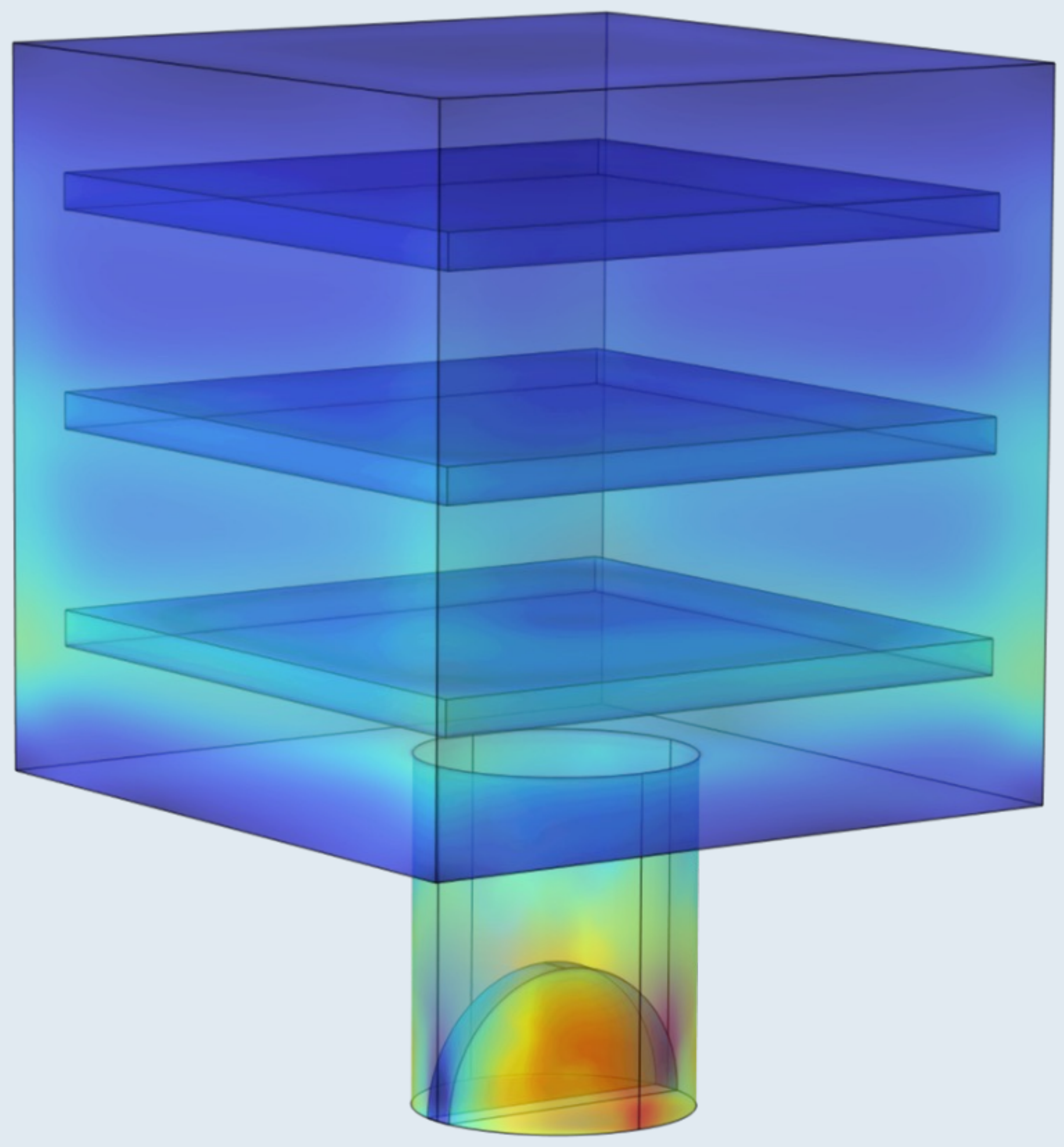

CFD Simulation of Sublimation Flux into a Freeze-Dryer

Investigation of fluid dynamics inside a freeze-dryer during the primary drying of a lyophilization process

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Abstract

Freeze-drying is a widespread technology particularly suitable for heat-sensitive materials that could be damaged by high temperatures. One of the crucial phases of lyophilization is the primary drying. This step, is strongly influenced by the conditions within the chamber, in terms of pressure and temperature. During the primary drying, the water vapor, produced by ice sublimation, flows through the drying chamber to the condenser, where it is removed by freezing process on the walls, in order to maintain vacuum conditions.

