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Niowave Design and Analysis of a High Power Converter – FY 21

In Partial fulfillment of the Deliverable Requirement for Niowave LANW-A1 Support by LANL

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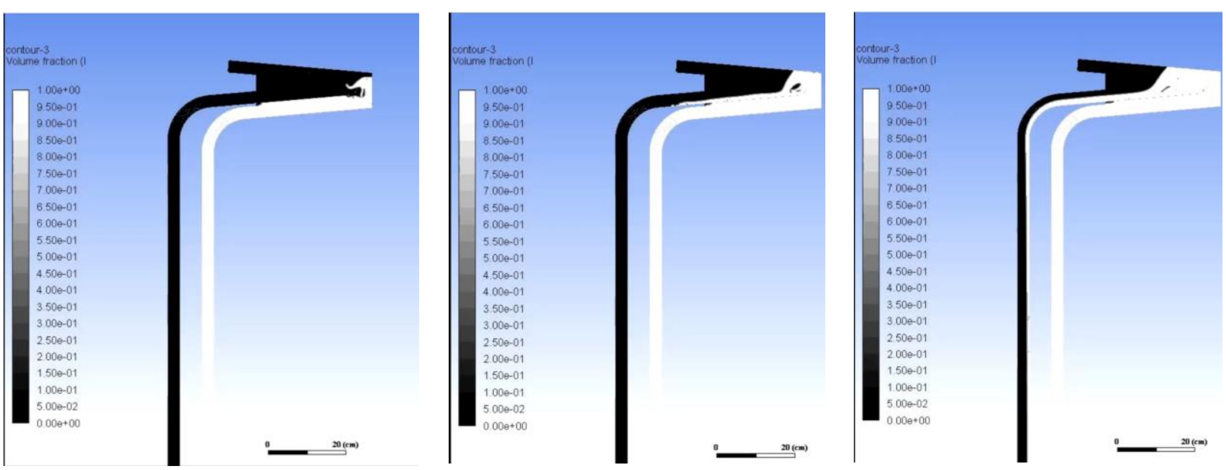
1 Introduction

LANL provided support to Niowave Inc. on the design and analysis of the Mk. 4 and Mk. 5, 20 kW converter. The Mk. 4 converter design consisted of lead bismuth eutectic (LBE) flowing over a divider plate to create a waterfall. Niowave, with feedback from LANL, improved on the Mk.4 divider plate and "horn" region of the converter to create the Mk. 5 version of the converter.

2 Computational analysis and flow visualization of first-generation 10 kW converter

A first generation 10 kW converter was designed, and computational fluid dynamics (CFD) analysis was performed. The converter consisted of LBE (in white in Figure 1 below) pumped through the inlet pipe, over a steel plate, creating a waterfall effect, and flowing down through the outlet pipe, driven by gravity. The CFD simulations initialized LBE in the fill tube, as well as in the bottom portion of the target. The results show a recirculation zone, as the flow goes over the divider plate in Figure 1(a). The core of the vortex is observed as a region with no LBE in Figure 1 (b). As the flow continues, the converter is almost completely filled with LBE, Figure 1 (d).



(a) (b) (c)

Figure 1: CFD analysis of LBE flow over a 10 kW converter design, creating a waterfall effect.

