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VOC level control by ventilation improvement of Flexography printing room using CFD modeling

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Abstract

Using Computational Fluid Dynamics (CFD) technique, the dispersion contours and the exposure rate of Flexographic printing workers to VOCs in a printing department is evaluated. Firstly, VOCs distribution is determined in the printing room due to the existing ventilation system. Through next steps, 4 scenarios for lowering VOCs concentration and its exposure rate to workers are analyzed. Concentration distributions of ethylene glycol (MEG) as a representative of VOCs are determined for 4 scenarios. The results show that, regarding the existing ventilation, the concentration of MEG at the breathing height is 1×10-5 mg/m^3 and it is higher than the standard permissible level. Finally, the findings of this study lead to lowered VOCs concentrations to 13.87×10-9 mg/m^3 via changing the ventilation system for the Flexography Printing Room.

Keywords: CDF, VOCs pollution, Numerical modeling, Turbulence, Flexography printing.

1. Introduction

Indoor air quality is a major concern for businesses, building managers, tenants, and employees because it can influence the health, comfort, well-being, and productivity of the building occupants. Most people spend 80% of their time indoors and many spend most of their working hours in an office environment [1-7].

Studies conducted by the U.S. Environmental Protection Agency conclude that indoor environments may sometimes show levels of pollutants that are in fact higher than outdoor levels [8]. Pollutants in an indoor environment can increase the health risks. Several studies by USA/EPA, states, and independent scientific panels have consistently ranked indoor air pollution as an important environmental health quality problem [8].

While most buildings do not have severe indoor air quality problems, even well-managed ones can sometimes experience the incidence of a poor indoor air quality [1-3, 8]. Volatile Organic Compounds (VOCs) constitute an important class of indoor air contaminants. Evidence from a variety of non-industrial building investigations and systematic studies found that 60% of VOCs indoor emissions come from building material and furnishings [9]. Various VOCs have been associated with certain symptoms of “sick building syndrome” and multiple chemical sensitivities, and other health effects [10].

Flexography printing is one of the industrial activities which make use of chemical products containing volatile organic compounds (VOCs) that are widely used mainly because of their high volatility. In the printing departments, the main indoor sources for VOCs are solvents and inks and due to their low vapor pressure, significant amounts of toluene, xylenes, and other volatile compounds are emitted during the printing process. Furthermore, the cleaning procedures can result in emissions that are several times higher than those emitted during other tasks because these cleaning products are petrol-based. The inks used in the Flexography process are made basically of a mixture of resins, vegetal or mineral oils, pigments, and solvents. The main ingredients of the conventional inks are pigments, binders, carriers, and additives. Compared with the solvent-based ink, the water-based ink uses water as a carrier to substitute the majority of organic solvents and thus its development and application lead to the reduction of VOC emissions as one of the main driving forces of the product innovation.

Recent studies have related cholangiocarcionoma to the exposure of high concentrations of dichloromethane (DCM) and dichloropropane (DCP) used in the Flexography printing process [11, 12]. The lack of proper ventilation in the printing sections has been reported as the main cause of the widespread illnesses among the printing workers. In a report by the ministry of health in Japan [13] cholangiocarcionoma patients appeared among former or current workers of the printing company, and the total number of patients increased to 17 and all of the 17 patients were exposed to 1, 2-DCP. Besides, 11 of the patients were exposed to DCM, and 8 of them were also exposed to 1,1,1-TCE. On the other hand, Kubo [14] reported that many other chemicals had been used in the printing department including (dichlorofluoroethane, 2-butanol, 2-methylpentane, 3-methylpentane, n-hexane, cyclohexane, isopropyl alcohol, ethanol, diethylene glycol monobutyl ether, propylene glycol monomethyl ether, 2-methyl-2,4-pentadiol, 3-methyl-3-methoxybutanol, solvent naphtha, xylene, mineral oil, hydrocarbons, aromatic hydrocarbons and inks), but these chemicals were ruled out as possible causative agents because of their low amount used in the printing process and/or the short period of exposure to them.

