

TOXIC RELEASE OF EMISSIONS PRODUCED DURING THE COMBUSTION OF SPENT LUBE OILS

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ABSTRACT: The direct combustion of fossil fuels for the generation of electricity and energy has led to catastrophic and widespread pollution in specific areas due to emissions of carbon dioxide, hydrocarbons, SO_x and NO_x to the atmosphere. Air pollution arising from the combustion of used oil under inappropriate conditions can be a major threat to both humans and animals as well as plants. Personnel working in the field of road construction, Power Plants or Cement Kilns are exposed to different types of air pollutants that have negative effects on their health. The aim of this research is to monitor the air quality to which the labor are subjected to inside the work places and under the working conditions, throughout the period of their working day. To achieve this objective, a portable ambient air analyzer as well as an atomic absorption spectrophotometer was used to assess the extent of the air pollution in a confined environment laboratory. The results of this research study showed that the levels of benzene were above both the Egyptian and International Standards concentrations limits for air quality.

Keywords: Air Pollution, Used Lube Oils, Ash, Emissions, Volatile Organic Compounds, Combustion.

1. INTRODUCTION

Lubricating oils are used to minimize friction and reduce wear between rubbing surfaces by introducing a film of material between them [1]. Used mineral oils, especially those collected from either combustion engines, transmission systems, turbines and hydraulic systems etc; such oils have become unsuitable for use due to the presence of contaminants or impurities or the loss of their original properties. In accordance with the existing European Regulations, used mineral oils are classified as hazardous waste due to their effects on both the health and the environment [2]. The processing of used mineral oils has been practiced for many years. As a matter of fact, the organized recycling of engine lubricating oil from various vehicle fleets is well established since the 1930s [3]; furthermore, the Management of Used Oils is very important because of the large quantities that are generated globally. These used oils have the potential for Direct Re-Use, Reprocessing, Reclamation or Regeneration; consequently, such oils may cause detrimental effects on the environment if they are not properly handled, treated or disposed of. Actually, Used lubricating Oils and Other Oils represent a significant portion of the volume of organic waste liquids that are generated worldwide. The three most important aspects of those used oils are: Content of contaminants, Energy value and Hydrocarbon properties [4].

There are many practical uses for Used Motor Oil; its primary use, however, is to Re-Refine it to a base stock for the manufacture of 'finished lubricating oils'. Such Re-Refining process is very similar to the refining of crude oil. The resulting re-refined oil usually has a high quality as high as the virgin oil product itself. A secondary use of the Used Motor Oil is to produce heat energy; in fact, some large industrial boilers are able to efficiently burn the used oil with minimum extent of pollution. Consequently, some of the Used Oil is sent to Power Plants or Cement

Kilns for burning as a fuel. Finally, small quantities of used oils are burned in specially designed heaters to provide space heating for small businesses.

Trace elements are usually emitted from the combustion of used oils; the quantity of such elements entering the combustion device depends solely on the fuel composition. As a matter of fact, the quantity of trace metals emitted from the source depends on the combustion temperature; the fuel feed mechanism as well as on the composition of the fuel. The temperature generally determines the degree of volatilization of the specific compounds that are contained in the fuel. The fuel feed mechanism however, affects the separation of the emissions into what is known as bottom ash and fly ash. In general, the emitted quantity of any given metal depends on many aspects, namely, the physical and chemical properties of the element itself, the concentration of the metal in the fuel, the conditions of the combustion in addition to the type of particulate control device used, and the efficiency of its collection as a function of particle size.

It is important to note that, the volume of used oil that is burned is more than Four times the volume that is Re-refined; such action is in spite of the environmental benefits that favor Re-Refining wherein the toxic heavy metals (like zinc, cadmium, chromium, lead, and others) are extracted from the Used Oil. Actually, on comparing Re-Refining Processes to combustion processes, the former have the advantage of separating the heavy metal compounds that are subsequently solidified and stabilized into solids, consequently posing minimal Environmental Risks. In the Combustion Processes, however, the metals in the combustion flue gases must be treated with air pollution abatement equipment prior to their release to the atmosphere. It is important to mention that Combustion in Cement Kilns, Steel Mills, and other large-scale industrial combustion processes generally comprise 'state-of-the-art' Flue Gas Treatment Units that are effective in addressing the environmental issues.

