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Analysis and Simulation Model of Indoor Air

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ABSTRACT

The purpose of this study is to perform an experiment of which the mathematical model was developed. The model could be utilized to predict the time taken of removing hazardous gases from 1 m^3 indoor air space. In this study, a simple experiment was conducted where time was measured from smokes produced by burning waste tire tubes. It was noted that the experiment produced a very reliable mathematical model after 7 cycles of experiment with R^2 is equivalent to 0.97. The mathematical model obtained after burning waste tire tubes ranging from 11 grams to 80 grams accordingly.

Keywords: *Mathematical Model, Indoor Air Quality, Correlation Determinant*

1. INTRODUCTION

It is well known that in the developed world, more than 80% of people's lives are spent indoors, whether it is in the home, office, school, workplace, or public building, etc. (Simoni *et al.,* 2003) therefore, the air quality of such spaces may effect of their occupants. Even time spent within an enclosed vehicle can be considered to be in an "indoor" environment. The World Health Organisation (WHO) has estimated that there are 2 million annual deaths worldwide attributable to indoor air contaminants (IAC), and the WHO has also ranked this phenomenon as the tenth avoidable risk factor in importance for the health of the general population(WHO, 2009). The potential contaminants are distinct in origin: those derived from combustion, biological processes and agents, hazardous gases and volatile organic compounds (VOC). Contaminants and the pathological processes derived from exposure to them differ according to income level, geographical location and individual cultural determinants. In countries with greater socioeconomic development, IAC are influenced by the architectural design of building, outdoor sources of pollution, construction materials and ventilation and air conditioning (Fernandez *et al.,* 2013). The factor that indoor air quality (IAQ)are deficiencies in ventilation, outdoor air quality and the presence of indoor contaminant Fernandez *et al.,* 2013) Ventilation can be used for three completely different functions in the building: maintaining (IAQ), cooling the human body and cooling the structural mass of the building. Each of these has different requirements that affect the building and the ventilation system. Good IAQ is usually indirect positive product of ventilation system. It is prepared for the purpose of reducing the volume of gas, dust, vapor and smoke in closed spaces. All of the harmful substances in the air are then flowed in ventilation systems that are carried away to a device that collects the air pressure which happens from a fan.

All workers almost want work environment safety and health. When the conditions for good air ventilation are unfulfilled, it impacts indoor air pollution on human health, comfort and productivity (Laverge and Jassens, 2012). Worker's occupational exposure to airborne particles, which on occupational hygiene is defined as the concentration of airborne particles in the worker's breathing zone during a working day measuring period (Elihn, *et al.,* 2011). It brings effect on the respiratory illness on the person and other effect on their health. The relationship of indoor and outdoor particulate concentrations is important as the indoor levels can be influenced by outdoor levels and by particle generation indoors. The sensitivity issue of IAQ being influenced by outdoor air has raised concerned locally to vulnerable group especially school children when recently study conducted has shown that exposure to indoor air of PM_{10} and NO_2 concentrations may risk of getting respiratory symptoms and reduction of lung function (Ayuni *et al.,*2014). International researcher has also raised the same concerned to this group as studied related to ventilated IAQ was performed (Bekö *et al.,* 2010). Through outdoor trap into the building, particles of different sizes deposit in different compartments of human respiratory tract upon inhalation, possibly affecting health in different way. In industrial manufacturing workplace, one of the factor major hazards inhalable are from indoor air contaminants. One of the sources of indoor air contaminants is air flow from outdoor environment. It may not be seen with a naked eye, but researches and journal references shows dust particles exist everywhere, one of the especially it is in manufacturing workplace which need to be mitigated, as an example by practicing green manufacturing concept (Raja Manisa and Norsilawati, 2014). This scenario leads to a question of whether the existing environment of air quality level contributing to the adverse effect of the employees for the long-term inhalable air contaminants during in the industry.

