THE ASSUMPTION EFFECT OF USING BIODIESEL AS AN AIRCRAFT FUEL ON AIR QUALITY IN SOME EGYPTIAN AIRPORTS

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ABSTRACT

Total Landing and Takeoff Cycle (LTO) emissions from aircrafts at SSH for year 2013 were estimated as 442.047 t /y for HC, 37660.742 t /y for CO, 69340.331 t /y for NO_X, and 9.674 t /y for PM. The predicted total LTO emissions from aircrafts at Sharm El-Sheikh International airport(SSH) for the year 2050 were calculated as 4928.8241 t /y for HC, 419917.27 t /y for CO, 773144.69 t /y for NO_X, and 107.8651 t /y for PM. The aircrafts at SSH are the major sources of NOx emissions (99.95%), Boeing 777 (large aircraft) has the biggest portions in NOx total emissions, in which contributing 6.836t /LTO for NO_X. Flight numbers are expected to reach 483822 by 2050. The emissions concentrations at SSH are below the air quality limit values given in Law No. (4/1994) of Egypt and its amendment. The assumption of using biodiesel (Soy biodiesel B_{20}) for aircraft engines at SSH for year 2013 leads to the substantial reduction in PM, HC and CO emissions 0.987 t/ year, 93.272 t/ year, and 4142.682 t/ year, respectively accompanying with the increase in NOx emission 1386.806 t/ year. Moreover, the prediction of reduction in emissions for year 2050 are estimated as 11.00505 t/ year for PM, 1039.9828 t/ year for HC, and 46190.9043 t/ year for CO, accompanying with the increase in NOx emission 15462.8869 t/ year. There are very little effect on emissions reduction when using biodiesel (Soy biodiesel B_{20}) for APU & aircraft handling comparing with aircraft main engines. The measurement of average concentration of the regulated air emissions (HC, NOx, CO) at distance away 8 km from Runway were estimated for using

Diesel (Jet A1) as 0.8281 µg/m^3 for HC, and 4.617 µg/m^3 for CO, and 343.7607 µg/m^3 for NOx, while for The assumption of using biodiesel (Soy biodiesel B_{20}) for aircraft engines as 0.6534 µg/m^3 for HC, and 4.1091 µg/m^3 for CO, and 350.6359 µg/m^3 for NOx.

Keywords: Biodiesel; Aircraft; Air quality: air pollution; Airport

INTRODUCTION

Interest in aircraft and airport air pollutant emissions has been on the rise ever since the substantial increase in commercial turbojet traffic in the 1970s (ICAO, 2011).

A flight is usually divided into two main parts: LTO cycle and cruise. The International Civil Aviation Organization (ICAO) defined LTO in 1993 as all aircraft operations that occur below 3000 feet, including taxi out, takeoff, a portion of climb out, a portion of approach, and taxi in (Rypdal, 2008).

Jet fuels are very similar to kerosene or No. 2 distillate oil, and can be reasonably represented by N-decane, $C_{10}H_{22}$ (Sweriduk, 2001).In the literature, the three main pollutants evaluated are carbon monoxide (CO), oxides of nitrogen (NOx), and unburned hydrocarbons (UHC). In 1981, ICAO first adopted standards relating to the control of smoke and gaseous emissions (UHC, CO, and NOx) from turbojet and turbofan engines intended for subsonic and supersonic propulsion (Herndon *et al.*, 2006).

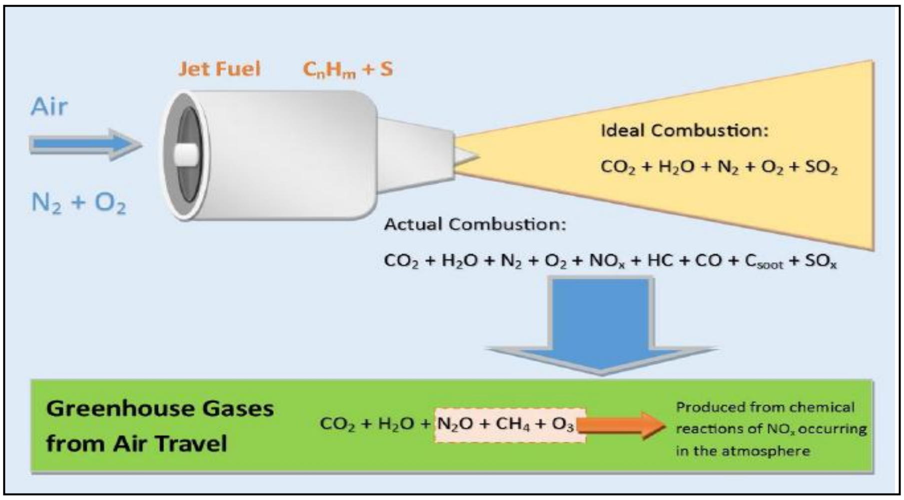


Figure (1): This schematic shows the climatic impacts of aviation by-products (Wuebbles *et al.*, 2007)

Biodiesel refers to a vegetable oil- or animal fat-based diesel fuel consisting of long-chain alkyl (methyl, propyl or ethyl) esters. Biodiesel is typically made by chemically reacting lipids (e.g., vegetable oil, animal fat (tallow) with an alcohol producing fatty acid esters (U.S. Census Bureau, 2012 and Bioenergy association, 2012).

