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THE ANALYSIS OF INDOOR AIR QUALITY INSIDE THE KELANA JAYA LIGHT RAIL TRANSIT TRAIN IN KUALA LUMPUR

HIDAYATULLAH BIN MASJUD

Tesis ini dikemukakan sebagai
memenuhi syarat penganugerahan
Ijazah Sarjana Sains Kejuruteraan Pengangkutan Rel

Pusat Pengajian Siswazah
Universiti Tun Hussein Onn Malaysia

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ABSTRACT

Indoor air quality needs attention due to most people in the modern era now allocate more time to be in an enclosed space such as inside buildings and vehicles compared to an open space with ambient air. This study was conducted to analyze the air quality in four-car LRT Kelana Jaya train during operations. The study was conducted during off-peak hour which is between 9:00 am until 1:30 pm for four weeks consecutively. The measurement devices were located at the center of the train which is at the gangway. The real time monitored method is used and three main parameters measured which are the concentration of carbon dioxide (CO_2), Particulate Matter (PM_{10}) and Total Volatile Organic Compound (TVOC). The study found that the CO_2 level inside the train in the acceptable range. But it's sometime exceeded the acceptable limit which reached until 1392 ppm. The PM_{10} levels were increased from week one to week four and sometimes exceeded the acceptable range which is reached until 0.478 mg/m^3. While for TVOC concentration, all data recorded are not over permissible range which is below 3 ppm. In order to ensure safety and health of the passengers train, the future research about how to control IAQ in the train should be conducted.

ABSTRAK

Kualiti udara dalaman perlu diberi perhatian berikutan kebanyakan manusia dalam era moden kini memperuntukkan masa yang lebih lama berada dalam ruangan yang tertutup seperti di dalam bangunan dan kenderaan.berbanding diruangan terbuka dengan udara persekitaran. Kajian ini dilakukan untuk menganalisis kualiti udara di dalam LRT Kelana Jaya empat gerabak ketika sedang beroperasi. Kajian dilakukan bukan pada waktu puncak iaitu diantara jam 9:00 pagi sehingga 1:30 petang selama empat minggu berturut-turut. Alat pengukuran yang digunakan diletakkan di bahagian tengah tren iaitu diantara gerabak tiga dan empat. Tiga parameter utama yang diukur iaitu kepekatan gas *karbon dioksida (CO_2), Particulate matter (PM_{10}) dan Total Volatile Organic Compound (TVOC)*. Kajian mendapati tahap CO2 yang direkodkan ada yang melepasi julat yang dibenarkan sehingga mencapai 1392 ppm. Tahap PM10 meningkat dari minggu pertama hingga minggu ke empat yang mana ada bacaan yang direkodkan sehingga mencapai 0.478mg/m^3. Manakala kesemua nilai TVOC yang direkodkan adalah tidak melebihi tahap maksimum yang dibenarkan iaitu di bawah 3 ppm. Untuk memastikan keselamatan dan kesihatan penumpang tren, kajian berkenaan bagaimana untuk mengawal kualiti udara di dalam tren adalah perlu dilakukan.

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ASHRAE	-	American Society of Heating, Refrigeration and Air-Conditioning Engineers
CFM	-	Cubic feet per minute
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
DOSH	-	Department of Safety and Health
ERL	-	Express Rail Link
KLIA	-	Kuala Lumpur International Airport
KTMB	-	Keretapi Tanah Melayu Berhad
LRT	-	Light Rail Transport
PM_{10}	-	Particulate Matter
PPM	-	Parts Per Million
SPMB	-	Syarikat Prasarana Malaysia Berhad
MOT	-	Ministry of Transportation

CHAPTER 1

INTRODUCTION

1.1 Introduction

The innovation of the different areas was rapidly done nowadays. The main purpose of innovation is to make comfort and convenience of human life. In the era of modernization and development of technology, health and safety factors must always put in high consideration for survival of human. The environmental sustainability or green technological knowledge is a priority in many fields nowadays and it is closely related to the issue of environmental pollution such as water pollution, noise pollution and air pollution. For sustainable development, all the factor that could cause pollution need to be studied.

Among of the various types of pollution, more attention should be given to the issue of air pollution because humans live are always depend on the air at all time. The air quality is divided into two category which are indoor air quality (IAQ) and outdoor air quality. Poor of air quality will give implications to the human health. Every day, people need 10-20m^3 and 1-2 litres of air and water respectively (WHO, 2010).

1.2 Background of study

In the modern era, mode of life style and transportation were different from the previous. Among the top ranking of mode of transportation in certain city now a days is by using railway like Mass Rapid Transit (MRT), Light Rail Transit (LRT), subway and etc. But to have all this facility, safety issues such as environmental impact must always put into consideration. There are lots of IAQ study in buildings have been conducted before. However, when the transport system is booming, IAQ studies especially in public transport vehicles, was began since the 1990s. Whereas, studies of air quality in the train only began in the 20^{th} century by some cities such as Hong Kong, Seoul, Los Angeles and Beijing. This study was conducted to analyse air quality inside the LRT Kelana Jaya which is one of the urban rail transports in Kuala Lumpur.