Employee exposure to air contaminant can vary due to differences in industrial setting, work area ventilation, types of processes and material used (Antonini *et al.*, 2007). Ventilation system is important to control dust, gas and aerosols climate and factor thermal equilibrium (WHO,1999 : Antonimi *et.al.*, 2007). For example, continuous exposure to dust might lead to lung fibrosis, allergic reaction and asthma attack. All the variety of gas and aerosol (WHO,1999) mix in the air will cause damage to human respiration and skins. The ventilation system provides air and should be sufficient to dilute the contaminants to levels below human perception and those considered detrimental for health (Burgess *et al.*,2004: Fernandez *et al.*, 2013). It is because safety and a healthy workplace which involved three main components which is first, awareness of potential hazards , second assessment of these hazards and the third one is abatement of these hazards. Looking into the above mentioned scenario, this paper is intended to perform experiment of which this could be used to develop a mathematical model so that IAQ status could be approximately predicted

2. METHODOLOGY

In order to carry out this experiment, a simple experimental flow chart was developed (Figure 1). In general, the experimental consist of 3 main components; indoor air, source of hazardous air and exhaust system.

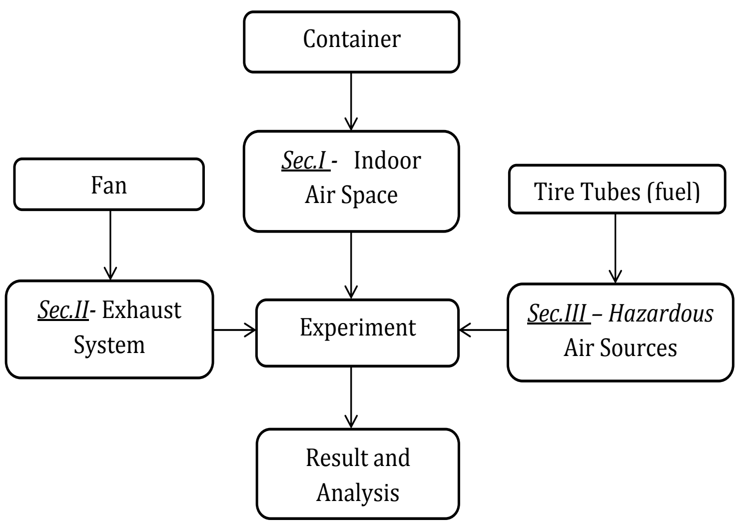

Figure1: Experiment flow chart

1. An indoor air space

To create the indoor air, a 1 m^3 container was fabricated (Figure 2). The function of the container was to trap air. 1 m^3 volume was chosen to ease the data taken and calculation to how much time of 1 m^3 of air being extracted by the exhaust system.

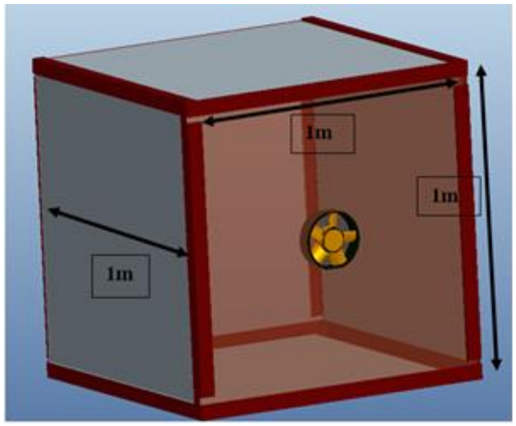

Figure 2: Container of 1 m^3

2. Exhaust system.

A small fan was utilized as exhaust system during the experiment (Figure 2). The function of the fan was to extract air inside the container. The fan capacity was at 5.4 - 6.6 m^3/min with the average of 6.0 m^3 /min. By simple ratio calculation, the fan should be able to fully extracted air from 1 m^3 container within 10 minutes. The extraction process could be easily noted providing that smokes flow out from the container could be physically observed.

3. Source of hazardous air

Waste tire tubes was utilized for this experiment as fuel that generates smokes. The purpose of selecting waste tire tubes was due to it's physical characteristics of producing black smokes while burning. This was required as part of the activity during the experiment which was to observed black smokes being extracted from the container. The waste tire tubes was cut into pieces and weight accordingly. The tube was cut into an approximate weight of 10 grams each which was approximately 1/32 part of a waste tire tubes (Figure 3).

(a)

(b)

Figure 3: (a) Waste tire tubes and (b) Waste tire tubes cut into pieces

The experiment was conducted as these 3 components were integrated together. The cut tires tube at specified weight was burned and smokes produced was intentionally trapped inside the container until the tire tubes were fully burned. The fan was switched on to extract smokes from the container and time was recorded accordingly until all smokes being extracted. The experiment cycles were repeated accordingly until all experiment cycles were completed. Data of the tire tube weight versus time obtained during experiment would be recorded accordingly as the following format (Table 1).