In this research, we intend to model and analyze the VOCs pollution distribution from 2 flexographic printing machines in the printing department of Razavi Publishing in Iran. We use OpenFOAM, a general purpose open-source computational fluid dynamics (CFD) code package to model the building, ventilation and to compute the pollutant distributions. In addition to the present ventilation setup, 4 scenarios are suggested and analyzed to improve the ventilation and to lower the VOCs concentration to a permissible limit point.

2. Materials and methods

2.1 CFD analysis of Printing Hall

To evaluate and improve the local ventilation facilities of the printing department of Emam Reza Press, a full CFD model is developed. As illustrated in Fig.1, a VOC emitting blanket or ink roller, a printing worker performing the cleaning procedures and a push-pull LEV device are depicted. The height of the printing worker was 1.73 m. The head was modeled

In this CFD model, the turbulent airflow was assumed to be on a steady state, but the VOC dispersion was in a transient mode. The mathematical fluid dynamic model consisted of the Navier-Stokes and continuity equations in an ensemble-average format. The turbulence was modeled by the standard two-equation k-ε model. The transient VOC dispersion was determined by the discrete particle transport model. First, the model is verified to evaluate the air velocities at the printing room inlets and outlets correctly.

Fig. 1 presents the plan view of the printing room with a floor area of 19 x 24=456 m2. The details of the flexography printing machine arrangement are presented in this figure. In this study, different air inlets corresponding to different air pattern distributions and mixing schemes, were chosen as parameters to investigate the VOCs concentration, while the overall ventilation rate was set constant in compliance with California/USA regulations and ASHRAE Standards 62.2-2003.

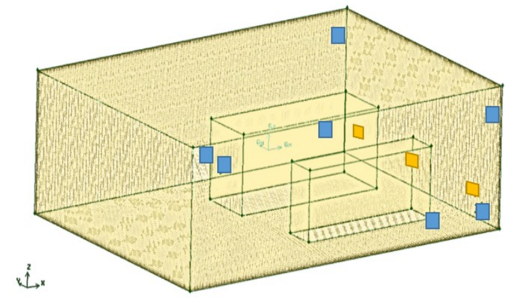


Fig. 1. The printing room, the locations of flexographic printing machines, inlet windows (Blue) and exhaust fans (Yellow).

2.2 Boundary Conditions

2.2.1 Input Parameters

The locations, the number of inlet windows and the number of exhaust fans are the three variables for which scenarios composed and calculations performed. Table 1 describes the conditions and scenarios under which calculations performed. The basis for these scenarios is preserving the present setting of inlet windows while increasing the number of exhaust fans to achieve the lowest maximum concentration in the printing hall.

The uniform velocities were applied at the inlets while inlet temperature is set at 20°C, level of the kinetic energy of turbulence κ was set at 0.25% of the mean flow, and the turbulence energy dissipation rate ε was estimated on the assumption that turbulent viscosity was 1000 times greater than the laminar one.

The CFD Code PHOENICS®, which is based on solving the full 3-D Navier Stokes equations for turbulent flow and scalar conservation equations, was used. Major indoor pollution sources, VOCs and MEG emitting materials and their emission characteristics were calculated through the use of emission factors. To analyze the characteristics of the indoor environment, different mixing ventilation schemes (different locations of the fans/windows and air inlets) were chosen as the parameters to investigate the printing room environment. The fields of VOCs and MEG for several air inlets window positions and ventilation parameters were calculated and compared.

Table 1. Different scenarios for inlet and exhaust fans and the maximum concentration level of MEG.

