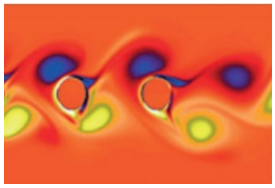
GrateCFD – Enabling optimum Grate fired woody biomass and waste to energy plant operation through Computational Fluid Dynamics



Newsletter 2-2018

Introduction

The main objective of GrateCFD is development of CFD aided design tools and operational guidelines for optimum grate fired BtE and WtE plant operation through:

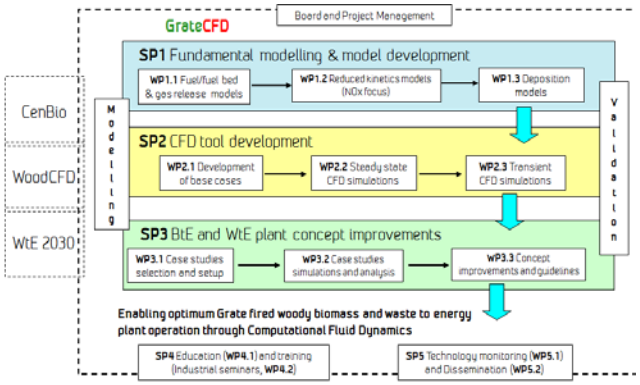
- **Model development**: improved fuel/fuel bed and gas release models, heat-exchanger deposition models and reduced kinetics models (NOx); and validation of these
- **Simulations**: transient and steady state CFD simulations of BtE and WtE plants; and validation
- **Concept improvements**: BtE and WtE plant case studies selection, setup, simulations and analysis, giving design and operational guidelines

The sub-objectives are:

- Develop improved fuel, gas and particle sub-models to be included in the CFD simulations
- Develop numerical tools that are tailored to study concept improvements for grate fired BtE and WtE plants, with focus on emission reduction, combustion performance, energy efficiency and availability
- Obtain operational and retrofitting guidelines for optimum operation of grate fired BtE and WtE plants through CFD simulation case studies
- Education of highly skilled candidates within this area and training of industry partners
- Monitoring of activities and state-of-the-art within this area and dissemination of knowledge to the industry partners, and other interested parties when applicable

Main anticipated results of the project are guidelines that will be aimed at improving combustion conditions, obtaining optimum operation over a wide range of thermal loads, decreasing emission levels at significant variations in fuel composition and production demand and increasing combustion and plant efficiency and availability.

The Work Breakdown Structure of GrateCFD is:



GrateCFD management and work break down structure and project links and information flow. (WoodCFD: Clean and efficient wood stoves through improved batch combustion models and CFD modelling approaches, http://www.sintef.no/woodcfd; CenBio: The Norwegian Bioenergy Innovation Centre, http://www.cenbio.no; WtE 2030: KPN project starting in 2018)

GrateCFD will run for four years (2017-2020) and has a total cash budget of 24 million NOK, which is 80% financed by the Research Council of Norway through the ENERGIX program and 20% financed by the industrial partners.

The GrateCFD consortium

The project consortium covers all the necessary aspects, and includes large and central industrial players in the biomass to energy (BtE) and waste to energy (WtE) areas in Norway, Sweden and Switzerland.

SINTEF Energy Research leads the project and focus on both modelling and experimental activities. **NTNU** (Norwegian University of Science and Technology) supervise the PhD, the PostDoc and Master candidates, and lead specific modelling activities.

The industrial partners contribute with finances as well as access to plants and their extensive industrial knowledge generated through their commercial activities within the BtE and WtE areas: Statkraft

- a Knowledge-building Project for Industry (KPN) co-funded by the Research Council of Norway through the ENERGIX-programme.
Contact: oyvind.skreiberg@sintef.no

SINTEF

Varme AS, Oslo EGE, Returkraft AS, Vattenfall AB, Hitachi Zosen Inova AG.

The constellation of project partners is very strong, bringing together leading research organisations within the field and major industrial players.

Project background

Biomass to energy (BtE) and waste to energy (WtE) plants in Norway need to comply with stricter emission limits and/or adjust to tighter profit margins. EU has for example recently adopted a further reduction of emission limits from medium (scale) biomass combustion plants through the so-called MCP Directive. Tighter profit margins mean that poorer/cheaper fuel qualities become interesting, as well as operational optimization with respect to efficiency and capacity maximization. NOx, particulate and CO emissions are special concerns, as well as the operational challenges following particle deposition on heat transfer surfaces. The majority of the operational BtE and WtE plants in Norway are grate fired plants, and even though different grate technologies have been developed, they suffer from both variations in fuel quality and changing operating conditions, resulting in non-optimum operating conditions. The most cost-effective measure to abate the resulting operational challenges, including increased emission levels, are with primary measures.

Computational Fluid Dynamics (CFD) is the ultimate design tool for BtE and WtE plant combustion and heat transfer sections, however, cost-effective sub-models need to be developed, implemented and used in an optimum way. Moreover, the CFD simulations need to be carried out for transient conditions, to study the effect of changing operating conditions, and minimize the impact of these through improved plant operation and operational guidelines.

