Numerical Modeling and Performance Optimization Study of a Dehumidification Process in Nuclear Waste Storage

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Introduction: one of the main parameters to consider during the nuclear waste storage design phase is the drums corrosion risk. To reduce this risk an alternative technique rather than installing HVAC system is using dehumidifiers. The main objective of this study is to develop a numerical model that replicates the functioning of industrial isothermal dehumidifiers in order to obtain indications about their performance and best positioning (3 layout studied). The geometry of the rad-waste interim storage and its thermo-physical properties, considered during simulations, are taken from a specific ongoing project while the characteristic functioning curves of the dehumidifiers (2 different machines) represent the industrial state of art.

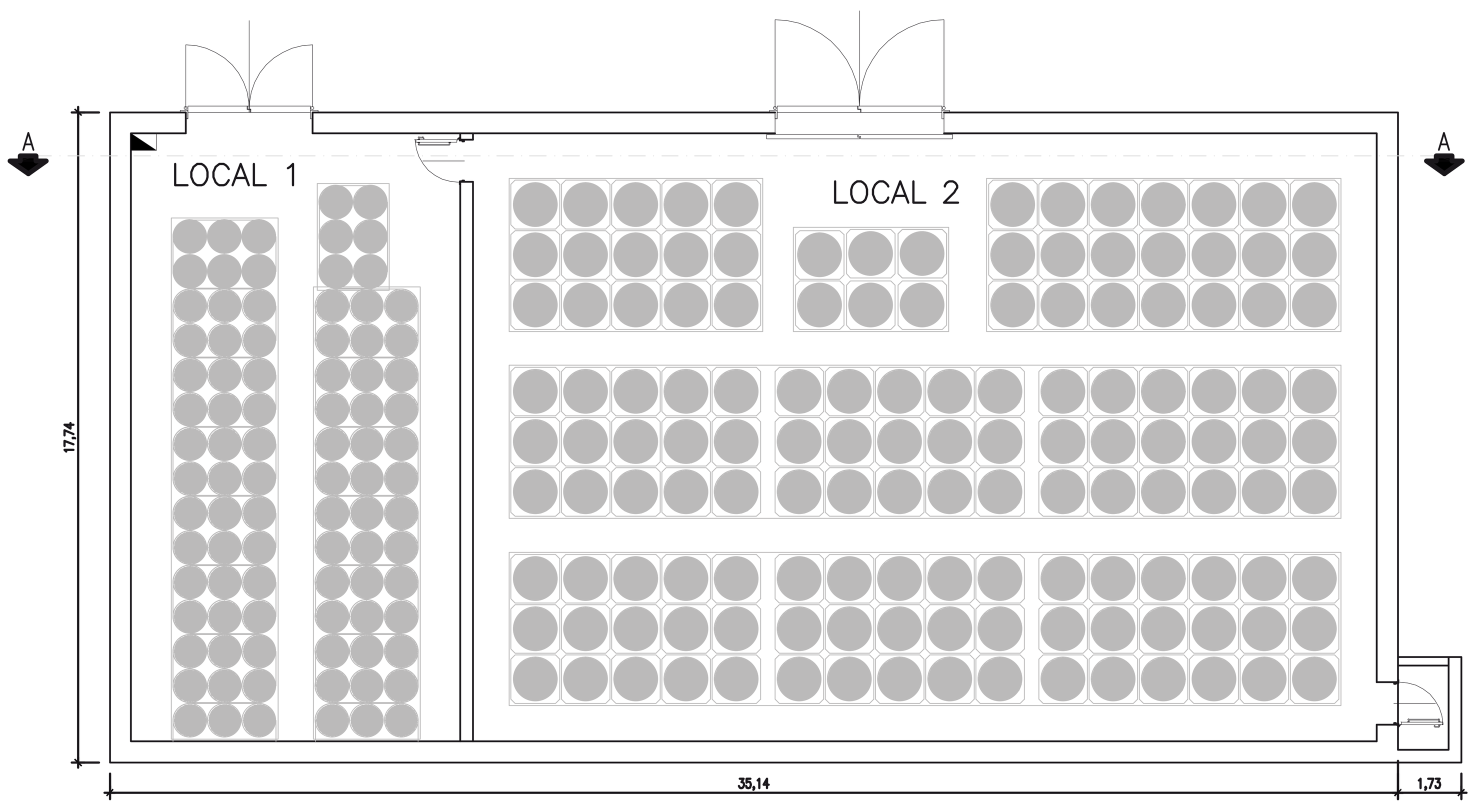

Figure 1. Plan of waste disposal

Computational Methods: The simulation is performed with Comsol Multiphysics 4.3b – Heat Transfer Module and is based on the following steps: 1) stationary fluid flow study (single-phase incompressible turbulent k-eps closure model); 2) time dependent fully coupled heat and moisture transfer study (heat transfer in fluid by forced convection and transport of diluted species to reproduce humidity field).

