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ORIGINAL ARTICLE

Designing a Local Exhaust Ventilation System to Control Toluene Diisocyanate and Dust in Woodworking Industries

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ABSTRACT

Spreading wood particles and attached colored materials in workplaces can cause many problems for woodworking industry workers. The aim of this study was to design and implement a local exhaust ventilation system to control wood dust and toluene diisocyanate simultaneously. The study was conducted on 18 workstations in the paint plant of a wood door industry in west Azarbaijan, 2015. The National Institute for Occupational Safety and Health (NIOSH) 500 and 5522 methods were used to measure the concentration of wood dust and TDI (2, 4-toluenediisocyanate), respectively. In order to control the worker exposure to the pollutants, a semi-downdraft spray chamber was chosen and implemented based on American Conference of Government Industrial Hygienists (ACGIH) control air pollution method. Finally, after the establishment of a new ventilation system, the emissions were re-measured and the results were evaluated. Before design and implementation of local exhaust ventilation system, the emissions in workstations were measured as 0.0165 ± 0.0025 ppm for TDI and 0.42±0.01 mg/m3 for total dust. The concentration of TDI and total dust after implementing the local exhaust ventilation system were measured respectively as 0.003± 0.0007 ppm and 0.15± 0.07, which had a significant ($P<0.05$) lower concentration than before the implementation. In addition, the measured concentrations after the implementation had met the ACGIH limits. The system efficiency for wood dust and TDI were 64% and 82% respectively. After design and implementation of the spray chamber, both pollutants were significantly decreased ($P<0.05$).

KEYWORDS: *Ventilation system, Spray chamber, Toluene diisocyanate, Woodworking industry*

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INTRODUCTION

Wood is a natural material used in the woodworking industry and construction of various facilities. Woodworking industry is one of the industries where workers are exposed to dust and organic solvents.

Isocyanates as subsets of the organic solvents are highly reactive compounds, found in raw materials of woodworking industries such as polyurethane foam, glue, and paints [1-2]. Wood and Toluene diisocyanate in the workplace cause different diseases due to their stimulant properties [2-3].

Wood dust can cause allergic rhinitis and diseases such as asthma. All organic solvents affect the central nervous system and skin. Workers who work with organic solvents inhale its vapors and their skins are exposed to these materials. Solvents may cause dermatitis and other different burns on the skin. However, on average, the risk of exposure to these chemicals in paint plants, have been reported 80 times more than other industrial units [3-6]. From 2002 to 2003, 3.6 million workers in Europe were exposed to wood dust [2].

Clean air in the workplace is very important. The pollutants must be prevented from entering the worker's respiratory system. The first way to achieve this goal is to apply technical measures. Ventilation system design is the most important measure to control the workplace pollutants [7-8]. Toluene diisocyanates lead to occupational asthma, and dust particles besides their health effects can reduce the quality of production, too. The proper ventilation system can reduce these effects [9].

The suction hood (in most cases, the capture velocity is about 0.5 meters per second) cannot control exhausted pollutants of painting gun (exhaust velocity is about 100 m per sec) and be unsuitable for controlling the isocyanates [10-11]. Painting workstations can spray up to 1.5 ppm of toluene diisocyanate. However, TLVTWA is 0.005ppm for TDI by the American Conference of Government Industrial Hygienists (ACGIH) standards. The exposure to isocyanate is 300 times more than the Threshold Limit Values [12].

This practical descriptive study was conducted with the aim of surveying and measuring the wood dust and TDI (2,4-toluenediisocyanate) pollutants and improving the workspace air quality by designing and implementing a new and appropriate ventilation system.

MATERIALS AND METHODS

The study was conducted on 18 workstations in the paint plant of a wood door industry in west Azarbaijan, 2015. In this workshop workers were painting by spraying with paint gun. The workshop was located in a place near a carpentry workshop and woodwork dust arising from the carpentry workshop was spread over the place under study. In addition, other activities such as sanding and removing of wood dust were caused workers exposed to combination of wood dust and isocyanates. The study steps are as follows:

A review of work plan and emission sources position: The chosen workroom had 10 workstations that were located beside the local exhaust ventilation system that is conventional exhaust fans without any airflow Information. Workers were painting the pieces using airbrush gun. After completing the activity, the pieces were transferred to the dryer. The activities such as release of dust from sanding and removing segments can cause increased exposure to wood dust. Fig. 1 shows a Schematic overall view of the research area.

