OPTIMIZING GAS FLOW IN A FURNACE THROUGH NUMERICAL SIMULATION: A CASE STUDY USING QOBEO®

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ABSTRACT

This study focuses on optimizing the gas distribution and propagation in a sintering furnace to improve the process efficiency and product conformity. Indeed, ensuring a homogeneous and controlled gas flow in the furnace is essential to achieve a uniform thermal treatment quality for all the workpieces. The main goal was to understand the airflow behavior near the components being processed to analyze their interactions with the surrounding air. During the heating and debinding stages of a full batch of components, certain parts were found to be non-conforming, making it necessary to further investigate the furnace dynamics.
Using qobeo® software, we conducted a numerical simulation to analyze gas flow and heat distribution. The simulation allowed us to detect and identify critical zones where airflow irregularities occurred. These zones correspond to racks where non-compliant parts were observed. This analysis provided valuable insights into the airflow behavior and patterns and allowed us to pinpoint areas requiring optimization.
Based on these findings, a targeted solution was proposed to optimize the flow into the furnace (by adjusting the geometry of the load). Before implementation in the actual furnace, this modification was also simulated using qobeo® software to assess its effectiveness. The results confirmed that the addition of elements leads to more uniform gas circulation between the shelves. After its implementation, the modification of the racks showed significant improvements in the furnace performance, reducing the occurrence of non-compliant parts. The overall product quality was enhanced.
This work shows the value of numerical simulation in diagnosing industrial challenges and validating a proposed solution. The presented findings highlight the potential of this methodology and the use of numerical tools such as qobeo® to improve manufacturing efficiency and product quality in industrial settings.

1. INTRODUCTION

Alliance-MIM, a metal injection molding (MIM) expert, expressed concerns about a potential gas leak, and/or a non-uniform flow distribution within their furnace. These suspicions were based on irregularities observed during the debinding stages, suggesting heterogeneities that could impact the final properties of the loads.
To investigate this issue, a test was done by voluntarily oxidizing several components with a hydrogen (H2) deoxidation treatment to picture the gas path. The components' surface in

contact with H2 will whiten, making this treatment a great indicator for evaluating gas exposure. The image below (Figure 1) is one of the results observed following this treatment: for a same furnace level, some parts are unwhitened, confirming the hypothesis of a non-uniform flow. Alliance-MIM requested then a flow simulation to further validate and understand the origin of this heterogeneity of the flow in the furnace. The objective is to identify the potential causes and provide recommendations to improve and optimize the furnace to obtain an even flow.

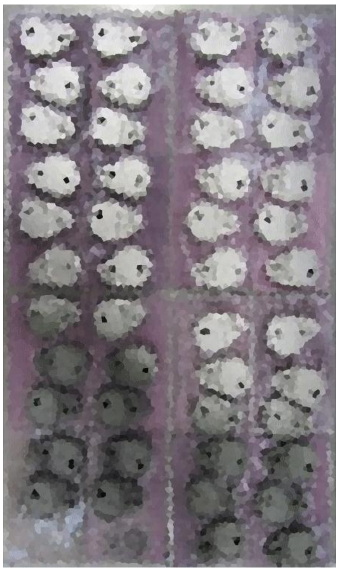

Figure 1: Image of the parts obtained following the dixydation treatment (Image blurred due to confidentaility)

2. SIMULATION WITH QOBEO®

The studied installation is a 0.27 m^3 sintering furnace used by Alliance-Mim. The study focuses on simulating the sintering cycle within the furnace. Heated gas is introduced in the furnace through several intlets pipes, while the internal pressure is maintained constant during the entire process. Exhauts at floor level of the furnace are considered to account for gas outflow.The furnace contains 11 shelves on which the components are placed during the sintering process.
To analyze, the gas flow behavior, a computonial fluid dynamics (CFD) study is conducted by solving the Navier-Stokes equations [1] with qobeo®.

