ANALYSIS

17(48), 2020

ISSN 2319–7757 EISSN 2319–7765

Indian Journal of Engineering

Impact of Olive Cake Combustion on Ambient Air Quality Using AERMOD Model

Kamel K. Al-Zboon

Professor, Environmental Engineering Department, Al-Huson University College, Al-Balqa Applied University, Jordan
Email: alzboon @bau.edu.jo, kalzboon@yahoo.com

✉**Correspondence to:**
Kamel Alzboon, Kalzboon@yahoo.com, alzboon@bau.edu.jo, Tel. +962777426557, P.O. Box, 50 Huson, Jordan, 21510.

Article History
Received: 29 April 2020
Accepted: 09 June 2020
Published: June 2020

Citation
Kamel K. Al-Zboon Impact of Olive Cake Combustion on Ambient Air Quality Using AERMOD Model. *Indian Journal of Engineering*, 2020, 17(48), 363-371

ABSTRACT

Energy recovery may represents an attractive option for sustainable disposal of solid olive mill waste. The high heat value, low cost and its availability promoted and encouraged the using of this material for heating. This study aimed to investigate air pollution due to the combustion of olive cake in a conventional combustor. Physical, chemical properties and heat value of the olive cake were determined. The concentration of CO, CO_2, NO, SO_x, H_2S, Cl_2 were measured during the combustion process. The impact of combustion on ambient air quality was determined using AERMOD dispersion model. The obtained results indicated that the combustion process has high impacts on indoor air quality where CO, NO, and SO_2 concentration exceeded the relevant standards. The concentration from the stack was very high and reached 20002, 18, 156, 0.5, 7, 0.9, ppm, for CO_2, CO, NOx, Cl_2, SO_2, and H_2S respectively. The result of the model revealed that the max hourly concentrations of CO_2, CO, SO_2, NOx, Cl_2, and H_2S from one source at height of 4m above ground level, were: 1050, 0.6, 0.53, 5.61, 0.042, and 0.0036 µg/m^3 respectively. The max hourly concentration occurs at a point of 200m downstream of the source (0, +200). Increase the stack height from 4 to 7m, resulted in a significant reduction in the maximum ground level concentration up to 64%. In comparison with single source, 10 and 200 sources resulted in increases in the concentration of pollutants up to more than 3 and 13 times respectively. It is recommended to enhance public awareness about the impact of olive cake combustion on human health, and to follow a safely procedure for controlling and management of the combustion process.

Keywords: Air pollution, Energy, Biosolids, olive cake, AERMOD, Air quality.

1. INTRODUCTION

Since the olive products are known as one of the healthiest food, they are considered as a significant source of nutrition and medicinal products. Also, olive trees represent a significant source of income especially for the people living in the rural areas. In Jordan, there are more than 17 million of the olive trees covers 36% of the total cultivated area with annual growth rate of 1 million tree [Al-Hamamre, 2015]. Milling of the ripe olive fruits generates high quantity of solid waste as by products called pomace or olive cake (OC). The amount of the generated byproducts depends on the type of fruits and the extraction technology. It was estimated that milling of one kg of olive fruit by the three phase centrifugal system (3PCS) yields about 0.2kg, 0.50kg, and 0.8 L of olive oil, olive cake and olive mill wastewater (OMWW) respectively [Al-zboon, 2017].

Olive cake as a slurry consists of pulp residue, organic matter and oil with chemical constituents of cellulose, lignin, protein, and polyphenols [Brlek et al., 2012]. Usually, olive cake is stored in open areas to achieve slowly drying under the sunlight, then it is disposed-off or reused for different purposes. Long drying process results in accumulation of toxic compound in the soil and contamination of surface water through runoff, and ground water through infiltration process.

Although direct disposal is not a legally accepted, many countries dispose the slurry waste to the river and lakes results in negative impacts to the receiving water such as eutrophication phenomenon, subsequently algae growth, disturbance in the aquatic life, depletion of water oxygen, intoxicated of fish and offensive odor. OMWW contains strong concentration of pollutants such as BOD (up to 100g/l), COD (up to 1220g/l), SS (up to 9g/l), with toxic level of phenolic compounds up to 24g/l [Stamatakis, 2010, Paraskeva and Diamadopoulos, 2006].

Several physical, chemical, biological and thermal process have been used to reduce the toxicity of OMWW on the environment and human health. These methods include: dilution, evaporation, centrifugation, sedimentation, coagulation, oxidation, membrane filtration, adsorption, aerobic/anaerobic digestion and composting. Although physical approach has lower cost than others, it is unable to provide an acceptable limit of organics and to reduce the toxicity of the final products. The high cost of chemicals in addition to their toxicity make the chemical approach deeply undesirable. Similarly, the biological method has many limitations such as: slow decomposition, sensitivity of the system for temperature and pH, and the quality of the final products [Paraskeva and Diamadopoulos, 2006]. Conducted researches indicated that all treatment methods are infeasible due to the high investment and operational cost, short duration of the production period, and small size of the olive mills [EcoMENA, 2017].