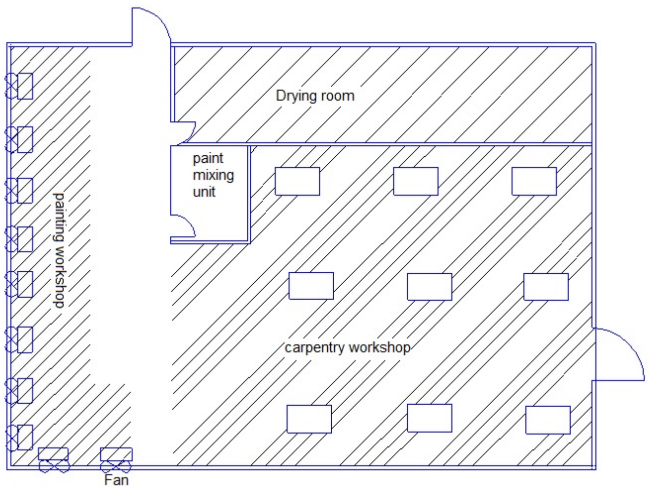

Fig.1. Schematic overall view of the research area, drawing by AutoCAD 2016 software

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Survey of contaminants before designing and implementing the spray chamber: Two pollutants, 2,4- toluene diisocyanate and wood dust, were examined in this study. To assess these emissions, the National Institute for Occupational Safety and Health (NOISH) Method 5522 were used. Two, four-toluene diisocyanate was sampled using a calibrated personal sampling pump (Model SKC XR) and impinge containing 2 ml of sampled medium of tryptamine 99% in dimethyl Sulfoxide. In addition, to measure the dust, NOISH500 method of sampling using calibrated pump (Model SKC XR) and a diameter of 37 mm PVC filter. Sampling of all workers was done in the worker's breathing zone before design and implementation in the workroom. In order to analyze the Toluene diisocyanate samples, a high-performance liquid chromatography device (HPLC) Manufacturing Co. (Berlin, Knauer Germany), with fluorescence detector (Shimadzu RF 10AXL), chart, columns and pumps recorder (Knauer smart line 1000 solvent pump) was used as well as Sartorius Scale to determine the wood dust weight with 0.01 accuracy.

Design, installation, and implantation of spray chamber system:

- ***Ventilation system***

The spray chamber was designed for a workstation including four workers. Studies on ventilation of velocity pressure according to the American Conference of Government Industrial Hygienists (ACGIH) were conducted. Depending on the type of contaminants, the Semi-down (semi-downdraft) spray chamber was selected. Capture velocity was determined in accordance with the VS-15-01 ACGIH recommendations and based on the other technical features. The system airflow was determined based on the relations between the area and required velocity (Equation 1). According to the available space in the workshop and airflow, the duct's diameter was calculated Pressure drop across the duct was calculated using the equations provided by Murphy and the velocity pressure method [6].

Other calculated parameters are the duct velocity (by equation (2)), the relation between the static pressure and velocity pressure, the pressure drop and the fan total pressure (FTP). The effect of environmental conditions on the ventilation pressure was determined using the density factor. Finally, the suitable ventilation was selected based on the ACGIH multi-rating table. Airflow rate was corrected for air temperature and pressure.

(Equation1):

$$Q=VA=WHVs$$

- ***Filtration system***

In order to prevent the entry of pollutants into the environment, a wet scrubber named orifice scrubber can be used in industrial painting rooms. The collected air will be passed through a narrow way using water to wash unwanted pollutants from the gas stream. The sludge generated from the new ventilation system was sent to the central sewer system in industrial zone powered by a suitable purification system to purify the isocyanates [13]. Fig. 2 shows a Schematic overall view of designed ventilation system.

Pollutant measurement after designing and implementing the spray chamber: Pollutants in indoor spraying were measured in four breathing zones for each worker based on the previous implementation method.