1.3 Problem statement

The population of people in industrialized countries spend more than 90% of their time in enclosed areas where air quality is lower than the open area (Snyder, 1990; Jenkins 1992; Posudin et al., 2010). At all times, people will do activities in an enclosed space such as in homes, offices, universities, schools, hospitals, business centres and other (Posudin, et al., 2010). Among other areas that can be expressed as a closed area is in a vehicle such as in cars, buses, trains, ships, airplanes and other (Posudin,et al.,2010)

Hunt and Space (1994), mentioned that, the low IAQ level in the plane will cause pain, fatigue, dizziness, nausea, headache, eye pain and irritation of the nose and respiratory problems among passengers. Low levels of IAQ can cause eyes and lungs irritation (LU Hao, 2007). Severe IAQ can also cause dryness of the skin and mucous membranes and may increase the likelihood of transmission of viral diseases (Pennsylvania University, 2014).

The high concentration of CO_2 will degrade the IAQ level. There are many study that show the level of IAQ was affected by the concentration of CO_2. In the plane, the low IAQ level is caused by low humidity levels and high concentration of CO_2 (Huanxin Chen, 2003).

In a study conducted by Tsairidi et al. (2013) found that the concentration of CO_2 is higher in the trains compare at the platform. A study by (Huanxin Chen, 2003) says that the air quality in the trains is getting worse due to congestion, wagons are too closed, contaminants present from the passengers, goods and dust from machine tools. The IAQ level is lower in the tunnel compare at the open area (Kwon, Park et al. 2012). According to Anderson (2007), up to 60 million people working in the building suffering from irritation of the eyes, nose, throat, headache and fatigue.

There are several factors that usually influence IAQ which are the concentration of Carbon Dioxide (CO_2), concentration of Carbon Monoxide (CO), Particulate Matter (PM), formaldehyde and volatile organic compounds (VOCs). The high concentration of these elements will be present risks to human health such as pain, dizziness, dryness of the throat and tongue, fatigue, chest tightness, dry skin and other (Huanxin Chen, 2003). Based on survey made on the 20 passengers at Kelana Jaya LRT, some of them often felt headache, drowsiness and dizziness when boarding the train. Among themselves believed the symptoms are due to environment in the train. There are many researchers in Malaysia and abroad who study IAQ in buildings, but very little research done on IAQ in the vehicle, especially in the train. Until now, there has been no research on IAQ in the train in Malaysia. There is also no standard procedure to determine and method how to measure IAQ in the train compare with inside the building. To look further at this issue, this study needs to be conducted as a baseline data of IAQ in the train.

1.4 Objectives

i. To determine the trend of IAQ level when the train running through along the line
ii. To evaluate and compare the IAQ data with code of practice on Indoor Air Quality 2010

iii. To identify the correlation between chemical parameters (PM_{10}, CO_2 and TVOC) with the physical parameters (Temperature, relative humidity, air movement and number of passengers).

1.5 Scope

i. The IAQ data collection is formed in 4-car train for Kelana Jaya light rail transit (LRT)
ii. The measurement was conducted during off-peak hours (9:30am to 1:00pm)
iii. The IAQ parameters were concentration of CO_2 , VOCs and PM_{10}
iv. There are only four device are used (TSI IAQ-calc 7545, Velocicalc Multifunction ventilation meter 9565, Toxic Gas Monitor TG-502 VOC Probes and Dust Track aerosol meter)

1.6 Significance of study

More than hundred thousands of people reported using LRT Kelana Jaya line every day. In 2011, the statistics released by the Malaysian Ministry of Transportation (MOT) shows that over 180 thousands passengers are using the service every day (MOT, 2011). Imagine if the IAQ level in the train and platform are over the safety limit, it will present the health risk to hundred thousands of passengers who use it every day. Based on preliminary result, some of the passenger had symptoms such as headache, drowsiness, dizziness, irritation of nose and eyes. Therefore, this study is important in order to ensure the safety and health of the passengers especially for those who are using the service daily.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Indoor air quality (IAQ) needs to be maintained so that is always in acceptable range. This chapter described in detail about the contaminants that cause indoor air pollution and also described the factors that influence the existence and development of each pollutant. Other than that, this chapter also describes the standards set to ensure the IAQ in order to cater the human health as well. The results from previous studies which are related to IAQ were also mentioned in this chapter as a reference.