Scenario	Number of Inlets Windows	Number of Exhaust Fans	Maximum Concentration of MEG (mg/m^3)
A	3 on side walls	6	2.0E-5
B	3 on side walls +3 in ceiling	7	1.0E-6
C	3 on side walls +3 in ceiling	8	2.0E-5
D	3 on side walls +3 in Floor	6	2.0E-5

The contour plots for each scenario is presented in figures 4 to 7. To estimate the pollution level at respiratory height for workers, three cross sections along the machines are selected to show the pollution distributions. The cross sections at which the contours are plotted are shown in figure 2 as A-A', B-B' and C-C'.

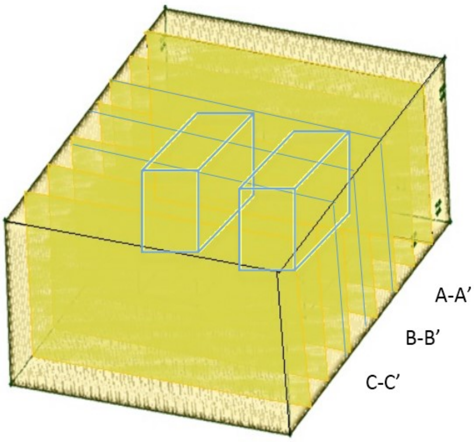


Fig. 2. Three cross sections along which the contours of concentrations levels are plotted.

2.2.2 Pollution Source

Ethyl Acetate, Ethyl glycol and Isopropanol are the main solvents used in flexography. There are 2 flexography printers of 6 and 8 colors in the room and they use 20 liters of ink daily. The ratio of solvents to ink is 0.25, 0.25 and 0.50 for Ethyl Acetate, Ethyl glycol and Isopropanol, respectively. As shown in Figure 3, there are 4 roller cylinders where the ink is applied and the solvents get dispersed into the air.

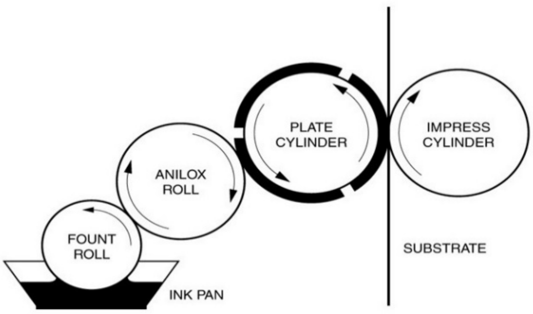


Fig. 3. Roller cylinders of an 8-color flexography printer where the solvents disperse into the air.

2.2.3 Overall Ventilation Rate

The existing ventilation of the printing room of 24×19×8 m consists of 6 exhaust fans with 1410 RPM and 450 m^3/hr. flow rate. There are also 3 inlet windows with 1 m^2 dimensions.

2.2.4 Boundary Conditions for Walls

For the wall surfaces the no-slip condition for velocities and "wall functions" for the near-wall values of the dependent variables κ, ε and the temperature were applied. The Zero gradients BC were set for pollutants concentrations variables. Walls were assumed not to emit VOCs based on the assumption that water-based paints were used.

2.2.5 Output Parameters

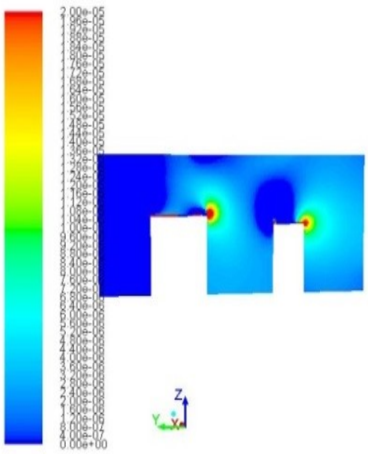
Calculations were performed for several values of inlet velocities and positions (Scenarios A to E, Table1), which corresponded to various indoor velocity vector distributions. Moreover, a zero reference external pressure was applied as output BC.

