ORNL/TM-2018/788
CRADA/NFE-16-06238

An Analysis of Advanced Manufacturing for Innovative Burner Nozzle Design

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February 19, 2018

**CRADA FINAL REPORT
NFE-16-06238**

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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

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CRADA/NFE-16-06238

Materials Science and Technology Division
Advanced Manufacturing Office

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Date Published:
February 19, 2018

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831-6283
managed by
UT-BATTELLE, LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

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ACKNOWLEDGEMENTS

This CRADA NFE-16-06238 was conducted as a Technical Collaboration project within the Oak Ridge National Laboratory (ORNL) Manufacturing Demonstration Facility (MDF) sponsored by the US Department of Energy Advanced Manufacturing Office (CPS Agreement Number 24761). Opportunities for MDF technical collaborations are listed in the announcement "Manufacturing Demonstration Facility Technology Collaborations for US Manufacturers in Advanced Manufacturing and Materials Technologies" posted at http://web.ornl.gov/sci/manufacturing/docs/FBO-ORNL-MDF-2013-2.pdf. The goal of technical collaborations is to engage industry partners to participate in short-term, collaborative projects within the Manufacturing Demonstration Facility (MDF) to assess applicability and of new energy efficient manufacturing technologies. Research sponsored by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Advanced Manufacturing Office, under contract DE-AC05-00OR22725 with UT-Battelle, LLC.

ABSTRACT

Utilizing the Arcam electron beam melting powder bed process, fuel nozzles designed by GTI and not manufacturable by traditional manufacturing techniques were produced. The fuel nozzles resulted in a 50% reduction in emissions and efficiency improvement. The goal of this project was to assess the cost and performance benefits of utilizing selected Additive Manufacturing (AM) approaches to fabricate an advanced premix nozzle for use in commercial burner applications that can only be manufactured by advanced AM methods, and which offers the potential for increased component performance.

1. AN ANALYSIS OF ADVANCED MANUFACTURING FOR INNOVATIVE BURNER NOZZLE DESIGN

This phase 1 technical collaboration project (MDF-TC-2016-092) was begun on July 19, 2016 and was completed on October 19, 2017. The collaboration partner Gas Technology Institute is a small business. The project demonstrated the ability to fabricate advanced fuel nozzle designs for commercial water heater applications via additive manufacturing to show an increased efficiency and reduction in NO_x emissions.

1.1 BACKGROUND

The Gas Technology Institute (GTI) has been involved in combustion and new burner design for over 70 years. The GTI project team considers additive manufacturing (AM) to have the potential to unlock new sophisticated design possibilities for burner components that will greatly improve burner performance, reduce manufacturing costs, and ultimately allow gas-fired equipment to compete more effectively. GTI partnered with the Oak Ridge National laboratory (ORNL) Manufacturing Demonstration Facility (MDF) to provide the knowledge and the capacity to evaluate the pros and cons of implementing different AM approaches to improved combustion design.

1.2 TECHNICAL RESULTS

1.2.1 Component Design

GTI and ORNL designed, developed and 3D printed an advanced low emissions high efficiency burner for commercial water heater applications. The design is well suited for 3D printing as the design is complex and cannot be manufactured by traditional manufacturing methods. The fuel nozzle designs were roughly 3” in diameter and 2” tall and consisted of multiple ports embedded within the design. In total, four design iterations were completed based on the ability to fabricate via AM methods. The design provides high turndown, improved efficiency and ultra-low emissions for non-attainment areas. The design was bench tested under conditions similar to a commercial water heater to demonstrate performance. It should be noted, the fuel nozzle design developed as part of this project is currently part of a pending patent application and details are not discussed further.

1.2.2 Component Fabrication

Inconel 718 was chosen as the material for fabrication of the burner nozzle and operational prototypes due to the known high temperature capability of the material, and the known processability in the Arcam electron beam melting (EBM) process. Due to the nozzle design including elements such as a significant number non-supported overhangs, the EBM processes was uniquely suited to rapidly fabricate the geometry without supported overhangs and need to develop processing parameters as would have been the case with selective laser melting (SLM) and binder-jet additive manufacturing (BJAM). Additionally, this allowed for a focused effort on the design iterations and feedback from ORNL to GTI on improving the fabricability of the design.