2.2 Rail transport in Malaysia

Kuala Lumpur is the capital of Malaysia. It has three types of rail transport system which are:

i. Intercity train
ii. Urban transit train
iii. Express train

2.2.1 Intercity train

Intercity train services operated by government companies, namely Malayan Railway (KTM Berhad). Network of services linking peninsular Malaysia with Singapore and Thailand. Divided into two sectors, namely the eastern sector (from Mersing, Johor to Tanjong Pagar, Singapore) and the west (from Bangkok, Thailand to Tanjong Pagar, Singapore). Both sectors are linked in Gemas station. Transportation services provided include the transport of goods and passengers. Besides the shuttle train services, express train services are also available to passengers where trains will stop at several stations only. Figure 2.1 and 2.2 shows a freight train and passenger train used for intercity services and route map.

Figure 2.1: The train used to move Cargo

Figure 2.2: The train used to carry passengers

2.2.2 Urban Transit Train

There are four types of urban transit train service in the City of Kuala Lumpur which are Light Rail Transit (LRT) for the Ampang Line, Kelana Jaya Line, Monorail Line and Commuter. Figure 2.2 shows the Klang Valley integrated rail system.

2.2.2.1 LRT Ampang Line

Began operations in December 1996 and It was then known as STAR LRT. Rapid Rail in 2005 after Malaysia took over the operation. The name was changed to the Ampang line and Sri Petaling Line. While in 2007 the name was changed again to the Ampang line. With a long track as far as 27km, it has 25 stations starting with Sentul Timur station to station Cahan Saw Lin and split into Ampang and Sri Petaling. While the figure 2.3 below shows the six cars rolling stock for LRT Ampang Line.

Figure 2.3: Rolling stock for LRT Ampang Line

2.2.2.2 LRT Kelana Jaya Line

It opened in September 1998 with a brand PUTRA LRT. It has 24 stations from Gombak to Kelana Jaya with 29 km overall length of track. This service uses a 4 car and 2 car trains. The service is operated by Rapid Rail Malaysia. Figure 2.4 below, show the 4-car rolling stock at LRT Kelana Jaya Line.

Figure 2.4: Rolling Stock for LRT Kelana Jaya Line

2.2.2.3 Monorail

It began operating in 2003. It's operated by Rapid Rail Malaysia starting 2007. Have 13 stations which the focus of services is in the middle of Kuala Lumpur. Figure 2.5 shows the picture for Kl Monorail Rolling Stock.

Figure 2.5: Rolling Stock for KL Monorail

2.2.2.4 Commuter

It's owned by Keretapi Tanah Melayu and operated by Keretapi Tanah Melayu Berhad (KTMB) began in August 1995. Have 53 stations from Tanjung Malim to Sungai Gadut. Figure 2.6 and 2.7 shows the rolling stock used.

Figure 2.6: Rolling Stock for commuter (EMU model)

Figure 2.7: Rolling Stock for commuter (SCS model)

2.2.3 Express Rail Link

Express Rail Link (ERL) began service in 2002. It is the first high-speed rail service in Malaysia. Two types of services are provided, namely rail express where the service covered between KL Central station to Kuala Lumpur International Airport (KLIA) and shuttle train which stops at six stations (KL Central, Bandar Tasik Selatan, Putrajaya, Salak Tinggi, KLIA 1 and KLIA 2). Figure 2.8 shows the ERL rolling stock.

Figure 2.8: Rolling Stock for ERL

2.3 Indoor Air Quality (IAQ)

Good IAQ is required for a healthy indoor work environment. Poor indoor air quality can cause a variety of short-term and long-term health problems. Health problem commonly associated with poor IAQ include allergic reactions, respiratory problems, eye irritations, sinusitis, bronchitis and pneumonia (DOSH, 2010). In Malaysia, the Code of Practice has been launched on July 2005 to ensure employees and occupants are protected from poor indoor air quality that could adversely affect their health.

2.4 The types of pollutants that affect IAQ

There are two main factors that cause low of IAQ level which are inappropriate design of air-conditioned and effects of pollutants (Sundell, 1996). Review by Godish (1995) states that there are several types of major pollutants that affect indoor air quality which are:

i. Organic Pollutants (Volatile Organic Compounds, formaldehyde, pesticides, polynuclear aromatic hydrocarbons, polychlorinated biphenyls)
ii. Inorganic pollutants (carbon dioxide, carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone)
iii. Physical contaminants (Particulate Matter, PM, asbestos, radon)
iv. Smoke tobacco products
v. Microbial and biological pollutants
vi. Radioactive pollutants
vii. Combustion-generated

In this study, IAQ was analysed based on the three major pollutants which are concentration of carbon dioxide, particulate matters and volatile organic compounds.

2.5 Carbon dioxide (CO2)

Content of high carbon dioxide in confined spaces such as in trains will cause low IAQ (Huanxin.C, 2003). CO_2 gas is usually derived from the human respiratory (Kwon *et al*. 2012) and burning process in the dining room in the trains as shown in table 2.1. If the ventilation device is not functioning properly, the content of CO_2 will rise uniformly (Cho *et al,* 2008).

