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LLNL-TR-821050

Development of Reduced Glass Furnace Model to Optimize Process Operation, Final Report CRADA No. TC02241

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Disclaimer

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Development of Reduced Glass Furnace Model to Optimize Process Operation

Final Report
CRADA No. TC02241.0
Date Technical Work Ended: July 6, 2017

Date: October 26, 2018 Revision 1

A. Parties

This project was a relationship between Lawrence Livermore National Security (LLNS) and PPG Industries, Inc.

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B. Project Scope

This was a collaborative effort between Lawrence Livermore National Security, LLC as manager and operator of Lawrence Livermore National Laboratory (LLNL) and PPG Industries to develop a reduced-order glass furnace model that enables plant operators to make informed, real-time process adjustments. This CRADA project was sponsored under the High-Performance Computing for Manufacturing (HPC4Mfg) Program of the Department of Energy's Advanced Manufacturing Office (AMO) within the Energy Efficiency and Renewable Energy (EERE) Office. This program ran from June 2016 to July 2017 with no extensions.

The Deliverables outlined were are associated with Tasks 1-4:

Task 1: Interrogate Full Model to Identify Key Furnace Characteristics and Input Parameters (PM 1-3)

Deliverable 1.1: PPG runs CFD current model and delivers single state file (PM 1). LLNL converts format as necessary and imports into VisIT.

Deliverable 1.2: PPG provides SME opinion on critical control variables and important observables delivers ~9 additional CFD runs that demonstrate SME opinion (PM 3).

Task 2: Develop a Reduced-Order Model (PM 2-9)

Deliverable 2.1: LLNL provides experimental design (PM 4).

Deliverable 2.2: PPG run ~20 CFD simulations per experimental design and provides state files (PM 7).

Deliverable 2.3: LLNL provides initial reduced-order model that will predict key flow observables from control parameters (PM 9).

Task 3: Validation and Uncertainty Analysis (PM 10-11)

Deliverable 3.1: PPG will run validating CFD simulations and provide state files. LLNL will quantify uncertainty in model (PM 10).

Deliverable 3.2: PPG will provide feedback on value of reduced model given uncertainty (PM 11)

Task 4: Knowledge Transfer (PM 11-12)

Deliverable 4.1: LLNL will provide PPG with a Final Report that includes instructions to use VisIT to import CFD state files and explore flow fields, instructions to set up experimental design to optimize other glass tanks and glass compositions, and instructions to set up a spreadsheet for of the reduced model and how to use it for real-time control (PM 12).

Deliverable 4.2: LLNL and PPG will deliver a Final Report and Abstract due within thirty (30) days of completion or termination of the project, as required under Article X of the CRADA.

C. Technical Accomplishments

The focus of this project was model reduction. Although model reduction techniques have advanced over the last 10-15 years, PPG did not have expertise in these techniques. LLNL has the expertise, making their involvement critical. Although this work does not establish a HPC capability for PPG, it provided a pathway for PPG to better utilize its existing computational resources with specialized tools, such as VisIT, to significantly improve its manufacturing process decisions. LLNL's HPC resources, in particular Surface – an unclassified resource for visualization and data analysis work, will be used to run the VisIT analysis initially.

D. Expected Economic Impact

PPG collaborated with LLNL under the HPC4Mfg program CRADA to develop a reduced-order glass furnace model that enables plant operators to make informed, real-time process adjustments. PPG's current glass furnace computational fluid dynamics (CFD) model has several million cells each for the molten glass and for the combustion space above the melt. The model execution times are on the order of one to two weeks. As such, PPG is unable to use this model to make timely adjustments to the production line. PPG estimates roughly two weeks of production per year per furnace is lost due to this delay and implementation of this reduced model should increase annual productivity by 2%. Extrapolating that improvement to the entire U.S. glass manufacturing industry suggests 2.5 TBTUs of energy and 130,000 metric tons of carbon dioxide emissions could be saved.

D.1 Specific Benefits

Benefit to DOE: This CRADA project between PPG and LLNL is sponsored under the High-Performance Computing for Manufacturing (HPC4Mfg) Program of the Department of Energy's Advanced Manufacturing Office (AMO) within the Energy Efficiency and Renewable Energy (EERE) Office. LLNL is the lead Lab for the HPC4Manufacturing Program. This CRADA project will develop tools to help analyze flow properties of glass production tanks to better control the production process. Better control over the production will prevent wasted material, decrease energy consumption, and cut greenhouse gas production.

Benefit to Industry: PPG anticipates the outcome of this project will help improve control over the plate glass production. This improved control over the production will prevent wasted material, decrease energy consumption, and cut greenhouse gas production.

Benefit to Taxpayer: The outcomes of this and all HPC4 Manufacturing Program projects are to improve energy efficiency and improve U.S. industry competitiveness.

E. Participant Contribution

PPG ran the Glass Service model to simulate typical furnace operation and sent the data to LLNL to import into VisIT. This data was in the form of a state file that described the flow velocities and temperatures associated with every cell of the full model. PPG limited this study to a single tank design and glass composition. The model was run to steady-state flow. The data described several million cells. After the initial dataset is delivered to LLNL, PPG continued to run additional cases using different values for input parameters and also using the typical limits of operation for input parameters. This data was used by the LLNL project team to determine the uncertainty or variability in the dependent variables (outputs) and to inform the experimental design.