The high energy content that is inherent in many used oil streams sometimes encourages their direct use as fuels, without any pretreatment and processing, and in such cases without any quality control or product specification. Actually, the Direct Uses of Used Oils do not constitute good practice, unless Combustion of the waste can be carried out in an environmentally sound manner. For this reason, Used Oils when used as fuels usually need to be subjected to treatments involving some form of preliminary settlement, to remove sludge and suspended matter. Such preliminary simple treatments as those can substantially improve the quality of the material, by the simple removal of the Sludge, Suspended matter, Carbon as well as some degrees of Heavy Metals [5].

Besides Re-refining and burning, Used Oils have been traditionally employed in other uses that include the following aspects: as a raw material in the production of asphalt (road oil flotation and forming oil), as a secondary lubricant, as a pesticide carrier, a weed killer, an all-purpose cleaner and a vehicle undercoating. Furthermore, under certain conditions, Used Oils can also be employed in oil refineries to aid the manufacture of other refined products. Finally, used oils have for many years been applied as a dust suppressant to gravel roads, especially those located in rural areas. This is because such rural areas have a high proportion of unpaved roads that are located some distance away from other used oil markets where Burning and Re-refining operations could be carried out.

The area of most concern appears to be in the unregulated combustion of used oils in the hydroponics, flower and related industries. Used oils are used as burner fuels to heat greenhouses as a substitute to the higher cost fuels. the main competitor of which is gas. In such circumstances, an environmental risk is quite apparent since

small furnaces do not require formal EPA approval; in such cases, used oils incorrectly used can lead to the formation of significant amounts of Polychlorodioxins. Needless to mention, the formation of Dioxin and Polyaromatic Hydrocarbons (PAHs) are serious issues that must be addressed in order to minimise any significant disruption to these valuable industries in the future[]. Small amounts of organic compounds are usually emitted from the combustion of used oils, the rate at which those compounds are emitted depends, to some extent, on the combustion efficiency of the boiler. The Total Organic Compounds (TOCs) include, semi-Volatile Organic Compounds VOCs, and condensable organic compounds. Emissions of VOCs are primarily characterized by the pollutant class of the unburned hydrocarbons[5,6]. Unburned hydrocarbon emissions essentially include all vapor phase organic compounds emitted from a combustion source. These are primarily emissions of aliphatic, oxygenated, and low molecular weight aromatic compounds which exist in the vapor phase at flue gas temperatures. These emissions include all alkanes, alkenes, aldehydes, carboxylic acids, and substituted benzenes (e. g., benzene, toluene, xylene, and ethyl benzene).

The Egyptian Law for Environment (Law No: 4/1994) stipulates that in order to grant a permit for the establishment of a project, the selected site chosen should be appropriate for its activity to ensure compliance with the accepted limits of air pollutants. Furthermore, this environmental law emphasizes that the total pollution, resulting from all the establishments in one area, should be within the permissible limits and stipulates that all operations must be carried out in a safe work environment that respects the exposure limits of the labor in addition to the fact that the workplaces must comply with the appropriate Health And Safety Guidelines that are specified. Finally, it is important to note that the Egyptian Law of Labor (No: 12/20030 and its Executive Regulations as stipulated by the Ministerial Decree (No. 211/2003), follows a philosophy, that provides for a high degree of consideration to Environmental Safety and the Health of workers inside workplaces [7].

2. EXPERIMENTAL WORK

2.1 Raw Materials

In the preliminary tests, both virgin lubricating oils and used automotive lubricating oils are locally obtained from an Egyptian gas station. The physical and chemical characteristics of both lube oils are given in Table 1.

2.2 Procedure

Air pollution arising from the combustion of used oil under inappropriate conditions can be a major threat to both humans and animals as well as plants. When oil is heated to high temperatures in a confined atmosphere, the light constituents are volatilised while the heavy constituents coke to a carbonaceous residue, which is determined by the standard method (ASTM D 189). The residue may contain metallic elements, which can be measured by the ash technique (UOP 391).

