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Logical Succession in Ventilation Systems of Industry Hall in Connection with the Issue of Spreading of Heavy Metal Microparticles

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Abstract: This article deals with problems of ventilation system and distribution of heavy metal microparticles in the interior of an actual industry hall. The case study being presented demonstrates not only the most significant and often logical mistakes of ventilation systems in industry halls, but also an example of possible systematic way of finding technical solutions. CFD code ANSYS Fluent was used for creation of three-dimensional numerical mathematical simulation of the problem. This case study could be used as an inspirational example of how similar problems in industry halls could be identified and solved systematically.

Keywords: CFD; microparticle; model; heavy metal; industry hall; ventilation.

1. Introduction

A system of natural or compulsory ventilation is an integral part of every industry hall. However, with older industry halls, which were subjected to a number of reconstructions and changes of production services, we frequently encounter issues with logical succession of components of individual ventilation systems. This situation is caused by an omission of air ventilation field analysis that is usually financially demanding and is not so far explicitly specified and frequently even not required by applicable standards and laws. This way ventilation conditions are created that not only do not improve working conditions in such halls, but on the contrary, they make it worse. The whole issue is getting bigger due to presence of some health endangering substance, in any state of matter, that should be safely taken away out of the building, but is endangering the employees instead.

To demonstrate the above stated issue, a following case study was conducted in an actual industry hall. Employees in this hall are processing loose raw materials in an electrochemical manufacturing process and are exposed to impact of micro- and nanoparticles of heavy metals during the manufacturing. Data on concentration of aerosol fractions and individual substances with significant impact on health in the working environment were used for defining the initial conditions of the quantification of emission sources model.

2. CFD numerical simulation

A software complex ANSYS Fluent 13.0 [1],[2] was used for numerical mathematical simulation of air ventilation field and spreading of heavy metal microparticles in solid state in the specific industry hall. The aim of this article can be defined by the following points:

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A) *to create numerical model of actual ventilation conditions in the manufacture hall;*
B) *to design optimization of actual ventilation conditions in the manufacture hall;*
C) *to create numerical model of heavy metal microparticles spreading from defined sources within the manufacture hall for the current and optimized ventilation conditions.*

Based on our experience from the initial testing calculations, all performed tasks were solved as non-stationary (time series model) with a time interval from 0 to 600 seconds and a pre-set time pace to 1 second. This is because of the calculation area (manufacture hall) complex outline and peripheral conditions that define the compulsory ventilation of the area (see below). Conceptual approach to the study is based on literature [3],[4],[5].

2.1. Geometry

Object of modeling was an actual industry hall with parameters 48.5 m (length), 21 m (width), and 4.9 – 5.9 m (height - shed roof with north-south rake). There are total 30 pieces of manufacturing machines and equipment placed in the hall. Cubic capacity of the internal space of the hall is approx. 5400 m^3, after deduction of the volume of all manufacturing machines. There are 6 door openings all together in the hall, out of which only 3–4 are actively used during the operation time as communication entrances, as well as a fresh air supply. There are also 4 ventilation units placed in the hall that serve as a distribution system for 7 distribution ventilation branches below the ceiling. These ensure the air circulation in the hall, as well as its heating in winter.

The shape of the geometry was created by using the DesignModeler software (see Figure 1) and the calculation grid by using ANSYS Meshing software that both belong to the ANSYS Fluent 13.0 software complex. The original number of cells of the calculation grid of the model was 1,816,315 ("Tethybrid" type of cells). After importing the geometry with the grid to the calculation environment of ANSYS Fluent 13.0 software, the grid was converted to a "Polyhedra" grid type [1],[2]. Due to this conversion, the grid was adjusted and its shape was optimized to final a number of 393,597 cells.

2.2. Calculation variants

Total of 6 calculation variants of air ventilation in the hall were performed, namely for the maximum, regular, and minimum operation modes, in summer and in winter (see Table 1 and Table 2 further below). Each variant of the operation mode had a different setting of activated air suction points on individual manufacture machines. Seasons were differentiated by number of open entrance doors, i.e. in number of fresh air supplies into the hall.