Blends of 20% biodiesel and lower can be used in diesel equipment with no, or only minor modifications (National Renewable Energy Laboratory, 2011), although certain manufacturers do not extend warranty coverage if equipment is damaged by these blends. The B6 to B20 blends are covered by the ASTM D7467 specification (ASTM, 2011).

In an EPA engine test-fueled with20% soy-biodiesel and 80% petroleum diesel, NOx increased2%, PM, HC, and CO decreased 10.1%, 21.1%, and 11.0%, respectively (United States Environmental Protection Agency, 2002).

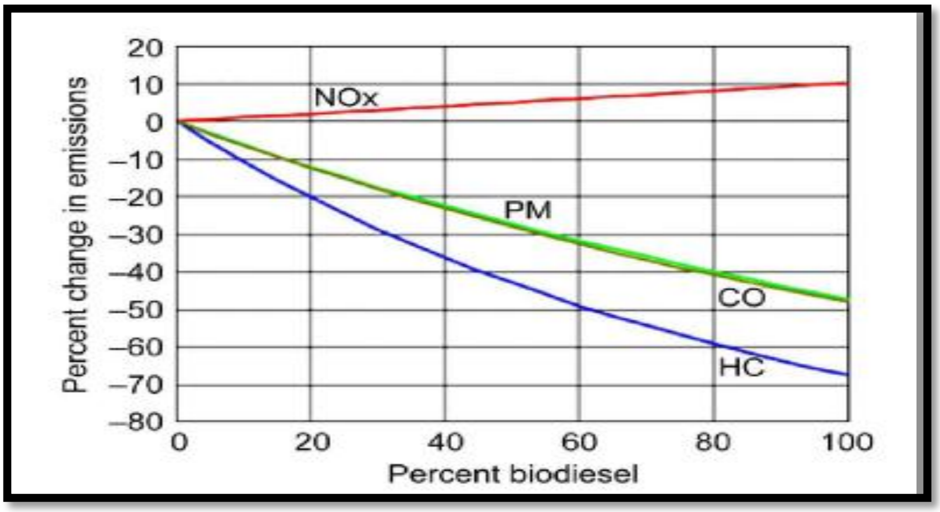


Figure (2): Diesel engine emissions with diesel-biodiesel fueling blends (from United Sates Environmental Protection Agency, 2002)

Krishna performed research on the performance of a Capstone C30 micro-turbine on biodiesel blends. Soy-based biodiesel was blended with heating oil for stationary gas turbine engine in blends of 20, 50 and 100% by volume. The research found that lower SO_2 and CO emissions, while NO_x emitted was approximately the same for the baseline fuel and the biodiesel blends. There is no significant change in thermal efficiency.

The purpose of this study is to compare, assumption of using Soy biodiesel (B_{20}) as an Aircraft fuel on Sharm El-Sheikh International airport's air quality vs. actual fuel used (Diesel or Jet A1) for year 2013 where the air traffic density in 2013 is more than 2014 & 2015.

MATERIALS AND METHODS

1. Methodology for the estimation of aircraft engine/ APU emissions

1.1 Emission calculation for aircraft main engines advanced approach

The advanced approach reflects an increased level of refinement regarding aircraft types, engine types, emission index (EI) calculations and time-in-mode (TIM). This approach requires specific airport-related information or qualified assumptions which are still publicly available but may be more difficult to obtain. It reflects local conditions in incorporating some sort of performance calculation of the aircraft. These improvements result in a more accurate reflection of main engine emissions over the simple approach, yet the total emissions are still considered conservative (ICAO, 2011).

Generally applies the operational and emissions parameters in a two-step process, as follows:

a) **Step one:** Calculate emissions from a single aircraft/engine combination by summing the emissions from all the operating modes which constitute LTO cycle, the emissions from a single mode could be expressed as:

1) Modal emissions for an aircraft/engine combination = TIM (estimated by Path planner software program for taxi in/out) x fuel used (at the appropriate power) x EI (at the appropriate power) x number of engines.
2) The emissions for the single LTO operational flight cycle are then a summation of the individual parts of the cycle.

b) **Step two.** Calculate total emissions by summing over the entire range of aircraft/engine combinations and number of LTO cycles for the period required.

1.1.1 Time-in-mode calculation

The takeoff time in mode (TIM) is based on the ICAO default values. The taxi (TIM) is estimated by Path planner software program, which is the total time spent in taxiing and idling during a complete LTO cycle, to reflect site-specific data, the approach and climb out TIM based on the following equations **(ICAO, 2011).**

Calculation of Time-In-Mode (min.) for approach:

$$T_{New} = T_{Old} \times \frac{H}{3000}$$

Calculation of Time-In-Mode (min.) for Climb:

$$T_{New} = T_{Old} \times \frac{H}{2500}$$

Where:

T_{New}**:** Adjusted time (min.)

T_{Old}**:** ICAO default time (min.)

H: Average mixing height

1.2 Auxiliary power –unit emissions calculation methodology

An auxiliary power unit (APU) is a small gas-turbine engine coupled to an electrical generator and is used to provide electrical and pneumatic power to aircraft systems when required. It is normally mounted in the tail cone of the aircraft, behind the rear pressure bulkhead, and runs on kerosene fed from the main fuel tanks. Not all aircraft are fitted with an APU (ICAO, 2011).