Figure 2: Furnace representation used for simulation (simplified due to confidentaility)

qobeo® is a 3D CFD (Computational Fluid Dynamics) software dedicated to the simulation of thermal system processes such as heating, cooling, and quenching. It is specifically designed to be user-friendly for heat treatment practitioners, enabling them to optimize complex processes through numerical simulation.
The software combines advanced numerical and physical models to solve the coupled interaction between fluid flow and thermal fields in a parallelized computational architecture. The resulting simulations are fully three-dimensional, providing detailed insight into the evolution of key physical quantities such as the velocity field and temperature distribution within the environment.

3. FLOW ANALYSIS AND RESULTS OBTAINED

The gas flow within the furnace is analysed in detail. To understand its evolution throughout the furnace, several vertical cross sections are taken along the length of the furnace (Figure 3). In addition, horizontal cross sections are taken at different heights to observe the flow distribution (Figure 4).

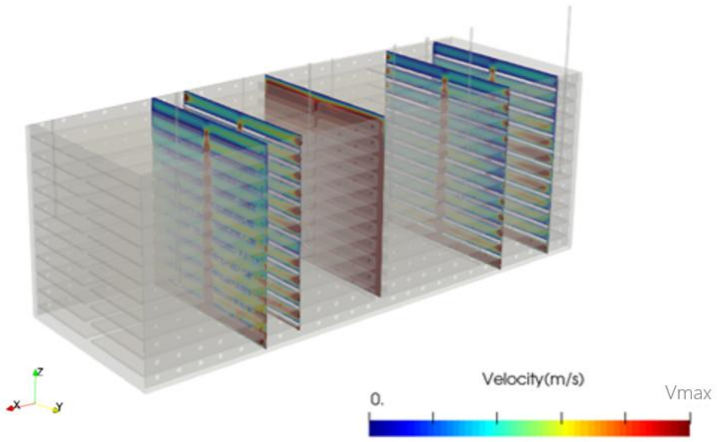

Figure 3: Velocity field evolution on vertical cross-sections along the furnace

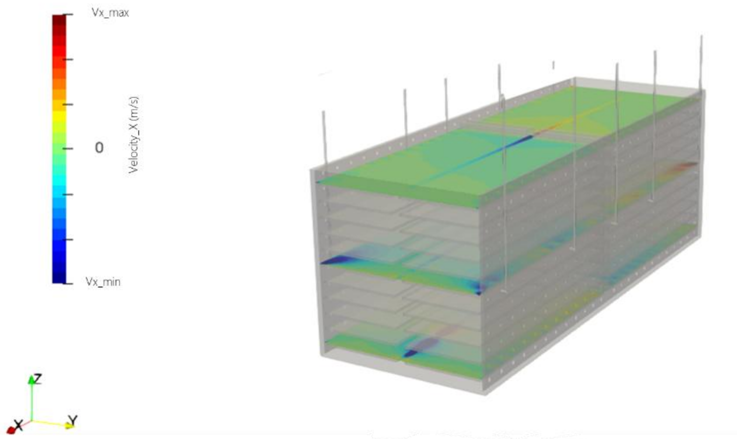

Figure 4: Velocity field evolution in the X-direction on horizontal cross sections for 3 different levels of the furnace.

At each vertical cross-section, the velocity field is found to be non-uniform. Specifically, the horizontal velocity component (Vy) appears to increase towards the bottom of the furnace (Figure 5). A strong recirculation is observed near the exhausts. This recirculation, along with the effect of the outlets, drives the gas flow downward toward the exit furnace.
By examining the horizontal cross-sections, we observe that the gas accelerates as it moves from the door towards the center of the furnace. This acceleration also leads to an uneven flow, resulting in non-uniform outcomes. This phenomenon becomes even more pronounced on the lower levels, near the exhaust outlets, which create strong recirculation zones.

