Performance Evaluation of Minimal Surface Heat Exchangers

Maiki Vlahinos*and Andreas Vlahinos†

* Senior Applications Engineer at nTopology
Fort Collins, CO USA
email: maiki.vlahinos@gmail.com, web page: http:/ntopology.com

† Chief Technical Officer
Advanced Engineering Solutions
Castle Rock, CO 80108, USA
email: andreas@aes.nu - Web page: http://www.aes.nu

ABSTRACT

Additive manufacturing industry continues to grow with new machines, faster processes and a large selection of materials. The design freedom presented by the additive manufacturing enable us to reimagine and optimize the geometry of heat exchangers.

A known minimal surface is a solution for Plateau's problem, defined as a part of calculus of variations by Lagrange in 1760 Reference 1. Minimal surfaces unlock nature's maximum structural efficiencies and can be found in the Callophrys Rubi butterfly's wings. Triply Periodic Minimal Surface (TPMS) geometries such as Schwarz-D and Gyroids separate a given volume domain into two separate continues volume regions. These minimal surfaces, by definition, have a zero-mean curvature Reference 2. These surfaces generate minimum potential energy states that result in stable equilibrium positions. These topologies increase the heat transfer surfaces per unit volume. They also intermingle smoothly the cold and hot fluid domains that reduce pressure drop and increase flow rate. Calcite particles form gyroid minimal surfaces for cooling and soap bubbles are minimal surfaces that comply with given prescribed boundaries. Triply Periodic Minimal Surfaces were discovered in the early seventies by mathematicians but they have not been used in product design. The two main reasons for this are:

1. The major CAD tools today are tailored towards subtractive manufacturing and they are not capable of generating gyroid surfaces. Minimal surfaces that conform to an arbitrary shape are difficult to generate even in specialized Additive Manufacturing specific geometry software tools.

2. It is impossible to build minimal surfaces such as Schwarz-D and gyroids with traditional subtractive manufacturing techniques.

We can now overcome both obstacles by utilizing modern geometry kernels with implicit geometry representation and Metal Additive Manufacturing.

Metal additive manufacturing of complex parts with overhangs typically requires the use of sacrificial support structures to hold the part during the manufacturing process. Minimal surface lattice structures such as Schwarz-D and gyroid do not require any support as their geometry keep turning to avoid large overhangs. This feature makes the manufacturing efficient and enables us to build complex geometries.

This presentation demonstrates the potential of significantly improving energy efficiency of heat exchangers using Minimal Surface topologies. This presentation will also demonstrate the process of integrating advanced CAD, CAE, CFD and optimization tools to optimize the geometric design of an oil cooler of a helicopter.

REFERENCES

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