

# The Possibilities of Simultaneous Operation (SIMOPs) and Practicality of Positive Pressure Habitat in a Hazardous Industry: Where Process Safety Meets Occupational Hygiene

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## **Author's contribution**

*The sole author designed, analysed, interpreted and prepared the manuscript.*

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## **ABSTRACT**

High risk industrial facilities require operational shutdowns to undertake maintenance activities when the interaction between maintenance activities and facility processes are potentially explosive. This study presents a model that circumvents this interaction thereby enabling simultaneous operations flammable hydrocarbon facility while hot work progresses. A mixed study in which qualitative data on Simultaneous Operation (SIMOPs) of a hydrocarbon facility, hot work and deployment of Positive Pressure Habitat were generated through a walk-through survey. Quantitative data on the exposures within and around the hot work activities were generated using air quality monitor to measure the concentration of welding particulates, portable ozone meter used to measure the ozone level, sound level meter to measure ambient noise level, personal noise dosimeter to measure personal noise level, Multi-gas Meter. While concentrations of chemical parameter, temperature, relative humidity, habitat pressure were not in exceedance of exposure limits; the average noise level and particulate matter (PM) 2.5 within the habitat were 87 – dB(A) and 65 µg/m<sup>3</sup>

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respectively. The exceedances in noise and PM<sub>2.5</sub> level was mitigated using hearing protection, respirator and local exhaust ventilation (LEV). A simultaneous operation involving live hydrocarbon facility and hot works was achieved using the Positive Pressure Habitat (PPH) as a buffer between flammable work environment and thermal energy emitted from hot work activities. Chemical pollutants were introduced by maintenance activities within the habitat but was however mitigated through occupational hygiene measures. This study validates the possibility of simultaneous operation in the event of two mutually explosive scenarios with the aid of process safety equipment's and occupational hygiene measurements and control measures. Globally, downtimes in high risk industries occasioned by maintenance activities could be prevented by deploying process safety and occupational hygiene control strategies concurrently.

*Keywords: Simultaneous operations; positive pressure habitat; hot works; simultaneous operation; process safety and occupational hygiene.*

## 1. INTRODUCTION

Aging oil and gas facilities such as commonly found in brown field assets are replete with failing hardware's with structural degradations, wears, corrosion, damages, defects, errors in design, fatigue, structural failures and cracks [1]. The concept of Asset Life Expansion (ALE) requires Oil and gas operators to operate facilities beyond their designed life span [1]. Operational safety is unachievable because of the aging effects on equipment thus affecting reliability and integrity [1]. Unmaintained facilities could completely fail and lead to loss of containment of flammable contents such as hydrocarbon gas, oil and gas with resultant explosion and fire. One of the downsides of a brown field facility (ageing installation) in a high-risk industry such as the oil and gas is the need for continual maintenance, repairs, modification, retrofitting, expansion of existing infrastructure, machinery and units in order to sustain production. These maintenances could either be preventive or corrective maintenance (PM, CM) involving different engineering interventions of which hot work is a sine-qua-non. Hot work refers to activities that generate heat from spark, flame, friction or by other ignition mechanisms with adequate thermal energy that could cause ignition of dust, gases or vapour. Hot work activities during maintenance could include welding, grinding, cutting, grinding,