Recovery of OC for energy production is an attractive option to control its impact on the environment and to reduce the energy bill. The high heat value of OC, and the high price of the conventional fuel, promoted people in Jordan and MENA region to utilize it as a local low cost material for heating energy especially for low income people in the rural areas [Al-zboon, 2017]. Combustion of OC in the conventional uncontrolled combustor causes series deterioration to the indoor air quality and could cause many related diseases especially for the respiratory system, irritation, and affects pulmonary function [Al-zboon, 2017, Al Smadi et al., 2009]. WHO reported that the concentration of some indoor air pollutants can reach 100 times more than the acceptable limit due to the combustion of solid fuel. Combustion of solid fuel is responsible for over 3.8 million death annually, of which: 27%, 18%, 27%, 20% and 8% are due to pneumonia, stroke, heart disease, pulmonary disease and lung cancer respectively [WHO, 2018].

Gaseous and particle plume from the stack cause high impact on the ambient air quality especially in the rural area where most of people using OC for heating. Many air dispersion models have been successfully used to predict the dispersion of air pollutants in the atmosphere such as: BLP, CALINE3, CTDMPLUS, CALPUFF and AERMOD models [EPA, 2017]. AERMOD would become EPA's preferred regulatory model for both simple and complex terrain due its capability in characterizing irregularly shaped area sources, applicable for different source types, different plume types, plume deposition and dealing with building effect [EPA, 2004,].

The aim of this work is to determine the impact of OC combustion on ambient air quality using AERMOD model. Also, the impact of stack height and number of combustion sources are investigated. To the best of the author's knowledge this is the first work concerning impact of OC combustion on ambient air using AERMOD model.

2. METHODOLOGY

2.1. Materials and measurements

The sample of olive cake was collected from a local 3PCs olive mill. Physical properties of the sample (water content, sieve analyses, lost on ignition, and ash content), chemical characteristics (elemental ratio and XRF) and heat value were determined in the labs of natural resources authority of Jordan (NRA).

Circular conventional combustors with manual and mechanical feeding were used to determine the impact of combustion on air quality. Each combustor was connected to a stack with diameter of 10cm, and raise one meter above the house's roof. The total height of the stack was 4m above the ground level.

Emissions from the stack were measured by Vario plus industrial gas analyzer using combined infrared (NDIR) technology and electro-chemical sensors for maximum versatility. It complies with USEPA methods CTM-030 and CTM-034 and international ASTM D6522. It has measurements ranges of: 0- 4,000 ppm, 0-30%, 0- 1000 ppm, 0 -2,000 ppm and 0-200 ppm, for CO, CO_2, NOx, SO2, and H_2S respectively. In addition, stack parameters include location, altitude, stack height, stack gas temperature, stack gas exit velocity and stack inside diameter were determined as input to AERMOD model. Metrological data for 20 years was used to determine the worst case scenario for pollutant dispersion. All used instruments were calibrated according to their manual guidelines. Indoor gaseous emissions were measured by a portable gas analyzer (Quest technologies).

2.2. Air pollution Modeling

Breeze AERMOD software was used in this study which is an updated version of the Industrial Source Complex Short Term (ISCST) model. This model can be used to estimate pollutant dispersion from industrial source points, flares, lines, areas, or volumes. AERMOD generates daily, monthly and annually concentrations of pollutants in the ambient air and unlimited number of point sources, source groups, receptors, and short- and long-term averages can be modeled. AERMOD modeling system consists of the dispersion model (AERMOD) and two pre-processors (AERMET and AERMAP). AERMET is a meteorological preprocessor which provides hourly surface data and upper air data while AERMAP is a terrain preprocessor that characterizes the terrain features and generates receptor grids for the dispersion model. The model was run for three sources' scenarios:

1. Scenario 1: where it was suggested there is only one single source.
2. Scenario 2: it was assumed there are ten identical sources, this case represents a small community in a rural area, all of them using olive cake as a source of heating where there is no other sources of conventional fuel in these areas.
3. Scenario 3: it was assumed there are two hundred identical source, which represent a case of small village with population of 4000 persons and 800 home, 25% of them (200 homes) are using olive cake as a source of heating and the remaining are using liquid fuel.

