UNIVERSITI TEKNIKAL MALAYSIA MELAKA

MONITORING OF ENVIRONMENTAL EMISSION FROM (SLS) 3D PRINTER USING 100% RECYCLED POLYAMIDE (PA12)

This report is submitted in accordance with the requirement of Universiti Teknikal Malaysia Melaka (UTeM) for the Bachelor of Mechanical Engineering Technology (Refrigeration and Air Conditioning Systems) with Honours

by

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This report is submitted to the Faculty of Engineering Technology of UTeM as a partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering Technology (Refrigeration and Air Conditioning Systems) with Honours. The member of the supervisory is as follow:

Signature: ………………….……………………………….

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ABSTRAK

Kualiti Udara Dalaman (IAQ) adalah sangat penting terhadap kesihatan dan keselesaan penghuni di dalam bangunan tersebut. Kualiti Udara Dalaman bergantung kepada jumlah bahan cemar udara bangunan itu. Kualiti Udara Dalaman yang teruk akan menyebabkan banyak kesan sampingan terhadap penghuni-penghuni seperti pening, kerengsaan, sakit kepala dan lain-lain. Pembuatan tambahan adalah salah satu teknologi baru yang muncul. Tetapi tidak banyak penyelidikan yang mengenai SLS pencetakan. Salah satu reka bentuk daripada pengeluar pencetak SLS telah dipilih untuk dicetak bagi mengukur pelepasan daripada pencetakan SLS. Bahan serbuk yang digunakan untuk penyelidikan ini ialah 100% serbuk nilon (PA12) yang dikitar semula. Data akan dikumpulkan bagi empat fasa pencetakan iaitu dari sebelum pencetakan, persediaan pencetakan, semasa pencetakan, dan selepas pencetakan. Parameter karbon monoksida (CO), karbon dioksida (CO2), jumlah kompaun organik yang tidak menentu (TVOC), Ozon (O3), Formaldehid, Particulate Matter (PM), suhu dan kelembapan relatif telah diukur dan dibandingkan dengan Kod Industri Amalan (ICOP) Dosh 2010. Kepekatan tertinggi zarah pernafasan diukur sebagai 0.492 mg / m3 pada selepas fasa percetakan yang melebihi had yang boleh diterima ICOP sebanyak 0.15 mg / m3 pada masa yang sama nilai puncak karbon dioksida CO2 sedang dalam persediaan untuk mencetak fasa 999 ppm hampir melebihi had 1000 ppm. Data yang dikumpulkan dari pelepasan sintering laser selektif (SLS) pencetakan 3D oleh serbuk nilon 100% yang dikitar semula menunjukkan bahawa sistem pengudaraan lokasi harus ditingkatkan untuk menghapuskan udara pencemar yang berlebihan dan udara segar mencadangkan untuk membekalkan terus kepada penghuni.

ABSTRACT

Indoor Air Quality (IAQ) is very important to the health and comfort of occupants inside building. The quality of indoor air is depends on the air pollutant inside the building. A bad IAQ will lead to a lot of side effect to the occupants such as dizziness, irritation, headache and others. Additive manufacturing is one of the emerging technology, but there are limited studies on emission of SLS printing technology. The design calibration block of SLS printer's manufacturer is selected to be printed to measure the emission from SLS printing. The powder material use in this research is 100% recycled nylon (PA12) powder material. Data will be collect for four phase of the printing that is from before printing, preparation printing, during printing and after printing. The parameter of carbon monoxide (CO), carbon dioxide (CO_2), total volatile organic compound (TVOC), Ozone (O^3), Formaldehyde, Particulate Matter (PM), temperature, and relative humidity were measured and compared with the Industrial Code of Practice (ICOP) Dosh 2010. The highest concentration of respirable particulate measured as 0.492 mg/m^3 at after printing phase which has exceed the ICOP acceptable limit of 0.15 mg/m^3 at the same time the peak value of carbon dioxide CO_2 is at preparation for during printing phase 999 ppm is almost exceed the limit of 1000 ppm. The data collected from the emissions of selective laser sintering (SLS) 3D printing by 100% recycled nylon powder suggest that ventilation system of the location should be improve to remove excess pollutant air and fresh air is suggest to supply constantly to the occupant.

DEDICATIONS

To my beloved parents, I acknowledge my sincere indebtedness and gratitude to them for their love, dream and sacrifice throughout my life. I am really thankful for their sacrifice, patience, and understanding that were inevitable to make this work possible. Their sacrifice had inspired me from the day I learned how to read and write until what I have become now. I couldn’t find the appropriate words that could properly describe my appreciation for their devotion, support and faith in my ability to achieve my dreams. Lastly, I would like to send my gratitude to any person that contributes to my final year project whether it is directly or indirectly. I would like to acknowledge their comments and suggestions, which are crucial for the successful completion of this study

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Thank you.

