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Analysis of air quality and ventilation systems in production working areas of PT. A

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Abstract

PT. A is a manufacturing industry specializing in plastic-based cosmetic packaging. The work area of blow molding and injection molding 1 & 2 is the center of the company's main activity, involving many employees with diverse roles. The high density of work activity and heat-generating machines pose significant challenges to the workspace temperature, impacting worker health and well-being. Indoor air pollution levels, 2 to 10 times higher than outside, raise serious concerns, given people's prolonged indoor exposure. Poor air quality can lead to discomfort, health issues, and work accidents, affecting company operations and customer confidence. Three production units of PT. A were analyzed, focusing on air quality and ventilation systems. Primary data collection involved observations and interviews with four company informants regarding the ventilation system. Secondary data included direct measurements of air pollutants, dust particles, and environmental conditions by designated third parties. PT. A has implemented multiple mechanical ventilation systems to enhance airflow within the production area. Although the air quality in the blow molding and injection molding 1&2 workspaces meets the standards of the Minister of Manpower of the Republic of Indonesia No. 5 of 2018, the working climate in these three production areas exceeds the specified thresholds. Engineering interventions are recommended to address this issue and improve worker safety, health, comfort, and productivity without long-term consequences.

Keywords: Air Quality; Ventilation System; Workspace; Safety; Health

1. Introduction

Air is a vital element for the survival of humans and other living creatures on Earth. In addition to providing the oxygen needed for respiratory processes, air also contains a variety of other substances that play an important role in ecological balance and environmental health. In a study by 'Camelia (1), it is said that indoor water quality (IAQ) problems are also driven by the fact that the indoor air population will be more difficult to spread when compared to outdoor air'. The United States Environmental Protection Agency (EPA) also notes that indoor air pollution levels can be 2 to 5 times higher than those outside (2). This is a serious concern given that the majority of people spend most of their time, about 80 to 90 percent, indoors, including in homes, workplaces, restaurants, and other places (3).

Based on the United States Environmental Protection Agency (EPA) report, some factors can affect indoor air quality including air exchange rate, outdoor climate, weather conditions, and occupant behavior (4). 'Rukma et.al (5) also mention that there are several factors influencing air quality in a workplace including air contaminants such as biological contaminants, airborne dust particles, and physical factors comprising temperature, air quality, humidity, air circulation velocity, and the ventilation system used'.

According to 'Nahar et.al (6) the impact of indoor air pollution is more dangerous to human health when compared to outdoor air'. Poor air quality in the workplace can be a source of discomfort, health disorders, and even work accidents, which can ultimately affect the company's operations as well as the image and confidence of customers. Poor air quality can cause a variety of health problems such as eye, nose, and throat irritation, respiratory impairment, to chronic

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respiratory disease. Moreover, it can interfere with the comfort and concentration of workers increase the risk of work accidents, and reduce work productivity.

PT. A is one of the leading manufacturing industries in the production of various kinds of cosmetic packaging made of plastic. Their production area, which includes Blow Molding and Injection Moldings 1 and 2, became the core of the company's activities. In this workspace, the work involved a large number of employees engaged in various roles, ranging from operators to production technicians, and accompanied by the use of large-volume industrial machines. However, the main problem faced here is the significant increase in temperature in the production room. With the compact work activity and the use of heat-generating machines, the temperature of the working room is one of the major challenges facing workers in the field. This raises concerns about the well-being and productivity of workers, thus affecting the quality of the products produced by the company. Therefore, there is a need for further review of existing ventilation systems and efforts to improve air quality in such production areas to address the high-temperature problem.