Table 1: Comparison of Virgin and Used Lubricating Oils Properties

Properties	Virgin Lube Oil	Used Lube Oil
Physical Properties		
Specific gravity	0.882	0.910
Dynamic viscosity SUS @ 100 F	-	324.0
Bottom sediment and water volume %	0.0	12.3
Carbon residue, wt%	0.82	3.00
Ash content, wt %	0.94	1.3
Flash point, F	-	348
Pour point, F	- 35	-35
Chemical Properties		
Saponification number	3.94	12.7
Total acid number	2.2	4.4
Total base number	4.7	1.7
Nitrogen, wt %	0.05	0.08
Sulfur, % wt	0.32	0.42
Lead, ppm	0.0	7.535
Calcium, ppm	1.210	4.468
Zinc, ppm	1.664	1.097
Phosphorus, ppm	1.397	931
Magnesium, ppm	675	309
Barium, ppm	37	297
Iron, ppm	3	205
Sodium, ppm	4	118
Potassium, ppm	< 1	31

2.2.1 Preliminary Trial Runs

Preliminary experiments were carried out in order to measure the emissions produced from the combustion of used oil at poor operating conditions till self ignition. 10 g of a sample of used oil were placed in a porcelain crucible sheltered from the air, and heated at high temperature and at fixed rate of heating using the closed cup Conradson Carbon Residue apparatus. The previous experiment was repeated for the same amount of used oil in the same apparatus and adopting the same

rate of heating after removing the cover that isolates the air from the sample as in furnaces. The total combustion period, after cover removal, was fixed at 30 minutes. The pollutant concentration levels were measured at 10 minute intervals and the results are given in Tables 3 and 4 and shown in Figures. 1 and 2. The Used oil sample, heated in absence of air, ignited in a shorter period of time of about 20 minutes as thermal degradation took place producing lighter hydrocarbons and gases. The observations of these preliminary experiments led to the selection of potential environmental pollutants, based on the chemical composition of used lube oil. The expected pollutants to be measured in the ambient air of the laboratory are the aromatic family BTX (Benzene, Toluene & Xylenes), carbon oxides (CO₂&CO), nitrogen and sulphur dioxides. The measuring device used for the experimental work was a portable Ambient Air Analyzer model [Moran Sapphire 205 A series].

Table 2: Pollutants in Produced from the Combustion of Used Oils in Absence of Air.

Compound	Pollutant Concentration (mg/m ³)	
	10	20
CO	2.4	5.4
N ₂ O	0.2	0.4
SO ₂	2.9	5.0
Benzene	2.9	3.5
Toluene	1.9	2.3
Xylenes	5.2	4.8

Table 3: Pollutants Produced from the Combustion of Used Oil under Poor Air Supply Conditions

Compound	Pollutant Concentration (mg/m ³)		
	10	20	30
CO	1.5	2.1	3.0
N ₂ O	0.0	0.2	0.4
SO ₂	4.4	7.9	12.3
Benzene	6.4	14.4	25.2
Toluene	4.1	5.6	7.5
Xylenes	4.3	6.1	10.0