$$\nabla \cdot \boldsymbol{u} = 0$$

$$\rho \frac{\partial \boldsymbol{u}}{\partial t} + \rho(\boldsymbol{u} \cdot \nabla)\boldsymbol{u} = \nabla \cdot [-p\boldsymbol{I} + \boldsymbol{\tau}] + \boldsymbol{F}$$

$$\rho C_p \left(\frac{\partial T}{\partial t} + (\boldsymbol{u} \cdot \nabla) T\right) = \nabla \cdot (k \nabla T) + \boldsymbol{Q}$$

$$\frac{\partial c}{\partial t} + \boldsymbol{u} \cdot \nabla c = \nabla \cdot (D \nabla c) + R$$

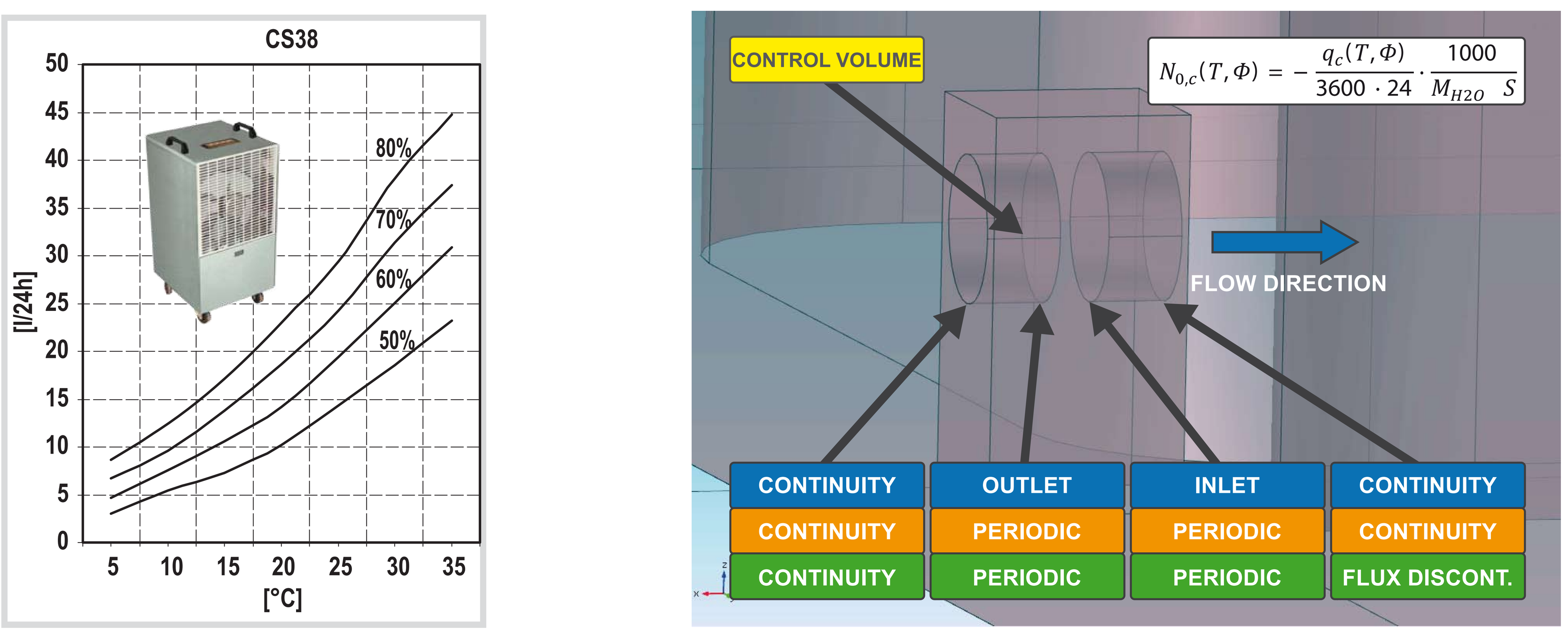

Figure 2. Dehumidifier performance and modelling. The boundary conditions applied are: in light blue fluid-dynamics, in orange thermal and in green chemical conditions.