Table 1: Data collecting format

Experiment Cycle (EC)	Portion of tire tubes	Weight (gram)	Time to extract smokes (second)
1	1/32	10	
2	2/32	20	
3	3/32	30	
4	4/32	40	
5	5/32	50	
6	6/32	60	
7	7/32	70	
8	8/32	80	
9	9/32	90	
10	10/32	100	

As hazardous gases from burning tire tubes are well known that could likely cause adverse effect to human (US FEMA. 1998; US FEMA. 2002: Cook and Kemm, 2004), a safety precaution had been taken to operator undertaken this experiment as they were equipped with safety mask while conducting the experiment. Recently research conducted had estimated the emission levels of CO, SO_2 and NO_2 produced from tires burning were approximately at 21 to 49 *u*g g^{-1}, 102 to 820 *u*g g^{-1} and 3 to 9 *u*g g^{-1} respectively(Shakya *et.al.*, 2008) of which this had been used as guidance/reference in other study on toxic emissions from open burning by the industrial waste (Estrellan *et.al.*, 2010). It was noted that SO_2 was measured as the highest among hazardous gases produced by burning tires.

3. RESULT AND DISCUSSION

3.1. Data Collection

As expected, the time taken to remove smokes from the container increases as the weight of fuel used increases. The actual minimum and maximum weight of waste tire tubes being burned was ranging from 11 to 103 gram respectively while the time taken to remove the smokes was ranging from 51 to 162 seconds accordingly (Table 2). It was noted that not all experiments cycle managed to be successfully conducted as planned due to unfavorable condition caused by the black smokes. This unfavorable condition could cause adverse effect to the operator as gases produced are hazardous to human health. The maximum cycles of experiment conducted was up to EC number 9.

Table 2: Data Recorded

Experiment Cycle (EC)	Portion of tire tubes	Actual Weight (gram)	Actual Time to extract smokes (second)
1	1/32	11	51
2	2/32	23	64
3	3/32	34	68
4	4/32	46	79
5	5/32	57	77
6	6/32	69	87
7	7/32	80	94
102	8/32	92	
9	9/32	103	162
10	10/32	-	-

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In order to comparatively identify gases produced by the black smokes that could cause adverse effect to operator conducted in this experiment, an analysis was performed taking consideration the ratio of the fuel weight with respect to the hazardous gases produced. If the level of toxic smoke were to be linearly interpolated according to the weight ratio from the research previously conducted by Shakya *et. al.*, (2008) on open burning (analysis by per gram of tires burning), the gases concentration could be respectively predicted which was at 1,932 – 4,508 *u*g for CO, 276 - 828 *u*g for NO_2 and 9,384 – 75,440 *u*g for SO_2 for 92 grams weight of burning tire tubes (Table 3). These gases concentration increases accordingly to 2,163 – 5,047 *u*g for CO, 309 – 927 *u*g for NO_2 and 10,506 – 84,460 *u*g for SO_2 for 103 grams weight of burning tire tubes. These high values of concentration were considered within 1 m^3 of confined space which was referred to the volume of container built for the experiment

Table 3: Comparison of per gram hazardous gases release according to Experiment Cycles (EC)

	Hazardous gases	CO		NO_2		SO_2	
		Concentration (mg)					
	*Weight – Ref. (gram)	Min	Max	Min	Max	Min	Max
	1	0.021	0.049	0.003	0.009	0.102	0.820
EC no	Weight - Actual (gram)	Concentration (mg/m^3)					
1	11	0.231	0.539	0.033	0.099	1.122	9.020
2	23	0.483	1.127	0.069	0.207	2.346	18.860
3	34	0.714	1.666	0.102	0.306	3.468	27.880
4	46	0.966	2.254	0.138	0.414	4.692	37.720
5	57	1.197	2.793	0.171	0.513	5.814	46.740
6	69	1.449	3.381	0.207	0.621	7.038	56.580
7	80	1.680	3.920	0.240	0.720	8.160	65.600
8	92	1.932	4.508	0.276	0.828	9.384	75.440
9	103	2.163	5.047	0.309	0.927	10.506	84.460
10	-	-	-	-	-	-	-

*Shakya *et. al.*, 2008.