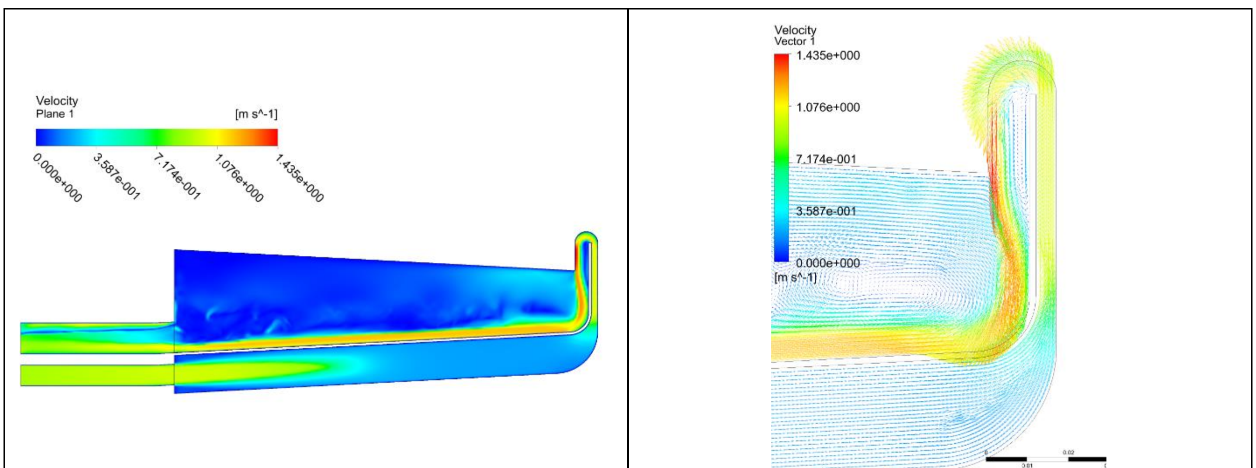
A quartz model of the 10 kW converter was designed and constructed at LANL and tested with water at LANL and with LBE at Niowave. The results from CFD were qualitatively similar to those from the experimental flow visualization using LBE. Figure 2 (a) shows the presence of some non-uniformity in the flow close to the divider plate, likely vortices, that dissipate when the flow has run for some time, as shown in Figure 2 (b).

(a) (b)

Figure 2: Flow visualization of LBE through a quartz model of the 10 kW converter.

3 Computational analysis of a 20 kW converter and improvements to the design

In the 20 kW converter, an improvement to the 10 kW system, the divider plate was made longer, and straighter. The previously flat top of the converter was replaced with a curved “horn” section, as development made by Niowave, to improve the shape of the LBE waterfall. This feature along with the sloped divider plate establish a streamlined, stable flow as the LBE falls. The CFD simulations once again initialized the LBE in the bottom of the converter and in the inlet pipe. The mesh density near the “horn” region was especially important to capture the flow separation and recirculation of the flow. Figure 3 shows the LBE velocity field contours and vectors. The “horn” is completely filled with LBE, and the velocity of the flow increases as the LBE flows over the divider plate. There is flow separation at the plate and the flow appears to be stable as it falls.



(a) (b)

Figure 3: CFD analysis of 20 kW converter with longer, straighter divider plate and curved “horn”.

To alleviate the issue of flow separation, a curved divider plate was designed by Niowave. The horn and divider plate height and curvature were iterated to ensure the horn was completely filled with LBE, and there was negligible flow separation at the plate at a flow rate of 2 GPM. The shape of the final 20 kW converter is shown in Figure 4.

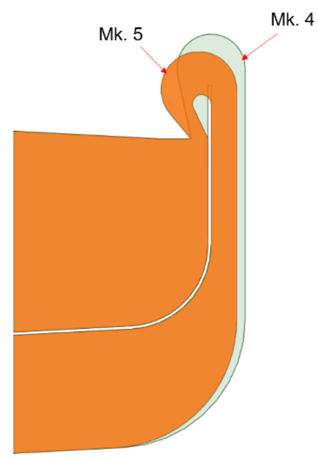


Figure 4: Design improvements to Mk. 5 converter made by Niowave

Flow visualization experiments were planned to assess the stability of the LBE flow with the new, Mk. 5 converter, details of this are given in [1].