3. RESULTS AND DISCUSSION

3.1. Biomass characteristics

The detailed biomass specifications of the tested sample are shown in table 1. It is clear that the organic matter represents the higher content (C=50.1%), which explains the high volatility of the sample (82.1%). Also it contains about 17.9% of fixed solids indicated significant content of minerals and inorganic compounds. High heat value of OC (19.54MJ/kg) buttressed the feasibility of using it as a source of energy. The presence of nitrogen and sulfur may cause high NO_2, SO_2, and H_2S emissions during the combustion process. Detailed result of the biomass characteristics can be found in a previous work [Al-zboon, 2017].

Table 1: Specifications of the raw OC materials

parameter	detail	unit	value
bulk density		kg/m3	645
average particle size		mm	5.66
Heat value		MJ/Kg	19.54
water content		%	11.6
fixed solid		%	17.9
volatile solid		%	82.1
XRF test	CaO	%	36.9
	SiO2	%	31.1

	Al2O3	%	6.6
Elemental analyses	C	%	50.1
	O2	%	41.2
	H2	%	6.3
	N2		2.3
	S	%	0.1

The average concentrations of gases from the stack were: 20070, 18, 156, 2.8, 7, and 0.9, ppm for CO_2, CO, NOx, Cl_2, SO_2, and H_2S respectively. It was found that the concentration of pollutants varies significantly during the sampling period. At the begging, lower temperature in the combustor resulted in incomplete combustion and high concentration of CO up to 45ppm, and lower concentration of CO_2 (13100ppm), NO_X (72ppm), SO_2(2.3), and Cl_2(0). As the combustion process progressed, combustion temperature increased resulted in a complete combustion within about 15min and significant reduction in CO(4.4ppm), H_2S (0.3ppm) with higher concentration of CO_2 (31105ppm), NOx(237ppm) and SO_2(9.4).

3.2. Outdoor-indoor air quality relationship

The average concentration of CO_2, CO, SO_2, NOx, Cl_2 and H_2S in the room where the combustor was located was 3019, 5.3, 0.3, 42, 0.5 and 0.2 ppm respectively, while O2 concentration decreased from 20.9 (initial) to 19.7% during combustion process. A comparison between indoor air quality and stack emissions, indicated that indoor concentrations of gases reached: 15, 29.2, 26.8, 18, 4.8, and 23.3% of the concentration from the stack for CO2, CO, NOx, Cl2, SO2, and H2S respectively. Concentration of indoor gases depends on the effectiveness of the combustion process, ventilation, and emissions during biomass feeding, and the leakage from the stack pipe and the combustor. In contrast, emissions from the stack is affected by the degree of combustion (complete or incomplete), ambient conditions (temperature and humidity), stack geometry, physical and chemical properties of the gases, and the percentage of indoor emissions leakage.

Indoor CO concentration exceeded USA national air quality standards (NAAQS) for 8 hours exposure time (9 ppm) while all measurements of NOx and SO_2 exceeded 1 hours NAAQS of 100ppb and 75 ppb respectively [EPA, 1999]. There is no NAAQS reference standard for H2S, CL_2, and CO_2. Regarding H_2S concentration, 58% of the samples have level exceeded the current California Ambient Air Quality Standard (0.03 ppm) [Collins and David, 2000]. The high concentrations of gases raise the importance and need for public awareness programs to avoid the impact of combustion process on human health. To achieve effective combustion process and better control of indoor emissions, it was recommended to provide the conventional combustor with automatic feeding system and an auxiliary air supplier [Al-zboon, 2017].

3.3. Impact on ambient air quality

The hourly, daily, weekly and annual concentrations of all gases were calculated by using AERMOD model and the max. 40 readings during the worst metrological conditions were determined. For one source with 4m altitude, the max hourly concentrations of CO_2, CO, SO_2, NOx, Cl_2, and H_2S were : 1050, 0.6, 0.53, 5.61, 0.042, and 0.0036 µg/m^3 respectively. The max hourly concentration occurs at a point of 200m downstream of the source (0, +200) as shown in figure 1. The concentrations decreased to less than 50% at a distance less than 200m from the point of max concentration (0+400). Also, the max daily concentrations decreased significantly at a point of 0+ 400 by 94.4%, 83.33%, 94.52%, 94.65, 95.23%, and 93.6 % for CO_2, CO, SO_2, NOx, Cl_2, and H_2S respectively. Similarly, the yearly max concentration decreased with ratios ranged from 90% for CO to 97.6% for the other parameters.

3.4. Impact of stack height

Increase of stack height is the simple and effective method to reduce ground level consternation of gaseous and particulate emissions. In this study, the concentration of pollutants were calculated for two proposed stack height: firstly for a stack height of 4m (single story house+1m above the roof) and secondly for a stack height of 7m (double story house+1m above the roof).

The max hourly concentrations of single source decreased significantly with range of 63.2% - 64.28% due to the increase of stack height from 4 to 7m (Fig. 2). The impact of stack height became less in case of 10 and 200 sources with average reduction ranges of 57.5% and 48% respectively. This result revealed the importance of raising the stack height.