APUs are not certificated for emissions, Emissions can be calculated at three suggested APU operating load conditions of:

a) start-up (no load);

b) normal running (maximum environmental control system (ECS)); and

c) high load (main engine start), to represent the operating cycle of these engines.

For each of these loads, the emissions can be calculated from the following formulae:

NOx = NOx rate x time at load;

HC = HC rate x time at load; and

CO = CO rate x time at load.

Where data for actual time at load cannot be identified accurately.

2. Flights Forecasting using series Linear regression Model

Regression means dependence and involves estimating the value of a dependent variable Y, from an independent variable X. In simple regression, only one independent variable is used, whereas multiple regression two or more independent variables are involved. The simple regression takes the following form **(Pannerselvam, 2012):**

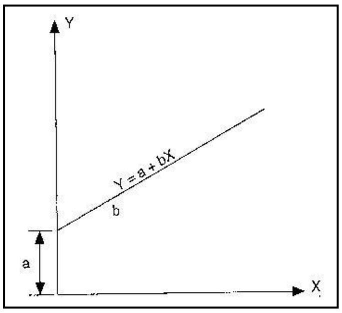
Y=a+bx

Where:

y: Number of Flights

a&b: Intercept & Slope (trend)

x: Time serial



3. Methodology for calculation of pollutants concentration at ground level (y=0, z=0, h=0) (Abdelrahman, 2008):

Gaussian plume model is used for pollutants dispersion modeling in order to determine the concentration of NOx, HC, CO, and PM at point away 8 km from Runway at SSH, after departure of an aircrafts.

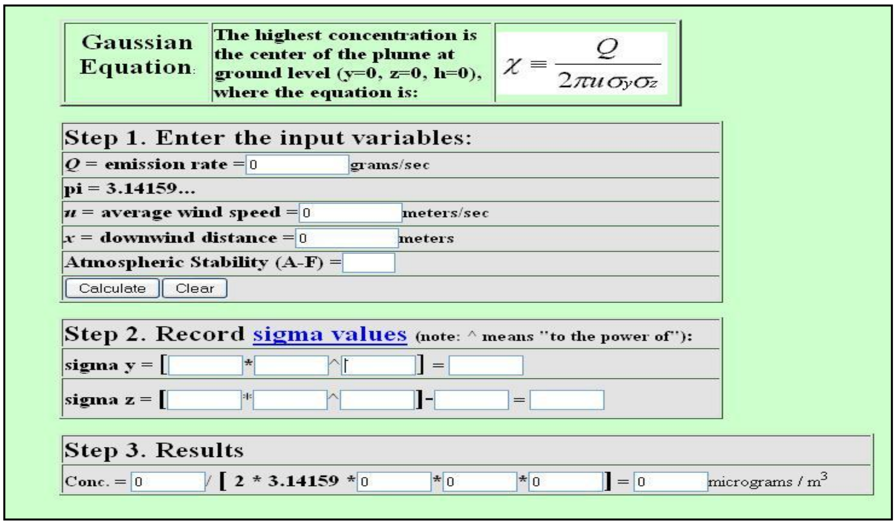


Figure (3): Gaussian plume model calculator

4. Methodology for calculation of the Ground level concentration for NO_x, HC, CO, and PM in the case of using Diesel & assumption of using Soy biodiesel (B_{20}) as a fuel for aircraft types B737 & A320 at the following downwind:1km, 2km, 3km, 4km, 5km, 6km, 7km, and 8km.

Gaussian plume equation is used for calculation of the ground level concentration at the point (x, y) as **(Turner, 1970):**

$X = ((Q10^6)/\pi \sigma_y \sigma_z U) \exp(-1/2(H/\sigma_z)^2)$ **Where:**

X : is the Ground level concentration, $\mu g/m^3$

Q: is the source emission rate, g/s

σ_y, σ_z: are the standard deviation of the concentration distributions in the crosswind &vertical directions respectively, meters

U: id the average wind speed, m/s

H: is the effective source emission height, m

$\sigma_y = c\, x^d$ & $\sigma_z = a\, x^b$ **Where:**

x: is the downwind distance from the source of emission in meters.

5. Methodology for measurements of Air pollutions at SSH.

The parameters of Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Nitrogen Oxides (NO_x), Nitric Oxide (NO), Ozone (O_3), Carbon Monoxide (CO), and Suspended Particulate Matter (PM_{10}) have been measured by Environmental department at SSH from the existing air quality monitoring station located at the SSH's airside as a fixed unit and it is considered as The Thermo Scientific portfolio of air quality product. The measured values are comparing with the air quality limit values given in Law no. (4/1994) and its amendment (9/2009) of Egypt and by the World Health Organization guideline values.

RESULTS AND DISCUSSION

The air traffic density at SSH is to a certain degree seasonal dependent as seen in Figure (1). The actual numbers of passengers as given by the statistics from 2013 were 5953034 passengers visiting Sharm El-Sheikh International airport, and the total number of flights were 43370.

