

MODELING AND DESIGN OF ODOR CONTROL SYSTEM WITH CFD ANALYSIS IN A MUNICIPAL SOLID WASTE TRANSFER STATION

¹UMUT BARIS YILMAZ, ²GOKHAN DEVECİ, ³CIHAN KAYHAN, ⁴CAGLAR DINCER, ⁵UNAL ALTINTAS, ⁶ZAFER YAMAN

¹Yuksel Project International Inc., Gazi University, Faculty of Engineering and Architecture, Dept. of Mechanical Engineering, Ankara, Turkey, ²Anova Engineering Co.

^{3,4,5}Yuksel Project International Inc., ⁶Fta Industrial Co.
E-mail: ¹barisyilmaz@yukselproje.com.tr, ²gokhan.deveci@anova.com.tr, ³ckayhan@yukselproje.com.tr, ⁴cdincer@yukselproje.com.tr, ⁵ualtintas@yukselproje.com.tr, ⁶zaferymn@gmail.com

Abstract - Due to increase of population in the developed cities, odor pollution caused by municipal solid waste in the landfill area or transfer stage is a public concern. At the stations where the transfer amount reaches 4000-5000 tons/day, it is demanded to eliminate the odor and minimize the environmental impact especially in facilities that are located in living areas. In this study, the design of the odor control system at Başakşehir Municipal Waste Transfer Station of Istanbul Metropolitan Municipality Directorate of Superstructure Projects is given with collection and treatment stages of the scented air. The aim is to optimize the ventilation system for odor control by using computational fluid dynamic method.

Keywords - Odor Pollution Control, Odor Treatment System, Odor Measurement, Municipal Solid Waste Transfer Station, Waste Management, CFD Analysis, Numerical Analysis, Wet Scrubber, Ventilation.

I. INTRODUCTION

Odor control system including dust and chemical wet scrubbers connected to GRP exhaust ductwork was designed. The duct and vent-holes (exhaust grills) located on the hopper where the waste dumped from

garbage truck into the hopper and most of dust, volatile organic compounds (VOC), hydrogen sulfide (H₂S), ammonia (NH₃) and similar offensive odor substance spread. Section view of waste transfer bay with main equipment mentioned above shown in Figure 1 below.

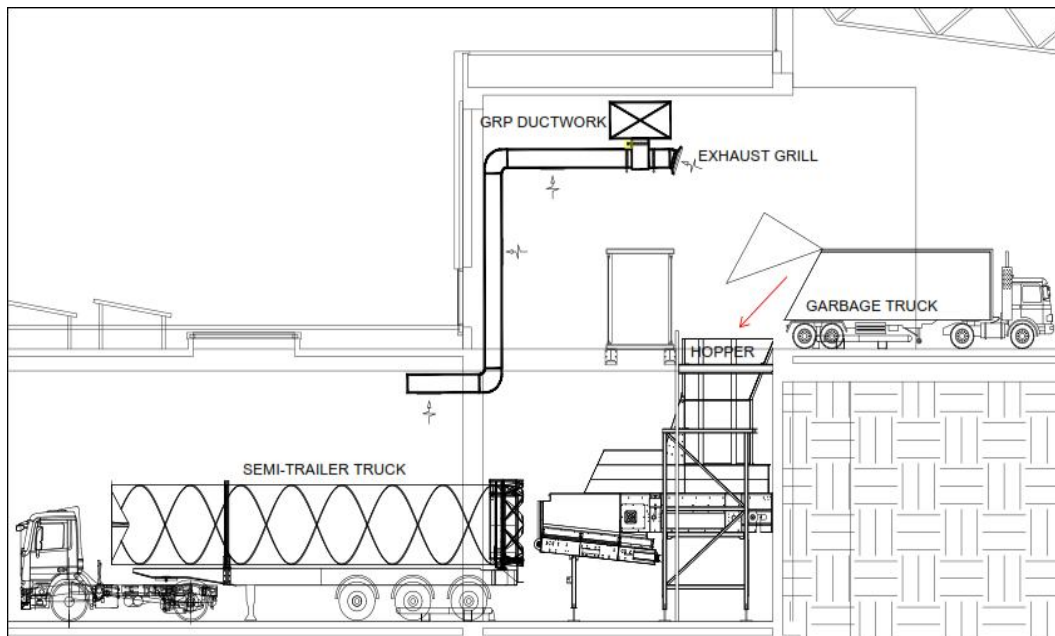


Fig.1. Section of waste transfer station

Wet scrubber system designed according to odor measurements performed on a similar station. Volatile organic compounds (VOC) measured based on TS ISO 16200-1 sampling method, hydrogen sulphide (H₂S) measured with the aid of electrochemical battery and ammonia (NH₃) measured as per NIOSH 6015 method. Odorous and

dusty air collected by means of exhaust ductwork in the hall first taken to the dust scrubber than passed through the deodorization chemical washing unit containing sodium hydroxide (NaOH) and sodium hypochlorite (NaOCl) chemicals before released into the air.