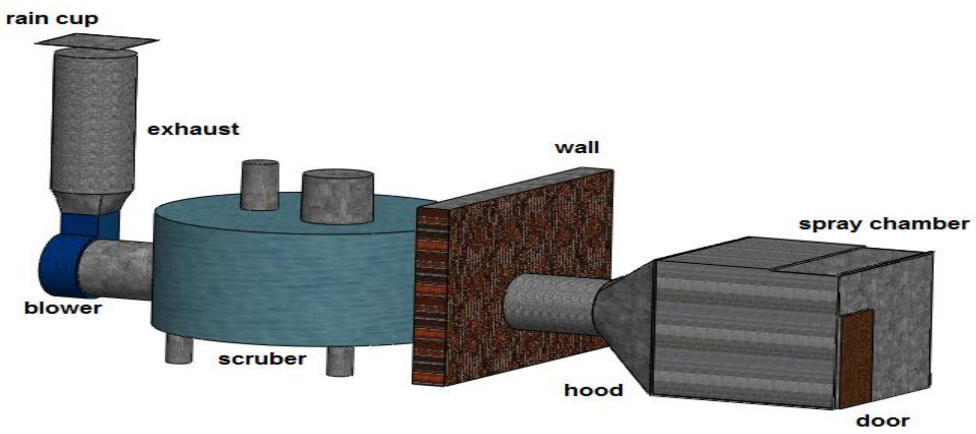

Fig. 2. The designed ventilation system, drawing by solid works 2014 software

Designed ventilation system efficiency: The new system efficiency is calculable through the equation 2 [13]. In this formula, the terms Cbefore and Cafter refers to concentration of pollutant before and after designing and implementing of the new ventilation system, respectively.

(Equation 2):

Efficiency= $(C_{before} - C_{after})/C_{before}$ ×100

RESULTS

Result of the pollutant concentrations measurement before the design and installation of the spray chamber: Measurements have shown that the concentration of 2,4-toluenediisocyanate at workstations exceeded the Threshold Limit Value - Time Weighted Average (TLV-TWA) but the concentration of wood dust was less than the TLV-TWA. The results of 18 measurements of work ambient showed that the concentration of 2,4-toluenediisocyanate and wood dust were respectively 0.0165 ±0.0025 ppm and 0.42±0.01 mg/m^3.

Design and implementation of the spray chamber:

- ***The spray chamber dimensions***

The spray chamber dimension was determined based on the dimensions of the largest piece supposed to be sprayed there. Therefore, the length, width, and height in feet were respectively 8.202, 8.202, and 7.217.

- ***Required airflow***

According to American Conference of Governmental Industrial Hygienists (ACGIH- 40 CFR 63.2984(e)), the required capture velocity (Vs) for painting contaminants is 100 FPM. To determine the required airflow for the spray chamber, the equation 1 was used.

Q=VA=WHVs=8.202×7.217×100= 5919.383CFM

- ***Duct diameter***

To move the painted particulates into ducts, the inlet pressure velocity must be 5 ”wg so that the particulates do not settle. Hence, Q = 5919.383 CFM and Vp = 5 ”wg, and the duct area (A), the duct diameter was calculated below:

(Equation 3):

$$\mathrm{Vp} = (\frac{\mathrm{V}}{4005})^2$$

(Equation 4):

$$D^2 = \frac{4A}{\pi}$$

V = 8955.452 FPM

Q =VA, A = 0.66 Ft

D = 0.916Ft

- ***Pressure drop calculation***

Calculating pressure drop in all parts of the ventilation system is necessary to select the appropriate fan power. Figure3 shows critical points of the ventilation system. All calculations related to pressure drop in the ventilation system are shown in Table 1.

- ***Air purifying***

Based on the main present pollutant in the painting room (organic solvents) Orifice scrubber was used. The orifice scrubber is kind of wet scrubbers which removes the pollutants from the gas by water.