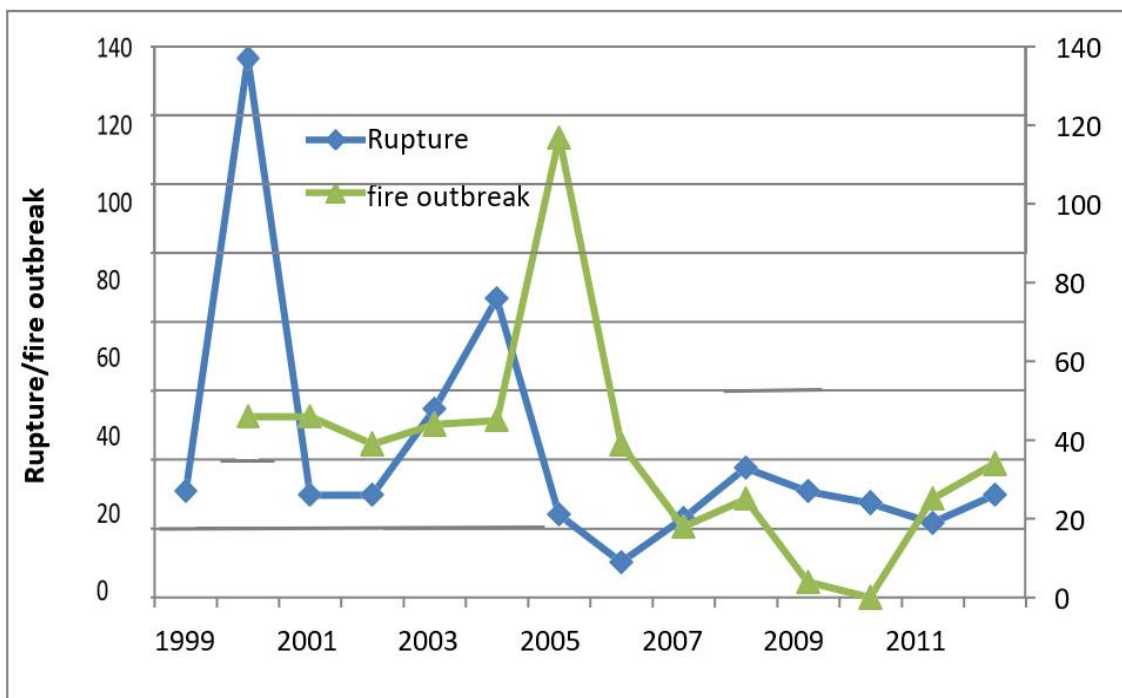
chipping, abrasion, blasting, soldering among others [2,3]. Hot works become more challenging when the maintenance area is in a classified hazardous zone. Hazardous zones such as found in oil and gas facilities are zones in which there is frequency and presence of explosive gas in the air or environmental ambience (HSE) as described in Table 1.

The implication of zones 0 & 1 is the possibility or grave potential for fire and explosion occurring with ignition resulting in collateral damages to humans, environment, assets, reputation, production, earnings, commerce and livelihood. Sources of thermal energy that could cause ignition include flames; use of cutting and welding torches with flames; hot surfaces; hot process vessels such as dryers, boilers and furnaces; mechanical machinery; live electrical equipment and lights, processes involving friction heating or sparks; impact sparks; sparks from electrical equipment; electrostatic discharge sparks; lightning strikes; electromagnetic radiation of different frequencies and wavelengths and more. Several incidents of fire and explosion in and around oil and gas infrastructures in Nigeria had occurred due to ignition of surrounding explosive atmosphere caused by rupture or vandalization of hydrocarbon containment with significant impacts as shown in Table 2 and Fig. 1.

**Table 1. Hazardous area classification**

Zone	Flammability descriptor
0	An area in which an explosive gas atmosphere is present continuously or for long periods
1	An area in which an explosive gas atmosphere is likely to occur in normal operation
2	An area in which an explosive gas atmosphere is not likely to occur in normal operation and, if it occurs, will only exist for a short time

*Source: Adapted from HSE [2,4]*



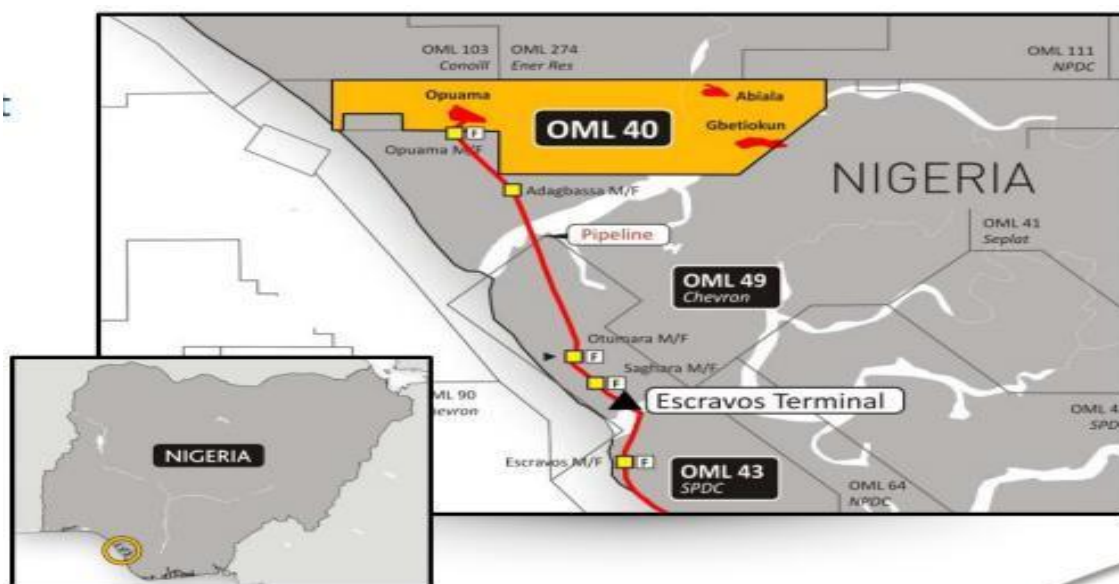
**Fig. 1. Number of rupture and fire outbreak in NNPC pipeline (1999-2013)**