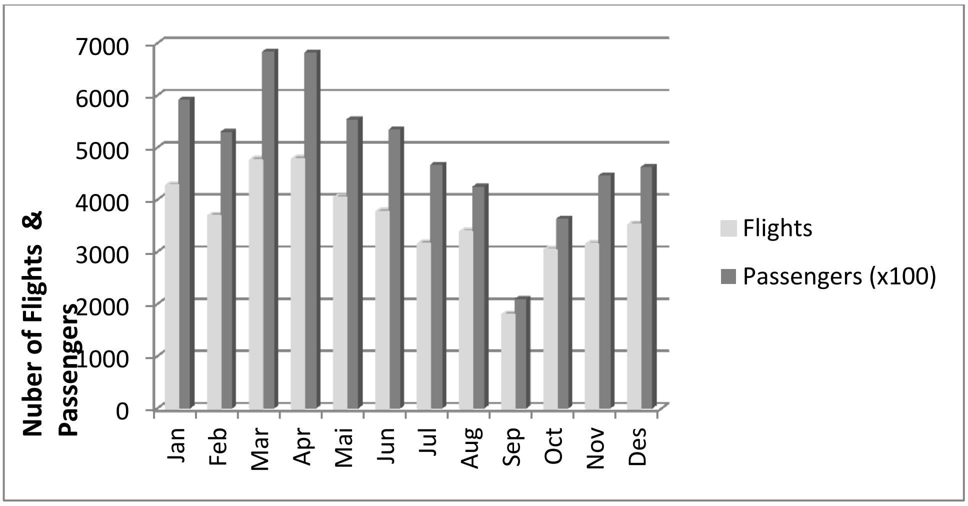


Figure (4): Annual distribution of Flights and passengers at Sharm El-Sheikh airport in 2013, Arrivals and Departures added.

The largest monthly number of passengers transported to Sharm El-Sheikh was recorded in March2013, which had 684212passengers. The number of flights in the same month was 4763 aircrafts. The largest number of flights was recorded in April 2013 at 4782.

The daily average number of flights in April was 159. The current airport capacity is estimated to 45 aircrafts at all Aprons per hour. This will be the aircraft peak hour capacity where prognoses for traffic densities indicated that this capacity will be met in 2040.

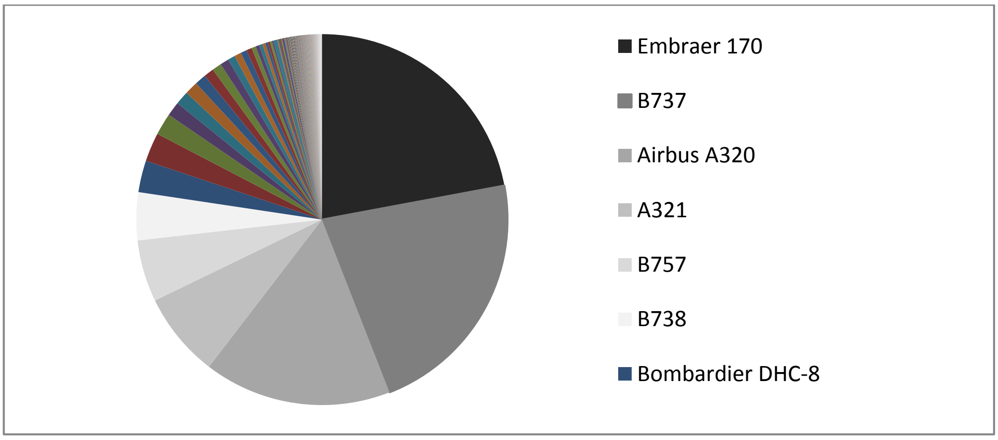


Figure (5): The most aircraft types used SSH for year 2013.

Flight growth forecast has been calculated by using series linear regression Model as mentioned in Materials and Methods, flight numbers are expected to reach 483822 by 2050. That represents a 5.42 % average annual growth in Flights at SSH. In the following forecasting of flights at Sharm El-Sheikh International Airport during some next years.

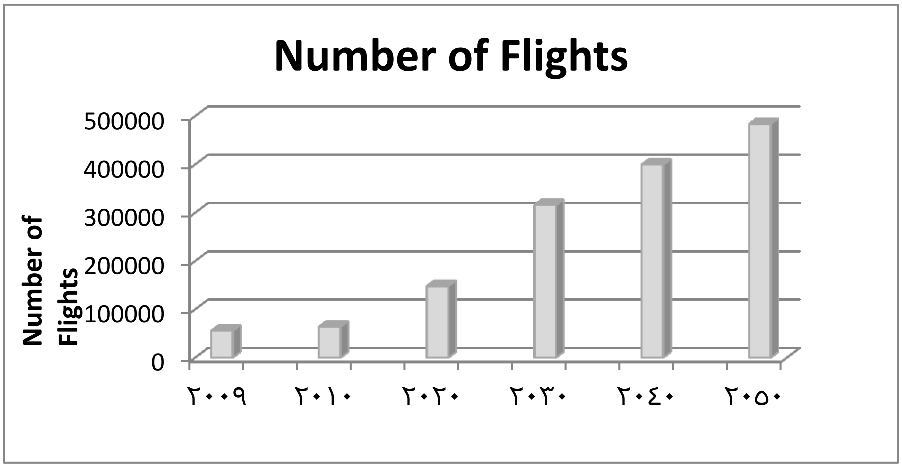


Figure (6): Forecasting Air traffic density at SSH during period of time

The annual aircraft fuel consumption during 2013 was 56547.280 t for LTO cycles at SSH, the estimated using fuel flow factors for each aircraft type in the ICAO Databank.