Table 1. The pressure drop calculation in the ventilation system

Step	Title	Description	Calculation*	Results
2-4-1	**The duct pressure drop**	According to the design, the duct length (except the outlet) was 2 meters, 1 meter (3.28 Ft) to be connected to the hood for filtering and purifying and 1 meter (3.28 Ft) to be connected to the blower with 0.916Ft diameter.	$\mathrm{Hf} = \frac{\mathrm{F}}{\mathrm{D}} = \mathrm{a}\frac{\mathrm{V^b}}{\mathrm{Q^c}}$, $H_L = LV_p H_f$	H_L =0.316 ”wg, Total inlet pressure drop to the blower: 2×0.316 = 0.632 ”wg
2-4-2	**Hood pressure drop**	Based on the space we had in the workstation, a 45degrees hood was used.	H_L= 0.15*Vp	H_L = 0.75 ”wg
2-4-3	**Outlet *duct* expansion (*Evase*) pressure drop**	Due to the 5 ° increasing angle, reduction in airflow and increase in length of 2.1 Ft, the outlet secondary diameter was 1.284 Ft.	H_g=R.(V_{p2}-V_{p1})	H_g =3.256 ”wg
2-4-4	**chimney tube's drop**	Chimney length is 4 meters (13.123FT)	$Hf = \frac{F}{D} = a\frac{V^b}{Q^c}$ $H_L = LV_pH_f$	H_L = 0.194 ”wg
2-4-5	**rain cap pressure drop**	-	H_{lcap}=K_{ca} .Vp	H_{lcap} =0.949 ”wg
2-4-6	**Orifice scrubber pressure drop**	Pressure drop based on the manufacturer's recommendations was 3-6 ”wg and for designing, the maximum pressure drop was considered of 6 ”wg.	-	H_L = 6 ”wg

* All equations are derived from ACGIH. Industrial ventilation 23rd Edition requirements [7]

Static Pressure calculation: Based on the airflow and pressure drop in different parts, velocity pressure and the static pressure have been determined. All calculations related to static pressure in critical points of the ventilation system performed based on the equations mentioned in ACGIH [7] is shown in Table 2.

Calculation of Fan Total Pressure (FTP): The total pressure in the exhaust was the increased total pressure:

$FTP= TP_{OUT} – TP_{IN}$ Equation5
$FTP= (SP+VP)_{OUT} – (SP-VP)_{IN}$
FTP= (3.256+5) – (-12.382+5)
FTP= 15.638 ”wg

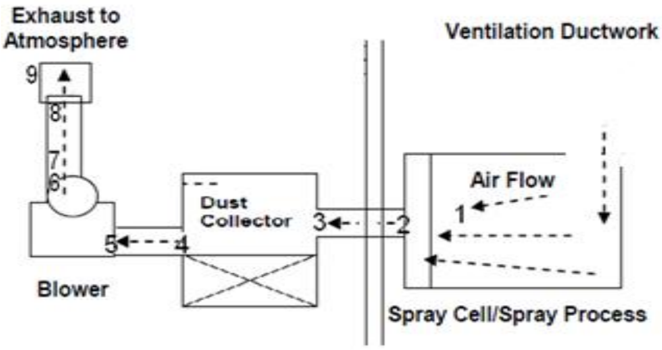

Fig.3. Critical points of the ventilation system

Table 2. The calculations related to static pressure in critical points of the ventilation system

Point number	Description	Calculation	Results
1	At this point, because of the low amount of pressure drop outside the hood and due to the static pressure’s thermal situation, the outside pressure was considered as well as the atmospheric pressure and the velocity was negligible.	-	S_{p1}= 0
2	Due to the hood’s pressure drop and the required velocity pressure for suction, the isocyanates static pressure was determined to be equal to 5.75 ”wg	$S_{p1}+V_{p1}= S_{p2}+V_{p2}+H_L$	S_{p2}= -5.75 ”wg
3	Effect of duct losses on the static pressure and velocity pressure	$S_{p2}+V_{p2} =S_{p3}+V_{p3}+ H_f$	S_{p3}= 6.066 ”wg
4	Scrubber drop effect on the static pressure and velocity pressure	$S_{p3}+V_{p3} =S_{p4}+V_{p4}+ H_f$	S_{p4}=-12.066 ”wg
5	-	$S_{p4}+V_{p4} =S_{p5}+V_{p5}+ H_f$	S_{p5}=-12.382 ”wg
6	Outlet duct expansion (*Evase*) effect on the static pressure and velocity pressure	$S_{p7}= S_{p6}- H_g$	S_{p6}= 3.801 ”wg
7	Outlet drop effect on the static pressure and velocity pressure	$S_{p8}+V_{p8}+ H_L =S_{p7}+V_{p7}$	S_{p7}=0.545 ”wg
8	Rain cap drop effect on the static pressure and velocity pressure	$S_{p9}+V_{p9}+ H_{lcap} =S_{p8}+V_{p8}$	S_{p8}=0.351 ”wg
9	This point will be out of the rain cap, the outside pressure was considered as well as the atmospheric pressure and the velocity was negligible.	-	S_{p9}=0

Determination of Fan Static Pressure (FSP): Fan static pressure was calculated using static pressure formula listed on the ACGIH [5].