2. Material and methods

The analysis unit or subject of writing the report is the Blow Molding and Injection Molding 1 & 2 production areas of PT. A. The object of this research is the air quality and ventilation systems in the production workspace. The data sources used in this study consist of primary and secondary data. Primary data were obtained through observation methods and interviews with four company informants related to the ventilation system used in the Blow Molding and Injection Molding 1 & 2 production areas of PT. A. Meanwhile, secondary data included direct measurements of air contaminant concentrations such as SO2, NO2, O3, NH3, H2S, CO, Pb gases/vapors, and dust particles, as well as direct measurements of physical environmental conditions such as the wet bulb temperature index consisting of dry temperature, wet temperature, radiation temperature, humidity, and air velocity by vendors or third parties with relevant certifications appointed by the company. From the collected data, descriptive statistical analysis techniques were then applied, and presented in narrative form to provide an overview of the actual situation.

3. Results and discussion

3.1. Air Contaminants in the Blow Molding and Injection Molding 1 & 2 Production Areas

Air contaminants or pollution are contaminations that occur within or outside the environment by chemical, physical, or biological agents that can alter the natural characteristics of the atmosphere (7). The measurement of pollutants at PT. A consists of several types of gases or vapors, including Sulfur Dioxide (SO2), Nitrogen Dioxide (NO2), Ozone (O3), Ammonium (NH3), Hydrogen Sulfide (H2S), Carbon Monoxide (CO), and Lead (Pb). Each of these hazardous gases or vapors is measured using calibrated measuring instruments such as a Spectrophotometer, AAS flame & AAS Graphite Fumace, and CO Meter GCO-2008. The measurement methods used for each type of gas or vapor also vary, involving several standards such as electrochemical techniques, the National Institute for Occupational Safety and Health Method (NIOSH), and the Occupational Safety and Health Administration Method (OSHA). In addition, dust particle measurements as air contaminants are conducted using Rocker Pump and Flow Meter instruments calibrated with measurement methods according to the SNI 16-7058-2004 standard for measuring total dust levels in workplace air. Next, the results of air contaminant measurements in the Blow Molding and Injection Molding production workspaces are presented in the following table.

Based on the data of air contaminant measurements in the production workspaces of Blow Molding and Injection Molding 1 & 2 as presented in the above table, several significant findings are evident. Firstly, the concentration of Sulfur Dioxide (SO_2) in the Blow Molding production workspace is 0.0002 ppm, while in Injection Molding 1 and 2, the SO_2 level is even lower, at < 0.0001 ppm. The SO_2 levels in these production areas are below the Threshold Limit Value (TLV) set by Regulation of the Minister of Manpower of the Republic of Indonesia No. 5 of 2018, which is 0.1 ppm. Similarly, the measurement results of Nitrogen Dioxide (NO_2) concentration in the Blow Molding production area show a value of 0.01 ppm, which also falls below the government's TLV of 0.2 ppm. Similar results are observed in the Injection Molding 1 and 2 production areas, with NO_2 levels of 0.004 ppm each. Furthermore, the measurement results of Ozone (O3) concentration in all three production workspaces indicate low levels compared to the government's TLV of 0.08 ppm, indicating the absence of ozone-producing equipment such as lasers, UV lamps, or ionizer machines.

Table 1 Air Contaminant Measurement Results in Production Workspaces of Blow Molding and Injection Molding 1&2 at PT. A

Workspace	Air Quality							
	SO2 ppm	NO2 ppm	O3 ppm	NH3 ppm	H2S ppm	CO ppm	Pb (mg/m3)	Total Dust (mg/m3)
Blow Molding	0.0002	0.01	<0.007	<0.0003	<0.012	<1	0.0003	0.001
Injection Molding 1	< 0.0001	0.004	<0.007	<0.0003	<0.012	<1	0.001	0.02
Injection Molding 2	< 0.0001	0.004	0.03	<0.0003	<0.012	<1	0.001	0.02

Source: PT. A

Likewise, the measured concentration of Ammonia (NH_3) in all three production workspaces also shows low levels, not exceeding the government's TLV of 25 ppm. The same applies to the concentration of Hydrogen Sulfide (H2S), which according to Regulation of the Minister of Manpower of the Republic of Indonesia No. 5 of 2018 has a TLV of 1 ppm, while in all three production workspaces, the measured H_2S level is even lower, at <0.012 ppm. Furthermore, the concentration of Carbon Monoxide (CO) is below the government's TLV of 25 ppm, indicating a production environment safe from CO exposure. Similarly, the concentration levels of Lead (Pb) and total dust in each of the production workspaces are also low, indicating compliance with the government's TLV requirements of 0.05 mg/m^3 for Lead (Pb) and 10 mg/m^3 for total dust.