*Adapted from El-Hassan, Smyth & Mooney [5]*

**Table 2. Fire and explosion in and around Oil and Gas infrastructure from 1998 to 2013**

Date & location	Consequence
17 <sup>th</sup> October 1998. Jesse in Delta State, Nigeria.	More than 1000 deaths, dozens injured, damaged farmland and environmental pollution
22 <sup>nd</sup> April 1999. Bayana in Delta State, Nigeria.	At least 10 deaths, damaged farmland, air and water pollution
8 <sup>th</sup> June 1999. Akute Odo in Ogun State, Nigeria.	At least 15 deaths, damaged farmlands, land and air pollution
13 <sup>th</sup> October 1999. Ekakpamre Ughelli in Delta State, Nigeria	Undetermined deaths, damaged farmlands, and environmental pollution
14 <sup>th</sup> January 2000. Gana community in Delta State, Nigeria.	At least 12 deaths, damaged farmlands, and environmental pollution
7 <sup>th</sup> February 2000. Ogwe in Abia State, Nigeria.	At least 15 deaths, damaged farmlands and environmental pollution
20 <sup>th</sup> February 2000. Lagos State, Nigeria.	At least 3 deaths, damaged farmlands, canoe, and environmental pollution
14 <sup>th</sup> March 2000. Umugbede Osisioma in Abia State, Nigeria.	At least 50 deaths, damaged farmlands and environmental pollution
4 <sup>th</sup> April, 2000. Uzo-Uwani in Enugu State, Nigeria.	At least 6 deaths, damaged farmlands and environmental pollution
3 <sup>rd</sup> June, 2000. Adeje in Delta State, Nigeria.	Undetermined deaths, forest damaged, destruction of high-tension power cable of two electricity plants, and police/youth clash
20 <sup>th</sup> June 2000. Ekuedjeba Warri in Delta	Undetermined deaths, damaged farmlands and environmental pollution

*Adapted from El-Hassan, Smyth & Mooney [5]*



**Fig. 2. Location of Incident [6]**

Although, aforementioned cases involved pipeline infrastructures that were compromised by rupture and vandalism; serious incidents of fire and explosion had occurred during maintenance involving hot works in zones 0 and 1 sections of oil and gas facility. In 2020, the regulatory body for oil and gas industry in Nigeria, the Nigerian National Petroleum Corporation (NNPC) announced the explosion of an upstream oil and gas facility in the Niger Delta region of Nigeria which resulted in significant structural damages, 7 fatalities and production shutdown of 22,000 barrel per day production. The facility is an Early Production Facility (EPF) located in the oil rich Niger Delta region of Nigeria which is approximately 75 kilometres north west of Warri. Fig. 2 shows the location of the block [5].

Preliminary investigation showed that the incident occurred during maintenance activity involving installation of a ladder to this platform in a shallow offshore location. Installation activity involved welding, fabrication, fitting and other hot work activities. These hot work activities were carried out concurrently with production ongoing in same facility. Apparently, the hot work activities provided the thermal energy which ignited the explosive atmosphere as described in zone 0 and 1 resulting in the explosion. This incident notwithstanding, the need for simultaneous maintenance and operational activities in a live hydrocarbon facility is sacrosanct giving the necessity for continuous

operation of such facility. The need for concurrent operations, activities and maintenances is rife and driven by the need for increased and sustained production. This study has been designed with aim of presenting a best practise scenario in a similar facility within same terrain for learning purposes and prevention of future occurrence of avoidable incidents in oil and gas operations. The objective of this study is to present the practical use of Positive Pressure Habitat as a control tool in simultaneous operation (SIMOPs) of mutually hazardous and flammable processes.