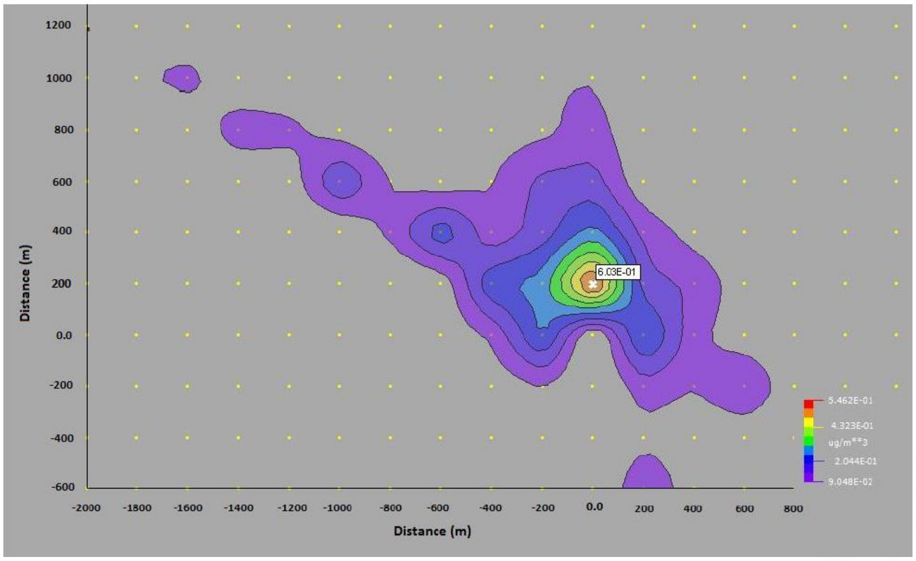

Figure 1 a: Impact of single source on hourly CO concentration

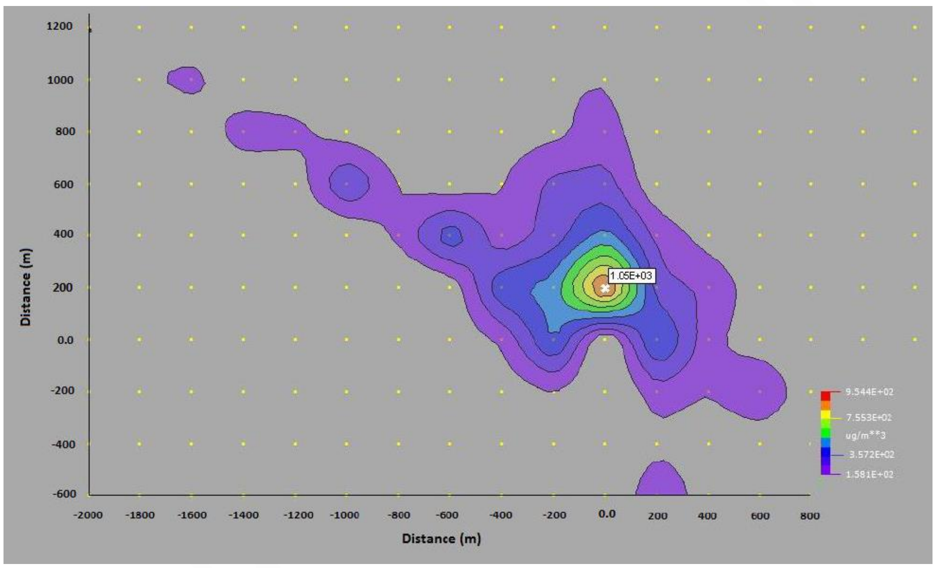

Figure 1b: Impact of single source on hourly CO_2 concentration

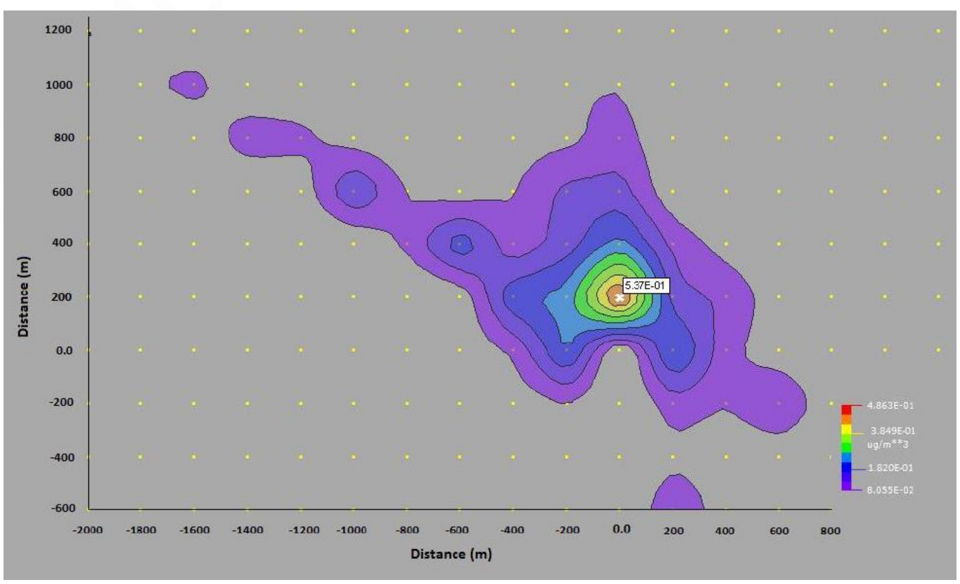

Figure 1c: Impact of single source on hourly SO_2 concentration

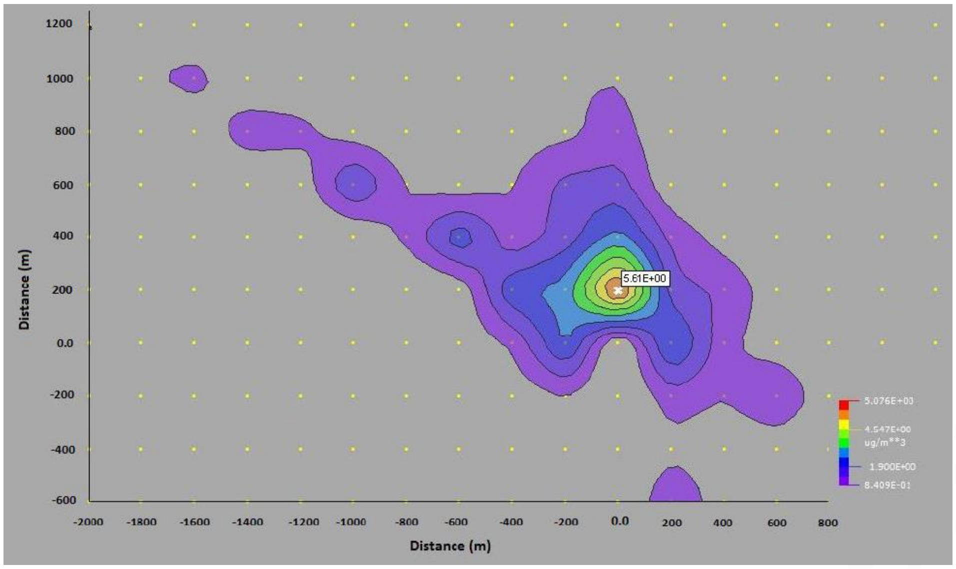

Figure 1d: Impact of single source on hourly NO_x concentration

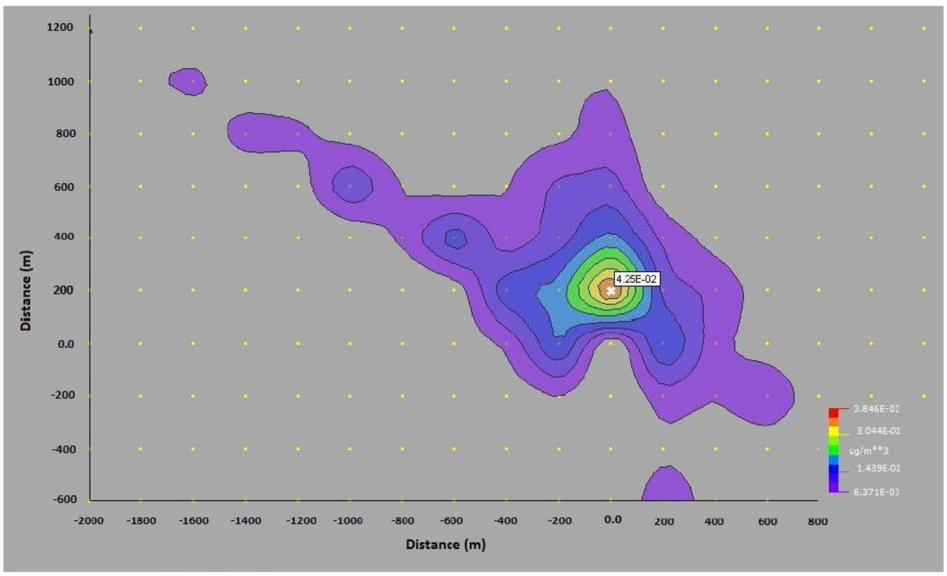

Figure 1e: Impact of single source on hourly Cl_2 concentration

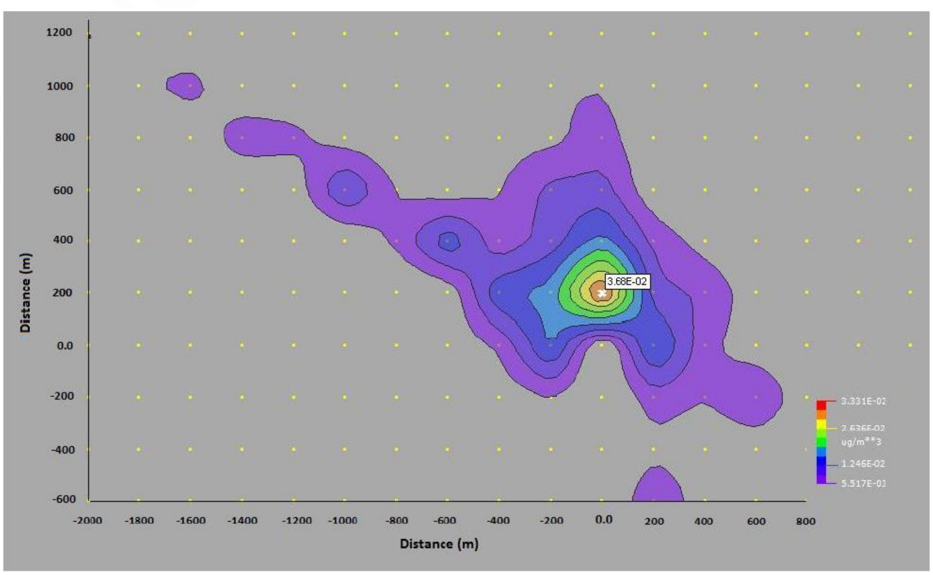

Figure 1f: Impact of single source on hourly H_2S concentration