Results: the simulations are based on the use of two different kind of dehumidifiers. The dehumidifiers kind "A" has a capacity of 33l/24h @ 32°C and RH 90% (air mass handled 380 m^3/h), the dehumidifiers kind "B" has a capacity of 45l/24h @ 32°C and RH 90% (air mass handled 600 m^3/h). The Layout 1 consist of four dehumidifiers of kind "A" positioned along the walls of the local 2 (Figure 3). The layout 2 is characterized by the use of two dehumidifiers of kind "B" positioned along the left wall of the local 2 (Figure 3). Respect to Layout 2, the layout 3 differs only for the position of the dehumidifiers, placed at the opposite corners of local 2 (Figure 3). The numerical study is based on the analysis of flow field and relative humidity RH.

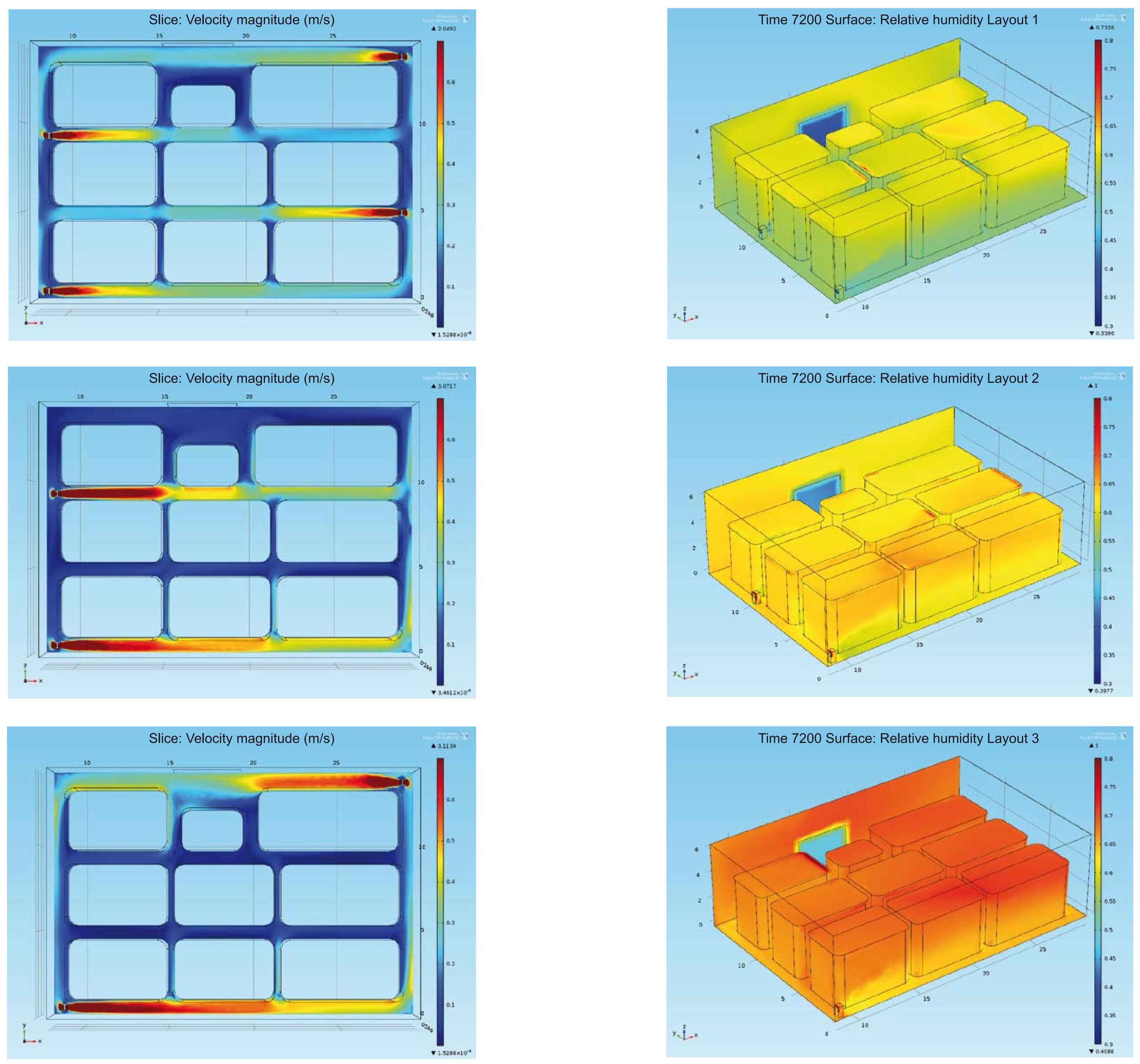

Figure 3. Velocity field and RH surface: the first column represents the velocity field, the second column the surface relative humidity RH after 7200 s for each layout studied. The first row represent the results for Layout 1, the second for the Layout 2 and the third for the Layout 3.