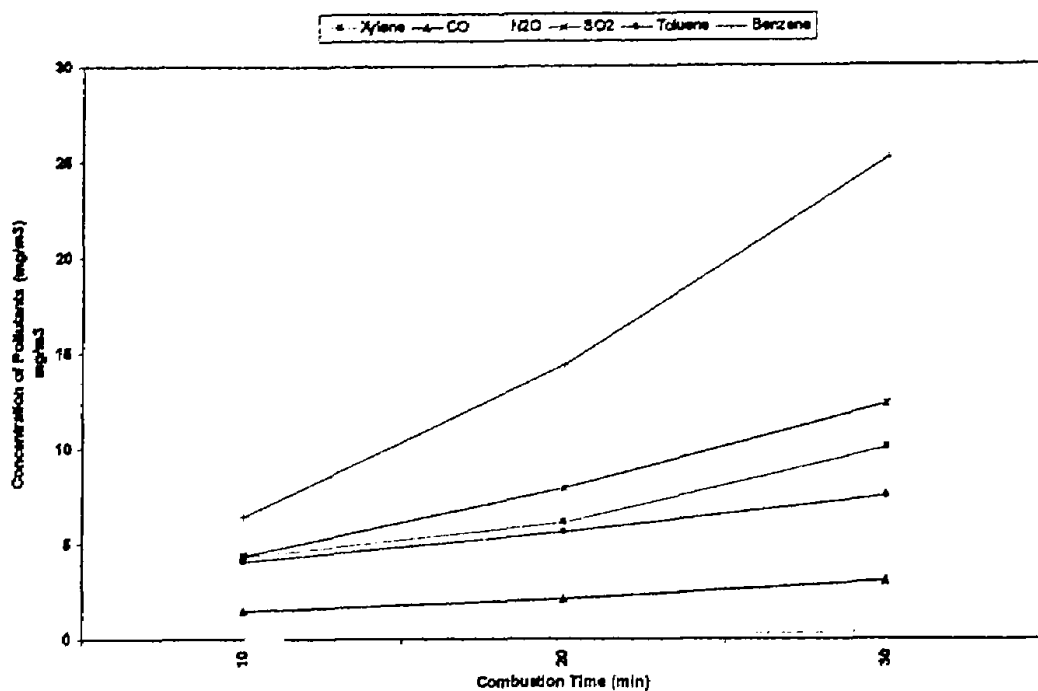


Figure 1: Pollutants Produced from the Combustion of Used Oil under Poor Air Supply Conditions

Table 4: Pollutants Produced from the Combustion Process of Virgin Oil under Poor Air Supply Conditions

Compound \ Combustion Time (min)	Pollutant Concentration (mg/m ³)			
	10	20	25	30
CO	1.5	5.6	5.6	7.7
N ₂ O	0.2	0.5	0.6	0.6
SO ₂	2.4	4.2	8.4	11.6
Benzene	5.6	7.7	14.4	20.4
Toluene	5.6	5.6	8.7	11.7
Xylenes	2.6	6.9	6.9	9.5

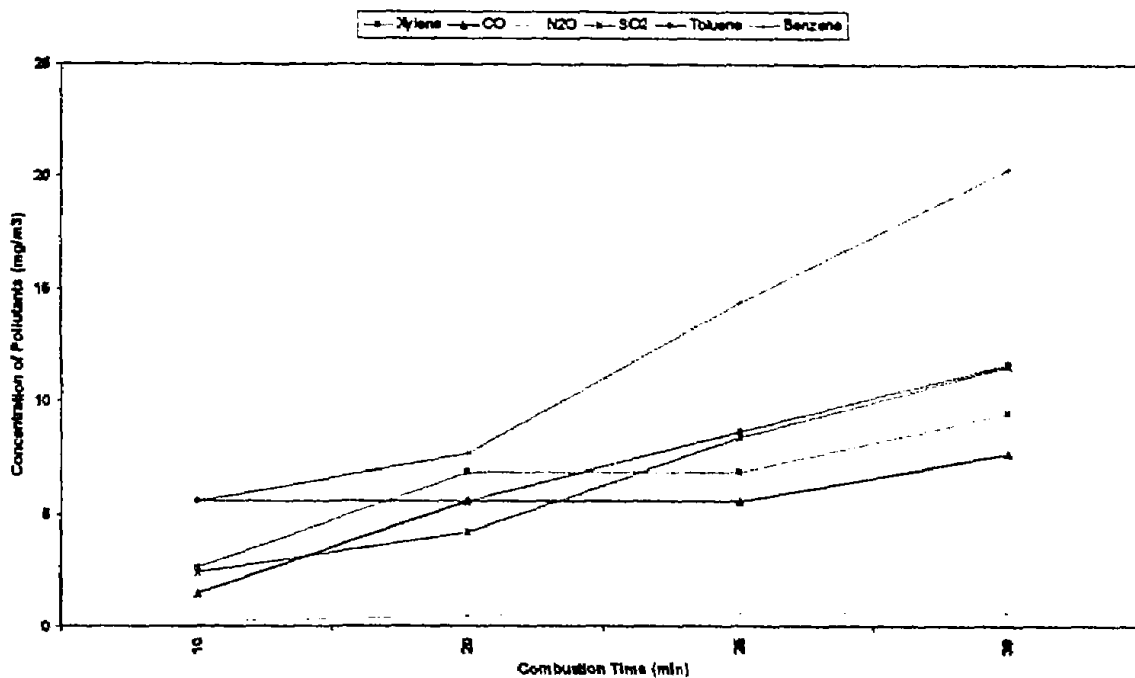


Figure 2: Pollutants Produced from the Combustion Process of Virgin Oil under Poor Air Supply Conditions

2.3 Combustion of Used Lube Oil under Sufficient Air Supply Conditions

The Conradson Carbon Residue apparatus when both the cover and the hood are removed and combustion takes place in presence of a good air supply become similar to many industrial furnaces. A 10 g sample of used lube oil was placed in a crucible then heated at high temperature in the modified Conradson apparatus until complete ignition. The concentration levels of pollutants produced during the fuel combustion period of 90 minutes was measured at different time intervals as given in Table 5 and shown in Figure 3. The concentration of the trace metal present in 0.38 g of the ash that remained in the bottom of the crucible was detected by the ash technique (UOP 391).