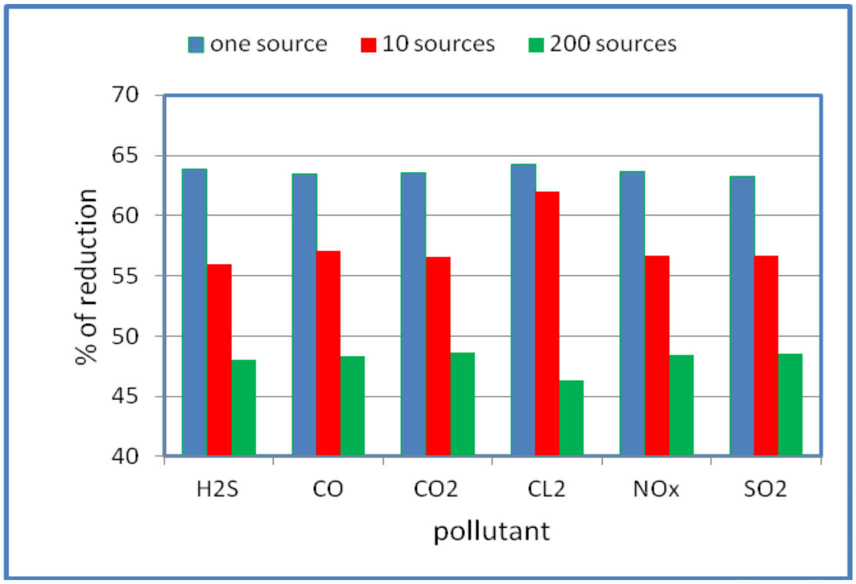

Figure 2: Rate of reduction when the stack height increased from 4 to 7m.

3.5. Impact the number of sources

It is certainly that many sources of pollution generate higher concentration of pollutants than one, but the total amount of pollution is not equal to the sum of them. Nonlinear relationship between the number of sources and the concentration of gases was determined as shown in figure 3. In comparison with single source with stack height of 4m; the max hourly concentration increased with ratios of: 277.4%- 364.3% and 1331.5%- 1357.1% for 10 and 200 sources respectively. For a stack height of 7m, the increases ranged from 421.5 to 425.6% for ten sources and from 1835.5-1908.7% for 200 sources. The percent of increase depends on the type and concentration of pollutant.

Also, it was found that the affected area increased significantly as the number of sources increase as shown in figure 4. For example the concentration of CO_2 of single sources spread over a distance of 1400m (-400, +1000), while it spread over a distance of 3000m (-1400, +1600) in case of 10 sources and reached more than 4000m (-2000, +2000) for 200 sources.