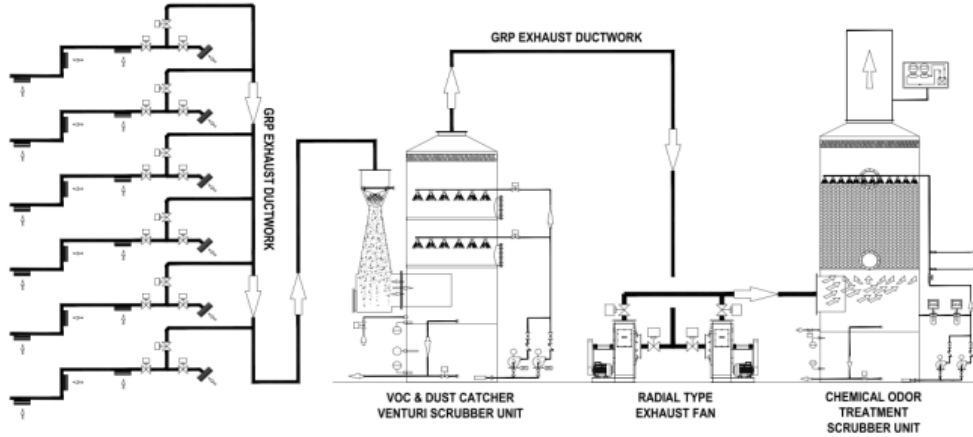


Fig.2. Odor Treatment System Flow Diagram

Location and sizes of exhaust ducts and exhaust grills optimized with the computational fluid dynamics (CFD) numerical analysis method. The CFD analyzes performed using the k-ε realizable turbulence model and the COUPLED algorithm in the ANSYS Fluent 17.0 software and 3D flow analysis performed. The boundary conditions calculated in line with the values obtained from the literature and results of odor measurements performed at Yenibosna transfer station. It was shown in the analysis results that the exhaust grill placement and flow optimization resulted in a 5% increase in odor control. The collected and treated air is intended to be kept below the odor thresholds specified in the standards such as local regulations (Odour control directive) and VDI 3881 Part 1-4 (Olfactometry, Odor Threshold Detection).

II. DESIGN

Contaminated, dusty and scented air spreads when the garbage dumped to hopper from garbage truck. It is necessary to prevent H₂S, VOC and similar odorous compounds spreading to the atmosphere. Therefore, the wet type dust and deodorizing wet scrubber unit designed. The odorous and dusty air collected by means of ductwork located in the halls, passed through dust scrubber and deodorization chemical washing unit respectively before released into the atmosphere.

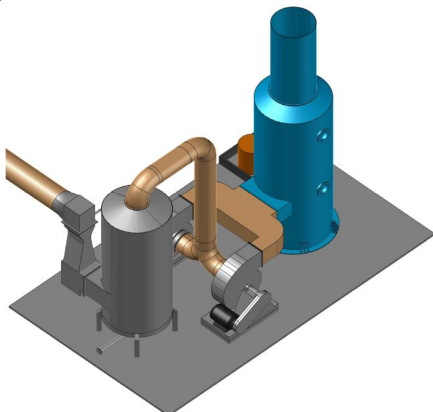


Fig.3. Two stage wet scrubber system

One of the ideal system developed for holding dust and odorous air absorbed from the environment is the chemical wash tower (wet scrubber). In these systems, the velocity of the absorbed air in the wash tower reduced to 2-3 m/s to ensure that the pollutant components are retained. The spraying system in the dust-collecting wash tower, holds the dusts passing at low speed and precipitates them into the liquid waste tank. In the deodorizing washing tower, the rushing rings which increase the surface area are used and the odorous components are washed with the chemical added circulating fluid and precipitated into the liquid tank. In this way, the airborne components trapped with the fluids in the towers and take into the waste liquid tank. These liquids are discharged periodically according to the stated of pollution. In order to be able to hold the contaminants in the air, first dust holder washing unit is used. The dusty air exposed to intensive water pulverization at the entrance to the washing tower and the dust precipitated into the liquid tank at the bottom. The accumulated muddy water is periodically discharged according to the viscosity. The air removed from the dust is directed to the other chemical trap washing tower to separate it from its odorous components. In Figure 4, odor treatment system isometric view is shown.

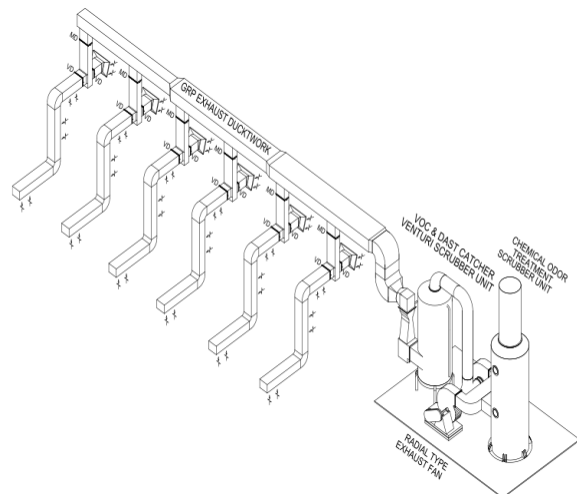


Fig.4. Odor treatment system isometric view

In this washing tower, sodium hydroxide (NAOH) and sodium hypochlorite (NAOCL) chemicals added to the circulating fluid to remove air from the H₂S gas components. PH balance in the water is adjusted with these chemicals and Hydrogen Sulphur are precipitated to circulation liquid. Then, PH balance of circulation liquid is protected with these chemicals and continuous holding of H₂S smelling component is provided and clean gas is thrown out from the chimney.