F. Documents/Reference List

Published Reports / Invited Talks

- "Analysis of Glass Furnace CFD Models in VisIt", LLNL-TM-72272, J. Henrikson, A. Furmidge, V. Castillo, April 2017
- "Development of Reduced Glass Furnace Model to Optimize Process Operation", LLNL-POST-724919, V. Castillo, J. Henrikson, A. Furmidge, Industry Engagement Day, March 2017
- "HPC4Mfg Project Overview and Other Opportunities for National Lab, Academia, and Industrial Collaborations", LLNL-PRES-725521, V. Castillo, J. Henrikson, A. Furmidge, TMS-17, February 2017
- "DOE funds PPG manufacturing research projects", Press release, PPG Today Article, April 2016
- "PPG awarded DOE partnership for glass furnace modeling: High-performance computing project aims to reduce energy use during glassmaking", Press release, PPG, April 2016
- "TensorFlow in Manufacturing and Industry 4.0: Theory and Practice", J. Henrikson, V. Castillo, Panel Discussion, TensorBeat 2017, Sunnyvale, Ca, May 2017

Unpublished Reports

- "HPC4Mfg-PPG-Furnace Pre-Start Review", V. Castillo, June 2016
- "PPG Furnace Reduced order model PM-2 review", V. Castillo, October 2016
- "Mid-Project Status Report: PPG Flat Glass: Development of a reduced-order glass furnace model", V. Castillo, February 2017
- "PPG Furnace Reduced order model, PM-10 review", Vic Castillo, May 2017
- "HPC4Mfg FY16Q4 Quarterly Report", "HPC4Mfg FY17Q1 Quarterly Report", "HPC4Mfg FY17Q2 Quarterly Report", "HPC4Mfg FY17Q3 Quarterly Report", V. Castillo
- Using Deep Convolutional Auto-encoder as a Model reduction technique for Computational Multi-Phase Fluid Dynamics", V. Castillo, J. Henrikson, A. Furmidge, LLNL Global Security RoadShow, August 2017

Copyright Activity

Reduced order glass furnace model.

Subject Inventions

None

Background Intellectual Property

- VISIT version 0.9.2 ((LLNL Tracking Number CP00750)
- VisIt 1.5.2 (LLNL Tracking Number CP01128)
- VisIT v1.8 (LLNL Tracking Number CP01279)
- VisIt, v2.0.1 (LLNL Tracking Number CP01425)

BIP is available to the Participant and the public under an industry-standard open source license.

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G. Acknowledgement

Industrial Participant's signature of the final report indicates the following:

1) The Participant has reviewed the final report and concurs with the statements made therein.
2) The Participant agrees that any modifications or changes from the initial proposal were discussed and agreed to during the term of the project.
3) The Participant certifies that all reports either completed or in process are listed and all subject inventions and the associated intellectual property protection measures generated by his/her respective company and attributable to the project have been disclosed and included in Section E or are included on a list attached to this report.
4) The Participant certifies that if tangible personal property was exchanged during the agreement, all has either been returned to the initial custodian or transferred permanently.
5) The Participant certifies that proprietary information has been returned or destroyed by LLNL.

Brian Kornish es — November 16, 2018

Brian Kornish, Program Manager — Date
PPG Industries, Inc.

12/14/2018

Victor Castillo, LLNL Principal Investigator — Date
Lawrence Livermore National Security, LLC

12/19/18

Michael S. Sharer, Manager, Technology Commercialization — Date
Lawrence Livermore National Security, LLC

Attachment I – Final Abstract

Development of a Reduced Glass Furnace Model to Optimize Process Operation

Final Abstract (Attachment I)
CRADA No. TC02241.0
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B. Purpose and Description

This was a collaborative effort between Lawrence Livermore National Security, LLC as manager and operator of Lawrence Livermore National Laboratory (LLNL) and PPG Industries to develop a reduced-order glass furnace model that enables plant operators to make informed, real-time process adjustments. This CRADA project is sponsored under the High-Performance Computing for Manufacturing (HPC4Mfg) Program of the Department of Energy's Advanced Manufacturing Office (AMO) within the Energy Efficiency and Renewable Energy (EERE) Office. This program ran from June 2016 to July 2017 with no extensions.

C. Benefit to Industry

PPG anticipated the outcome of the project would help improve control over the plate glass production. This improved control over the production would prevent wasted material, decrease energy consumption, and cut greenhouse gas production.

D. Benefit to DOE/LLNL

This CRADA project was sponsored under the High-Performance Computing for Manufacturing (HPC4Mfg) Program of the Department of Energy's Advanced Manufacturing Office (AMO) within the Energy Efficiency and Renewable Energy (EERE) Office. LLNL was Lead Lab for the HPC4Manufacturing Program. The CRADA project would develop tools to help analyze flow properties of glass production tanks to better control the production process. Better control over the production will prevent wasted material, decrease energy consumption, and cut greenhouse gas production.

E. Project Dates

June 6, 2016 to June 6, 2017