## 2. MATERIALS AND METHODS

### 2.1 Data Source

A mixed study (see Fig. 3) involving a walk-through survey of deployed Positive Pressure Habitat (PPH) in a simultaneous operation of flammable (operational) hydrocarbon gas flow station; and generation of quantitative data through exposure monitoring of workplace parameters.

Qualitative information was derived through a walk-through survey of the maintenance site involving direct field observation of hot-work habitat and welding operations. Moen had opined that walk-through survey is a veritable instrument used to obtain essential information about activities in an occupational environment [7].

Walk through Survey entails conducting physical worksite visit to identify potential and existing hazards, identification of workers at risks, designing controls with evaluation strategy to assure effectiveness of controls [8]. The Walk-through Survey was supplemented with unstructured interview of Health, Safety and Environment (HSE) personnel, technicians, welders, and health experts. Quantitative data was generated through exposure monitoring

within the habitat using air quality monitor to measure the concentration of welding particulates, portable ozone meter used to measure the ozone level, sound level meter to measure ambient noise level, personal noise dosimeter to measure personal noise level, Multi-gas Meter to measure carbon monoxide (CO), hydrogen sulphide (H<sub>2</sub>S), oxygen (O<sub>2</sub>), ambient temperature, relative humidity (RH) and Hot wire anemometer to measure air velocity.

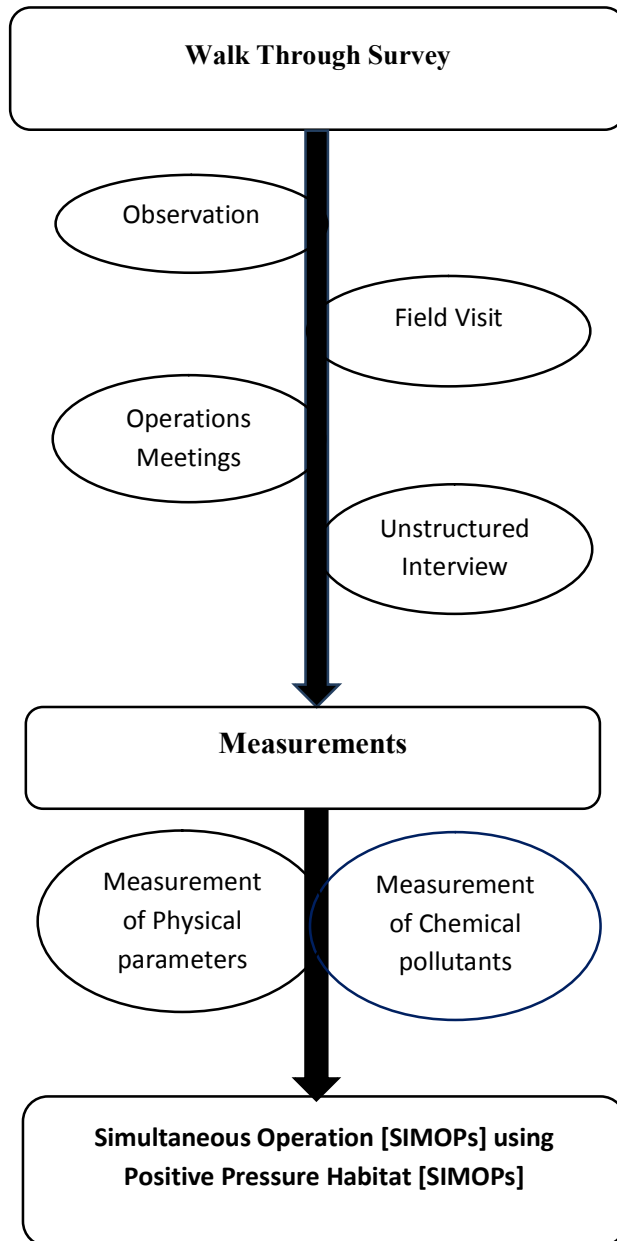


Fig. 3. Flow chart of research method



**Fig. 4. Niger Delta Area of Nigeria**

Source: Adapted from Diercke International Atlas [17]

## 2.2 Analysis

Quantitative parameters were benchmarked with the United Kingdom Occupational and National Institute for Occupational Safety and Health (NIOSH) exposure limits [9,10,11,12,13,14,15,16].