$FSP=FTP-VP_{OUT}$ ***(Equation6)***
FSP=15.638 – 5= 10.638 ”wg

Density correction: When the air temperature is less than 100 °F, the humidity correction is not necessary. In order to correct the density, the FTPs = FTP × dF equation was used where dF was the density correction factor and was achieved through tables of the industrial ventilation handbook [7]. To be able to calculate dF, the altitude above sea level and ambient temperature must be available. Due to the altitude of 10 meters (32.8 feet) and an ambient temperature of 24 °C (75.2 °F) in this study, dF was obtained by an interpolation of approximately 0.98.
As a result,

$FTPa = \frac{FTPs}{dF} = \frac{15.638}{0.98} = 169”wg$ ***(Equation7)***

Fan selection: According to Table 3 (the

ACGIH multi-rating table), a fan with the ability to pass a large volume and low static pressure were needed. The first option in choosing fan was vane axial fan (with tube air conductivity) that was able to produce up to 16 inches of water pressure. Therefore, the fans with 24.7 HP power and 2594 RPM had been suitable for this location.

Table 3. ACGIH multi-rating table [7]

VEL FPM	PIPE DIAMETER & AREA IN SQ.FT. 4" 0.0873		5" 0.1364		6" 0.1963		7" 0.2673		8" 0.3491		10" 0.5454		12" 0.7854		14" 1.0690		16" 1.3963		18" 1.7671	
	CFM	FL	CFM	FL	CFM	FL	CFM	FL	CFM	FL	CFM	FL	CFM	FL	CFM	FL	CFM	FL	CFM	FL
2600	227	3.10	355	2.36	511	1.89	695	1.57	908	1.33	1418	1.01	2042	0.81	2779	0.67	3630	0.57	4595	0.50
2800	224	3.57	382	2.72	550	2.18	748	1.80	977	1.53	1527	1.17	2199	0.93	2993	0.77	3910	0.66	4948	0.57
3000	262	4.07	409	3.10	589	2.48	802	2.06	1047	1.75	1636	1.33	2358	1.07	3207	0.88	4189	0.75	5301	0.65
3200	279	4.6	436	3.51	628	2.81	855	2.33	1117	1.98	1745	1.50	2513	1.20	3421	1.00	4468	0.85	5655	0.73
3400	297	5.16	464	3.93	668	3.15	909	2.61	1187	2.22	1854	1.69	2670	1.35	3635	1.12	4747	0.96	6008	0.82
3500	305	5.46	477	4.16	687	3.33	935	2.76	1222	2.34	1909	1.78	2749	1.43	3742	1.18	4887	1.01	6185	0.87
3600	3.14	5.76	491	4.39	707	3.51	962	2.91	1257	2.47	1963	1.88	2827	1.51	3848	1.25	5027	1.06	6362	0.92
3700	323	6.06	505	4.62	726	3.70	989	3.06	1292	2.60	2018	1.98	2906	1.59	3955	1.32	5166	1.12	6538	0.97
3800	332	6.38	5.18	4.86	746	3.89	1016	3.22	1326	2.74	2073	2.09	2985	1.67	4062	1.38	5306	1.18	6715	1.02
4000	349	7.03	545	5.36	785	4.29	1069	3.55	1396	3.02	2182	2.30	3142	1.84	4276	1.53	5585	1.30	7069	1.12
4200	367	7.72	573	5.88	825	4.71	1122	3.90	1466	3.31	2291	2.52	3299	2.02	4490	1.67	5864	1.42	7422	1.23
4400	384	8.43	600	6.42	884	5.14	1176	4.26	1536	3.62	2400	2.76	3456	2.21	4704	1.83	6144	1.55	7775	1.35
4500	393	8.80	614	6.70	884	5.36	1203	4.44	1571	3.78	2454	2.88	3534	2.30	4811	1.91	6283	1.62	7952	1.40
4800	419	9.94	654	7.57	942	6.06	1283	5.02	1676	4.27	2618	3.25	3770	2.60	5131	2.16	6702	1.83	8482	1.59
5000	436	10.7	682	8.19	982	6.55	1336	5.43	1745	4.61	2727	3.51	3927	2.81	5345	2.33	6981	1.98	8836	1.72
5200	454	11.6	709	8.82	1021	7.06	1390	5.85	1815	4.97	2836	3.79	4084	3.03	5559	2.51	7261	2.13	9189	1.85
5500	480	12.9	750	9.81	1080	7.85	1470	6.51	1920	5.53	3000	4.21	4320	3.37	5880	2.79	7679	2.37	9719	2.06
5600	489	13.3	764	10.2	1100	8.31	1497	6.73	1955	5.72	3054	4.36	4398	3.49	5986	2.89	7819	2.46	9896	2.13
5800	506	14.2	791	10.8	1139	8.7	1550	7.2	2025	6.1	3163	4.7	4555	3.7	6200	3.1	8098	2.6	10249	2.3
6000	524	15.2	818	11.6	1178	9.3	1604	7.7	2094	6.5	3272	5.0	4712	4.0	6414	3.3	8378	2.8	10603	2.4
7000	611	20.4	954	15.5	1374	12.4	1871	10.3	2443	8.7	3818	6.7	5498	5.3	7483	4.4	9774	3.7	12370	3.2