Table (1): Total calculated emissions mass of NOx, HC, and CO for A/C main engines, APU, and Aircraft Handling for year 2013 at SSH

Type of emission	A/C main engines (Jet A1)	APU (Jet A1)	Aircraft handling (Diesel)
	Total calculated emission mass (Ton)	Total calculated emission mass (Ton)	Total calculated emission mass (Ton)
NO_x	69340.331	12.399	32.802
HC	442.047	3.802	7.145
CO	37660.742	9.232	10.752
PM	9.674	----	7.758

Estimations above showed that the contribution of aircrafts in NOx emissions were 99.95% to the total NOx emission at SSH according to above table. In 2013, APU and Aircraft handling contributed with 0.51% to the total CO emissions. PM emitted from Aircraft handling is approximately equal to that emitted from Aircraft main engines.

Table (2): Total calculated emissions mass in different operating phases of B777 at SSH for year 2013.

	Total Fuel Flow of engine (kg/LTO)	Total emissions mass (kg)				
		CO	NO_x	HC	SO_X	PM
One engine of B777/LTO	2519.52	7.48	28.96	0.37	0.002	0.102
Two engine of B777/LTO	5039.04	14.9	57.93	0.74	0.004	0.008
All B777 at SSH for year 2013 (118 LTO)	594606.7	1766	6836	87.9	0.475	0.951

Boeing 777 (large aircraft) has the biggest portions in NOx total emissions, in which contributing 6.836 t /LTO.

Table (3) : Comparison between calculation of total emissions mass of NO_x, HC, CO, and PM for all Aircraft using SSH during 2013 when using Diesel & assumption of using Soy biodiesel (B_{20}) for Aircraft engines.

Type of emission	Jet A1	Soy biodiesel (B_{20})	Difference (%)	Difference (Ton)
	Total calculated emission mass (Ton)	Total calculated emission mass (Ton)		
NO_x	69340.331	70727.137	+2%	+ 1386.806
HC	442.047	348.775	-21.10%	- 93.272
CO	37660.742	33518.06	-11%	- 4142.682
PM	9.674	8.687	-10.10%	- 0.987

The emission reduction in HC in case of using Soy biodiesel (B_{20}) for Aircraft main engines according to above table is equal to that emitted from 1072 LTO for B777.

Table (4) : Comparison between calculation of total emissions mass of NO_x, HC, and CO for APU & Aircraft Handling at SSH for year 2013 when using Diesel & assumption of using Soy biodiesel (B_{20}).

Type of emission	APU (Jet A1)	APU (B_{20})	Aircraft handling (Diesel)	Aircraft handling (B_{20})
	emission mass (Ton)	emission mass (Ton)	emission mass (Ton)	emission mass (Ton)
NOx	12.399	12.647	32.802	33.458
HC	3.802	3.0002	7.145	5.638
CO	9.232	8.216	10.752	9.569

The emission reduction in CO in case of using Soy biodiesel (B_{20}) in APU according to above table is equal to CO emission emitted from 72 LTO for B777 (see table (2)), in the Aircraft handling is equal to CO emission emitted from 84 LTO for B777.

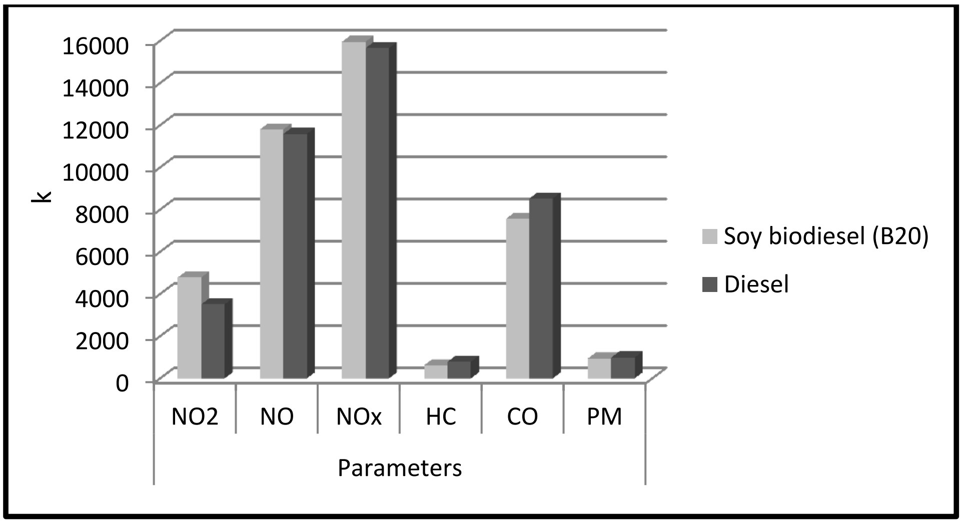


Figure (7): Comparison between calculation of total emissions mass for landing and takeoff cycle of Aircraft different types from10-14/4/2015 at SSH when using Diesel & assumption of using Soy biodiesel (B_{20}) for Aircraft engines.