## 2.3 Study Area

An oil and gas flow station located in the shallow offshore, Niger Delta Region of Southern Nigeria (see Fig. 4). Facility produces an average of 8 million m<sup>3</sup>/d of gas with a variation of between 4-6 million m<sup>3</sup>/d together with 4000 m<sup>3</sup>/d of condensate. The terrain is rich in oil reservoirs, remote, swampy and dense in petroleum facility and activities. It borders the Gulf of Guinea, stretches over 70,000km<sup>2</sup> across 9 states on the coastal Atlantic shelf. The facility largely consist of a section of metering skid, export pumps which were 2 Sulzer and 3 Emsco pumps; surge vessels, high and low pressure separators (HP & LP), several valves and pipes, saver pits, cathodic protection, Emergency Shut Down valves, inlet and outlet manifold, generator among other smaller units.

## 3. RESULTS

### 3.1 Walk through Survey

Unstructured discussion with workers revealed that study facility was shut down for over 4 years

following militant agitation and incessant attacks by youths in the region. Although minimal trouble - shooting and maintenance was done before re-entry, routine Occupational Hygiene area monitoring for Benzene, Toluene, Ethelene & Xylene (BTEX), showed exceedingly high level of BTEX values above 1.5ppm. Scope of work include brownfield modifications to the Central Processing Facility) CPF, sectional replacements of corroded pipes and sections of supporting gantry, trays; fabrication of new base to support collapsing valves. Retrofitting 2 low pressure (LP) separators with strengthening of its supporting base, tie-in of flowlines and trays for electrical and instrumentation cabling.

### 3.2 Observation

An over pressurised (bloated enclosure) and airtight Positive-Pressure Welding Habitat' was in place surrounding the section of pipe to be removed and replaced with newer pipe with the aid of hot works involving cutting, grinding and welding. A supporting framework made of scaffolding steel structures was erected around section of compromised pipes and steel infrastructures with a sheet metal plate on the enclosure floor. A fire-retardant aluminium frame door with transparent glass aperture and two fire retardant glass windows were fabricated into the side, fire-retardant panels (plywood) and framework thereby forming a large enclosure with seals achieved with the aid of Velcro and fire-retardant tapes. An air inlet duct connected

to a blower to blow fresh controlled air into the enclosure from a distant location (300metres) outside the core zone. A further air outlet duct is affixed to the habitat and connected to an air expeller to enable outflow of fume, particulates, contaminated and used air to a distant location outside the core zone. The habitat is equipped with different sensors and fixed equipment within and outside the enclosure. These include air quality monitor with alarm, Magnehelic Pressure detector (manometer), multiple gas detectors, real time digital monitors with alarm capabilities for harmful concentration of contaminant such as Oxygen, Hydrogen Sulphide, Carbon Monoxide and physical properties such as ambient temperature, relative humidity and the Lower Explosive Limit.

### 3.3 Activities

Arc welding with welding gun designed with a fume extraction nozzle was used to undertake welding within the enclosure, other activities include minimal manual handling, cutting, grinding and extensive welding. Two full kitted technicians were involved helmet mounted welding visor and earmuffs, respirator, protective clothing, hand gloves and safety shoes. Technicians stood all through activities with occasional awkward posture. Externally, a fire watch was standing by observing through the transparent window and keeping watch on the control panel (console, alarm and lighting). Personal sampling train with samplers mounted on breathing zones and on lapel for personal

sampling of metals, noise dosimeter for personal noise measurement.

### 3.4 Document Review

Sighted document includes Permit to Work (PTW) approval document, training documents for the technicians on use of Positive Pressure Habitat, Minutes of Meeting (several) and fire cover, fire watch, fire extinguisher and several sand bucket.