III. ODOR MEASUREMENT

VOC, gas and ammonia (NH₃) measurements performed at 2 points including conveyor - waste discharge platform and bunker loading platform in the 3000-3500 tons/day transfer capacity IMM Yenibosna Solid Waste Transfer Station. The results used in the boundary conditions of the numerical analysis of computational fluid dynamics (CFD) with data from the literature [1].



Fig.5. Odor measurement at Yenibosna SWTS

Standards, procedures, methods and regulations in measurement, analysis and reporting are tabulated and given as follows:

Table 1: Odor Measurement Procedure

| Measured Parameters | Measurement-Analyzer and Calibrator | Standard / Regulation / Procedure / Method Used |
|---------------------|---|--|
| VOC | VOC Measuring, Analysis Devices and Rotameter | TS ISO 16200-1 of 5 March 2003 "Workplace air quality - Sampling from volatile organic compounds and analysis by solvent desorption / gas chromatography - Part 1: Method of sampling with a pump" |
| | | DP.18 - "Sampling and Analysis of Volatile Organic Compounds (VOC) in Ambient Air Test Procedure" |
| | | Implementing Regulation on Health and Safety Precautions in Working with Chemical Substances |
| | | OSHA Table AC-1 Permissible Exposure Limits For Chemical Contaminants |
| | | American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV) - 2009 |
| Gas in Medium | Ambient Gas Measuring Device | Measurement principle of Carbon monoxide (CO), Carbon dioxide (CO ₂), Hydrogen sulfide (H ₂ S), Oxygen (O ₂) gas by Infrared Cell Method |
| | | Implementing Regulation on Health and Safety Precautions in Working with Chemical Substances |
| Ammonia | Ammonia Measuring, Analysis Devices and Rotameter | The National Institute for Occupational Safety and Health (NIOSH): Metot 6015 |
| | | Implementing Regulation on Health and Safety Precautions in Working with Chemical Substances |

IV. CFD ANALYSIS

3 different analyses (Revision 1, Revision 2, and Revision 3) was performed time dependent for 420 sec. and used ANSYS Fluent 17.0. The ventilation system optimized according to CFD results.

4.1. Solid Model and Mesh

Space Claim Direct Modeler was used for the extraction of fluid region, shown in Figure 6.

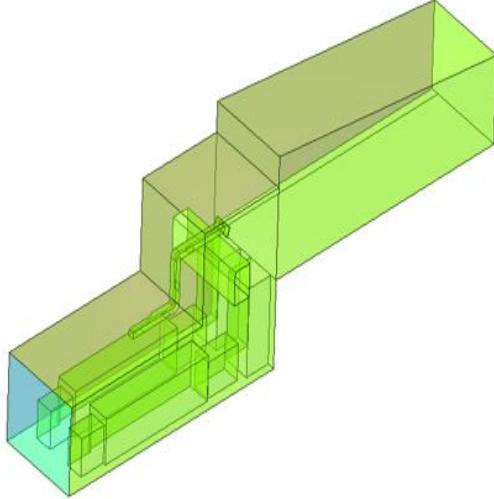


Fig.6. Extracted fluid region

Mesh generation was performed on extracted fluid region using ANSYS Meshing and it contains 12 million polyhedral cells, shown in Fig. 7.

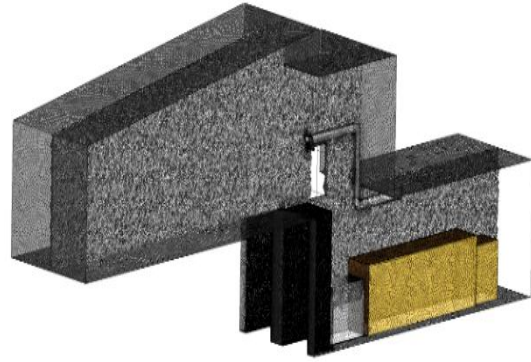


Fig.7. Mesh view of analyze model

4.2. Boundary Conditions

In literature, amount of the released odor pollutants are 20 kg/day for a municipal waste transfer station operated 12 hour daily and the capacity is 1200 t/day (Zhao et al., 2015). Basaksehir municipal waste transfer station has 5000 t/day capacity. There are 2 semitrailers during the 420 sec in transfer station. In the light of this information; total amount of odor pollutants is calculated 6.427×10^{-6} kg/sec. It's accepted that equal flow are spread from bunker and conveyors.

Mole fractions of the pollutants calculations were performed using partial pressures of pollutants with the ideal gas equation according to the measurements in the transfer station and the fractions of pollutants spreading from bunker and conveyor surfaces are shown in Table 2 and Table 3.

