Topology Optimization for Additive Manufacturing of Porous Media Burners

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ABSTRACT

Topology optimization is a computational design approach to realize optimal material distribution in a given framework of constraints. In this work, we aim to identify a deterministic way of designing such systems that also considers the feasibility of manufacturing while pushing the limits of optimization. Topology optimization methods are applied to identify porous structures that improve combustion performance, while improving experimental efficiency by significantly reducing the number of trials for testing.

MATHEMATICAL METHOD

We can express the mathematical formulation as a constrained solution of the flow equations. If J stands for the cost function to be minimized, the optimization problem can be stated as follows:

$$\text{Minimize}: \ J = J(\alpha, \mathbf{v}, p) \qquad \text{Subjected to}: \ \mathscr{R}(\alpha, \mathbf{v}, p) = 0$$

where $\mathbf{v}$ and p stand for velocity and pressure, respectively, and α represents the design variables, i.e. the porosity distribution. $\mathscr{R} = \left(R_1, R_2, R_3, R_4\right)^{\mathrm{T}}$ denote the state equations, in our case the incompressible, steady-state Navier–Stokes equations:

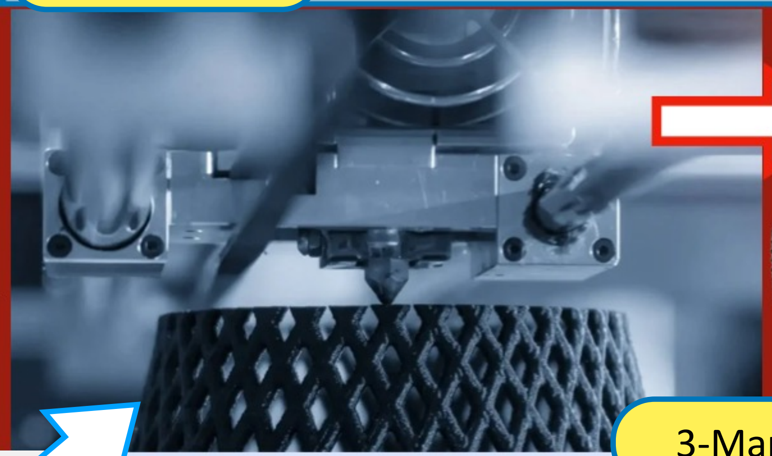
$$\left(R_1, R_2, R_3\right)^{\mathrm{T}} = (\mathbf{v} \cdot \nabla)\mathbf{v} + \nabla p - \nabla \cdot (2\nu \mathrm{D}(\mathbf{v})) + \alpha \mathbf{v}$$

