: Soot on plant leave. (PM News Nigeria)

This translates to 61 camps in 2016 in Bayelsa that reduced to 48 due to security activities, but in Rivers State the number of camps increased from 535 to 1,275 camps indicating increase in capacity and increase in soot production. The total supply chain earnings increased twenty four fold from an estimated 24 million pounds in 2012 to 578 million pounds five years after in 2017 in both states of Bayelsa and Rivers State. (SDN, 2018).
The expanding artisanal refinery in the face of security checks, land and water pollution as more 5.9 million litres of crude oil was spilled in 2019 (SDN, 2020) and life damaging hazards indicates the need for a lasting solution to stop the perceived but obvious economic rape of the nation's resources, the feeling of deprivation by the indigenous people of the Niger Delta region of Nigeria, lack of employment for the teaming youths and increasing environmental hazards caused by unregulated artisanal refining of crude oil calls for an urgent acceptance and gradual modification of the artisanal refineries.

2. MATERIALS AND METHODS:

2.1 Illegal Refining of Crude Oil Process Description

The illegal production of petroleum products majorly produces three components which are diesel, fuel and kerosene.
This process is unsafe and also produce components of petroleum products with impurities. The first step in the artisanal process is the loading of crude oil into a cylindrical reactor (pot) which will then be heated at the base of the cylindrical reactor. Crude oil from an open tank which serve as fuel to the system is channelled to the bottom for continuous burning and to increase the intensity of the heat on the reactor as desired. The artisanal distillation process after 2 to 3 hours of heating results in the evaporation of components that pass through a pipe at the top of the cylindrical reactor Plate 6. These components mostly kerosene and diesel will be received by an open tank. The flow diagram of this process is seen in Plate 7.

Plate 6: Artisanal Refining Process in Progress (Advocacy Centre, 2015)

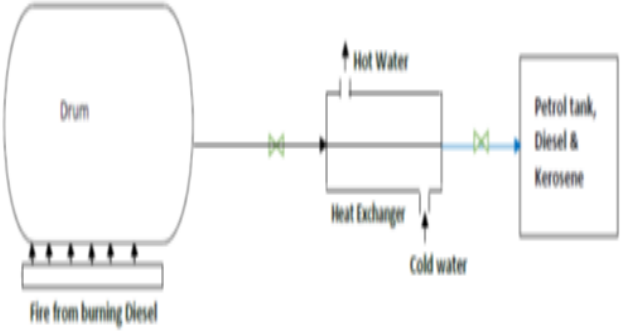

Plate 7: Current Artisanal Refining Process in Progress

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The kerosene and diesel collected in different tanks will then be cooled by inserting a water hose inside the heat exchangers for kerosene, diesel and Petrol to condense. When these component have been cooled, then the water will be allowed to flow out through an opening at the bottom of the receiver (tank of kerosene, Petrol and diesel). After the heating is carried out on the cylindrical tank, there will be residue at the bottom of the tank which is discharged through an opening at the base of the tank into the surrounding.

Based on the difficulties associated with total eradication of artisanal crude oil refining, prevalent soot challenge leading to dangerous climate change with global impact, the associated health implications and the lack of political will and resources to invest in Modular refinery, a simple but efficient artisanal refining process is required to quickly transit from a production process that produces massive soot to one that drastically reduces the extent of soot discharged to the environment. To achieve this objective, this paper presents an alternative option – a modified process that ensures improved quality of product, service delivery (Izionworu & Ukaeme, 2014) and eliminates soot production using a chimney box during artisanal production of petrol, diesel and kerosene and a Counter Current Flow Packed Tower (CCFPT) a Water wash for collection of the soot generated in the furnace housed by the Chimney. It is a process that provides an immediate solution to eradicate soot production and an initial artisanal refining process that can be modified further with use.

2.1 Materials for the Modified Process of the Artisanal Production of Petroleum Products

To eliminate soot production and improve the method in the production of petroleum product during artisanal refining the equipment modification shown in Figure 1 is recommended:

2.1.1 Equipment Description

The equipment required for the crude system modification are:

i. Open squared drum: where the crude that serve as fuel is stored.
ii. Cylindrical drum (the distillation Colum): this is where the crude is loaded.
iii. Furnace: This is a system set up to generate heat to the process.
iv. Chimney: This is a housing set to accommodate the distillation Colum and also the furnace and contain the soot resulting from the burning process seen in Plate 8.
v. Counter Current Flow Packed Tower (CCFPT) (Water wash): Plate 8 shows the Counter Current Flow Packed Tower used to trap the soot while the gas will be allowed to flare.
vi. Heat exchanger: There is one heat exchanger in the Crude oil tank and a set of three heat exchangers for condensation of products from the separation tank to the Receivers.
vii. Receivers (Kerosene, PMS and diesel Receivers): The Receivers shown in Plate 8 receives and temporarily stores the refined products before transfer to product storage tank.