The results of measuring the concentration of pollutants in the paint spray chamber: After designing and implementing the spray chamber, the sampling was repeated in the worker's environment [6] where the concentrations of 2,4-toluenediisocyanate and wood dust were examined. The concentration of TDI in the spray chamber was 0.003 ± 0.0007 ppm and the total dust was 0.15 ± 0.07 ppm for this workstation.

Air-conditioning efficiency: The system efficiency for wood dust and TDI were determined 64% and 60%, respectively. According to the equation2, and the concentrations of TDI and wood dust before and after the implementation of new ventilation system, the efficiency was calculated through the following statements [13]:

$$E_{isocyanates}=\frac{0.0165-0.003}{0.0074}\times 100 = 82\%$$

$$E_{wood\ dust}=\frac{0.42-0.15}{0.42}\times 100 = 64\%$$

DISCUSSION

Wood dust and isocyanates Exposure cause the pulmonary diseases [2]. Because of some hazardous pollutants in wood industry, designing and complementing of appropriate ventilation system seems very necessary to prevent work-related diseases as one of the priorities in such industries. Threshold Limit Value (TLV_{twa}) for TDI and wood dust were 0.005 PPM and 0.5mg/m^3 respectively [9-10].

In this study, toluene diisocyanate and wood dust were measured before and after the implementation of the new ventilation system. The first result showed that TDI (0.0165 ± 0.0025 ppm) was above the Threshold Limit Value TLV_{twa}, although the wood dust concentrations (0.42 ± 0.01 mg/m^3) were below the occupational exposure limit. Therefore, the local exhaust ventilation was adequate for dust.

The local exhaust ventilation system is a good way to control wood dust, but it is better to use the spray chamber to control isocyanates. Proper design of spray chambers can reduce about 90% of the air pollution exposure [15].

The effect of spray chamber was surveyed in various workrooms. In most workplaces, the downdraft spray chamber with 8800CFM average airflow was being used [16]. In 81% of downdraft spray booth, 74% of semi-downdraft spray booth and 92% of cross flow spray chambers, the worker exposure to toluene diisocyanate exceeded the recommended limit that shows the spray booths had an ineffective design in most cases [13].

In the present study, semi-downdraft spray chamber was used. In addition, according to the type of pollutants and other factors affecting the design, the airflow was calculated 6000CFM. Measurement results after the installation of the new ventilation system showed the significant difference (*P*<0.05) in the concentrations of both pollutants, also measured values were less than the occupational exposure limits.

Concentration of wood dust was less than the standard limit before and after the implementation of the new ventilation systems. Concentration of toluene diisocyanate before the implementation of the new ventilation system exceeded the permissible exposure limit although it was reduced to less than the permissible exposure limit after designing. The designed system efficiency in other studies has not been calculated [8, 12, 14]. After the implementation of the new ventilation system, the system efficiency for wood dust and toluene diisocyanate were determined 64% and 82% respectively. This is because of this spray chamber's structure designing for organic solvents.

CONCLUSION

After implementation of new ventilation system, the output concentrations of both pollutants have been decreased to less than the occupational exposure limits, which shows that the purpose of study has been achieved. The new ventilation system is efficient for using in the mentioned workroom. Hence, the designed ventilation system can be recommended for similar workplaces.

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