Table 5: Pollutants Produced from the combustion of Used Oil under Sufficient Air Supply Conditions

Combustion Time (min) \ Compound	Pollutant Concentration (mg/m ³)					
	5-10	15-20	25-30	35-40	45-50	80-90
CO	16.5	26.1	18.7	23.0	31.7	31.1
CO ₂	352.7 min 665.8max	518.3 683.8	120.6 165.6	99.0	36.0	190.7
N ₂ O	1.3	1.8	2.0	2.7	3.1	4.3
SO ₂	5.0	8.4	8.9	6.5	2.5	4.9
Benzene	73.7	96.3	119.6	148.3	171.3	215.0
Toluene	31.2	23.3	21.4	22.6	27.8	36.9
Xylenes	45.5	55.5	63.7	71.1	83.7	103.4

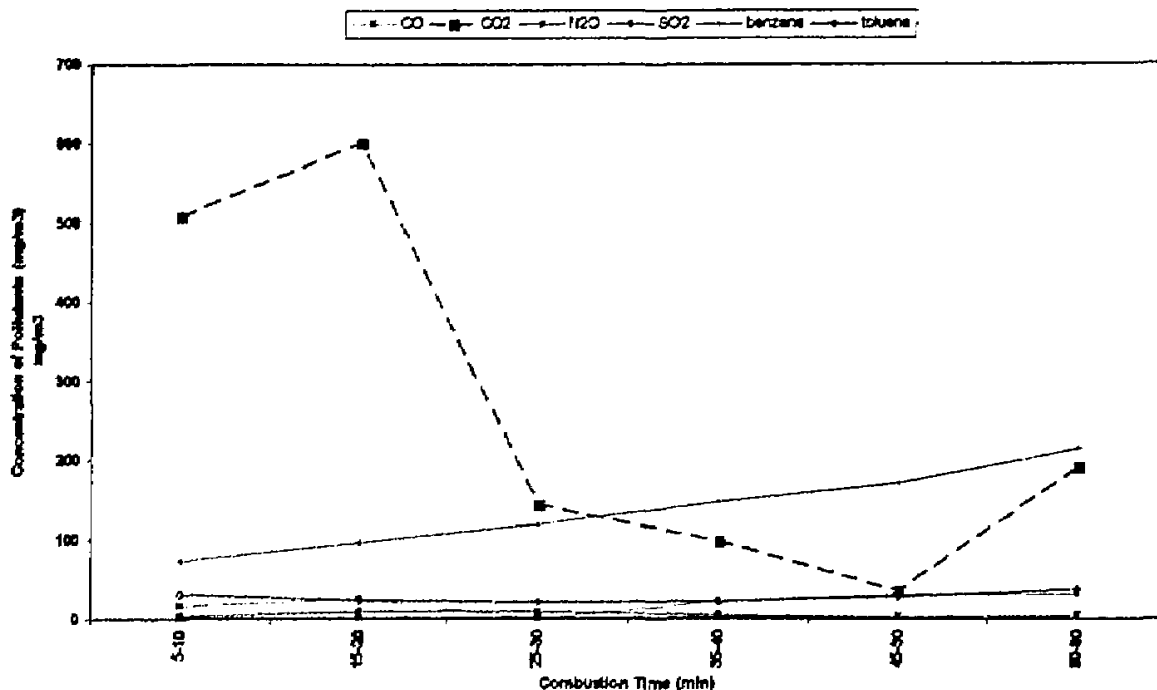


Figure 3: Pollutants Produced from the combustion of Used Oil under Sufficient Air Supply Conditions

2.3.1 Determination of Trace Metals In Petroleum Products Using Atomic Absorption Spectrophotometry

This method was conducted to determine the trace concentrations of iron, nickel, vanadium, copper, sodium and potassium using the Atomic Absorption Spectrophotometry (AAS). The Atomic absorption spectrophotometer used was capable of measuring the 200 to 800 nm wavelength range.