Enclosed space such in the train will prevent outside contaminated air from entering the area. But this will result in discomfort and drowsiness caused by increased carbon dioxide (Kwon *et al*. 2012). High rate of CO_2 will cause headache, fatigue, dizziness and other (Cho *et al*.2008). The CO_2 limit that has been set by the

Department of Safety and Health, Malaysian Ministry of Human Resources is not more than 1000 ppm as shown in Table 2.2.

Table 2.1: Primary pollutants in the air-conditioned train (Huanxin Chen, 2003)

Contaminants	Sources
CO_2	Combustion of fuel in the dining room, breathing of passengers
CO	Combustion of fuel in the dining room, smoking
Odor	Body odor, smoke, foodstuffs
VOC	Paint, furniture

Table 2.2: List of indoor air pollutants with acceptable limits (Department Of Occupational Safety and Health Ministry of Human Resources, 2010)

Indoor air contaminants	Acceptable Limit		
	ppm	Mg/m^3	Cfu/m^3
Chemical pollutants			
A. Carbon Monoxide	10	-	-
B. Formaldehyde	0.1	-	-
C. Ozone	0.05	-	-
D. Respirable Particulates	-	0.15	-
E. Total Volatile Organic Compounds (TVOC)	3	-	-
Biological pollutants			
A. Total bacterial counts	-	-	500*
B. Total fungal counts	-	-	1000*
Ventilation indicator			
A. Carbon dioxide	C1000	-	-

American Society of Heating, Refrigerating and Air -Conditioning Engineers (ASHRAE 62-2001) also set the limit of CO_2 must not exceed 1000 ppm which is 20 CFM (cubic feet per minute) for new air-conditioning equipment is to be made (Pennsylvania State University, 2014). However, in another study conducted by Kwon et al. (2012) were states that CO_2 must be controlled and not exceed 2000 ppm during normal hours and not exceed 3000 ppm during peak hours for train and bus services.

CO_2 concentration varies along the train route. Based on a study made in the Metro trains, CO_2 level in the train during through underground contains approximately 20-150% more than when the train through on the ground (Yu-Hsiang Cheng *et al*., 2012). The study of high-speed railway in Korea found the content of CO_2 in the train exceeds the safe limits 1000 ppm (Cho *et al*.2007). By increasing the duration of the trip, the CO2 content will increases up to 5000 ppm depending to the number of passengers on the train (Kwon *et al*. 2012).

2.6 Particulate Matter (PM)

Particulate Matter (PM) is a complex mixture of particles that are usually divided in fractions according to particle size. PM is the major element contributes to air pollution that negatively affect to humans (Carvalho, 2013). Particles which have a total particle aerodynamic diameter below 10 mm (PM_{10}) can travel through the conductive airways and affect breathing.

Epidemiological studies have shown that the PM may bring negative effects on human health such as respiratory and cardiovascular disease (Burnett *et al.,* 2002). Cheng *et al., (*2008) also found that the increase of 10 $\mu g/m^3$ PM in polluted air is associated with an increased risk of 4 %, 6 % and 8 % of cardiovascular disease , lung cancer and death . There are studies that find content PM in the subway less than 8 times genotic than on ordinary roads and can result in 4 times of oxidative stress in lung cells (Karlsson & Nilsson, 2005)

The level of PM is authorized by DOSH is $0.15 mg/m^3$ which is shown in table 2.2. The standard is same set by the Ministry of Transport of Korea where 150 $\mu g/m^3$ on a regular basis and should not exceed 200 $\mu g/m^3$ during peak hours (Park, *et al.* 2012).

The presence of PM into the train is influenced by the external environment (Jung *et al.,* 2010). Spread through the movement of trains and passengers also encourage the presence of PM (Chan *et al*. 2002). This is because the clothing of passengers is also one of the causal agents of PM into the train and the floating of PM in the train is influenced by the flow of air and the movement of people (Cho *et al.,* 2008). The major source of PM is come from friction between the wheel and rail, spark resulting from electric contact (electric contact) and brake wear (Chillrud *et al.*, 2004). PM may also result from integration of mechanical problems on the subway system. There are a lot of metal with particles in the subway system as Fe , Mn , Cr , Ni and Cu (Pope *et al* . 2004; Salma et al., 2007).

In the study of IAQ in Metro passenger train in Athens, found that the content of PM in the trains and subway platform is 2 to 5 times higher than the normal levels in the surrounding environment that is monitored by the Ministry of Environment (Tsairidi *et al.* 2013). While, Metro trains in Taiwan, shows the contents of PM on the train when going through the underground is approximately 20-50 % higher than during through on the ground (Yu-Hsiang.C *et al.,* 2012) . The study also received though the train use the same route, but the content of PM is different for the different way and it shows that PM level are influenced by environmental conditions.