Table 2: Moles fractions of pollutants spreading from conveyor

| Conveyor | | Concentration (mg/m ³) | Molecular Weight (g/mole) | Mole Fractions |
|-------------------------------|--|------------------------------------|---------------------------|----------------|
| Ethanol ¹ | C ₂ H ₅ OH | 0.999 | 46.07 | 5.33780E-07 |
| Ethyl Asetat ¹ | C ₄ H ₈ O ₂ | 0.205 | 88.066 | 5.73007E-08 |
| Toluen ¹ | C ₇ H ₈ | 0.495 | 92.13 | 1.32257E-07 |
| Metanol ¹ | CH ₃ OH | 5.185 | 32.04 | 3.98356E-06 |
| DimetilSulfid ² | C ₂ H ₆ S | 0.155 | 62.13 | 6.14108E-08 |
| Methanethiol ² | CH ₄ S | 0.0775 | 48.11 | 3.96535E-08 |
| Hydrogen Sulphid ² | H ₂ S | 0.325 | 34.08 | 2.34746E-07 |

Table 3: Moles fractions of pollutants spreading from bunker

| Bunker | | Concentration (mg/m ³) | Molecular Weight (g/mole) | Mole Fractions |
|-------------------------------|--|------------------------------------|---------------------------|----------------|
| Ethanol ¹ | C ₂ H ₅ OH | 0.995 | 46.07 | 5.31639E-07 |
| Ethyl Asetat ¹ | C ₄ H ₈ O ₂ | 1.112 | 88.066 | 3.1082E-07 |
| Toluen ¹ | C ₇ H ₈ | 4.634 | 92.13 | 1.23813E-06 |
| Metanol ¹ | CH ₃ OH | 10.574 | 32.04 | 8.1238E-06 |
| DimetilSulfid ² | C ₂ H ₆ S | 0.155 | 62.13 | 6.14105E-08 |
| Methanethiol ² | CH ₄ S | 0.0775 | 48.11 | 3.96532E-08 |
| Hydrogen Sulphid ² | H ₂ S | 0.325 | 34.08 | 2.34745E-07 |
| Isobutilalkol ¹ | C ₄ H ₁₀ O | 0.071 | 74.08 | 2.36709E-08 |
| Heptan ¹ | C ₇ H ₁₆ | 0.12 | 100.204 | 2.96752E-08 |

Vent hole types, bunker and conveyor surfaces are different type revision. shown that Fig. 8, Fig. 9 and Fig. 10 for the 3