Loss of control of chamber pressure is one of the causes of failure of this technique. This can be due to the occurrence of what is called "choked flow". This condition is reached inside the duct, where the flow section is restricted. In fact, the presence of this restriction results in an increase of the flow speed, which can reach the speed of sound. For these reasons, the speed that the flow generated by the sublimation process reaches during its pathway is one of the crucial aspect for the success of the process.

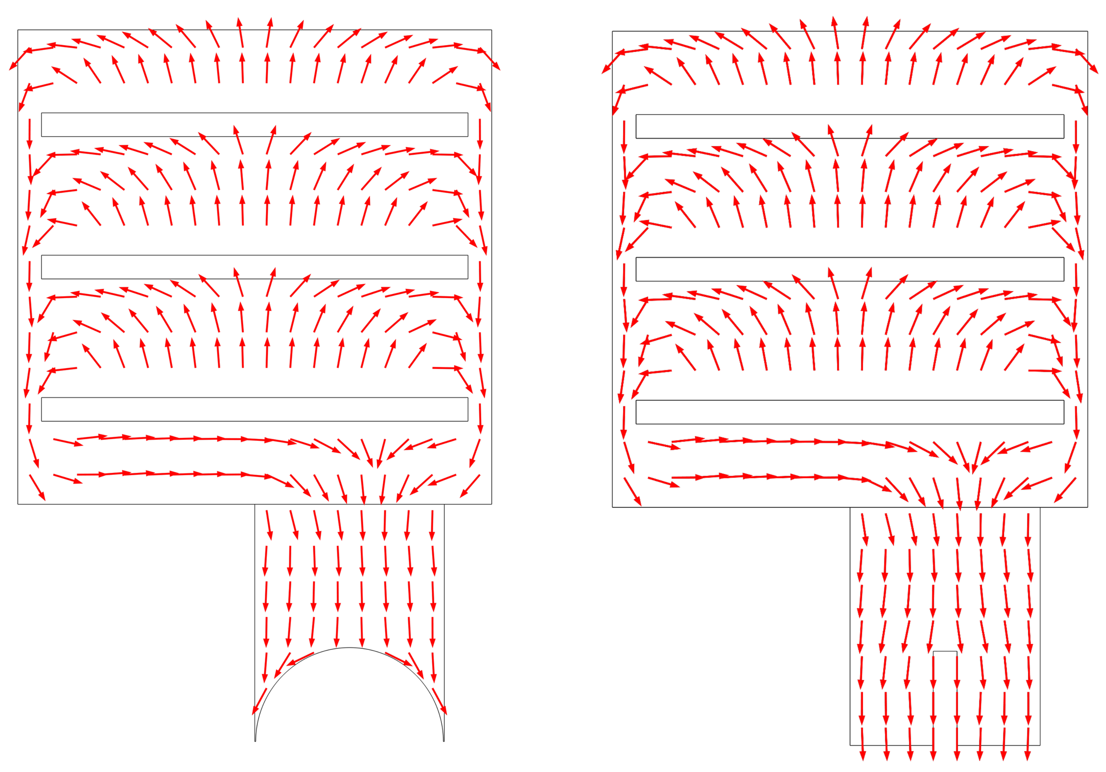

FIGURE 1. Mass flow direction. Left: xz view. Right: yz view.

Methodology

A freeze-dryer is composed of two chambers: drying chamber and condenser, connected by a duct. The two chambers can be isolated by closing a valve located within the duct.

The implemented model provides a three-dimensional geometry representative of the freeze-drying chamber, with three shelves on which the product to be dried is stored, and the duct. Since from the fluid dynamics point of view, the most critical zone is within the duct, the condensation chamber is not present. The product has been represented as a mass flow exiting from the upper side of the shelf. The developed model combines the turbulent model k-ε with Heat Transfer in Fluids.