The emission reduction in CO in case of using Soy biodiesel (B_{20}) for different types of aircraft from 10- 14/4/2015 at SSH according to Figure (4) is equal to that emitted from 66 LTO for B777.

Table (5): Emissions as one-hour average from 2nd April to 4th April 2015.

Date	No. of Flights	Avg. NO_2 ($\mu g/m^3$)	Avg. CO ($\mu g/m^3$)	Avg. CO_2 ($\mu g/m^3$)	Avg. O_3 ($\mu g/m^3$)	Avg. PM_{10} ($\mu g/m^3$)	Avg. SO_2 ($\mu g/m^3$)
02/04/2015	84	10.7	0	474	30.9	34.9	1.5
03/04/2015	60	8.7	0.31	468	52.1	65	1.6
04/04/2015	93	11.8	0.28	462	42.4	71	1.8

The measurements above undertaken by The Air quality Monitoring Station at the Airside of SSH during 18-day, The emissions concentrations shown are normally well below the air quality limit values given in Law no. (4/1994) and its amendment (9/2009) of Egypt and by the World Health Organization guideline values.

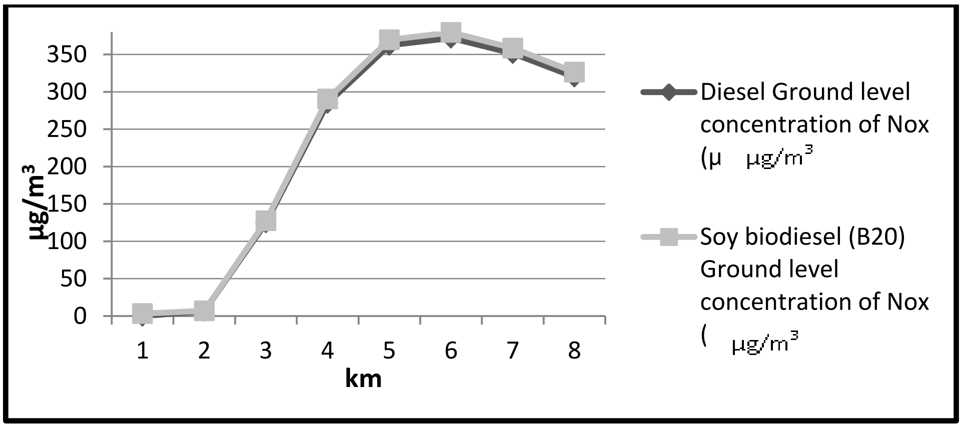


Figure (8): The Ground level concentration for NOx in the case of using Diesel & assumption of using Soy biodiesel (B_{20}) as a fuel for Aircraft type B737 at the different downwind distance

The Ground level concentration for NO_x in the case of using Diesel & assumption of using Soy biodiesel (B_{20}) as a fuel for aircraft type B737 at above different downwind which calculated by Gaussian model, there is no big difference between the two values and still below the air quality limit values given in Law no. 4 of Egypt and by the World Health Organization guideline values with take into consideration (NO_x=76% NO+23%NO_2+1%HONO).

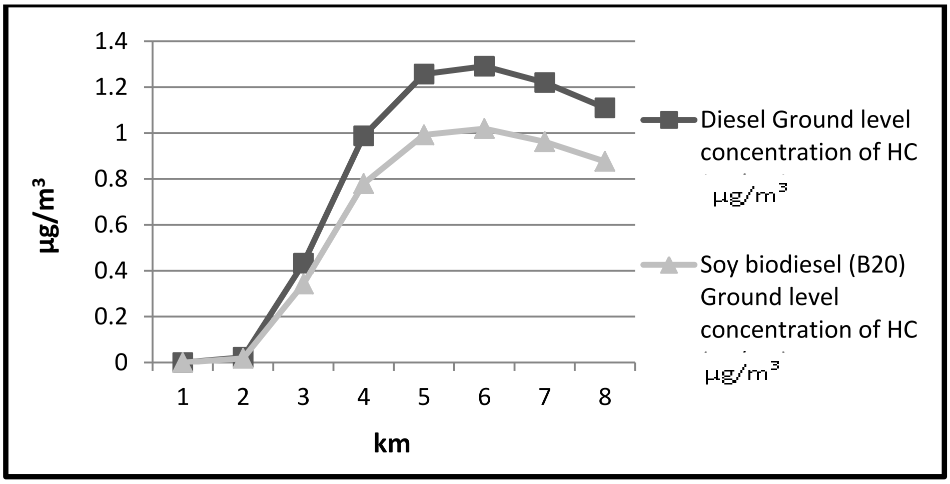


Figure (9): The Ground level concentration for HC in the case of using Diesel & assumption of using Soy biodiesel (B_{20}) as a fuel for Aircraft type B737 at the different downwind distance