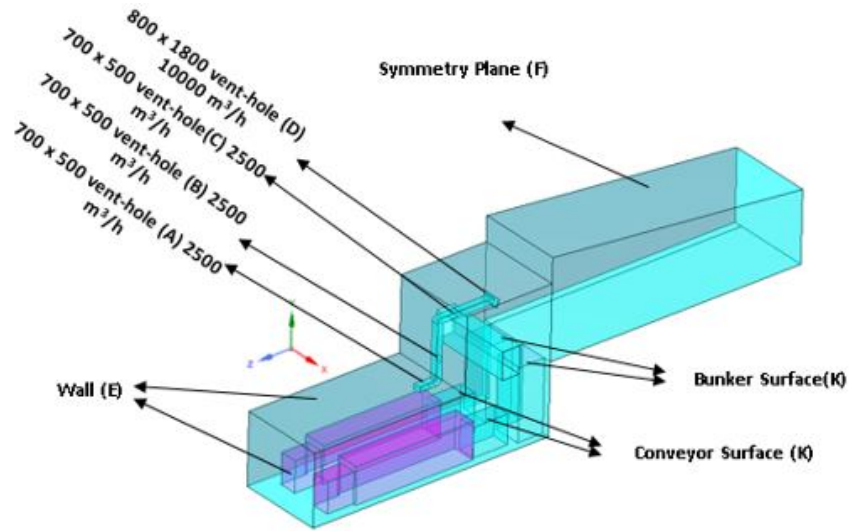


Fig.8. Vent-holes, bunker and conveyor surfaces for revision-1

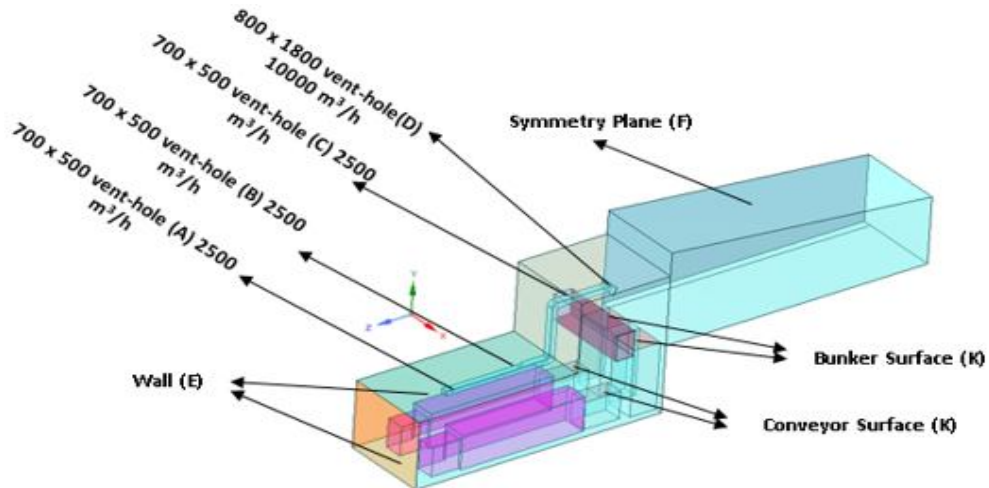


Fig.9. Vent-holes, bunker and conveyor surfaces for revision-2

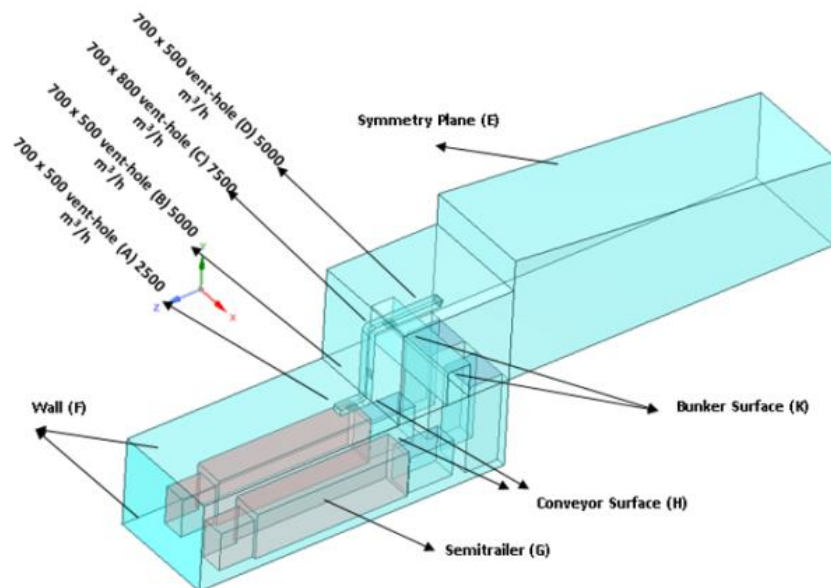


Fig.10. Vent-holes, bunker and conveyor surfaces for revision-3

Types and values of boundary conditions are given in Table 4 for the revision-3. Normally, transfer station has 6 same section (bays) so; one of the section was analyzed with symmetry boundary condition type.

Table 4: Boundary conditions and types for revision-3

| No | Name | Type | Value | Unit |
|----------------|----------------------|-----------------|----------|------|
| A | 700 x 500 2500 m3/h | Velocity-Inlet | -2.00 | m/s |
| B | 700 x 500 5000 m3/h | Velocity-Inlet | -4.00 | m/s |
| C | 700 x 800 7500 m3/h | Velocity-Inlet | -4.00 | m/s |
| D | 700 x 500 5000 m3/h | Velocity-Inlet | -4.00 | m/s |
| E | Symmetry Plane | Symmetry | - | - |
| F | Hangar - Door | Wall | - | - |
| G | Semitrailer Surfaces | Wall | - | - |
| H ¹ | Conveyor Surfaces | Mass-Flow-Inlet | 1.60e-06 | kg/s |
| K ¹ | Bunker Surfaces | Mass-Flow-Inlet | 1.60e-06 | kg/s |

V. RESULTS AND DISCUSSION

5.1. Results

Analysis setting has an important role for the sensitivity. Solutions executed with COUPLED algorithm and used k-ε turbulence model. Analyses performed by using a cluster of parallel 32 Intel Xenon processors.

k- ε turbulence model equations;

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho U)}{\partial x} = 0$$

$$\frac{\partial \rho U}{\partial t} + \frac{\partial(\rho U \cdot U')}{\partial x} = -\frac{\partial P}{\partial x} + \partial \left[\mu_{\text{eff}} \left(\frac{\partial U'}{\partial x'} + \frac{\partial U}{\partial x} \right) \right] + S_M$$

$$\mu_{\text{eff}} = \mu + \mu_t$$

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho U k)}{\partial x} = \partial \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \left(\frac{\partial k}{\partial x} \right) \right] / \partial x + P_k - \rho \varepsilon + P_{kb}$$

$$\frac{\partial(\rho \varepsilon)}{\partial t} + \frac{\partial(\rho U \varepsilon)}{\partial x} = \partial \left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \left(\frac{\partial \varepsilon}{\partial x} \right) \right] / \partial x + \varepsilon / k (C_{\varepsilon 1} P_k - C_{\varepsilon 2} \rho \varepsilon + C_{\varepsilon 1} P_{\varepsilon b})$$

$$\mu_t = \frac{C_\mu \rho k^2}{\varepsilon}$$

It's chosen that standard wall function for near-wall treatment model. The time dependent mole fraction of pollutants distribution are shown in Fig 11, Fig 12, Fig 13, Fig 14, Fig 15 and Fig 16. Maximum velocity of exhaust grill is 4 m/s. The majority amount of pollutants gather around the vent-holes.