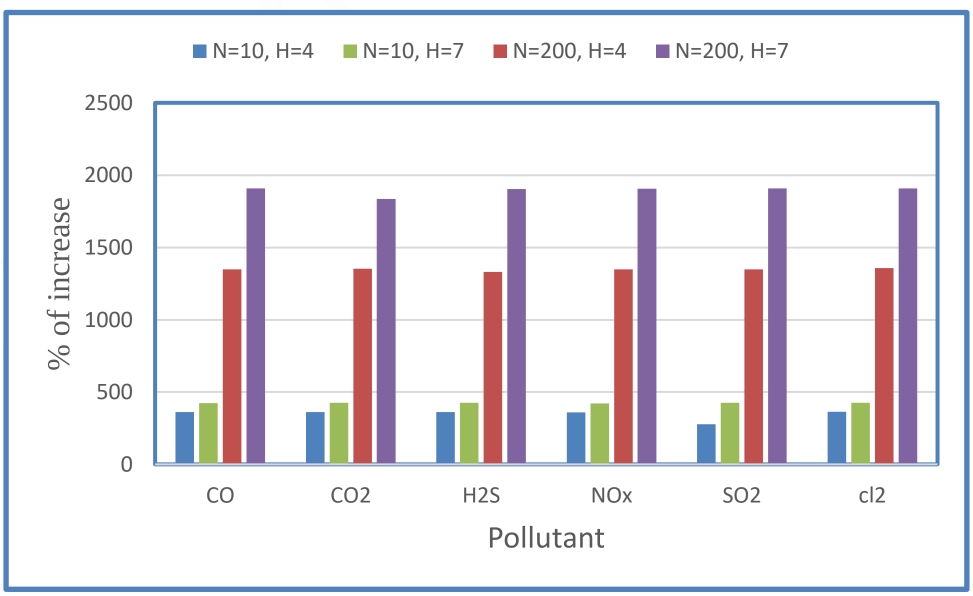

Figure 3: percent of increase in hourly max. Pollutants' concentration for different number of sources (N: number of sources, H: height of stack).