The above linear interpolation could be implemented as it involved only one element which was the concentration of hazardous gases whereas nonlinear interpolation involved more elements such as temperature and humidity in related to time (Aminuddin, *et al.*, 2012). The concentration of these hazardous gases were further analyzed and compared accordingly to Occupational Safety & Health Acts (OSHA) legislation and discovered that the permissible level of 8 hour time weighted average air born concentration for SO_2 were above the permissible level from EC number 5 onward at the minimum concentration range and for all the EC at the maximum concentration range (Table 4).

Table 4: Hazardous condition on Experiment Cycle

	*8 hour time weighted average (mg)	Hazardous condition	
CO	29.0	Min Concentration	Nil
		Max Concentration	Nil
NO_2	5.6	Min Concentration	Nil
		Max Concentration	Nil
SO_2	5.2	Min Concentration	EC 5 & above
		Max Concentration	All

*OSHA Act 514-1994, 2006

As for the conclusion, the above experiment conducted were found to be hazardous to operator mainly on high level of SO_2 during certain number of EC and therefore safety consideration shall be thoroughly considered under those stated conditions.

3.2. Simulation Model

From the experiment conducted, a mathematical model could be developed by plotting a graph of time versus the weight of fuel used. If the graph plotted up the experiment no 9, the correlation determinant obtained was at 0.77 (Figure 4). On the other hand, the correlation determinant obtained was much improved which was at 0.97 with less experiment cycle conducted (8 cycles) (Figure 5). Comparatively, the correlation tends to improve as less experiment cycles being conducted. This was mainly due to uncontrolled condition as more experiment cycles were repeated. Therefore, equation on Figure 5 is more reliable to be applied in predicting the parameters concerned either the time or the weight of the tire tubes used in the experiment as on equation 1.

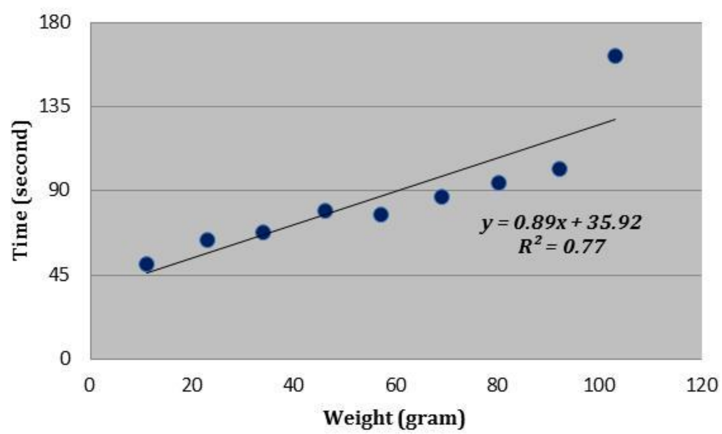

Figure 4: The weight of tire tubes against time for 9 experiment cycles

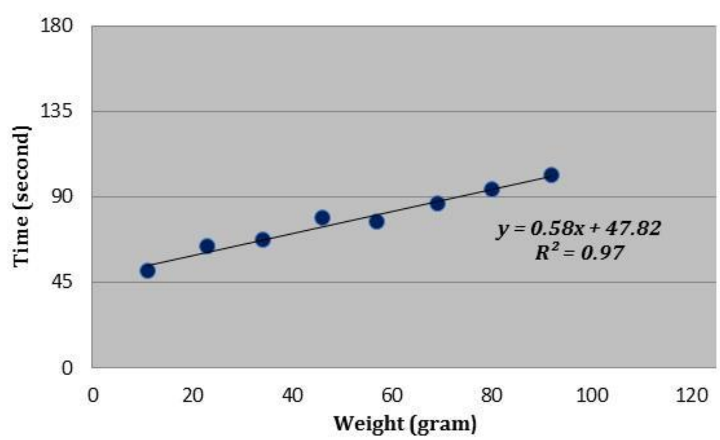

Figure 5: The weight of tire tubes against time for 8 experiment cycles

$$y = 0.58x + 47.82 \qquad \text{Eq.1}$$

where
y = time (second)
x = weight (gram)

4. CONCLUSION

This research has been successfully conducted which leads to the form of equation that enables to relate the two factors which were the time and weight of burning fuel. The equation could be implemented in similar environment to approximate either one of the unknown parameters. However, it is highly suggested that future experiment be conducted in more systematic manner so that a more reliable equation model could be developed. The experiment may suggest be include proper measuring equipment of hazardous gases. With a simple mathematical model being developed, this research could be further enhanced as such relationship in between the air volume, air pressure and fan performance could be identified (Akande and Moshood, 2013).

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