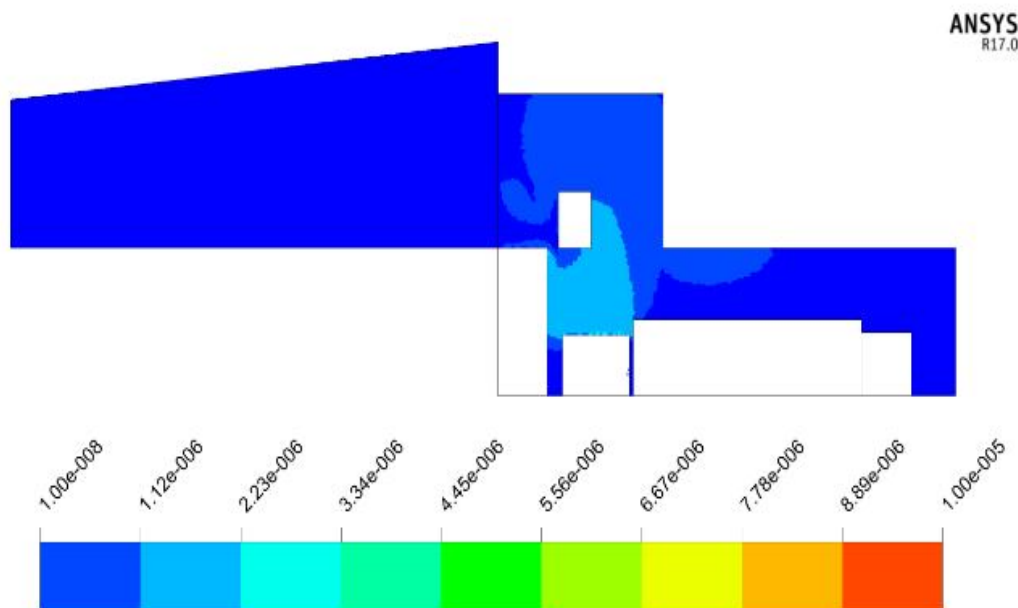


Fig.11. Time: 120 sec. pollutant mole fractions

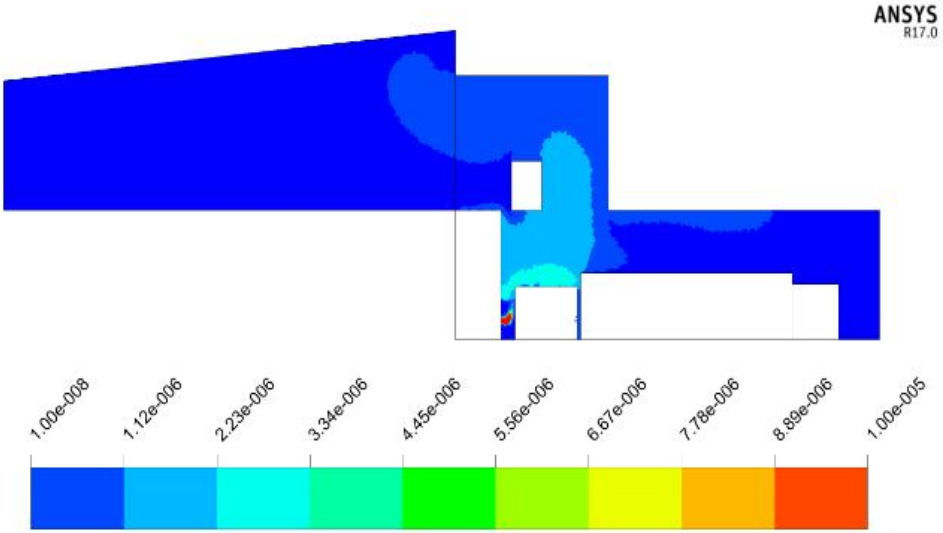


Fig.12. Time: 180 sec. pollutant mole fractions

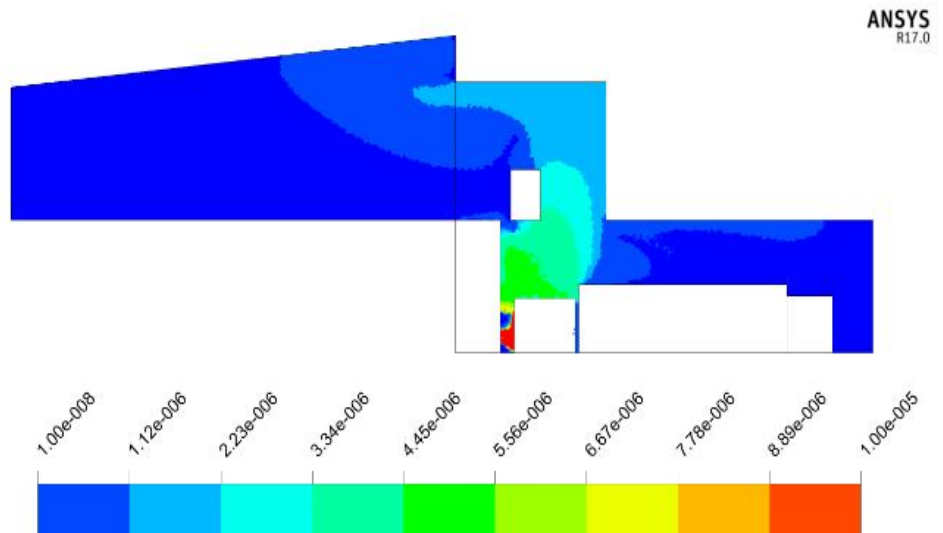


Fig.13. Time: 240 sec. pollutant mole fractions

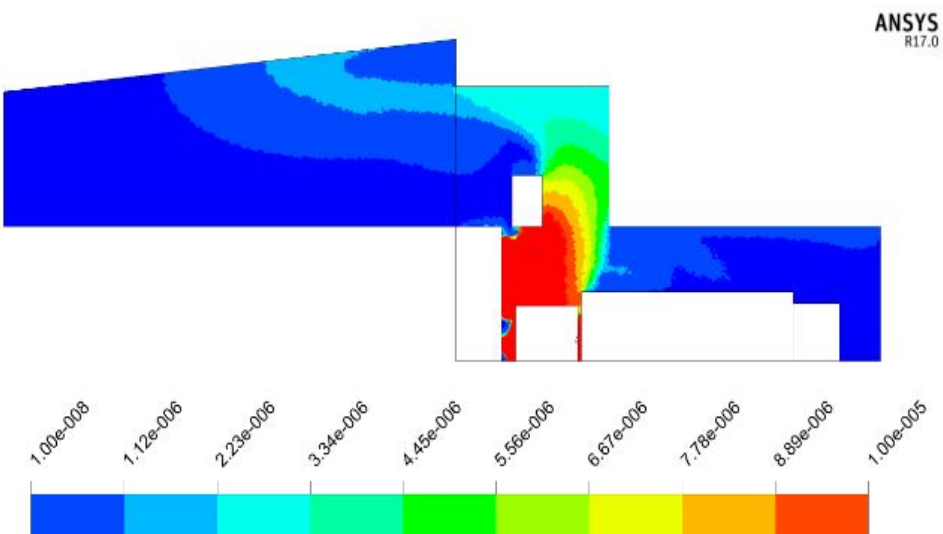