Only one variant out of the 6 variants mentioned above was selected for the purposes of this study, namely the one for calculation of motion and scattering of the heavy metal microparticles in dependence on the ventilation conditions in the hall.

The selected variant corresponds to the maximum operation mode of the hall in summer (see Fig. 2), i.e. the maximum number of activated air suction points on manufacture machines and a maximum number of doors open in order to supply fresh air. An influence of each individual open door opening and each ventilation component (ventilation Units and ventilation Branches) on ventilation conditions, motion, and scattering of the undesirable substance microparticles was tested.

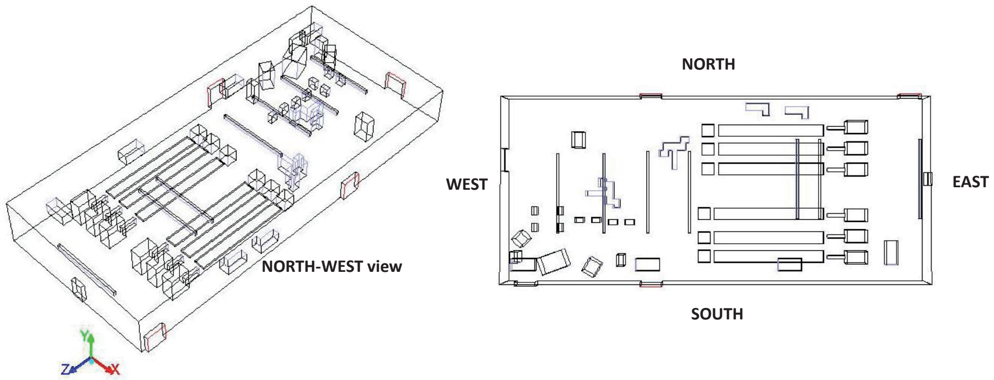


Fig. 1: *Geometry (manufacture hall building) for CFD simulation.*

2.3. Boundary conditions

For all areas that do not permit any air to come through a boundary condition "Wall" was set in the ANSYS Fluent 13.0 software complex, a boundary condition "Outflow" was set for all door openings, and a condition "Velocity Inlet" for all air suction areas and air supply areas (see Table 1). Sources of heavy metal microparticles with particles sized 1 µm and weight flow rate of 0.0648 µg.s^{-1} were defined by function "Injections" from the area, which always corresponded with the area of the upper surface of the manufacture machine (see Table 2) [1],[2].

Doors B, D, E, and F are open in the summer, while doors B, E, and F are open in the winter (see Figure 2). Ventilation units I. through IV. are active in both seasons of the year. Their defined volume flow rate is 3.06 m^3.s^{-1} while the surface area of the input suction opening is 1.69 m^2. The units are sucking the air from the interior space of the hall and the air is returning back to the hall through the 7 ventilation branches (Branches no. 1–7) that are connected to them. Thus a compulsory air circulation is created.

Ventilation units II. – IV. are always connected to the two closest ventilation branches. Unit I. is the only unit connected to a single ventilation Branch no. 1, which is also the reason for a higher flow speed rate of air through this branch (1.37 m.s^{-1} with the overall surface area of ventilation openings of 2.225 m^2). For ventilation Branches no. 2, 3, 6 and 7, the value of flow speed rate is 0.69 m.s^{-1} in each branch, with the overall surface area of ventilation openings equal to 2.225 m^2 in each branch. Ventilation Branches no. 4 and 5 are a little bit longer than the others, therefore the air flow speed rate for each one equals 0.67 m/s with the overall surface area of ventilation openings equal to 2.275 m^2.