Based on the results of air contaminant measurements in the production workspaces of Blow Molding and Injection Molding 1&2 at PT. A, it is found that these three production areas have air quality that meets the expected standards. The measured air quality has fulfilled the requirements for implementing workplace housekeeping as a form of hygienic environment. Thus, the air quality in these three production workspaces can be indicated as safe and healthy for the workers as it complies with the regulations set forth by the Minister of Manpower of the Republic of Indonesia No. 5 of 2018.

3.2. Working Environment Climate in the Production Areas of Blow Molding and Injection Molding 1 & 2 at PT. A

Table 2 The Results of Wet Bulb Globe Temperature (WBGT) Measurement in the Production Workspaces of Blow Molding and Injection Molding 1&2 at PT. A

Workspace	Clothing	Type WBGT Correction Value (°C)	Allocation of Working Time and Rest in One Work Cycle	Metabolic Rate Category	Total WBGT (°C)	TLV (°C WBGT)
Blow Molding	A polo shirt and long pants	0	100%	Moderate	28.3	28.0
Injection Molding 1	A polo shirt and long pants	0	100%	Moderate	30.5	28.0
Injection Molding 2	A polo shirt and long pants	0	100%	Moderate	29.1	28.0

Source: PT. A

The working environment climate can be determined using the Wet Bulb Globe Temperature (WBGT) index assessment, which takes into account dry temperature, wet bulb temperature, and radiant heat temperature along with the body heat dissipation rate of the workers as a consequence of the work performed. Concluding the Threshold Limit Value (TLV) of the working environment climate based on the standards of the Minister of Manpower of the Republic of

Indonesia No. 5 of 2018 is determined by considering the WBGT correction values for the type of work clothing worn by the workers, allocation of work and rest time within one work cycle, and the category of metabolic rate.

Based on the data from the measurement of the production working environment climate in the Blow Molding and Injection Molding 1 & 2 workspaces conducted by a third party or vendor appointed by the company to perform such tests, can be seen in the following table:

Based on the results of the Wet Bulb Globe Temperature (WBGT) workplace climate measurements in the three production workspaces, as presented in Table 2.2, it can be observed that these workspaces have WBGT values with relatively high severity levels, exceeding the government-established TLV of 28ºC. These findings depict poor working climate conditions and indicate potential risks to the safety, health, and comfort of the workers.

3.3. Ventilation System in the Blow Molding and Injection Molding 1 & 2 Production Areas at PT. A

The ventilation system has an impact on air quality and hot working climates in the workplace environment. An adequate ventilation system is designed to ensure sufficient air circulation, regulate air temperature and humidity, and remove or reduce air pollutants within the workspace.

Based on interviews, initially, the blow molding and injection molding production areas were equipped with natural ventilation but were later covered with acrylic to comply with Good Manufacturing Practice (GMP) policies to minimize the risk of dust or insect contamination. Mechanical ventilation systems became an important consideration when natural ventilation available in the production areas was insufficient. With the semi-close room workspace characteristics, these production areas require mechanical ventilation systems to ensure optimal air circulation. Referring to SNI 03-6572-2001 requires a mechanical ventilation system when natural ventilation is inadequate. Furthermore, the standard states that closed buildings or rooms must be equipped with mechanical ventilation systems to remove dirty air from inside, and at least 2/3 of the room's air volume must be at a maximum height of 0.6 meters from the floor. The recommended air exchange rate for mechanical ventilation can be adjusted according to the type of building or workspace. According to the SNI 03-6572-2001 standard, factory buildings must have a minimum fresh air supply of 18 m^3/h per person.