The content of PM either on the platform or in the train are generally higher than outdoor air (Nieuwenhuijsen *et al.,* 2007). Referring study of IAQ in the high speed train in Korea, it was found that the contents of PM increased when the train stopped at the station. The increase of PM was due to air flow into the cabin train (Cho *et al.* 2008). This happens because of the airflow is move from areas which has relatively high pressure to low pressure. Therefore, one of the methods to control PM in the train is by controlling PM level in the station. Table 2.3 shows the level of PM_{10} in the Metro trains for several Cities in the world.

Table 2.3: The level of PM_{10} in the Metro trains for several cities in the world.

City	PM_{10} level (µg/m^3)		Reference
	Range	Mean	
Beijing	-	250	(Li *et al*. 2007)
Beijing	36-373	108	(Li *et al*. 2007)
Berlin	-	147	(Fromme *et al*. 1998)
Guangzhou	26-123	67	(Chan et al. 2002)
Hong Kong	23-85	44	(Cheng et al. 2008)
Los Angeles	6-107	24	(Kam et al. 2011)
Prague	21-218	114	(Braniš 2006)
Seoul		144	(Park and Ha 2008)
Seoul	287-356	312	(Kim et al. 2008)
Taipei	-	65	(Tsai et al. 2008)
Taipei	10-97	41	(Cheng et al. 2008)

2.7 Volatile Organic Compounds (VOC)

Volatile organic compounds mean that emissions gas is produced from a solid or liquid containing chemical that are harmful to human health (Posudin et al., 2010). The study by Posudin et al., (2010) also lists some common organic compounds such as aromatic of hydrocarbon, aliphatic and alicyclic hydrocarbon, ketones, alcohols, glycol ethers, esters, phenolics, chlorinated hydrocarbon, terpenes, aldehydes, acetates and other compounds. The presence of VOCs was emanating from carpet, wood panelling, occupants, paint, paper, clothing, floor covering, furniture and others. VOC concentrations are dependent on conditions such as the internal structure of the house, room climate regime, ventilation system, air velocity, temperature, humidity and season (Volland *et al.*, 2005). Temperature and humidity affect the rate of gas emissions, but the ability or the strength is highly dependent on the type of product or building material and the type of VOC (Posudin et al., 2010).

The most consistent effects of VOCs exposure in indoor air include irritation to the eyes, nose, headache, throat, nausea, and other (Hessa.K, 2002). Over 60 million employees working in the indoor area have health problems effects of VOCs (Anderson *et al.*, 2007). Health problems caused by the VOC contaminants would typically be located on the construction of a new building or a new car and it is referred to as the "new building syndrome " or " new car syndrome" (Cho *et al.* 2007). Table 2.4 shows the effect of different concentrations of VOCs.

Table 2.4: The effect of different concentrations of VOCs to the human

Concentration of VOC (mg/m^3)	**Human Response**
<0.20	Comfortable
0.20-3.00	Irritation
3.00-25.00	Acutely uncomfortable
>25	Correspond to toxic action on human organism

In the study of VOC level in the various of modes transport in Guangzhou China, was founds that the commuter exposure to VOCs is heavily influenced by the choice of public transport (Chan et al., 2003). The study also found that VOC levels measured at peak hours during the evening is a little higher than the afternoon peak hours. This is due to the difference in the number of passengers for the two time periods. There was also study that shows the average VOC concentration of indoor air in winter is higher than during the summer (Sakai *et al.*, 1999). In another study showed higher concentrations of VOCs in newly built houses associated with building materials and solvents used (Yamashita *et al.*, 2001). Many substances which produced VOCs are because of temperature effect. While for the tiles and paints because of moisture effect (Seo *et al.*, 2006). Table 2.5 shows the limits for some specific parameters issued by the department of occupational safety and health (DOSH), Ministry of human resource Malaysia.

Table 2.5: Acceptable limit for IAQ (Department Of Occupational Safety and Health Ministry Of Human Resources 2010)

Parameter	Acceptable range
Air temperature	23-25 C
Relative humidity	40-70%
Air movement	0.15-0.50 m/s

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2.8 Sources of pollutants

IAQ pollutants may be formed from a source in a building or enclosed area and it can also come from outside the building or open area (Pennsylvania State University, 2014). The cause of the presence of contaminants in the building is from cleaning agents, new furniture and carpet, sewer gas from dry trap, tools that are not properly maintained, cosmetics, moisturizer tools that are not properly maintained and cigarette smoke. While the sources of pollutants are present outside of the building is smoke, vehicles, construction and renovation, the smell of landscape materials as well as cigarette smoke. Therefore, the air flow acts as an agent of pollutants from outside to inside a building or vehicle. For situations in a vehicle such as in the train, when the number of passengers exceeds the limit, it will cause poor IAQ levels, but if the number of passengers is less than specified, it will be a waste of energy (Huanxin Chen, 2003).