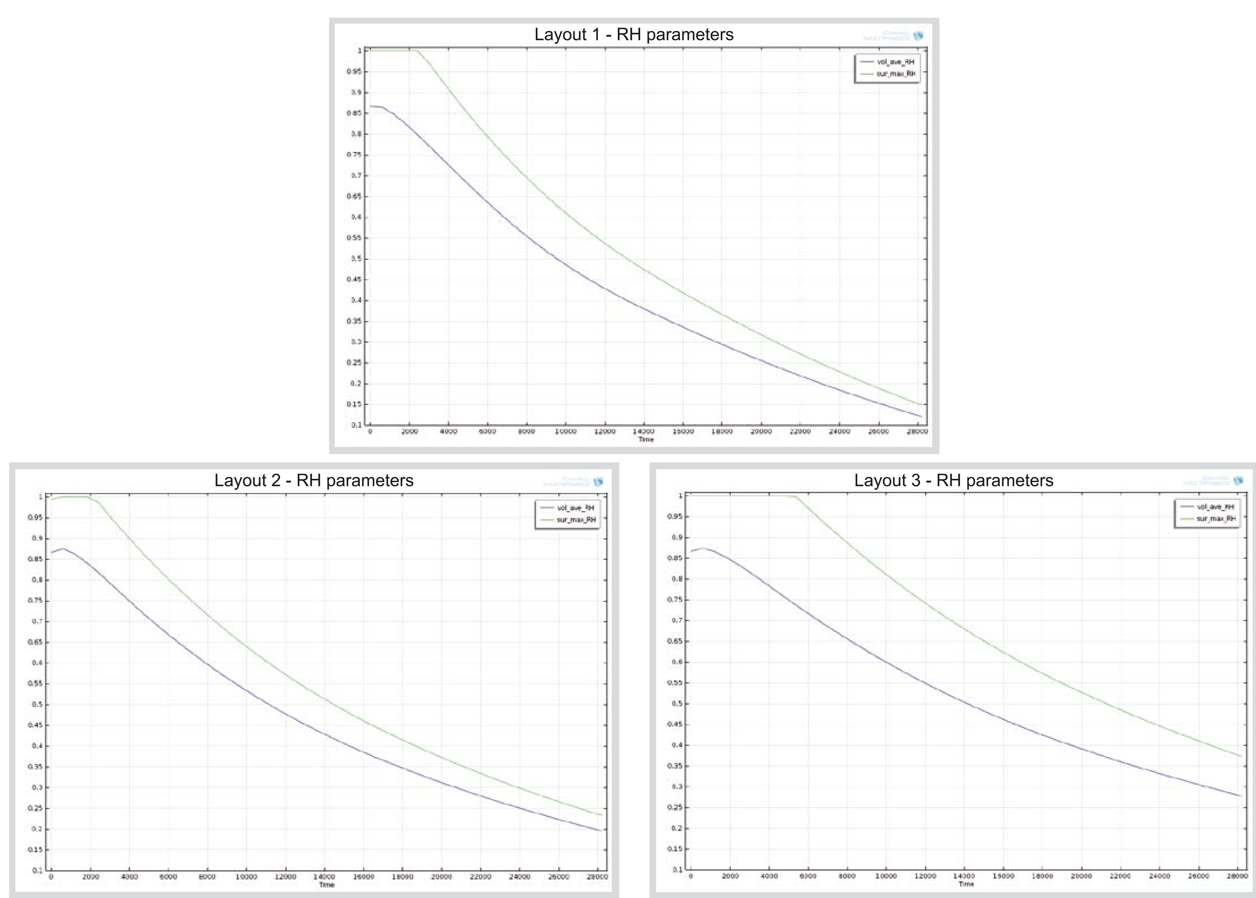

Figure 4. RH parameters and dehumidifiers performance: volume average RH and maximum drums surface for the layout investigated.

Conclusions: In this study the capability of Comsol Multiphysics for solving three-dimensional heat and moisture transfer problems is shown. The study allowed to choose the optimal machine layout configuration (Layout 2) limiting the existence of stagnated flow regions and, at the same time, increasing machines efficiency, so that the drum corrosion risk is reduced.