The observation results show variations in the types of mechanical ventilation systems installed in each production area. The blow molding production area is equipped with 8 blowers and 28 roof-mounted turbine ventilators, as well as 5 exhaust fans on the walls. Meanwhile, the injection molding 1 production area has 6 blowers, 17 roof-mounted turbine ventilators, and 5 exhaust fans installed on the roof and walls of the production building. On the other hand, the injection molding 2 production area is only equipped with 2 exhaust fans since it was originally designed for a closed workspace type.

Given that the air pollutant measurements did not exceed the threshold values in the three production areas, the hot working climate in these workspaces indicates the complexity of poor working environment conditions. Although the air quality in the production areas is maintained within safe limits, the excessively hot conditions raise concerns about worker welfare and productivity. This suggests that other factors may be influencing these conditions. According to interviews, the company does not have standards for planning mechanical ventilation systems. The company does not have specific standards for determining the specifications of the installed ventilation systems, nor are there specific calculations related to the location points for installing these ventilation systems in the production areas. Additionally, the company lacks data on the suction capacity in the specifications of the mechanical ventilation used, which could potentially affect the actual required number of ventilation systems.

These conditions are not aligned with the requirements in SNI 03-6572-2001 regarding the design of mechanical ventilation systems. According to this standard, ventilation design must be adjusted to the ventilation air needs and room functions, fan capacity, and air distribution systems, whether using air ducts or fans installed on walls or roofs. Adjustments are needed to ensure that the airflow rates provided by the ventilation system are in line with room requirements, maintain stable indoor air temperatures, are comfortable for workers, and ensure the quality of the products produced is maintained.

Furthermore, observations of the ventilation system conditions in the three production areas indicate that the turbine ventilators and wall-mounted exhaust fans are in good and serviceable condition. Moreover, the replacement of wall-mounted exhaust fans with new units in all three production areas indicates maintenance and repair efforts by the company. However, special attention needs to be given to the blower ventilation system, which appears to be very dirty and dusty. Information from interviews indicates that this condition is due to limited equipment or manpower to clean the blowers, especially considering the height of the building and the high frequency of blower usage in supporting daily production processes. As is known, inadequate maintenance of the ventilation system can lead to serious problems. Dirty air filters or clogged ventilation can obstruct the flow of fresh air into the production area, which can ultimately worsen the working climate conditions inside the production area.

3.4. Improvement Efforts for Hot Working Climate Conditions in the Blow Molding and Injection Molding 1 & 2 Production Areas at PT. A

a. Establishing the standard air circulation requirements or Cubic Meter Hour (CMH) within the Blow Molding and Injection Molding 1 & 2 production areas.

The need for exhaust fans in a room is based on the principle that the volume of air expelled by the exhaust fan must be sufficient to evacuate dirty or contaminated air from the room. The calculation to select a ventilating fan suitable for the Blow Molding and Injection Molding 1 & 2 production areas is as follows:

$$CMH = Room\,Volume\ \times ACH$$

Where :
CMH = Cubic Meter Hour or the need for air circulation within the room
Room volume = volume of the production room in cubic meters (m^3)
Air Changes per Hour (ACH) = the required air changes per hour within the room

Given:
Air Changes per Hour (ACH) for the production area = 5 times
Volume of the Blow Molding room = 60m × 20m × 10m
Volume of Injection Molding 1 room = 60m × 20m × 12m
Volume of Injection Molding 2 room = 30m × 20m × 10m

Thus, for each production room, the air circulation requirement can be calculated as follows:

1) Blow Molding :
CMH = 12000 × 5 = 60000 m^3/hour
2) Injection Molding 1:
CMH = 14400 × 5 = 72000 m^3/hour
3) Injection Molding 2 :
CMH = 7200 × 5 = 36000 m^3/hour

Therefore, the air circulation requirements in each production room are as follows 60.000 Cubic Meter Hour for Blow Molding, 72.000 Cubic Meter Hour for Injection Molding 1, and 36.000 Cubic Meter Hour for Injection Molding 2.

b. Establishing the required opening area size for grill louvers in HVAC (Heating, Ventilation, and Air Conditioning) systems.