4 Heat exchanger and condenser design for cooling of LBE

Along with the converter, LANL supported Niowave in the development and analysis of a heat exchanger and condenser system to cool the LBE after irradiation. Details on the heat exchanger design can be found in [2]. The heat exchanger design consisted of an inner tube carrying the LBE and an outer tube containing water. The water flow rate was driven by the rate of steam generation and the system was estimated as a pool boiler. To dissipate 20 kW of heat, LANL analytically estimated that a 17 inch long heat exchanger was needed, assuming the inner tube was completely full of LBE. A momentum balance to estimate the volumetric flow rate in a gravity driven flow (Equation 1) showed that the inner tube, tilted at 1.69^0 would be sufficient to flow all the LBE through without build up, however it was unclear whether the inner tube would be completely full of LBE.

$$\dot{V} = \frac{\pi \rho g \sin \sigma \, a^4}{8\mu} \tag{1}$$

where $\dot{V}$ is the volumetric flow rate, ρ_{LBE} the density of LBE is $10321\ kgm^{-3}$ g the acceleration due to gravity is $9.81\ ms^{-2}$, the tilt angle σ is 1.69^0, a the inner pipe diameter is $0.022\ m$ and μ_{LBE} the dynamic viscosity is $1.7e-3\ Pa.s$.

Experiments are needed to verify this. Niowave tested a 14 inch long heat exchanger with about 5 kW heat input and found it sufficient to dissipate the applied heat, the experiments also confirmed that at a 1.69^0 tilt was sufficient to avoid LBE build up. A 20 kW test was not performed.

A helical coil condenser was proposed by Niowave, with initial dimensions also proposed. LANL performed a heat transfer analysis and iteratively calculated possible sizes of the condenser shell and inner tube needed to condense the steam generated by the heat exchanger. Proposed condenser sizes from the analysis are shown in Figure 5.

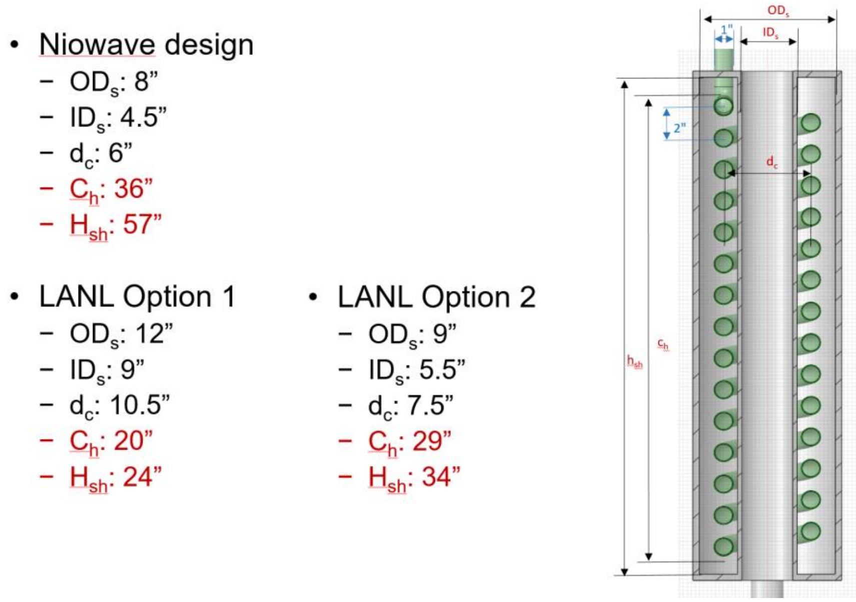


Figure 5: Shell and tube condenser sizing options

5 References

[1] Singh, B. S., Woloshun, K. A. W., & Miera, C. G. M. (2022, April). Niowave Flow Testing of the High Power Converter - FY 21 (LA-UR-22-23916).

[2] Singh, B., & Woloshun, K. A. (2022). Niowave Ancillary Systems–FY21 In Partial Fulfillment of the Deliverable Requirement for Niowave Ancillary Systems Support by LANL (No. LA-UR-22-20580). Los Alamos National Lab.(LANL), Los Alamos, NM (United States).