1.2.3 Cost Evaluation

This project explored advanced burner designs that have the ability to increase the overall performance and fuel efficiency that can only be built through additive manufacturing. However, it is necessary that the advanced AM designs can also match the economics of the components that they replace. While the focus of this study has been on demonstration of the component's design benefits on increasing efficiency, overall economics for manufacturability is an important factor.

Summarized in Table 1 is the cost per part if parts were scaled for production using the currently available additive manufacturing techniques and assuming the ability to nest parts (pack) per build envelope inside the Arcam printer. In preparing the cost evaluations, the following costs were assumed: Machine Set-up-$180 per build and Powder costs-$22 per part. It should be noted, that through nesting the parts within a build area, and investing in optimizing the geometry for fabrication in the binder-jet AM process, costs of the nozzle can be reduced by over an order of magnitude and would allow the AM variant to be economically competitive with the traditionally fabricated nozzles of today.

However, it should be noted for the fuel nozzle to be fabricated using the binder-jet process, and prove economical, focused efforts on the shrinkage/warpage of the specific geometry during densification are required and are considered part of a future extended effort at driving the economic case of this advanced nozzle design. Additionally, while provided in the cost analysis summary, current SLM technology is not capable of building the component.

Table 1: Cost projections for novel fuel nozzle design fabricated through various AM methods.

Per part	A2 (1 part)	A2-Nested (24-parts)	Q10+ Nested (24 parts)	Q20+ Nested (80-parts)	SLM Nested (25 parts)	Binder-jet (60 parts)
Powder Cost	$22	$22	$22	$22	$22	$22
Machine Set-up	$180	$7.5	$7.5	$2.25	$7.5	$4
Machine Costs	$800	$200	$100	$83.33	$100	$10
Powder Removal	$90	$90	$90	$90	$45	$35
Post-processing	$225	$225	$225	$225	$225	$30
Cost per Part Total:	$1,317	$545	$445	$423	$400	$101

1.2.4 Component Design Evaluation

The AM burner design was 3D printed by ORNL and tested at GTI on a bench scale at simulated water heater conditions. The design showed good performance in terms of emissions (50% reduction), efficiency, and turndown. Additionally, the AM process has the potential to increase time-to-market by 25% over current techniques. Also, the design was capable to with stand the high flame temperatures and not show any material degradation for the multiple hours of testing. To optimize performance of the fuel nozzle, surface roughness and key geometric features such as the ports require optimization to bring the allowable pressure drop into specification with current fuel nozzles and further increase efficiencies. As such, these areas would be considered for a future extended effort on further optimizing the processing parameters of the EBM process specifically associated with these features and investigating the feasibility of BJAM to successfully build the nozzle geometry.

1.3 IMPACTS

Given the significance of nozzle design on burner performance, and the already relatively high costs for nozzle fabrication (casting and machining), the project team anticipates that AM process may have a slight to moderate cost advantage over conventional nozzle designs when performance is taken into account. Performance advantages anticipated due to the new design include burner stability, improved turndown ratio, increased efficiency, and reduced emissions. The design will act as a single burner model for multiple firing ranges with minimum modifications for the water heater that will translate to reduced inventory and simpler logistics and supply chain requirements for the manufacturers, and leading to cost reductions to the end-user.

1.4 CONCLUSIONS

The preliminary metrics for evaluating 3D printing as a method of manufacturing were met. The fabrication from ORNL and design iterations to improve performance demonstrated the value proposition for 3D printing and the burner performance. The next steps are to further refine the design to ensure repeatability and specifications are being met, and to evaluate and implement cost reduction strategies and large-scale production pathways. This will require a future effort that considers booth the optimization of the EBM process further to address performance observations during these trials and to drive the per part cost down, and the processing science necessary to fabricate the component using binder jetting due to the projected business case. The burner will be commercialized with a manufacturer, it is important to ensure that all the key parameters are reviewed and met in discussions with the manufacturer.

2. GAS TECHNOLOGY INSTITUE BACKGROUND

Gas Technology Institute (GTI) is a leading R&D organization serving the energy marketplace by developing reliable, affordable, safe, and clean technology-based solutions for consumers, industry, and government. GTI has been pioneering innovative natural gas system designs for over 70 years and has over 1000 patents and publications covering virtually all aspects ranging from small water heater burners to fuel cells science and engineering.