2.2.6 Computational domain and computational details

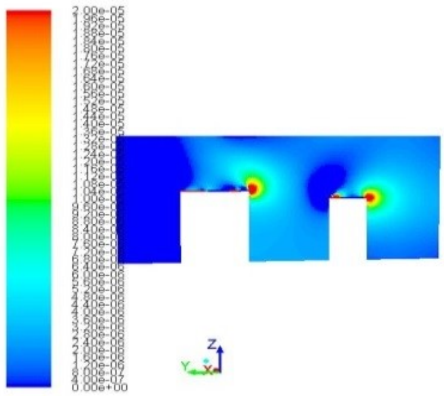
A rather coarse grid was used in the computations which covered a computational domain of 24×19×8 m. Both uniform and non-uniform grids were experienced and the stability test showed that the non-uniform numerical grid consisted of 3648000 differential volumes, 240 cells in the x direction, 190 cells in the y direction and 80 cells in the z direction. The grid covered that part of the printing room which consists of the printing machines on the condition of present obstacles. Almost 4000 iterative sweeps of the domain were necessary to obtain convergence. The corresponding computer used in this process was 3.5 GHz Intel core i7 with 16 GB RAM. The execution time per 4000 sweeps for the calculation grid was around 15 hours CPU. The grid was optimum in terms of computational efficiency versus CPU time between three sets with increasing complexity.

3. Results and discussion

The results of the indoor VOC pollutant concentration contours for scenarios A to D are presented in Figs. 4 to 7 (along the 3 planes A-A’, B-B’ and C-C’ depicted in Fig. 1). In Figure 4 the contour plots of the present ventilation system with 6 fans and 3 inlet windows is illustrated. As can be seen, the VOCs concentration at the respiratory level reaches 2×10-5 mg/m3.



Section A-A’



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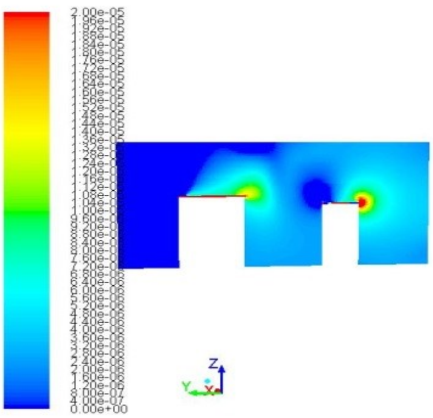
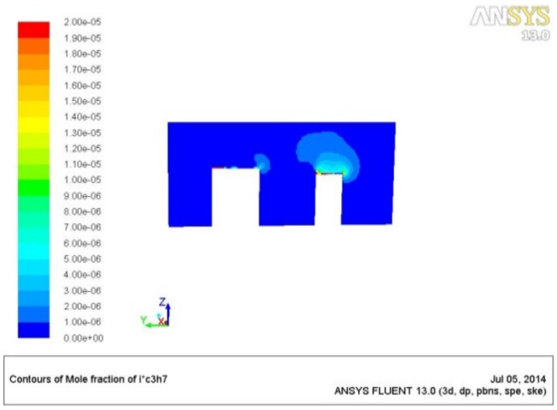


Section C-C’

Fig. 4. VOC concentration contours for the existing ventilation system (Scenario A-6 fans and 3 Inlet windows) at 3 cross sections.

By adding 3 inlet windows (in the ceiling) and one exhaust fan, the VOCs concentration is plotted and illustrated in Figure 5. It shows that the concentration level has decreased by a decade (2×10-6 mg/m3) below the standard level

(1×10-5 mg/m3).