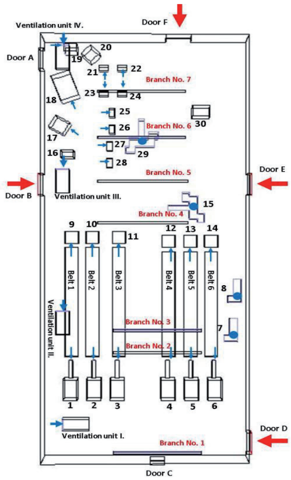
Table 1: *Overview of activated air suction points and their parameters for each of the manufacture machines in the manufacture hall according to the defined operation modes - boundary condition "Velocity Inlet".*

Machine	Suction area [m^2]	Suction speed [m.s^{-1}]	MIN. mode	REG. mode	MAX. mode
č. 1	0.4	-0.466		X	X
č. 2	0.4	-3			X
č. 3	0.4	-3		X	X
č. 4	0.4	-3	X	X	X
č. 5	0.4	-3		X	X
č. 6	0.4	-3			X
č. 7	2.58	-0.23			X
č. 8	2.58	-0.23			X
č. 9	2.18	-0.47		X	X
č. 10	2.18	-0.55			X
č. 11	2.18	-0.55		X	X
č. 12	2.18	-0.55	X	X	X
č. 13	2.18	-0.55		X	X
č. 14	2.18	-0.55			X
č. 15	39.82	-0.03	X	X	X
č. 16	2.32	-0.06			
č. 17	4.35	-0.06			X
č. 18	5.8	-0.06		X	X
č. 19	2.61	-0.06			X
č. 20	3.92	-0.06			
č. 21	1.2	-0.13		X	X
č. 22	1.2	-0.13		X	X
č. 23	1.2	-0.13			X
č. 24	1.2	-0.13		X	X
č. 25	1.2	-0.13		X	X
č. 26	1.2	-0.13		X	X
č. 27	1.2	-0.13			X
č. 28	1.2	-0.13		X	X
č. 29	39.82	-0.03		X	X
č. 30	19.56			X	X

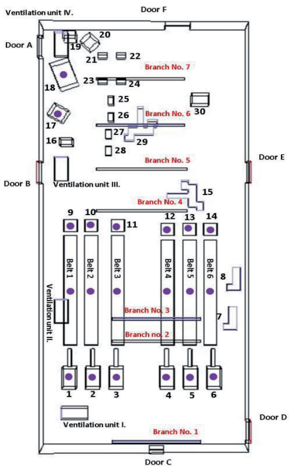
Table 2: *Overview of activated sources of heavy metal microparticles and their parameters for each of the manufacture machines in the manufacture hall according to the defined operation modes – boundary condition "Wall", function "Injections" (initial speed of the particles from all the sources was defined by value 0.2 m.s^{-1} in the direction perpendicular to the area of the source).*

Source	Weight flow rate of particles [µg.s-1]	Area [m^2]	MIN. mode	REG. mode	MAX. mode
č. 1	3.8	3.451		X	X
č. 2	3.8	3.451			X
č. 3	3.8	3.451		X	X
č. 4	3.8	3.451	X	X	X
č. 5	3.8	3.451		X	X

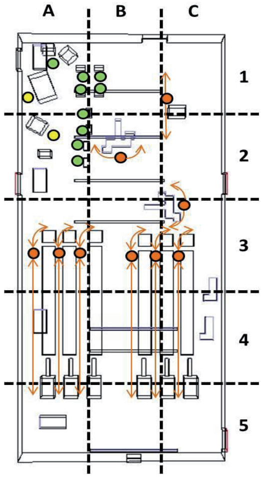
č. 6	3.8	3.451			X
č. 9	2.1	1.904		X	X
č. 10	2.1	1.904			X
č. 11	2.1	1.904		X	X
č. 12	2.1	1.904	X	X	X
č. 13	2.1	1.904		X	X
č. 14	2.1	1.904			X
č. 17	2.8	2.550			X
č. 18	6.6	6.000		X	X
Pas-1	18.8	17.109		X	X
Pas-2	18.8	17.109			X
Pas-3	18.8	17.109		X	X
Pas-4	18.1	16.456	X	X	X
Pas-5	18.1	16.456		X	X
Pas-6	18.1	16.456			X



I.