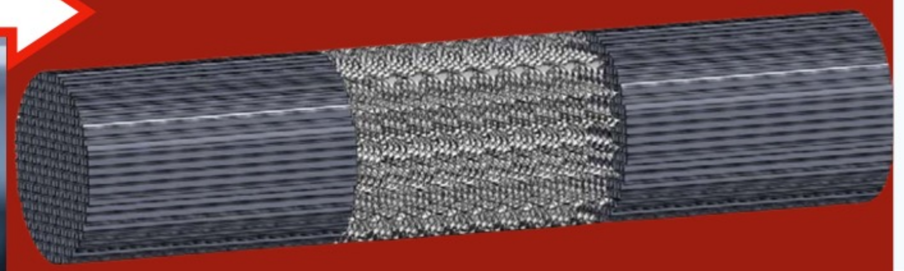
$$R_4 = -\nabla \cdot \mathbf{v}$$

1 -Formulate

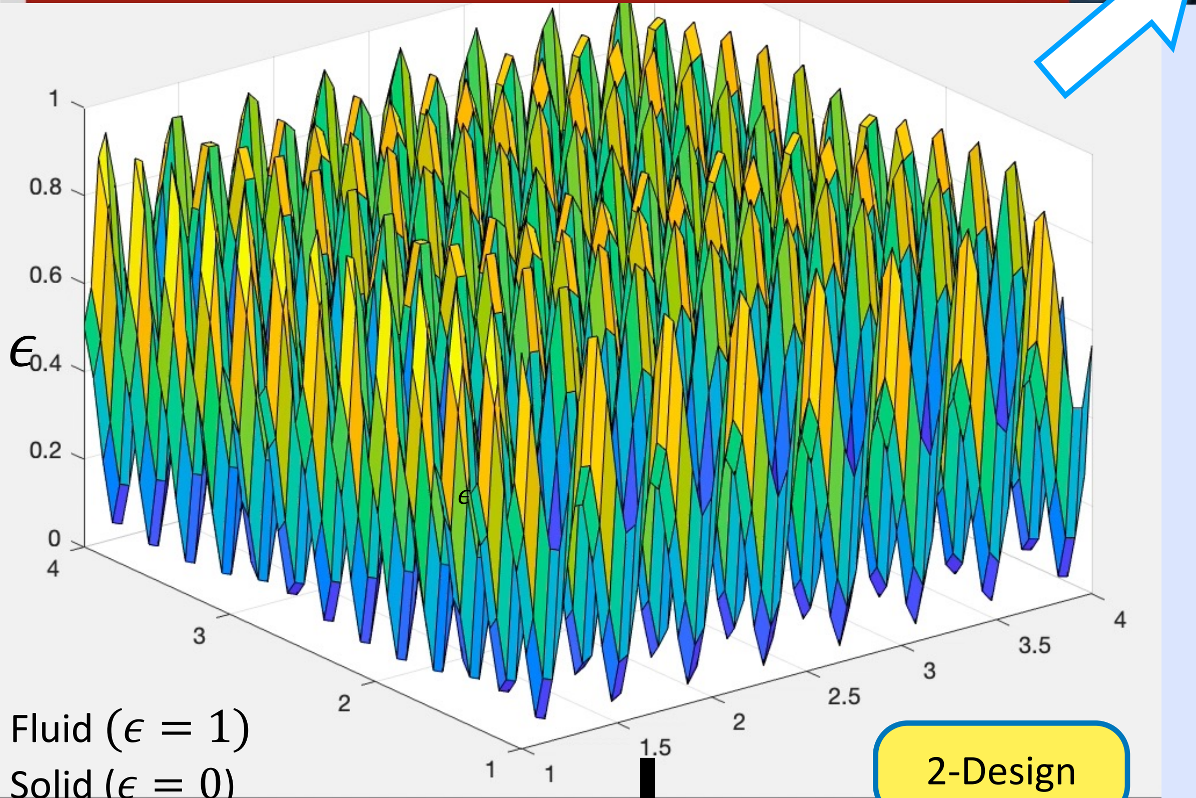
ADDITIVE MANUFACTURING

3D printing of porous ceramics that act as burners to optimize combustion.
These designs are outcome of computational simulations performed based on the constraints





3-Manufacture



Fluid ($\epsilon = 1$)
Solid ($\epsilon = 0$)

2-Design

- Efficient combustion in porous media is highly dependent on the characteristics of the geometry that define the burner in its ability to stabilize a flame
- Reducing unburnt hydrocarbons and other harmful emissions require an optimized interfacial area

OUTCOMES :

- Better geometry and material properties
- Cheaper and easier manufacturing due to less number of trials
- Corrosion resistant and durable

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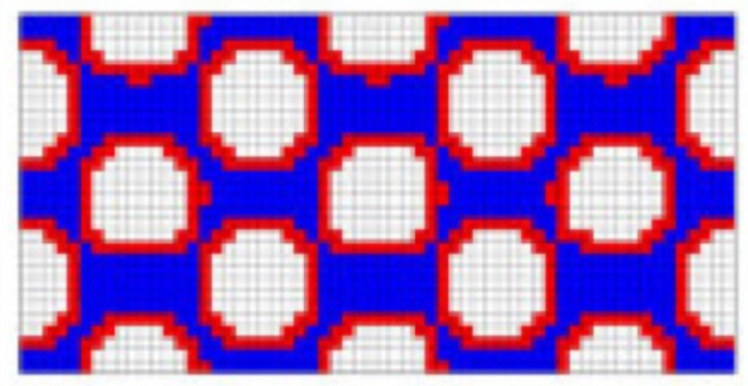
APPLICATION IN THERMO FLUIDS

The necessity to optimize various parameters in a flow can arise from the perspective of energy efficiency, increasing the speed of the process, inhibition of incomplete reactions and efficient distribution of heat.

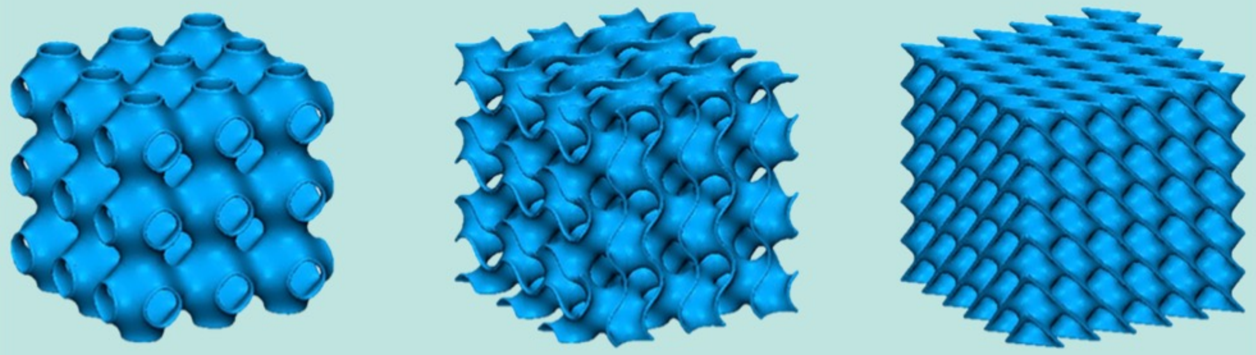
User defined cost functions J :

- Power loss during flow
- Heat loss across boundaries and interfaces
- Pressure loss across channel length
- Trajectory of particle in a flow



A typical distribution of material with spherical obstructions present in the fluid can be modelled using ϵ

- Fluid ($\epsilon = 1$)
- Interface (rapid change in ϵ)
- Solid ($\epsilon = 0$)



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