TABLE OF CONTENTS

PAGE

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVATIONS, SYMBOLS, AND NOMENCLATURE

et al.	-	Et alia
IAQ	-	Indoor Air Quality
3D	-	Three Dimensional
AM	-	Additive Manufacturing
VOC	-	Volatile Organic Compound
ABS	-	Acrylonitrile Butadiene Styrene
PLA	-	Polylactic Acid
FDM	-	Fused deposition modeling (FDM)
SBS	-	Sick Building Syndrome (SBS)
ICOP	-	Industrial Code Of Practice
RH	-	Relative Humidity
PM	-	Particulate Matter
CO_2	-	Carbon Dioxide
CO	-	Carbon Monoxide
IARC	-	International Agency for Research on Cancer
IEQ	-	Indoor Environmental Quality
USEPA	-	United States Environmental Protection Agency
HVAC	-	Heating, Ventilation, and Air Conditioning
OSHA	-	Occupational Safety Health Administration
TVOC	-	Total Volatile Organic Compound
ASHRAE	-	American Society of Heating, Refrigerating, and Air-Conditioning Engineers

WHO	-	World Health Organization
NCI	-	National Cancer Institute
NIOSH	-	National Institute for Occupational Safety and Health
SLA	-	Stereolithography
SLM	-	Selective laser melting
SLS	-	Selective Laser Sintering
DLP	-	Digital Light Processing
EBM	-	Electronic Beam Melting
LOM	-	Laminated object manufacturing
FFF	-	Fused Filament Fabrication
HEPA	-	High Efficiency Air Filter
MERV	-	Minimum Efficiency Reporting Value
ULPA	-	Ultralow Penetration Air Filters
PET	-	PolyEthylene Terephthalate
PVA	-	Polyvinyl Alcohol
DOSH	-	Department of Occupational Safety and Health Malaysia
BRSs	-	building related symptoms

CHAPTER 1

INTRODUCTION

1.0 Introduction

Individuals average spending 88% of their time in a buildings, and 7% in vehicles, and only spend 5% of time at outside (M.Liddament, 2005).The indoor air quality (IAQ) is an issue that are very important to everyone because people are spending most of their time in indoor. IAQ is related to health, performance and comfortability of the occupants (A.Melikov & J.Kaczmarczyk, 2012). Sources that release pollutant gases such as carbon dioxide and respirable dust into the air are the cause of indoor air quality problems. A bad IAQ will lead to many health problems. In modern day, technologies are revolving around us. From many kind of technologies that are emerging, additive manufacturing or three-dimensional (3D) printing technology stand out as one of the technology that has huge potential towards the society (Ford .S and Despeisse M, 2016). 3D printers are one of the new technology machines that can turn a digital design into three-dimensional objects, also can make almost every things of human daily life (Kwon et al., 2017). They are very useful because it can produce different kinds of objects, with different materials from the same machine. The machine is affordable also can make many things example like cups, survival whistle, bottle and others cool and useful stuff. 3D printer can be used by field such as automotive, aerospace, military, education, health and care, architects, designers, consumer products and others. However, everything has pros and cons, one of the most significant disadvantage of additive manufacturing (AM) is that the emission of chemical content such as volatile organic compounds (VOCs), respirable dust which will impact the Indoor Air Quality (IAQ) of the area (Rejeski et al., 2018). Occupant of the room inhaled polluted air and will have side effects to their health. The effects of the pollutants produced by these 3D printer may underestimated by people (Zhou et al., 2015). Hence, this study is to provide data of pollutant produced by 3D printing machine to increase public and users' awareness towards this issue.

1.1 Problem Statement

Nowadays, 3D printer is now a common machine to general public due to its rapid prototyping (B.Stephens et al., 2013). With the high efficiency of 3D printer, it starts to use by consumer, industrial, healthcare, and military to print the object they want in an indoor environment, such as offices, home, schools, or inside a building (R.Olson, 2013). For educational case, in some place such as university labs or classrooms, 3D printer is exposed to student for learning purpose. However, the use of these devices in nontraditional manufacturing environments may pose health risks to new group of people that are being exposed to the emission during the printing process of 3D printer (Mendes et al., 2017). Additive manufacturing machine can release volatile organic compounds chemical and particles into air when printing (Azimi et al., 2017). They are not build with air cleaning system (Bours et al., 2017), the situation could be worst if use in an enclosed space without proper air flow or ventilation. Studies show that VOC have negative impacts on human and environmental health (T.Simon et al., 2017). The health effect due to exposure to high VOCs is breathing problems, irritation of eyes, nose, throat, nausea, asthma, headache, and cancer (de Gennaro et al., 2013). All this happen is because lack of concern and emission control in this issue (Kwon et al., 2017). Lastly, there are a lot of research on emission of desktop FDM printer but lack on SLS printer therefore, the research on emission of SLS printer is done in this sector to rise the concern of the users.

1.2 Objective

a) To study the emissions of selective laser sintering (SLS) 3D printing.

b) To measure the respirable dust or particulate matter emission of 3D printing by 100% recycled nylon powder.

c) To compare the IAQ emission of SLS printing by 100% recycled nylon powder with ICOP, DOSH 2010 standard.