II.



III.

Fig. 2: *Functional and situation schemas (summer, max. operation mode): I) schema of ventilation conditions in the hall (BLUE arrows - suction of the air out of the hall; RED arrows - supply of the air into the hall; the rest of the numbers and text descriptions are describing the manufacture machines, ventilation units, distribution ventilation branches or entry points to the area - doors); II) schema of distribution of particle sources in the hall (PURPLE circle – active sources of heavy metal microparticles); III) schema of distribution of workers in the hall (GREEN circle - workers in sitting position; YELLOW circle - workers in standing stationary position; ORANGE circle - workers in standing position and moving away from their position to a distance longer than 2m), the space is divided into zones A1 to C5 for better identification of the area.*

3. Results and discussion

The results are assessed in a form of filled in contours of particles concentration in 2D (two-dimensional) longitudinal cross-sections within the 3D calculation area. Height of the cross-section has been set to 1.5 m (breathing zone of an average standing person). For further assessment of an extent to which the individual workers are endangered during the shift, for comparison and good orientation, it is possible to use Figure 2 (III.), where the positions of the workers, their status, or movement are visible. Also, a system of coordinates (A, B, C and 1, 2, 3, 4, 5) has been established that enables us to identify and name sectors in the area with greater accuracy. It is convenient to divide the results into the following two groups for further assessment:

A) Results related to the ventilation system of the hall (in general):

1) The more manufacture machines (with air

suction) are in operation, the faster is the air flow in the hall and turbulences are more intense.

2) In case of a constant number of manufacture machines (with air suction) in operation, and with the number of supply openings for fresh air supply (doors) decreasing, the air flow in the rest of the openings is accelerating, which makes the air circulation field in the hall more dynamic.

3) Horizontal ventilation (caused by the open doors and air suction points on the machines) is setting the main trends and directions of air flow in the hall.

4) Vertical ventilation (caused by ventilation Units I.–IV. and by the ventilation openings in the ventilation branches under the ceiling of the hall) has an impact on dissipation of the main air flows and thus has an influence on the extent of the local turbulence.

5) From the ventilation point of view (in relation to the fact of conducting away the microparticles of the undesirable substance), the MOST IDEAL scenario is represented by the Variant 1 (Summer, MAX. operation mode). The area is well ventilated, with the maximum supply of fresh air, which is an ideal cleaning mechanism for the given environment.

6) On the other hand, from the ventilation point of view (in relation to the fact of conducting away the microparticles of the undesirable substances), the WORST CASE scenario is represented by Variant 6 (Winter, MIN. operation mode). The area is badly ventilated, with the minimum supply of fresh air, which is a bad cleaning mechanism for the given environment (basically, the existing concentration of pollutants is only being swirled by the vertical ventilation units).

B) Results related to the spreading of the microparticles of the undesirable substance (in general):

1) Presence of microparticles of the undesirable substance has only insignificant impact on the air flow field properties and sources of microparticles for the given definition of the air flow field.

2) On the other hand, the settings of ventilation conditions in the hall have a significant impact on