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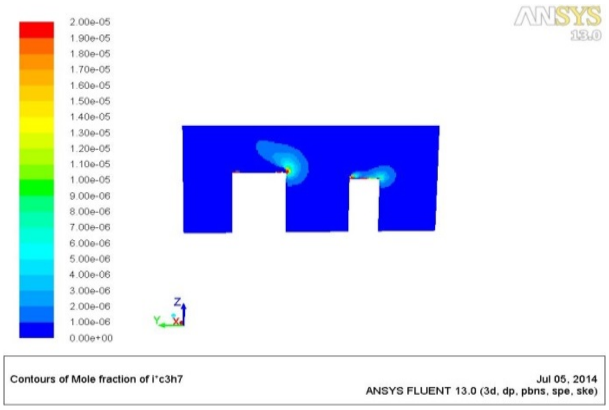

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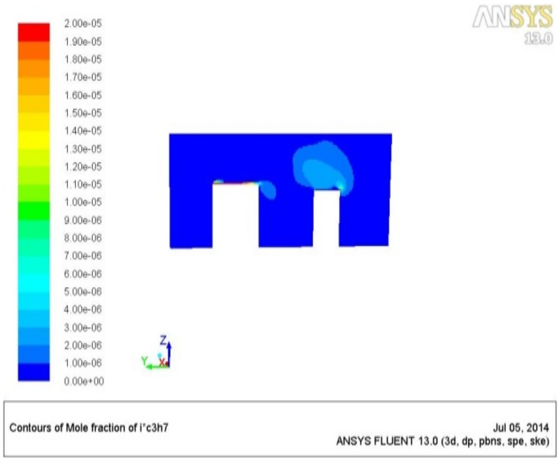
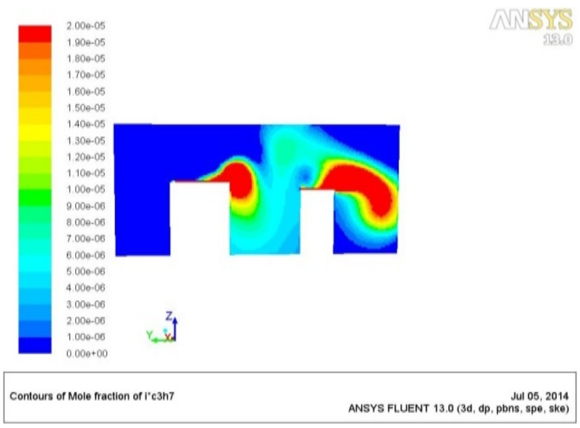


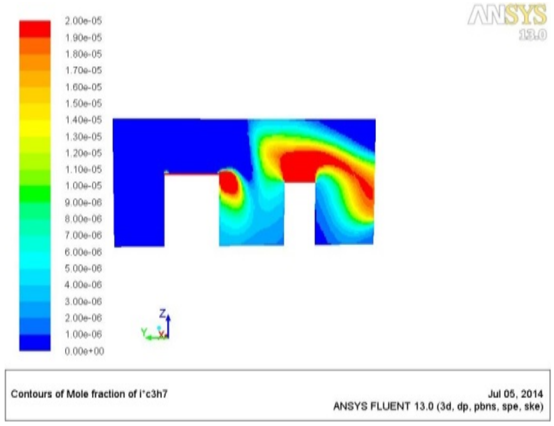
Section C-C'

Fig. 5. VOC concentration contours for the existing ventilation system (Scenario B -7 fans and 6 Inlet windows) at 3 cross sections.

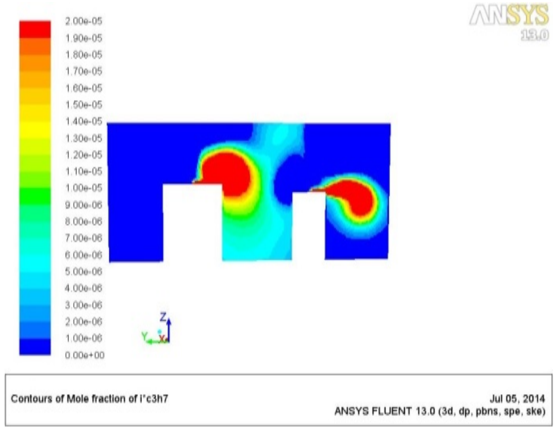
To further improve the ventilation, the number of exhaust fans raised to 8 with 6 inlet windows. Due to the increased turbulency, the concentration levels increased (2×10-5 mg/m3) and this scheme did not reduce the VOC level at the respiration height (Figure 6).