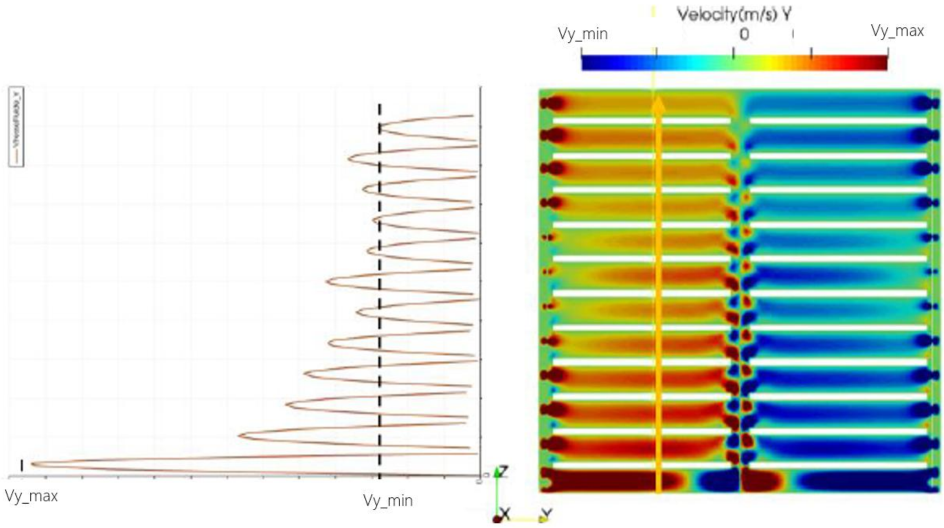

Figure 5: Exemple of the Velocity evolution (Y-direction) on a vertical cross-secton. (the velocity values have been redacted due to confidentaility)

At the corners of the furnace, the gas flow appears to be relatively strong (Figure 6). The horizontal cross-sections at various heights, particularly the central one, reveal higher flow velocities near the corners. This observation is consistent with experimental results from the production, which indicate heterogeneity in the treatment outcomes for parts located near the corners on the same furnace level (black components of Figure 1).

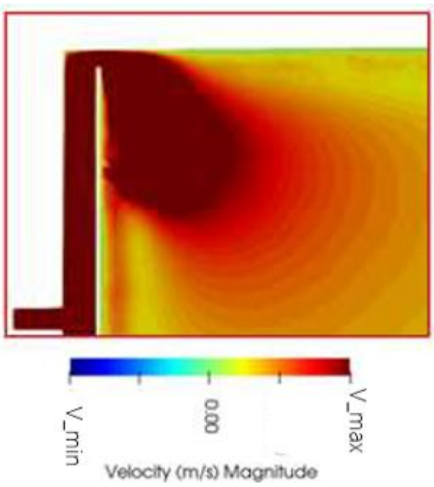

Figure 6: Zoom on the velocity at the corner (center of the furnace)

4. SIMULATION INSIGHTS AND FURNACE OPTIMIZATION

The simulation plays an important role in identifying the problematic areas in the furnace, especially where the flow is uneven, leading to heterogeneous results. The detailed analysis of the flow patterns confirms our initial hypothesis: the gas distribution inside the furnace was not homogeneous, especially along the horizontal planes and near the exhaust zones. The insights were essential in understanding the main causes of the inconsistencies observed in the final products.

Following this phase, a second step was imperative to explore potential solutions aimed at making the gas flow more uniform and controlled in the identified critical areas. Due to confidentiality requirements, we cannot display all the details of the optimized configuration, however, we are able to achieve a more homogeneous behavior of the gas flow inside the furnace (and thus granting higher quality of the final workpieces). It is important to note that it was identified using simulation testing with qobeo®: we are able to converge to a configuration that significantly improves the flow uniformity without imposing huge changes to the initial furnace configuration.

This solution is validated by Alliance-Mim team at the production site. The implementation of the proposed changes has led to having more homogeneous parts, meeting their quality requirements.

This successful result shows the effectiveness and value of using simulation tools for optimizing complex industrial processes. These tools can confirm theoretical assumptions but also guide the development of solutions.

REFRENCES

[1] E. Hachem, «Stabilized finite element method for heat transfer and turbulent flows inside industrial furnaces», PhD thesis, 2009