2.9 Technique to control IAQ

In order to maintain IAQ, it has a several method that conducted by previous researcher. Here, it has some technique that might be applied to control IAQ in the passenger cabin.

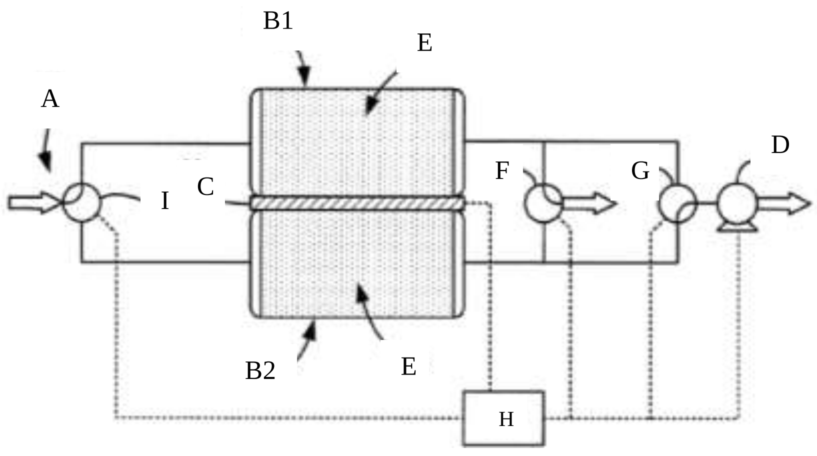
2.9.1 Reducing CO_2 concentration

Park et al. (2012) were studied about the possibility of absorption at the atmospheric pressure and room temperature was reviewed with use of reactor that can practically be applied to indoor space and a CO_2 absorption system was developed to install at ceiling as shown in Figure 2.9 In this case, when the CO_2 level of passenger cabin exceeds a certain limit, the absorption system will control the CO_2 by mixing the air with zeolite.

Figure 2.9: Prototype of CO_2 absorption system (Park et al., 2012)

This study found that the concentration of CO_2 rapidly reduced for the first 15 min, but then relatively gentle curve is shown. It's mean that CO_2 is rapidly absorbed through micro pores of absorbent at the initial stage when high-concentration of CO_2 flows to the absorbent but absorption efficiency is rapidly reduce with elapse of time. The best way to control CO_2 is by increase the air from outside. But that method will directly increase the energy to heat and cool to makes passengers comfort. Another method that possible to apply in other to decrease the CO_2 level inside the train is by using a specific liquid or solid material that can absorb CO_2. It has a several absorbent material that can absorb CO_2 such as Zeolite, Amine, NaOH and Na_2CO_3.

Papale *et al.*, (2012) was invented Carbon dioxide Removal system such shown in Figure 2.10. Regarding his idea, a carbon dioxide (CO_2) removal system includes first and second sorbent beds, a heat exchange system, and means for reducing pressure. The sorbent beds each have a solid amine sorbent for adsorbing and desorbing CO_2. At a given time, one of the sorbent beds adsorbs CO_2 and the other sorbent bed desorbs CO_2. The heat exchange system cools the CO_2 adsorbing bed and heats the CO_2 desorbing bed so that the temperature of the CO_2 desorbing bed is greater than the temperature of the CO_2 adsorbing bed. The means for reducing pressure reduces CO_2 pressure at the CO_2 desorbing bed. A method for removing CO_2 includes supplying a gas stream to a sorbent bed containing a solid amine sorbent to absorb CO_2, reducing pressure at another sorbent bed to desorb CO_2, heating the CO_2 desorbing bed, cooling the CO_2 adsorbing bed, and removing CO_2 from the CO_2 from the CO_2 desorbing bed.