2.3.2 Sample Preparation and Test Procedure (according to UOP 391)

The sample was wet ashed with fuming sulfuric acid and the resulting coke was oxidized in a muffle furnace. The inorganic residue remaining was dissolved in a mixture of acids and diluted to a specific volume. The sample solution is aspirated into the flame of an AAS instrument and quantization is achieved by comparison to matrix-matched standard solutions.

Table 6: Concentrations of Trace Metals in Virgin and Used Lube Oil Samples

Lube Oil Samples	Virgin Lube Oil ppm	Used Lube Oil ppm
Trace metals		
Calcium	12	56
Copper	<0.1	5.8
Iron	1	2.4
Magnesium	<0.1	5.4
Nickel	<0.1	<0.1
Potassium	<0.1	0.6
Sodium	2	5.4
Vanadium	<0.1	1.2
Zinc	1	428

3. RESULTS AND DISCUSSIONS

Tables (2 to 6) give the concentration levels of pollutants emitted during the combustion of used oils. The Pollutants generated are essentially Carbon oxides, SO_x, NO_x, VOCs and trace metals. Each of these pollutants is briefly discussed in the following items including its conformity to the maximum limits of air pollutants in work places. The limits for the short term exposure of 60 minutes during the working period were chosen considering the relatively small weight of the samples used.

The Ambient Air Quality Criteria (AQC) for the protection of human health as well as the local Egyptian and International maximum limits of air pollutants inside the work places are also in Appendixes I and II.

3.1 Sulphur Oxides Emissions

It is obvious from the data given in Tables 3 and 4 and illustrated in Figures.1and 2 that during the preliminary tests the concentration of SO₂ increased continuously during the combustion of both types of oils. The Sulphur oxides (SO_x) emissions reached high values of 11.7 and 12.3 mg/m³ for virgin and used oils respectively after a combustion period of 30 minutes. The emissions generated may be attributed to the oxidation of the sulphur compounds that are already present in both fuels, as illustrated in Table 1. The resulting emissions of SO_x from conventional combustion systems are predominantly in the form of SO₂; they were actually below the maximum limits of air pollutant inside work places of 13 mg/m³ that is specified by the Egyptian Law for Environment for short time workers exposure period. The SO₂ emissions concentrations however reached their highest value of 8.9 mg/m³ after half an hour of combustion of used oils at 'sufficient air' supply then reached its lowest value after 90 minutes of combustion as shown in Fig.3. As a matter of fact the

presence of sufficient air supply may be the cause for such drop or alternatively the SO₂ may have been converted to another form of sulphur compounds.

3.2 Nitrogen Oxides Emissions

The term Nitrogen oxides NO_x formed during the combustion processes can be either due to thermal fixation of atmospheric nitrogen in the combustion air thermal NO_x, or due to the conversion of chemically bound nitrogen in both fuels. From the previous Figures and from Tables 2 to 6, the nitrous oxide concentrations measured during the preliminary and final experimental test runs were all within the acceptable Egyptian limits of 90 mg/m³ that are specified for the mean exposure time of workers as stipulated in the labor law 12/2003.

3.3 Carbon Oxides Emissions

Carbon monoxide (CO) emissions from combustion sources depend on the oxidation efficiency of the fuel [5]. Thus, if a unit is operated improperly, as in the preliminary test trials, the resulting concentrations of CO as well as organic compounds may increase by several orders of magnitude as shown in Figs.1 and 2. The recorded values were below the 60 mg/m³ which are the maximum limit for an exposure period of 30 minutes. The Carbon monoxide concentrations however accumulated at 'sufficient air supply' exceed the 30 mg/m³ which are the maximum International standard concentration limits for one hour period as given in Appendix II.

The insufficient oxygen led to the presence of CO in the exhaust gases of the combustion systems which results principally from incomplete fuel combustion. It is worth mentioning that, the CO₂ emissions were detected only when the combustion conditions changed by the introduction of 'sufficient air' quantity; the average values detected reached a peak of 600 mg/m³ after 20 minutes then dropped to 190.7 mg/m³ at the end of combustion which are within the limits for the short time exposure period.