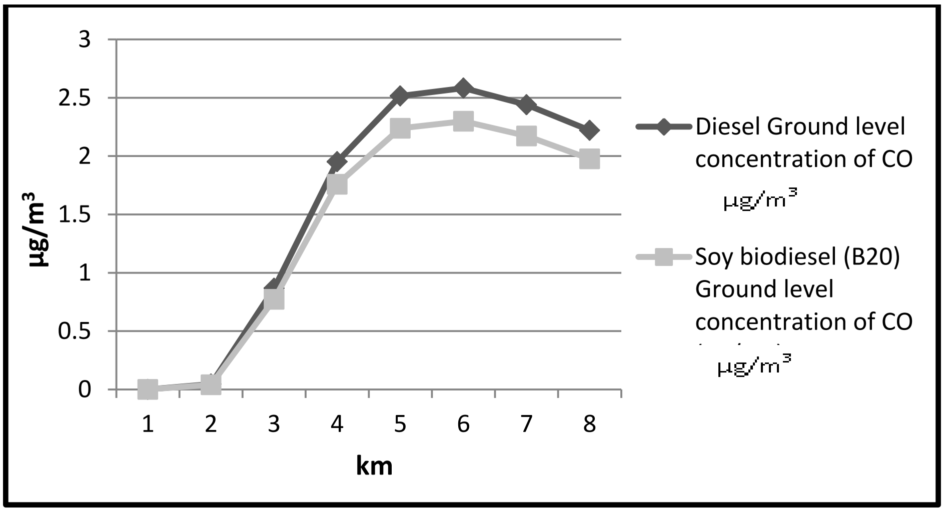


Figure (10): The Ground level concentration for CO in the case of using Diesel & assumption of using Soy biodiesel (B_{20}) as a fuel for Aircraft type B737 at the different downwind distance

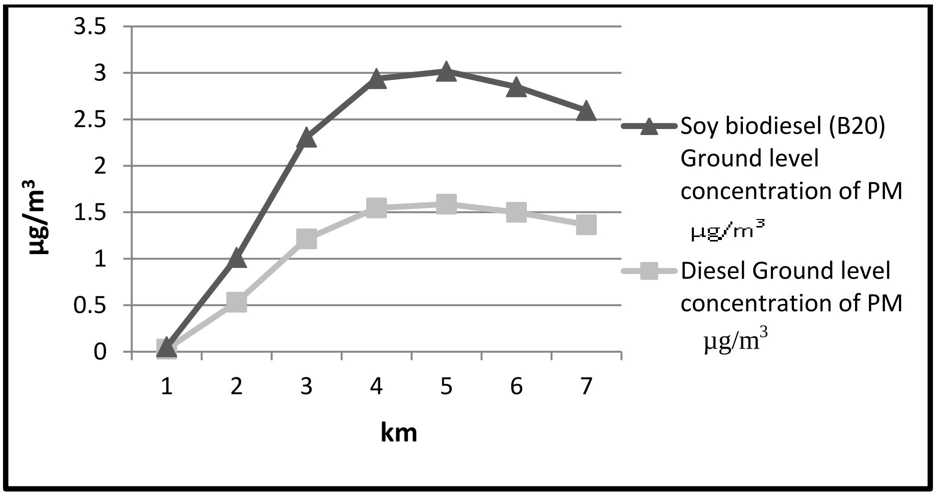


Figure (11): The Ground level concentration for PM in the case of using Diesel & assumption of using Soy biodiesel (B_{20}) as a fuel for Aircraft type B737 at the different downwind distance.

The observation from figures (6, 7, and 8) that there is an improvement in air quality of SSH if the aircrafts using Soy biodiesel B20 as a fuel instead of using traditional fuel (Jet A1).

CONCLUSIONS

This study describes the estimation of engine exhaust gaseous emissions from aircrafts at SSH for the year 2013 & predicted emissions for year 2050. The landing and takeoff (LTO) emissions of HC, CO, and NO_X are calculated using the flight data recorded by the Egyptian Airports Company and emission factors from the ICAO Engine Exhaust Emission Databank. The LTO emissions calculated in this study do not include emissions caused by aging of the engine, maintenance, in-flight condition, and refueling of the aircraft. The first point demonstrated in this work is that total LTO emissions estimated for year 2013 as 442.047 t /y for HC, 37660.742 t /y for CO, 69340.331 t /y for NO_X, and 9.674 t /y for PM. The predicted total LTO emissions from aircrafts at SSH for the year 2050 were calculated as 4928.8241 t /y for HC, 419917.27 t /y for CO, 773144.69 t /y for NO_X, and 107.8651 t /y for PM So, the total emissions will increase 11 times for year 2050.

The assumption of use biodiesel (Soy biodiesel B_{20}) for aircraft engines at SSH for year 2013 leads to the substantial reduction in PM, HC and CO emissions to be 8.687 t/ year, 348.775t/ year, and 33518.06 t/ year, respectively accompanying with the increase in NO_x emission to be 70727.137 t/ year. Moreover, the prediction of reduction in emissions for year

2050 are estimated to be96.86005 t/ year for PM, 3888.84125 t/ year for HC, and 373726.369 t/ year for CO, accompanying with the increase in NO_x emission 788607.5776 t/ year. The finding here is that Soy biodiesel (B_{20}) will be an appropriate solution now days to improve airport's air quality, while in the next years to reach 2050.So, The use of biodiesel should be mandated for aircraft engines as soon as possible to save our air and save our lives.

RECOMMENDATIONS

1- An aircraft standard taxi-route must be established and implemented by airport's administration for all different types of aircrafts for ensuring taking the least time during taxi mode.

2- A long-term plan must be prepared by Egyptian government to Growing Better Biofuel Crops to produce mass production of biodiesel.