1.3 Work Scope

The scope of this research is to study the emission of the 3D printer machine with Selective Laser Sintering (SLS) technology. In this research, the nylon powder are the selected material, it is use to print a calibration object. The object that is selected to print is chosen from the standard given by the manufacturer of the 3D printer machine. Also the powder can be mix in three different ratio when print but in this project only 100% recycled nylon powder is selected. The indoor air quality is measured in four stages that is before printing, preparation of printing, printing and after printing process. This research is conduct in a SLS 3D printing lab that is located at Faculty of Engineering Technology (FTK), UTeM.

1.4 Significant of study

Many process in human daily life will related to the environment. In field of additive manufacturing, the pollution produced is high but human are not aware of it. With the revolution in AM, there is a 3D printing technology which can created prototype that is strong in a very short period of time. One of the issue is that manufacturer has started to invent 3D printer that are small in size and can use in small room of indoor environment. Hence, this study will point out the dangerous of usage of 3D printer in indoor condition to human health to raise the awareness of people.

1.5 Conclusion

This chapter only briefly introduces the aim of the project. This study is to provide SLS 3D printer emission information for the user to increase their concern towards this issue so that they can prevent and limit the exposures to pollutant air during the printing process.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction of Indoor Air Quality (IAQ)

IAQ is where the quality content of indoor air that could affect the occupants inside the building. For example, a bad IAQ could induce health effects, comfortability, productivity or performance of the occupants in the space, room or workplace (Norhidayah et al., 2013). IAQ has huge relation to the health of a people that exposes to the pollutant (Zhou et al., 2015). Recently, the effect of indoor air quality on health is being concern by community (C.Teodosiu et al., 2017). During the revolution of world, the building design is also developed without our intuition, the building design is changing into more airtight to get higher energy efficiency (Jones, 1999), moreover greater amount of synthetic building materials is used in our building today. The synthetic materials will produce contaminants into the indoor environment (M.Trantallidi et al., 2015), combined with an airtight building design the IAQ of the building can be worst. A poor indoor air quality may lead to sick building syndrome (SBS). IAQ level can be measured by taking the physical parameter, and air contaminant by following what has been identified from the Industrial Code Of Practice (ICOP) that is temperature, relative humidity (RH), air velocity, particulate matter (PM), volatile organic compound (VOC), carbon dioxide (CO_2), carbon monoxide (CO), formaldehyde, ozone, bacteria, and fungi (Lee et al., 2017). An acceptable IAQ means that at least 80% of the occupants are not express any dissatisfaction (Stanke et al., 2007) and there is not known contaminants that can cause harm is at high concentration levels.

2.1 Indoor Environmental Quality (IEQ)

The IEQ of a building is determine by four aspects that are thermal comfort , indoor air quality, noise level and lighting level, The IEQ of buildings determines the occupants or employee comfortability, healthy, and productivity (T.Ben-David & M.Waring, 2018). The United States Environmental Protection Agency (USEPA) has performed a comparative risk studies and listed IAQ as one out of five of environmental risks to public health (Lai et al., 2009). The Heating, Ventilation, and Air Conditioning (HVAC) systems of a building will impact two parameters of IEQ , that are thermal comfort and indoor air quality (Pantelic et al., 2018).

2.2 Occupational Safety Health Administration (OSHA)

One of the United States agency that protects labors so they can work in a safe and healthful working condition by controlling the standard of working condition. In this research, it is about IAQ. The factors affect IAQ are poor ventilation, poor temperature controlling, humidity, and other activities inside or near the building that contributes to outdoor supply air. OSHA does not provide IAQ standard but it concerns about air ventilation, it said that a good ventilation can prevent and resolve IAQ problems. Other than that, OSHA also provided some air contaminants standard so that IAQ problem can be controlled. OSHA created a law "The General Duty Clause of the OSH Act" where it stated that employers are required to provide a safe and healthy working environment for their employees.

2.3 Feature that affect IAQ

There are two type of feature that affect the IAQ which are physical parameter and indoor air contaminant.

Table 2.1 Physical parameter (DOSH, 2010)

Parameter	Acceptable range
(a) Air temperature	23-26 °C
(b) Relative humidity	40-70%
(c) Air movement	0.15-0.50 m/s

Table 2.2: Air contaminants (DOSH, 2010)

Indoor Air Contaminants	Acceptable limits		
	ppm	mg/m^3	cfu/m^3
<u>Chemical contaminants</u>			
(a) Carbon monoxide	10	-	-
(b) Formaldehyde	0.1	-	-
(c) Ozone	0.05	-	-
(d) Respirable particulates	-	0.15	-
(e) Total volatile organic compounds (TVOC)	3	-	-
<u>Biological contaminants</u>			
(a) Total bacterial counts	-	-	500*
(b) Total fungal counts	-	-	1000*
<u>Ventilation performance indicator</u>			
(a) Carbon dioxide	C1000	-	-

For chemical contaminants, the limits are eight-hour-time-weighted average airborne concentration. C is the ceiling limit that shall not be exceeded at any time. Readings above 1000 ppm are indication of inadequate ventilation.