Fig.14. Time: 300 sec. pollutant mole fractions

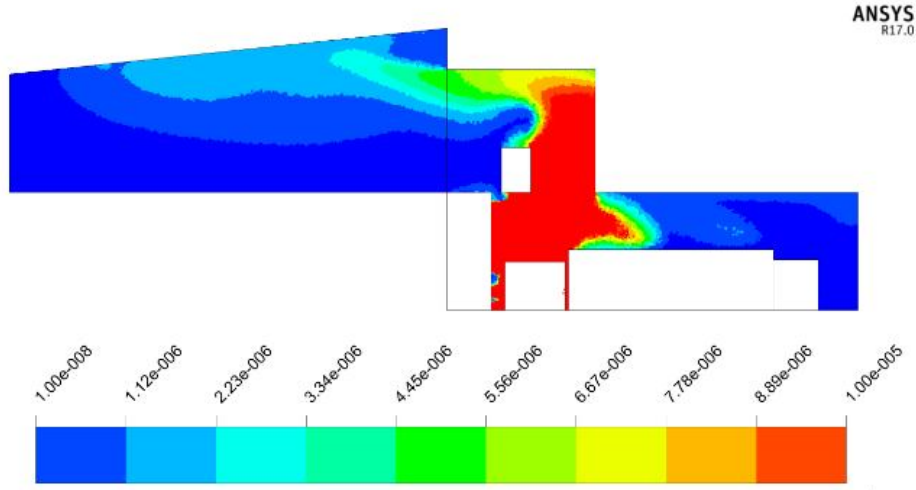


Fig.15. Time: 360 sec. pollutant mole fractions

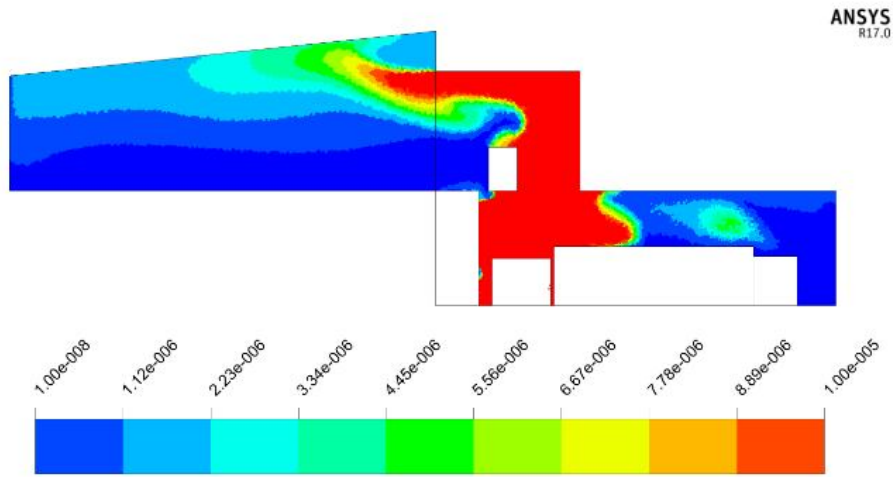


Fig.16. Time: 420 sec. pollutant mole fractions

In revision-3, distribution of pollutants which are fronted to the upper floor decrease because the vortex is reduced.