Section A-A'



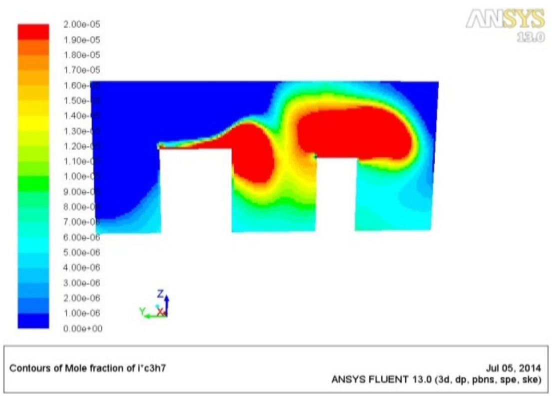
Section C-C'



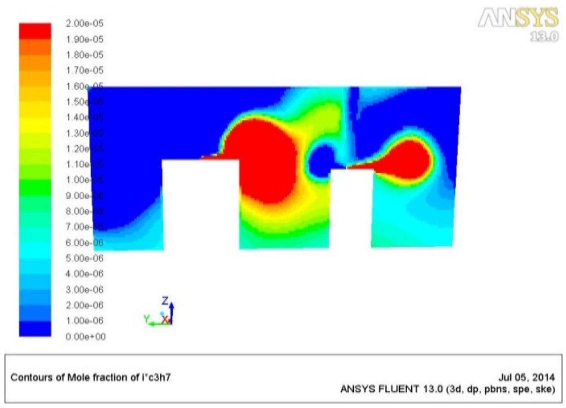
Section B-B'

Fig.6. VOC concentration contours for the existing ventilation system (Scenario C -7 fans and 6 Inlet windows) at 3 cross sections.

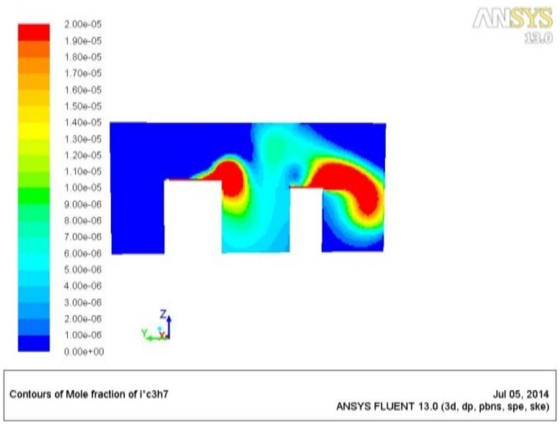
In our last scenario, we added 3 inlet windows in the ceiling and moved all 6 exhaust fans to the floor next to the printing machines. The results are depicted in Figure 7 and show increased concentration levels in all 3 cross sections. In this scenario, the air circulation around the machines has increased, and therefore, it has increased the VOC level locally at the respiration height.



Section A-A'



Section B-B'



Section C-C'

Fig.7. VOC concentration contours for moving the exhaust fan position and increasing the inlet windows (Scenario D -6 fans and 6 Inlet windows) at 3 cross sections.

Scenario B performs better while scenarios C and D perform poorer due to the creation of vortices related to jet inflows from the inlet windows. The inlet air location is critical since local recirculation and "hot-spots" of the stagnant air can appear within the room.

4. Discussion-Conclusions

The methodology of this study provides qualitative and quantitative data in order to evaluate and select measures and techniques that ensure the prevention of adverse threats to human health. The CFD investigation provides the fundamentals to achieve the best practical ventilation improvement in order to control the printing room VOC pollution.

The CFD model proved that increasing the air flow velocity does not necessarily lower the VOC pollution level and position of inlet windows and exhaust fans play the most important role in a ventilation system.

The results could be further improved by VOC sampling and measurements which could be used to convert CFD results to real concentration levels.

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