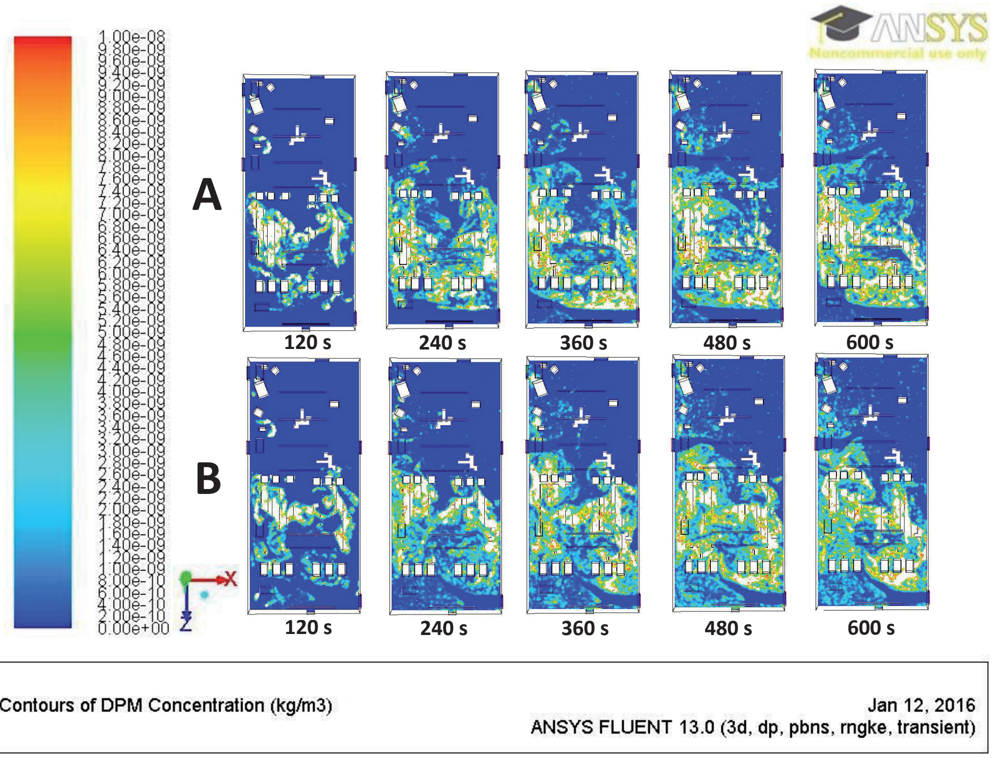


Fig. 3: *Filled contours of heavy metal particles concentration field in a horizontal cross-section through the calculation area 1.5 m above the floor of the hall: (A) ventilation in the lower part of a cross-section of the hall with the unit turned off (B) ventilation in the lower part of a cross-section of the hall with the unit turned on.*

motion and dissipation of the microparticles of the undesirable substance for the given definition of the air flow field.

Other subsequent principles have the same validity as for the previous point A (see above).

Specific recommendations and discovered logical errors for the given working environment can be summarized in the following points:

I) Keep the workplace clean (i.e. vacuum clean the dust + wet mopping of the residues).

II) Use the openings (doors) leading to the open outside area (not to the adjacent contaminated halls and spaces) in order to supply the fresh air.

III) Limit presence of workers in the insufficiently ventilated hall areas to an absolute minimum.

IV) Optimize movement and presence of workers in such way, as to enable them to move and work in the cleanest and the most ventilated zones of the hall.

V) Do not use vertical ventilation of the hall in the zones, where there are no permanently working persons (this only causes unnecessary stirring of the dust and pollution) – specifically, in this case, turn off the ventilation Unit I. (see Figure 2). The results of the simulation had shown that this unit is functionally useless and has a strong influence on stirring up the microparticles of the undesirable substance within the area of the hall (see Figure 3).

4. Conclusions

The above mentioned case study demonstrates an example of possibility how logical errors may have appeared in ventilation systems design of manufacture buildings that were renovated without an in-depth analysis of ventilation conditions. However, the path to optimization and rectification usually consists of simple arrangements leading not only to better working conditions for the workers, but also to energy savings for the company (turning off the purposeless ventilation unit leads, beyond doubt, to lowering energy costs, which could be used more effectively elsewhere).

With the fact in mind that this case is surely not an exception among the manufacture halls, it would be definitely beneficial to perform similar analyses also in other buildings and working areas. ANSYS Fluent software complex was found out to be a very complex and effective tool for these purposes. The common aim of employers and safety staff should be not only ensuring sufficient working productivity, but mainly occupational safety and safety of the environment for the workers. The study above may be one of the examples how to get closer to this goal.

5. Acknowledgements

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