3.4 Organic Compounds Emissions

As with CO emissions, the rate at which organic compounds are emitted depends, to some extent, on the amount of oxygen used for the combustion. The BTX family (Benzene, Toluene and Xylenes) as given in tables 3 to 5 recorded frightening values for only benzene. Toluene and Xylenes however maintained a continuous increase of the concentration emissions as shown in Figs.1 to 3. As previously mentioned, the resulting concentrations of organic compounds may increase by several orders of magnitude when a device is improperly operated. Typical of such aspect is the concentration of Benzene particles emitted, ranged from 73.7 to 215 mg/m³; and that was far above both the Egyptian and International limits. The presence of aromatic benzene inside the work place may be due the chemical composition of both oils with the added quantities produced from the decomposition of other aromatic compounds.

3.5 Trace Elements Emissions

The presence of metal Particulates in the air results from activities such as fossil fuel combustion, metal processing industries and waste incineration. The analysis of the

ash resulting from the combustion of both virgin and used oils to determine the trace elements was given in Table 6. The results showed higher values of metal concentrations in used oils, this may be attributed to the decomposition of some of the additives used in virgin lube oil manufacture as well as metal particles resulting from engine wear. It is worth mentioning that the resulting heavy metals like vanadium and copper recorded higher values in the ash that result from the combustion of the used oil.

4. CONCLUSIONS

The Measurement of some environment pollutants, produced during the combustion of used lube oils under inappropriate conditions, led to the following conclusions:

1. The BTX family (Benzene, Toluene and Xylenes) maintained a continuous increase in the concentration of the emissions. Toluene and Xylenes emissions are considered within the allowable limits; Nevertheless, the exposure to VOC's is responsible for headaches, loss of concentration, nausea, damage to liver and central nervous system. It is suggested that tougher exposure limits to VOC's must be added to the Egyptian Environmental law No 4 of 1994.
2. The substantially high values of benzene obtained are quite alarming because they exceeded both the Egyptian and International Standards concentration limits needless to mention that benzene is known to cause cancer in humans.
3. Nitrogen Oxides (NO_x) cause a variety of health and environmental impacts because of the various compounds and derivatives in the family of nitrogen oxides. The effect of short-term exposure is still unclear; it is recommended that further studies should be conducted on continued or frequent exposure to concentrations levels that are much higher than those ranges investigated.
4. The Uncontrolled burning of used oils generates heavy metal particles that may be inhaled through the respiratory tract thereby causing health impairment. The smaller particles are the most dangerous of those, because of their ability to reach the lower regions of the respiratory tract. The installation of Electrostatic precipitators is therefore highly recommended in oil-fired power plants to avoid such health problems.

5. REFERENCES

1. Used Oil Re-refining Study 2005 Addressing the Energy Policy Act, Section 1838. The U.S. Department of Energy, The Office of the Oil and Natural Gas.
2. 'Recycling Possibilities and Potential Uses of Used Oils', Regional Activity Centre for Cleaner Production, Spain November, 2000.
- 3 Technical Guidelines on the various uses of used oils and re-refining processing', Basel Convention series/SBC No. 02/05, first published in 1997 and reprinted in November 2002. (www.basel.int)

4. Denis, J., Briant, J., Hipeaux, J.C., 'Lubriant Properties Analysis& Testing'
Editions Technip, Paris, 2000

5. Carbon Blacks Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Humans;
Polynuclear Aromatic Compounds, Part 2. Vol.33, pp 245, 1984. The International Agency for
Research on Cancer (IARC), France.

6. The Emission Factor Documentation, Fuel Oil Combustion, EPA, NC, April 1993.

7. The Egyptian Environmental Affairs Agency (EEAA). Law No 4/ 1994, Egypt.

Appendix I: Maximum Egyptian Standard limits of air pollutants inside work places