Results

As shown in Figure 2, the chamber pressure variations at constant mass flux are one of the most influential factors on the maximum velocity within the volume; the relation between the two variables considered can be expressed by a power law. Moreover, the mass flux has a linear correlation with the maximum velocity reached. The coefficients of the identified relationships will closely depend on the freeze-dryer geometry. On the other hand, shelf temperature shows a much less significant impact and therefore can be neglected.

Based on the model, it will be possible to predict the conditions for which choked flow is achieved for the equipment.

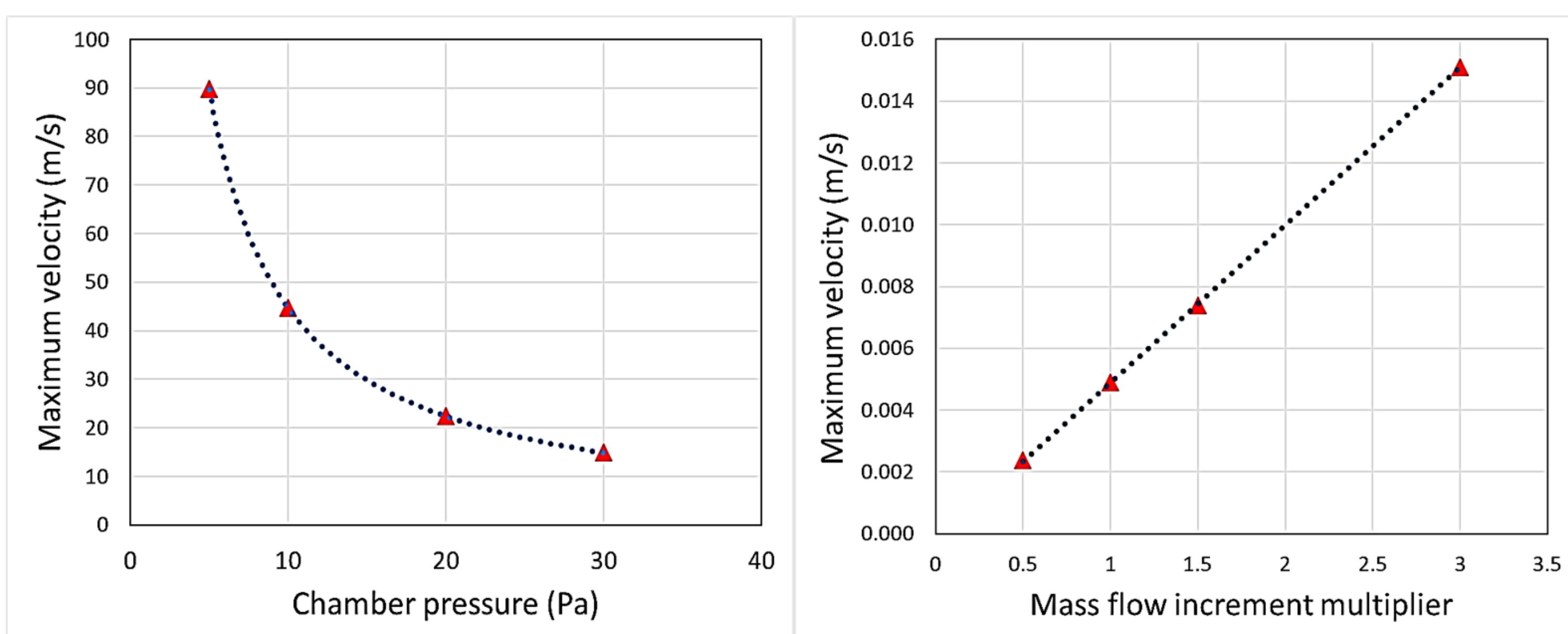

FIGURE 2. Left: Maximum velocity variation in function of chamber pressure. Right: Mass flow increment multiplier (Target J_w = 1.0e-4 kg/s).

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