### 3.5 Exposure Measurements

Some of the measured parameters (see Fig. 4) were found to be below occupational exposure limits as evidenced by ozone (O<sub>3</sub>) - 0.09 [(Occupational Exposure Limits -OEL)-0.2]mg/m<sup>3</sup>, carbon monoxide (CO) to be 19 [OEL-55] mg/m<sup>3</sup>, manganese (Mn) 1.8 [OEL- 5] mg/m<sup>3</sup>TWA (Time Weighted Average) 8hours long-term exposure limit, hydrogen sulphide (H<sub>2</sub>S) 7 [OEL-15]] mg/m<sup>3</sup>, chromium VI (CrVI) 0.4 [OEL-1] mg/m<sup>3</sup>TWA ( 8hours long-term exposure limit). The average particulate matter (PM) and personal noise dose were in exceedance as evidenced with 65 [35] µg/m<sup>3</sup> and 87 [OEL-85] dB(A) for an eight-hour day, respectively. Other parameters were normal values, these include relative humidity (RH) 70%, ambient temperature 21°C, air velocity 1.2 metre per second, oxygen (O<sub>2</sub>) - 21.4%, habitat pressure of 50 pascal, trace values of iron, lead and nickel.

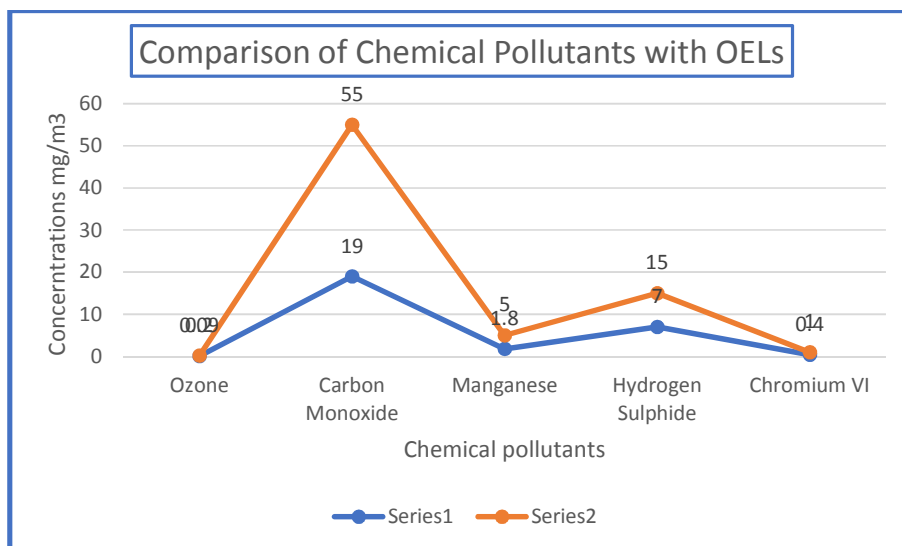


Fig. 5. Chemical Pollutants [Blue] and OELs [Orange]

Source- Author generated

### 3.6 Simultaneous Operation (SIMOPs)

Discussion with station attendants and team leader revealed that the facility was live while maintenance activities were undertaken. Crude oil flows from well head or Christmas tree into the facility through the inlet manifold via the metering skid into the facility. The crude is processed through various mechanism involving separation at the separators, dehydration, desulphurisation, filtration, de-ionization, cooling, compression and distribution.

## 4. DISCUSSION

This study presented a model to salvage operational downtimes caused by the explosive interaction between a potentially flammable work environment and source of thermal energy. The strength of the study lies on the mixed approach of data acquisition though qualitative and quantitative methods. However, the limitation lies in the study being substantially observational. Maintenance of facility was necessitated by the aging effects on the infrastructure which constantly led to fugitive emissions. The walk-through survey revealed increased fugitive emissions to be due to corroded pipes within the process area. Fugitive emissions are leaks and releases of gases or vapour from different containment such as vessels, pipes or valves [18]. Other sources of emissions include equipment leaks, process venting, accidental loss of containment, waste disposal and evaporative processes [18]. In this contest it was the leakage of hydrocarbon gas from multiple sources on the flowlines within the plant. Given that hydrocarbon gas is explosive when subjected to thermal energy, it therefore became necessary to carry out widespread preventive maintenances and modifications whilst simultaneously sustaining continuous gas production. Attempts to carry out maintenance activities involving hot works in live hydrocarbon facilities had resulted in explosion and fire with several casualties and fatalities [6]; maintenances introducing thermal energy in flammable work environment default to shutting down such facility with resultant loss of time, money and customers dissatisfaction. Clearly, as shutting down is not an option in the oil industry, circumventing downtimes and operational disasters during concurrent production and hot work engineered maintenances in hazardous zone would require a process safety strategy. This is achieved through the Simultaneous Operations (SIMOPs) model involving the use of