3. REVIEWERS COMMENTS

3.1 Process Description

The crude oil is first loaded inside the distillation Colum (cylindrical tank) and the heat is generated from the furnace to raise the temperature at which the petroleum products will be heated to their separation temperature. A crude stored in a squared tank which flows through a pipe serves as fuel for this process.

When the crude has been heated to an elevated temperature, the lighter product evaporates and then is collected by the receiver. The other components are also collected through the same procedure at their distillation temperature.

In the crude oil tank a tripled-pipe concentric heat Exchanger is used to preheat the crude oil before it is trasfered to the drum for heating at higher temperature required for the product separation before they are collected.

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The soot that is generated in the cause of this process is collected by the Chimney and transferred through piping connection to a concentric heat exchanger in the crude oil tank. The soot temperature reduces at this point and is sent to the CCFPT (water wash) to wash off the soot, while the gas is collected in a tank and used as fuel to heat up the crude oil in the crude oil separation tank.

The estimated production capacity of a modified process of artisanal refining is 30000 barrels/day

The Strength of Materials and Specifications for the components of the modified process are as follows:

Metal material for distillation colum and Chimney -

i) Stainless steel has the capcity to always go back to normal use after a fire incident (Euro Inox, 2014), hence, soot fire resistant, anti rusted stainless steel with a life span of about 70 years is recommended.

ii) The suggested Stainless steel material should be:

A product of EN1856-1, with an operating temperature of 450 ^{o}C. It should withstand a high pressure rating of 1.2 – 1. 25 atm and resistance to wet condensate, soot fire and corrosion. It should also have good material thickness.

3.2 Chimney

The chimney Box compartment will be 6 nos sheet as seen in Plate 8. Internally welded flanged and bolted sections

i. Each with 2 no. Lifting points.
ii. 1 no internal ladder for full height of chimney.
iii. Tight flanges.
iv. Internal surface treatment of the shell and liners by degreasing wire brushin followed by the application of heat resistant aluminum paint is recommended.

The dimensions and specifications of all operational components are subject to the desired production capcity.

Considering various corrosion inhibition options available (Izionworu *et al.*, 2019).

The following corrosion treatment will be provided for the metal surfaces:

Blast clean to SA 2.5 followed by the application of 1 x 80 microns alkyd first coat, 2 x 40 microns and alkyd finishing coats with a total thickness of coating approximating 160 microns. The coating serves as the corrosion inhibitor.

4. CONCLUSION:

The researchers suggest the following as practical answer to the disastrous artisanal process currently in use for crude oil refining that discharges massive particulate matter – soot into the environment:

i. Legalize artisanal refining in Nigeria with products sold to practitioners who over time with research will advance the process to a modular refinery.
ii. Modification of Current Artisanal process by provision of simple chimney and other component parts.
iii. Soot slurry should be collected in a tank and treated. A simple water treatment line that will become an associated component of the artisanal refining process is recommended. In the mean time soot slurry should be treated at the water treatment plant in Port Harcourt Nigeria.
iv. Provide level 3 Health Safety and Environment (HSE) training for artisanal refinery operators.
v. Vehicular emissions monitoring and control with strict conditions should be inforced.
vi. Rather than burn illegally refined petroleum products, tank farms for storage of seized petroleum products should be established while the modified process is implemented.
vii. All foods should be covered in homes and markets and transparent display units should be used by all food dealers. All surfaces should be cleaned regularly, and personal hygiene encouraged through regular advocacy.
viii. The establishment and equipment of the state of the art cardio-respiratory

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centre to manage and diagnose all forms of cardio-respiratory conditions will be of great advantage to residents of each State in the Niger Delta region. Similarly a cancer treatment centre in the region will raise the bar on the standard of medical treatment services and set stage for anticipatory medical intervention for existing health condition resulting from black soot inhalation.