Static pressure is used to calculate the required opening area size for grill louvers in HVAC (Heating, Ventilation, and Air Conditioning) ventilation systems. Grill louvers are components of the ventilation system designed to protect it from external elements such as rain, insects, or other objects that may enter the system. Additionally, grill louvers play a role in directing the airflow, both into and out of the room, as well as regulating air distribution within the room. To determine the required opening area size for grill louvers, the following formula is used:

$$A = \frac{Q/3600}{v}$$

Where:
A = Area Size (m^2)
Q = Desired airflow (CMH)
v = Air velocity (m/s)

Given:
Air velocity = 1.5 m/s

Therefore, for each production area, the required opening area for the grill louver in the HVAC ventilation system is calculated as follows:

Table 3 Calculation of the required opening area size for grill louvers in the HVAC ventilation system in the production workspaces of blow molding and Injection molding 1 & 2

Work Area	**Air Change per Hour**	**Air Velocity (m/s)**	**Ventilation Capacity (m^3/h)**
Blow Molding	5	1,5	60000
Injection Molding 1	5	1,5	72000
Injection Molding 2	5	1,5	36000

1) Blow Molding :

$$A = \frac{Q/3600}{v} = \frac{60000/3600}{1.5} = \frac{16,6}{1.5} = 11,1 \text{ m}^2$$

$$\text{Size grill louver} = \frac{A}{\text{Free grill area (\%)}} = \frac{11,1}{0,8} = 13,8 \text{ m}^2$$

2) Injection Molding 1 :

$$A = \frac{Q/3600}{v} = \frac{72000/3600}{1.5} = \frac{20}{1.5} = 13,3 \text{ m}^2$$

$$\text{Size grill louver} = \frac{A}{\text{Free grill area (\%)}} = \frac{13,3}{0,8} = 16,6 \text{ m}^2$$

3) Injection Molding 2 :

$$A = \frac{Q/3600}{v} = \frac{36000/3600}{1.5} = \frac{10}{1.5} = 6,6 \text{ m}^2$$

$$\text{Size grill louver} = \frac{A}{\text{Free grill area (\%)}} = \frac{6,6}{0,8} = 8,2 \text{ m}^2$$

By knowing the calculated opening area required for the grill louver in each production area, can serve as a basis for determining the appropriate size of the grill louver needed. With the required dimensions identified, the next step is to select a grill louver that matches these calculations. The chosen grill louver should provide adequate ventilation to optimize air circulation within the production space, while also meeting the requirements for balanced air distribution and maintaining good air quality.

4. Conclusion

Based on the ventilation system analysis in the Blow Molding and Injection Molding 1 & 2 production areas at PT. Several key findings can be identified. Despite Blow Molding being equipped with a more comprehensive ventilation system compared to Injection Molding 1 and 2, the overall adequacy of mechanical ventilation remains a concern. The evaluation also highlights significant heat stress in all three production areas, which can impact the well-being and productivity of workers. The lack of clear standards in ventilation system planning and inadequate maintenance are major challenges. Observations reveal dust accumulation on blowers, highlighting maintenance challenges that need to be addressed. The implementation of standards for indoor air circulation requirements in production areas and the calculation of opening area sizes for grill louvers provide crucial guidance in selecting appropriate ventilation equipment. Overall, addressing these issues and implementing appropriate improvements will be crucial in creating a safer and healthier work environment for employees.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest is to be disclosed.

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