CFD Modelling of Potroom Ventilation

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Abstract

In the industrial aluminium smelting process, hundreds of cells are placed inside the potroom building. Ventilation of this space is primarily provided by natural convection, where the electrolysis cells are the heat sources. Occasionally, the ventilation is also affected by winds accessing the building through its openings and windows.

In previous studies, the simulation of potroom ventilation has been shown to be a difficult task, particularly regarding the appropriate choice of the turbulence model, which greatly affected the predicted flow pattern. Difficulties in finding a turbulence model that can correctly represent the thermal plume that forms above the cells and rises towards the roof have been reported. Two-equation turbulence models such as k-epsilon and k-omega have been shown to be inadequate. The Reynolds flux model was found to give good results, but this turbulence model is no longer supported by the major commercial codes, allegedly due to its limited range of flows applicability.

In this work, the physical model studied by Dupuis [1] is revisited. The buoyant flow numerical simulations of the physical model are compared with the experimental results. Both Large Eddy Simulation (LES) and Detached Eddy Simulation (DES) are intrinsically transient turbulence models, and both model results are shown to be representative when compared with the experimental work. Finally, DES is used in an industrial potroom ventilation simulation. DES proved to be the most suitable choice of turbulence modelling for industrial potrooms while maintaining accuracy of the results, because it requires less time and space discretization than LES.

Keywords: Potroom ventilation, Buoyant flow, Turbulence modelling, Detached Eddy Simulation, Large Eddy Simulation.

1. Introduction to Potroom Ventilation

Industrial aluminium electrolysis is an intensive energy-consuming process, producing a huge amount of heat dissipation by the cells as well as gaseous contaminants originated from electrolysis or the parallel reactions associated with raw materials impurities (such as SO_2 and HF). In modern smelters, the adequate ventilation of the potroom building is crucial in many aspects:

- At the working level, fresh air at ambient temperature must be supplied for the thermal comfort of workers. In addition, the gases produced in the cell cavity must be removed from the working area, bringing the contamination levels of breathing air within a standard acceptable range.

- The cell heat removal has to be efficient in order to maintain the shell, busbars, cell hoods, and all adjacent equipment in adequate temperatures; otherwise, the cell parts can overheat, potentially leading to catastrophic failure.
- Environmental regulations are becoming tighter in many regions of the world for the benefit of workers, the external environment, and society. This is demanding better solutions for pot gas collection, gas treatment, and heat dissipation.

As a general concept, the potroom contains one or two rows of cells. Intensive heat generation is produced by each cell (typically in the order of 500–1000 kW). This thermal power is then lost by means of natural convection and an air "plume" is formed towards the building roof. Usually, the potroom presents a "roof vent" geometry specially designed to extract heat and gases as efficiently as possible while preventing rain and snow to enter. Potroom windows and openings strongly influence the resulting flow intensity, and these openings have to be designed accordingly. Another important factor is the wind regime to which the potroom is subjected during the year. Wind can help or hinder natural convection efficiency depending on its intensity and direction.

2. Literature Review: Turbulence Models Applied to Potroom Ventilation

The flow generated by natural convection in the potroom is intensely turbulent. Turbulence is an intrinsic transient phenomenon present in fluid flow, characterised by chaotic fluctuations in flow velocities and other transported quantities (pressure, temperature, concentration) both in time and space. Turbulent flows present intermittent formation and collapse of eddies of various sizes over time. Numerical simulation of turbulent flows is challenging and has been extensively studied by academic and industrial analysts. Many turbulence models have been developed over the years, each with its own assumptions and applicability limitations. Moreover, there is no universal turbulence model, and each Computational Fluid Dynamics (CFD) study has to carefully choose a suitable one depending on the simulations' objectives and expected flow characteristics.

Turbulence models can be divided into the following categories:

- Reynolds Averaged Navier-Stokes (RANS). Steady state models, aiming to statistically describe the turbulence as an average over time. Turbulence acts as an increase in the flow viscosity (turbulent viscosity field is created). Example of one-equation formulation: Spallart-Allmaras. Examples of two-equations formulations: k-epsilon, k-omega, Shear Stress Transport (SST). Example of six-equations formulations: Reynolds Stresses Model (RSM).
- Unsteady Reynolds Averaged Navier-Stokes (URANS). The same formulation used in RANS, but including the transient term. Some fluctuations in the flow can be described depending on the mesh and timestep resolution.
- Large Eddy Simulation (LES). Eddies larger than the mesh are directly simulated, and eddies smaller than the mesh are modelled with the "sub grid scale model" (SGS modelling). This turbulence modelling approach is always transient, and the computational cost is high because it requires fine spatial and temporal discretization.
- Detached Eddy Simulation (DES). This is a hybrid model where larger eddies are calculated as LES and the rest of the flow is modelled using URANS turbulence model, mainly near the wall regions. It is a compromise solution between accuracy and computational cost for industrial applications.

During the last decades of the twentieth century, CFD started to be used as a tool for analysing the potroom ventilation flow [1–3]. At that time, only RANS turbulence models were considered of practical use, in two-dimensional steady state models. In the work presented by Dupuis et al. [1] in 1989, physical model measurements (reproduced in Figure 1) were compared with CFD

The DES model was used to simulate natural convection in an industrial potroom. When compared with the URANS SST k-omega model, the DES model presents a more detailed description of the flow. However, the integrated contaminant massflow resulted to be very close in both the models. There is less discrepancy in this case because the pot superstructure is breaking the cross flow coming from the side windows. A steady state solution for the geometrically complex model of the industrial potroom does not exist. This is because the large eddies are intermittently formed and dissipated by the natural convection. Only a transient numerical simulation predicts these flow structures.

In industrial applications, analysts have to carefully choose the turbulence models according to the simulation objectives, the desired degree of detail in the flow description, and the computational effort required for the task. In future works, the authors intend to demonstrate the behaviour and applicability of the turbulence models in side-by-side potlines, where a single potrow is commonly placed in the building, in an asymmetric position with respect to the vertical building's center plane. This potroom arrangement may present a different flow pattern from the results present in this work.

6. References

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