ix. There should be massive tree planting in the State by individuals who own buildings and properties in the cities , to absorb carbon dioxide (CO_2), and the control of other potentially harmful gases such as sulphur dioxide (SO_2), carbon monoxide (CO). Trees sequester carbon, removing CO_2 and other greenhouse gases, and it moderates surface temperatures through albedo (solar radiation). It is a fact that a mature canopy tree absorbs enough carbon and releases enough oxygen to sustain two human beings. Government and its regulatory authorities should drive this course.

x. Asphalt production process in the State should incorporate gaseous emission control methods in their operations.

xi. Again, since it is difficult to further breakdown the resulting atmospheric residue to derive vacuum products by continuous heating under atmospheric condition without straining the furnace and fouling of both the heating medium and product settler, and a future decline of efficiency of the heater this study recommends further research on a local alternative to manage the resulting Heavier Fractions which at the moment will be treated at Port Harcourt Refinery, Port Harcourt Nigeria.

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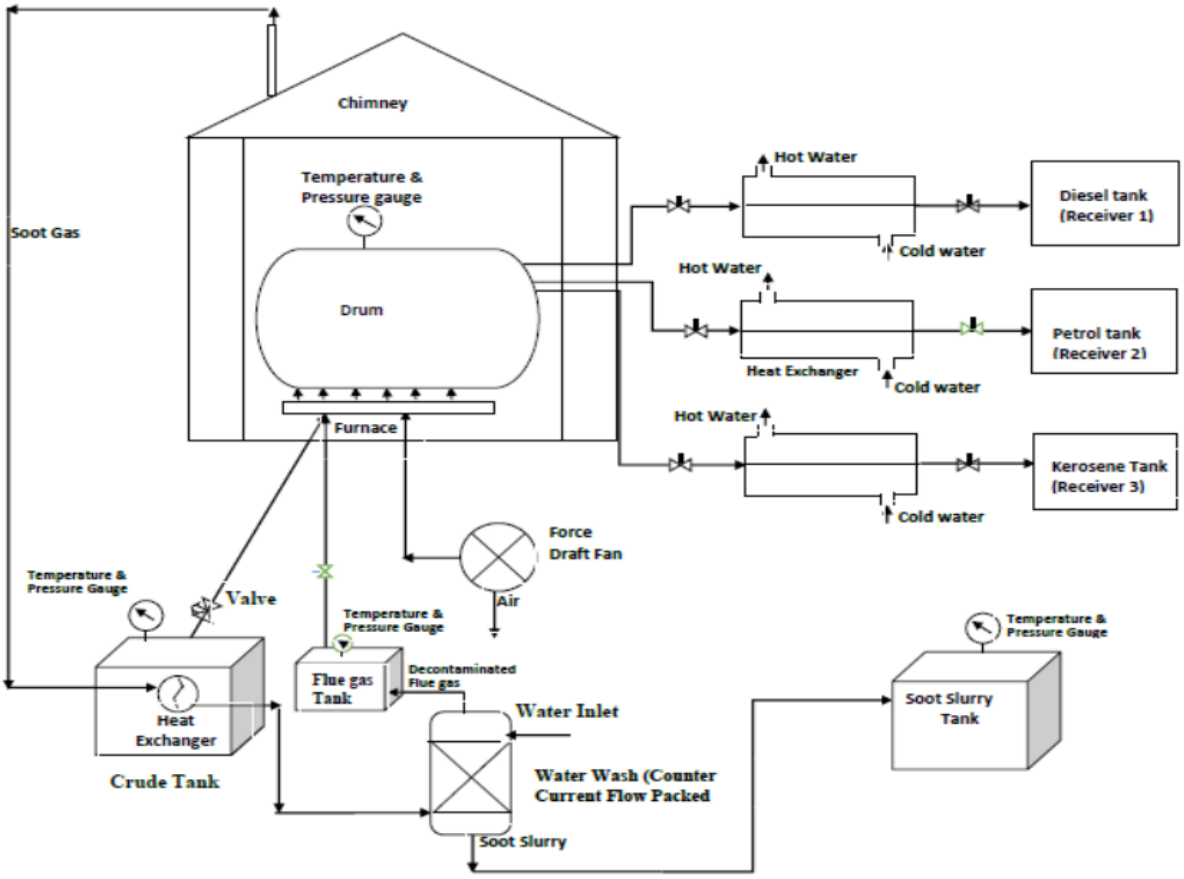

Figure 1. Modified Process of the Artisanal Production of Petroleum Products