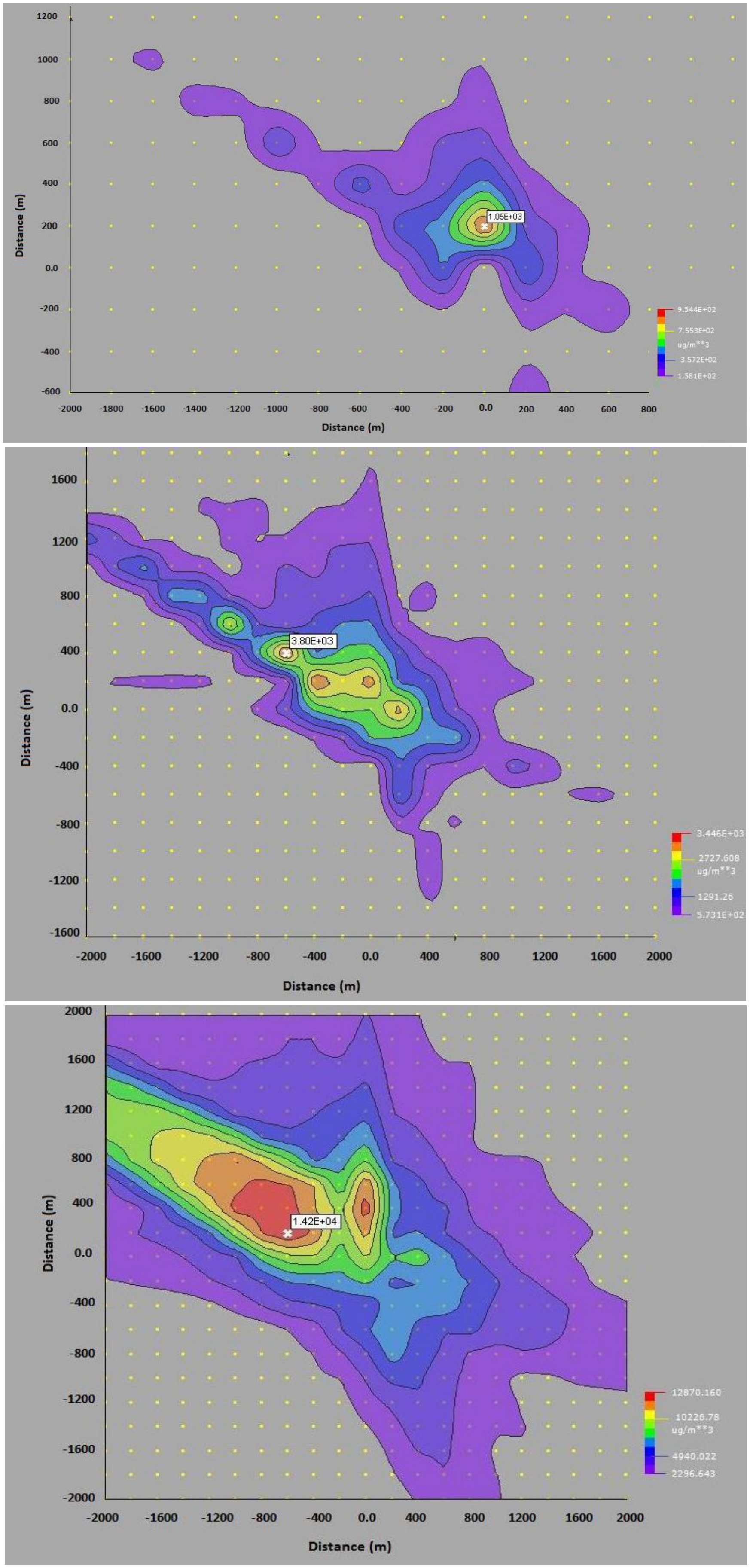

Figure 4: Effect of number of sources on the affected area for hourly CO2 concentration with stack height of 4m (upper: single source, middle: ten sources, down: 200 sources)

4. CONCLUSION

In many countries in MENA region, olive cake is the main source of household winter heating especially in the rural areas. Usually they are using uncontrolled combustors for this purpose which emit high concentration of emissions for indoor and ambient air.

This paper aimed to investigate the impact of olive cake combustion on ambient air quality. AERMOD model was used to predict the dispersion of pollutant in the surrounding area. It was found that the max concentration occurred at distance of 200m downstream of the source and deceased significantly with distance. Impact of OC combustion on the surrounding area can be decreased by increasing the stack height. The relationship between number of sources and the concentration of pollutants is nonlinear. To reduce the gaseous emissions inside the homes, it is necessary to improve the combustion conditions. Also, the conventional combustor should be modified with automatic feeding system, auxiliary air and better distribution of biomass in the bed to enhance combustion process.

Acknowledgment

We would like to place on record our sincere appreciation for the funding provided by Deanship of scientific research, Al-Balqa Applied University. Also our thanks to engineer: Walaa Matalqa and eng. Samer Dharagmah for their help in sampling and lab analyses.

Funding: Funding provided by Deanship of scientific research, Al-Balqa Applied University.

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

REFERENCE

1. Al Smadi Bashar M., Kamel K. Al-Zboon, and Khaldoun M. Shatnawi , 2009, Assessment of Air Pollutants Emissions from a Cement Plant: A Case Study in Jordan, Jordan Journal of Civil Engineering, 3, 3, 265-278.
2. Al-Hamamre Z., 2015, Potential of Utilizing Olive Cake Oil for Biodiesel Manufacturing, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 37, 23, 2609-2615
3. Al-Zboon Kamel K., 2017, Indoor air pollution due to household use of olive cake as a source of energy, International Journal of Environment and Waste Management, 19, 3, 248-267.
4. Brlek Tea, Neven Voća, Tajana Krička, Jovanka Lević, Đuro Vukmirović, Radmilo Čolović, 2012, Quality of Pelleted Olive Cake for Energy Generation, Agriculturae Conspectus Scientificus, 77, 1, 31-35.
5. Collins James, David Lewis, 2000, Hydrogen sulfide: evaluation of current California air quality standards with respect to protection of children, available: https://pdfs.semanticscholar.org/2e0a/8b21a6dc1f8365f6a0553f90a67337130d46.pdf?_ga=2.122057346.88923284.1590144732-890472752.1581541481, accessed on: 22/5/2020.
6. EcoMENA, 2017, available: https://www.ecomena.org/olive-oil-wastes/, accessed on: 22/5/2010, accessed on: 22/5/2020.
7. EPA, 1999, National Ambient Air Quality Standards (NAAQS), available: https://www3.epa.gov/ttn/naaqs/criteria.html, accessed on: 22/5/2020.
8. EPA, 2004, Aermod: description of model formulation, available: https://www3.epa.gov/scram001/7thconf/aermod/aermod_mfd.pdf, accessed on: 22/5/2020.
9. EPA, 2017, Air Quality Dispersion Modeling - Alternative Models
10. Available: https://www.epa.gov/scram/air-quality-dispersion-modeling-alternative-models, accessed on: 22/5/2020
11. Paraskeva Panagiota and Diamadopoulos Evan, 2006, Technologies for Olive Mill Wastewater (OMW) Treatment: A Review. Journal of Chemical Technology and Biotechnology, 81:1475–1485
12. Stamatakis George, 2010, Energy and geo-environmental applications for Olive Mill Wastes A review, Hellenic Journal of Geosciences, vol. 45, 269-282
13. WHO, 2018, Household air pollution and health, https://www.who.int/news-room/fact-sheets/detail/household-air-pollution-and-health, accessed on 19/5/2020.