Positive Pressure Habitat [19]. SIMOPs is the concurrent undertaking of independent operations in which the effects of the operations might interact and result in unwanted consequences which might affect the safety of workers, environment and asset. This implies that undertaking maintenance involving hot work in a live hydrocarbon facility is SIMOPs. To undertake SIMOPs and prevent the negative outcome of interaction between thermal energy generated by the hot works and the flammable hydrocarbon in the ambience of the hydrocarbon facility (zone 1 and 2); a process safety unit called the Positive Pressure Habitat (PPH) habitat is essentially required. Concomitant operation of a hydrocarbon facility with execution of a potentially hazardous activity such as hot works could result in an explosive incident. Safety can be achieved through buffering flammable hydrocarbon vapour and gases with the deployment of PPH, thus making the interaction between flammable vapours and thermal energy from welding unrealistic. The PPH isolates hot work activity thereby decouples the interaction between flammable vapour from thermal energy generated by the hot work, contains source of thermal energy, prevent the ingress of flammable gas, prevents egress of thermal energy from the hot work site. PPH leverages on positive air-pressure at 50pascal within a fire-retardant enclosure achieved by continuously introducing breathable and controlled air into the enclosure which in turn leaks via the outlet duct. While the multiplier effects of habitat include the safety of working environment, continuation of production, accelerated maintenance of structural integrity and increase productivity; the achilles heel is its confinement with associated drawbacks of confine space, potential concentration of welding fume contaminants, poor working ergonomics. Hot works within the PPH will introduce chemical pollutants which are potentially harmful to workers in an uncontrolled habitat. Although the chemical pollutants [O<sub>3</sub>, CO, Mn, H<sub>2</sub>S, Cr] [see Fig. 4] were below the OELs, there will be exceedances if controls are absent. An uncontrolled exceedance of O<sub>3</sub> could potentially cause lung irritation; CO could cause asphyxia, hypoxia and carboxyhemoglobin; Cr (VI) could potentially cause lung fibrosis, Mn could potentially cause metal fume fever, H<sub>2</sub>S could potentially cause convulsion, coma and death. Although physical exposures like RH, air velocity, habitat pressure and ambient temperature were below health limits, noise level and PM<sub>2.5</sub> were found to be very high as evidenced by a value of



91 – dB(A) and 65 µg/m<sup>3</sup> respectively. Noise exposure could potentially pre-dispose operators to hearing loss when exposed for a long period, hence the use of hearing protectors is recommended. Prolonged exposure to PM2.5 could potentially lead to lung disorder as it is a respirable dust. Previous studies [20] have shown that welding fume contains carbon monoxide, oxides of manganese and Chromium VI; this study further corroborated significant potential for heat stress, noise, oxygen deficiency, ergonomic risk of awkward positioning, respirable and inhalable particulates in an operational PPH within an oil facility. The existential health and safety risks caused by fluctuating chemical pollutants and operational hazards requires rafts of mitigations which include the use of Permit to Work (PTW) system of safe work method during hot work; use of fire proof tent rated for 2000°C and above; continual intra-tent overpressure; use of intrinsically safe equipment; continual real time monitoring of pollutants, oxygen, pressure, flammable vapours, explosive limit; training of workers on the concepts of SIMOPs and use of HHP; occupational hygiene control measures; exposure monitoring; workers training and the automatic synchronization of real time monitoring to facility shutdown mode.

## 6. CONCLUSIONS

This study has revealed the challenges encountered in the operation of brownfield assets and possibilities of SIMOPs in its maintenance. Related it reinforced the presence of harmful chemical pollutants during hot works. It further showed the centrality of exposure monitoring as a sine-qua non to circumventing the risks posed by chemical and explosive pollutants in the use PPH during SIMOPs in a hazardous area.

## 7. PRACTICAL IMPLICATIONS

Globally, maintenance activities in occupational settings should be planned with the process and operational safety, and industrial and occupational hygiene specialist involved. This will forestall unmitigated health and safety risks.

## DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and

producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

## COMPETING INTERESTS

Author has declared that no competing interests exist.

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