Pollutan	Maximum limits according to Law 4/1994				Maximum limits according to Labor Law 12/2003			
	Mean time		Short time		Mean time		Short time	
	ppm	mg/m ³	ppm	mg/m ³	ppm	mg/m ³	ppm	mg/m ³
Sulfur dioxide SO ₂	2	5.2	5	13	2	5.2	5	13
Carbon monoxide	25	29	-	-	25	29	-	-
Carbon dioxide	5000	9000	30000	45000	5000	9000	30000	45000
Nitrogen dioxide	3	5.6	5	9.4	3	5.6	5	9.4
Thoracic particulates, PM ₁₀	-	-	-	-	-	3	-	-
Benzene (petrol)	0.5	1.6	2.5	8	0.5	1.6	2.5	8
Butane	800	1900	-	-	800	1900	-	-
Ethanol amine	3	7.5	6	15	3	7.5	6	15
Gasoline	300	890	500	1480	300	890	500	1480
n-Heptane	400	1640	500	2050	400	1640	500	2050
n-Hexane	50	176	-	-	50	176	-	-
Phenol	5	19	-	-	5	19	-	-
Hydrogen sulfide	10	14	15	21	10	14	15	21
LPG	1000	1800	-	-	1000	1800	-	-
Toluene	50	188	-	-	50	188	-	-
Xylene	100	434	150	651	100	434	150	651
Carbon black	-	3.5	-	-	-	3.5	-	-
Volatile coal Tar products	-	0.2	-	-	-	0.2	-	-
Cyclohexane	300	1030	-	-	300	1030	-	-
Cycloheptane	600	1720	-	-	600	1720	-	-
Nitric oxide	25	31	-	-	25	31	-	-
Nitrous oxide	-	-	-	-	50	90	-	-
Nickel	-	1.5	-	-	-	1.5	-	-
Kerosene	-	-	-	-	-	100	-	-
n-propane	-	-	-	-	2500	-	-	-
Asphalt (bitumen)	-	0.5	-	-	-	0.5	-	-
Arsenic	-	0.01	-	-	-	0.01	-	-
Lead	-	0.05	-	-	-	0.05	-	-
Ammonia	25	17.4	35	24.4	25	17.4	35	24.4
Cobalt	-	0.02	-	-	-	0.02	-	-
Copper	-	0.2	-	-	-	0.2	-	-
Ethyl benzene	100	434	125	543	100	434	125	543
Iron oxide	-	5	-	-	-	5	-	-
Platinum	-	1	-	-	-	1	-	-
Particulates, mg/m ³	10				10			

Appendix II: Egyptian and International Ambient Air Quality Criteria (AQC) For Protection of Human Health

Pollutant	Egyptian Standards (Law 4) Conc. Limit	International Standards Conc. Limit	Averaging Period	Reference to International Guidelines or Standard
Carbon Monoxide	10,000 $\mu\text{g}/\text{m}^3$	10,000 $\mu\text{g}/\text{m}^3$	8 hours	WHO, UK
	30,000 $\mu\text{g}/\text{m}^3$	30,000 $\mu\text{g}/\text{m}^3$	1 hour	WHO
		60,000 $\mu\text{g}/\text{m}^3$	30 minutes	WHO
		100,000 $\mu\text{g}/\text{m}^3$	15 minutes	WHO
Nitrogen Dioxide (NO₂)	400 $\mu\text{g}/\text{m}^3$	200 $\mu\text{g}/\text{m}^3$	1 hour	WHO, EU, UK
		40 $\mu\text{g}/\text{m}^3$ (21 ppb)	1 year	WHO, EU, UK
	150 $\mu\text{g}/\text{m}^3$		24 hours	
Sulfur Dioxide (SO₂)		500 $\mu\text{g}/\text{m}^3$	10 mins	WHO
	350 $\mu\text{g}/\text{m}^3$	350 $\mu\text{g}/\text{m}^3$	1 hour	EU
	150 $\mu\text{g}/\text{m}^3$	125 $\mu\text{g}/\text{m}^3$	24 hours	WHO, EU
	60 $\mu\text{g}/\text{m}^3$	50 $\mu\text{g}/\text{m}^3$	1 year	WHO, EU
Particulate Matter <10μm (PM10)	150 $\mu\text{g}/\text{m}^3$	50 $\mu\text{g}/\text{m}^3$	24 hours	EU, UK
	70 $\mu\text{g}/\text{m}^3$	40 $\mu\text{g}/\text{m}^3$	1 year	EU
Benzene		16.25 $\mu\text{g}/\text{m}^3$ (5 ppb)	1 year	UK
		5 $\mu\text{g}/\text{m}^3$ (1.5 ppb)	1 year	EU
Toluene		260 $\mu\text{g}/\text{m}^3$	1 week	WHO
Xylenes (m/p)		260 $\mu\text{g}/\text{m}^3$	1 week	Based on Toluene