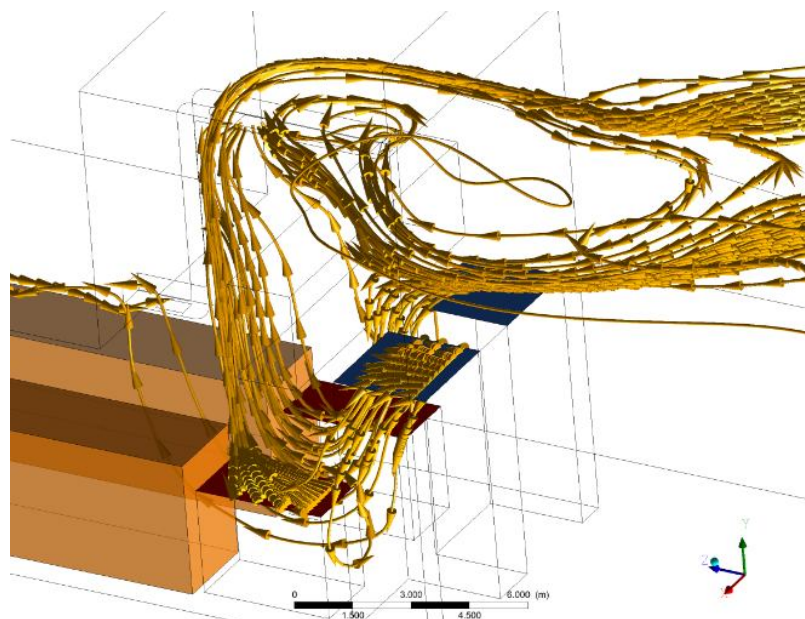


Fig.17. Orientation of the fluid vectors to exhaust grills from bunker and conveyor surfaces

5.2. Discussions

As a result of analyses made, the amount of pollutants formed in the system for 3 different revisions is shown in Fig 18.

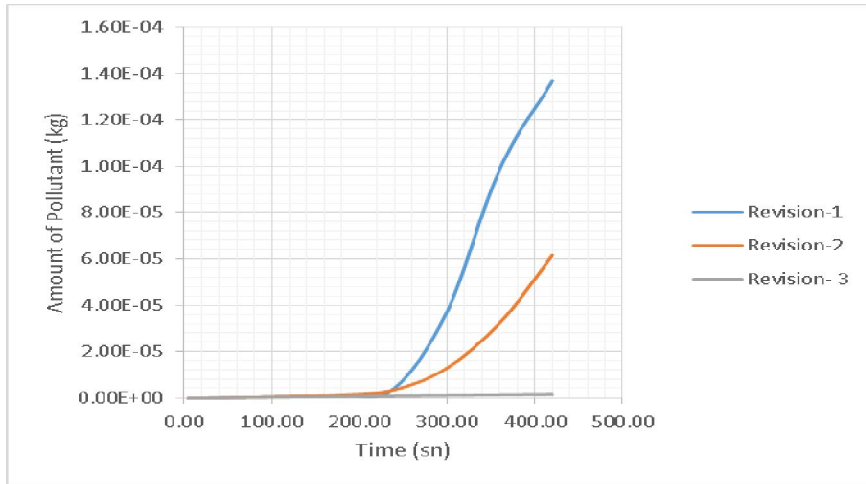


Fig .18. The amount of pollutants formed in the system

Efficiency calculation for revision 3;

$$\text{Eff. (\%)} = \text{Removed Pollutant} / \text{Released Pol. (Eq.1)}$$

Amount of total pollutant can be obtained from Fig 16 at the end of 420 sec. and this value is 1.64e-06. Total removed pollutant can be find out as;

$$\text{Removed Pollutant} = \text{Released Pollutant} - \text{Pollutant amount in system (Eq. 2)}$$

From equation 2;

$$\text{Removed Pollutant} = 0.00267876 \text{ kg} - 0.00000164 \text{ kg} = 0.00268 \text{ kg}$$

Therefore; exhaust efficiency from Equation 1;

$$\text{Efficiency (\%)} = 0.00268 \text{ kg} / 0.00267876 \text{ kg} = 99\%$$

Comparisons of exhaust grill performances for 3 different revisions at the end of 420 sec. are given in Table 5.

Table 5: Total pollutant fraction for the 3 different revisions

| Revision No | Geometry | Total pollutant fraction |
|-------------|----------|--------------------------|
| Revision 1 | | |
| Revision 2 | | |
| Revision 3 | | |

According to the Table 5; revision 3 has higher suction performance than others. Within the scope of the improvements, studies were made with different channel lengths for revision 1 and 2; but desired effect is not reached. 800 x 1800 type vent-hole cause high circulation, this reason increase to travel of pollutants inside the transfer station. In revision 3, flowrate of 800 x 1800 type vent-hole is reduced and other exhaust grills are increased. In addition, channel length is short in revision 3 like revision 1.

CONCLUSIONS

CFD analyses of Istanbul – Başakşehir Municipal Solid Waste Transfer Station was studied and major conclusions are as follows:

1. The wet scrubber system is a good alternative for odor control and treatment.
2. Alignment / size of exhaust grills and flowrates are very important because it causes to increase diffusion of pollutants.
3. CFD method is a strong way to design the ventilation ducts and cheaper than the tests.

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