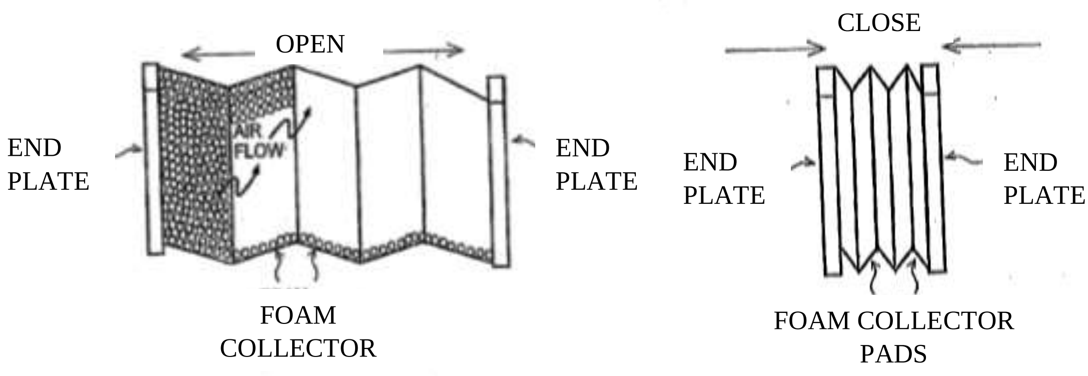


A	: Removal system	E	: Amine sorbent
B1	: 1st Sorbent beds	F	: Gas steam outlet valve
B2	: 2nd Sorbent beds	G	: Outlet valve
C	: A heat exchange system	H	: Controller
D	: Pump valve (mean for reducing pressure)	I	: Inlet valve

Figure 2.10: Carbon dioxide Removal system (Papale e*t al.,* 2012)

Regarding to the patent that invented by Prinz & Partner (2012), it has another method that can be used in other to remove CO_2 from air. The method is by using simple blocks of foam like filter material. Foam blocks have many advantages which are they can be shaped into arbitrary forms, they can hold some liquid and they are easily wetted; and open cell foams present a large internal surface area that can be used to absorb CO_2 from air flowing through the foam. A large foam block wetted with a liquid sorbent like NaOH or Na_2CO_3 will absorb CO_2 from the air.

Figures 2.11 (i) and 2.11(ii) shows flat plates squeezing the entire area of the foam collector pads. This would work particularly well for arrangements in which the airflow is aligned in the vertical direction and the compression of the foam is used to squeeze fluid in and out of the foam parallel to the air flow direction, which usually represents the smallest dimension of the foam pad.



(i): Open (ii): Close

Figures 2.11: Carbon dioxide remover (Prinz & Partner 2012)

It is also possible to turn the foam pad prior to squeezing and move it from an upright position into a horizontal position. A particular implementation where the foam is moving rather than the rollers would be design where the foam moves as a continuous loop. These loops could be arranged in various ways, in particular it is possible to run the loop vertically up and down, or run it horizontally.

2.9.2 Reducing PM_{10}

The research conducted by Park et al. (2012), two methods that they use to reduce the PM_{10} level inside the passenger cabins which are by using Cyclone Dust Collector and Roll-type filter as shown in figures 2.12 and 2.13 respectively.

The working principle of the PM separator is when air containing PM is intake into the tube, swirling flow is produced by vortex generator. When such whirl flow is produced, PM will removed out of the tube by centrifugal force of own weights and fresh air is only fed in the passenger cabin. This device is installed at inlet of HVAC system. Even the initial investment is large, but when the separator is applied, the PM level of passenger cabins may significantly reduce and PM larger than 4 micrometre will blocked from entering passenger cabins. This study shows that the dust collection efficiency was 98.8%.

Another method is by using roll-type filter. The roll filter is design for smooth air circulation with longer lifetime and smaller ventilation resistance. Two cross fans are installed at the both sides of filter for easy inflow air. The air blown in through the cross fans are sent to roll filter. The contaminated indoor air is purified passing the filter and is sent back to passenger cabins. This filter was design for easy maintenance with 6 month or longer replacement cycle rather than when used wire-mesh flat filters, its need every 5 weeks to replaced.

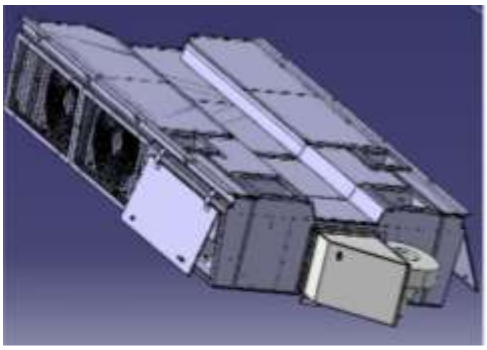


Figure 2.12: 3D image of cyclone type PM separator (Park et al., 2012)

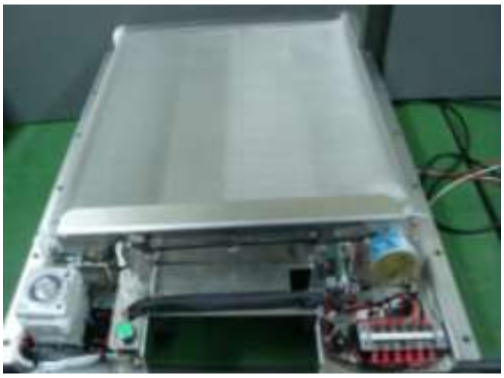


Figure 2.13: Prototype of roll filter (Park et al., 2012)

2.9.3 Reducing TVOC

To control TVOC accumulation in indoor air, air purifier device may use purifier air in the indoor environment. Hafsam (2011) was mentioned in his presentation, that there are many techniques to combat bacteria by using air purifier. Among the technique are ultraviolet germicidal irradiation (UVGI), Photoplasma, HEPA filter, activated carbon, photo catalytic oxidation (PCO) and many others.