3- The use blended biodiesel at least B_{20} for all airlines around the world must be mandated of by International Civil Aviation Organization.

4- Airlines must be encouraged and supported to use blended biodiesel by International Organizations (e.g. WHO, IATA, ACI, … etc).

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التنبؤ بأثر استخدام وقود الديزل الحيوى فى الطائرات على جودة الهواء فى بعض المطارات المصرية

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١) معهد الدراسات والبحوث البيئية، جامعة عين شمس ٢) لجنة حماية بيئة الطيران المدنى التابعة للمنظمة الدولية للطيران المدنى التابعة للأمم المتحدة ٣) إدارة السلامة، الشركة المصرية للمطارات

المستخلص

كمية الإنبعاثات الكلية الصادرة من الطائرات في مطار شرم الشيخ الدولي لسنة ٢٠١٣م تقدر بـ ٤٤٢.٠٤٧ طن/للسنة لإنبعاث الهيدروكربون، ٣٧٦٦٠.٧٤٢ طن/ للسنة لإنبعاث أول أكسيد الكربون، ٦٩٣٤٠.٣٣١ طن للسنة لإنبعاث أكاسيد النيتروجين و٩.٦٧٤ طن/ للسنة لإنبعاث الأجسام العالقة. كما تم التنبؤ لكمية الإنبعاثات التى سوف تصدر من الطائرات فى مراحل الإقلاع والهبوط لسنة ٢٠٥٠ حيث قدرت بـ ٤٩٢٨.٨٢٤١ طن/ للسنة لإنبعاث الهيدروكربون، ٤١٩٩١٧.٢٧ طن/ للسنة لإنبعاث أول أكسيد الكربون، ٧٧٣١٤٤.٦٩ طن/ للسنة لإنبعاث أكاسيد النيتروجين و١٠٧.٨٦٥١ طن/ للسنة لإنبعاث الأجسام العالقة. تعتبر الطائرات المصدر الرئيسى لإنبعاث أكاسيد النيتروجين حيث أنها تساهم بنسبة ٩٥.٩٥% منها، كما أن طراز الطائرة بيونج ٧٧٧ (طائرة كبيرة) يساهم بقدر كبير فى هذه النسبة حيث أن عملية إقلاع وهبوط واحدة لهذا الطراز يؤدى إلى إنبعاث ٦.٨٣٦ طن. سوف يصل عدد الرحلات فى المطار طبقاً للتوقعات فى سنة ٢٠٥٠ إلى ٤٨٣٨٢٢ رحلة. تركيز الإنبعاثات المقاسة فى المطار لايزال فى الحدود المسموحة طبقاً لقانون ٤ لسنة ٢٠٠٤ وتعديلاته. بفرضية إستخدام الديزل الحيوى (من زيت الصويا) تركيز ٢٠% كوقود للطائرات على جودة الهواء فى مطار شرم الشيخ الدولى فى سنة ٢٠١٣ سوف يؤدى إلى إنخفاض ملحوظ فى الإنبعاثات حيث ستنخفض إلى ٩٣.٢٧٢ طن/للسنة لإنبعاث الهيدروكربون، ٤١٤٢.٦٨٢ طن/ للسنة لإنبعاث أول أكسيد الكربون، و ٠.٩٨٧ طن/ للسنة لإنبعاث الأجسام العالقة كما يصاحبها زيادة فى إنبعاث أكاسيد النيتروجين تقدر بـ ١٣٨٦.٨٠٦ طن /للسنة. علاوة على ذلك تم تقييم الإنخفاض فى إنبعاثات الطائرات فى سنة ٢٠٥٠ بـ١٠٣٩.٩٨٢٨ طن/للسنة لإنبعاث الهيدروكربون، ٤٦١٩٠.٩٠٤٣ طن/ للسنة لإنبعاث أول أكسيد الكربون، و ١١.٠٠٥٠٥ طن/ للسنة لإنبعاث الأجسام العالقة كما يصاحبها زيادة فى إنبعاث أكاسيد النيتروجين تقدر بـ ١٥٤٦٢.٨٨٦٩ طن /للسنة. هناك تأثير ضئيل

جدا ما إن تم إستخدام الديزل الحيوى تركيز ٢٠% لمحركات الطاقة الإضافية فى الطائرات وكذا لمعدات الخدمات الأرضية. نتائج قياس متوسط تركيز إنبعاثات (الهيدروكربون، أكاسيد النيتروجين، أول أكسيد الكربون)على مسافة ٨ كم من المدرج فى حالة إستخدام وقود الديزل التقليدى ٠.٨٢٨١ مللى جرام/ م^{٣} لإنبعاث الهيدروكربون ، ٤.٦١٧ مللى جرام/ م^{٣}لإنبعاث أول أكسيد الكربون و 343.7607 مللى جرام/ م^{٣}لإنبعاث أكاسيد النيتروجين. و فى حالة إستخدام الديزل الحيوى (من زيت الصويا) تركيز ٢٠% 0.6534 مللى جرام/ م^{٣} لإنبعاث الهيدروكربون، 4.1091 مللى جرام/ م^{3} لإنبعاث أول أكسيد الكربون و 350.6359 مللى جرام/ م^{٣} لإنبعاث أكاسيد النيتروجين.