Maghpor M.N (2011) was found that when he applied BioZone air purifier device in the training room and in the office, the TVOC level significantly reduced. The correlation between VOC concentration and duration also shows negative correlation coefficient. Figure 2.14 and Figure 2.15 shows the changes of TVOC level in training room and in the office.

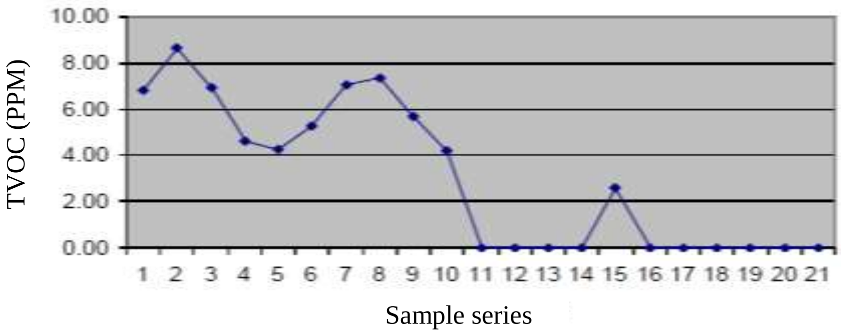


Figure 2.14: The changes of TVOC in Training Room (Maghpor M.N, 2012)

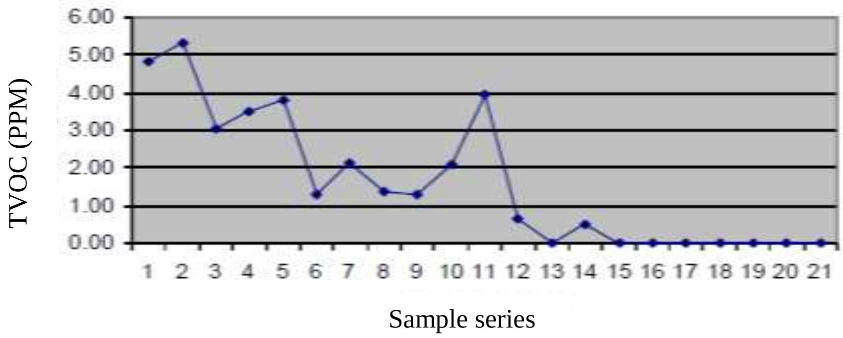


Figure 2.15: The changes of TVOC in Office (Maghpor M.N, 2012)

2.9.4 HAVC pressurization equipment

As mentioned before, increasing fresh air into cabin is the best way to reduce CO2 concentration in the cabin. The two major problems that always happened when allow fresh air entering the cabin is the energy need to cooling proses will increased and that will increase the operational cost. In order to solve the problem, Korea Train Express (KTX) was equipped with HVAC pressurization equipment (So *et al.*, 2008). Figure 2.16 shows the flap system that installed in KTX train

The equipment allowed the fresh air from the outside of the train to be mixed with inside air and it will provide the ideal atmospheric condition for passengers. When the train going through the tunnel, the KTX train used flap system for blocking the pressure waves from outside of the train. That arrangement protected the passengers from ear pains. At that time, the air circulated by returned air in the cabin.

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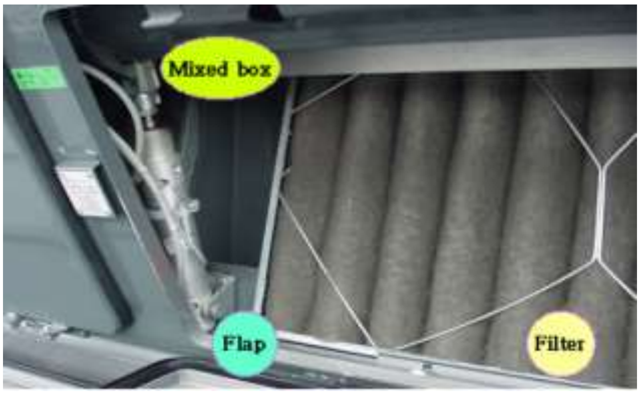

Figure 2.16: The photo of the flap system for blocking the pressure waves from outside of the train (So *et al*., 2008)

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the research work to be carried out, including the types of measuring tools used and the method of measurement. Eight parameters are involved in this research which is physical parameters (temperature, humidity and air movement) and chemical contaminant parameters ($CO_{2,}$ CO, TVOC and PM_{10}). In this chapter, the flow chart, equipment, and the procedure of data collection will be discussed. The details of equipment used will be explained and the analysis technique used in this study will be discussed. Figure 3.1 presents the flow chart of the research.

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