GrateCFD therefore focuses on enabling optimum grate fired BtE and WtE plant operation through CFD aided design and operational guidelines. Improved models and modelling approaches, in combination with targeted experiments/measurement campaigns, are keys for future's increased sustainable BtE and WtE plants. This will have a significant impact on two of the most important renewable value chains in Norway today, the BtE and WtE value chains.

Project overview

The project is divided into 5 subprojects (SP), each subproject is itself divided into several work packages (WP).

- Fundamental modelling & model development - SP1
- CFD tool development - SP2
- BtE and WtE plant concept improvements - SP3
- Education and training - SP4
- Technology monitoring and dissemination - SP5

Fundamental modelling & model development - SP1

The main objective of SP1 is to develop improved fuel, gas and particle sub-models to be included in the CFD simulations in SP2 and SP3.

CFD tool development - SP2

The major objectives of SP2 are to develop a numerical tool that is tailored to study concept improvements for grate fired BtE and WtE plants, with focus on emission reduction, combustion performance, energy efficiency and availability.

BtE and WtE plant concept improvements - SP3

The major objective of SP3 is to obtain operational and retrofitting guidelines of grate fired BtE and WtE plants through CFD simulation case studies.

Education and training - SP4

The major objective of SP4 is to strengthen the education within this field through MSc and PhD students, and a PostDoc candidate. The objective is also to increase the competence level in the industry. The long-term goal is competence building and strengthening of the education within combustion of biomass and biomass residues in BtE plants and MSW in WtE plants.

Technology monitoring and dissemination - SP5

The major objectives of SP5 are to monitor the latest research and technological developments and to disseminate research results.

Progress in 2018

In **2018** the work on model development and establishment of the CFD toolbox continues, including lab-scale and full-scale validation activity.

In **2017** the work was mainly focused on model development, establishment of the CFD toolbox, and preparations for experimental validation of models and CFD simulations.

GrateCFD workshop and steering committee meeting in Oslo

The third GrateCFD workshop and steering committee meeting were arranged in Oslo in November 2018. In the workshop, the partners gave presentations from ongoing activities. The work is in

good progress. The WtE 2030 project also arranged its first project workshop and a steering committee meeting there, and in between these two arrangements, an open workshop was arranged focusing on more overarching aspects of MSW combustion. Presentations at the workshop focused on Oslo as the European Green Capital 2019 and WtE development seen from Norway, while two plenary discussions addressed hot WtE topics, namely the Circular Economy and the upcoming, revised BREF WI. The program included a site visit (see picture below) at the EGE Oslo Haraldrud WtE plant.

Participants at the open workshop, visiting the EGE Oslo Haraldrud WtE plant

Earlier workshops and steering committee meetings

- The second GrateCFD workshop and steering committee meeting were arranged in Trondheim in May 2018.
- The first GrateCFD workshop and steering committee meeting were arranged in Zurich in November 2017. A site visit at the advanced Lucerne WtE plant was also arranged.
- The GrateCFD official kick-off took place at a combined kick-off and steering committee meeting in Trondheim on 29 June 2017.

PostDoc work

The PostDoc position within "NOx modelling and simulation" has been filled. The selected candidate is Corinna Netzer from Germany. She will start her work January 2019.

PhD work

The PhD position within "Computational fluid dynamics (CFD) modeling of biomass and waste to energy plants" is ongoing. Jingyuan Zhang from China, the PhD candidate, is progressing well.

GrateCFD in Geophysical & Astrophysical Fluid Dynamics

One GrateCFD connected work has been accepted for publication in Geophysical & Astrophysical Fluid Dynamics:
J. R. Aarnes, T. Jin, C. Mao, N. E. L. Haugen, K. Luo, H Andersson. Treatment of solid objects in the Pencil Code using an immersed boundary method and overset grids. The abstract is given below.

"Two methods for solid body representation in flow simulations available in the Pencil Code are the immersed boundary method and overset grids. These methods are quite different in terms of computational cost, flexibility and numerical accuracy. We present here an investigation of the use of the different methods with the purpose of assessing their strengths and weaknesses. At present, the overset grid method in the Pencil Code can only be used for representing cylinders in the flow. For this task, it surpasses the immersed boundary method in yielding highly accurate solutions at moderate computational costs. This is partly due to local grid stretching and a body-conformal grid, and partly due to the possibility of working with local time step restrictions on different grids. The immersed boundary method makes up the lack of computational efficiency with flexibility in regard to application to complex geometries, due to a recent extension of the method that allows our implementation of it to represent arbitrarily shaped objects in the flow."

GrateCFD at ICheaP14

One GrateCFD work has been accepted for presentation at ICheaP14 in Bologna, Italy, 26-29 May 2019:
Øyvind Skreiberg, Tian Li, Liang Wang, Mette Bugge, Terese Løvås. An evaluation of effects of fuel parameters and flue gas recirculation on NOx emissions through detailed chemical kinetics simulations.

GrateCFD at ICAE 2018

One GrateCFD work was presented at 10th International Conference on Applied Energy, 22-25 August 2018, Hong Kong, China:
Øyvind Skreiberg, Tian Li, Elettra Vantaggiato, Liang Wang, Mette Bugge, Terese Løvås. An evaluation of effects of operational parameters on NOx emissions through detailed chemical kinetics simulations.
A corresponding publication will be published in Energy Procedia.

GrateCFD at 37th International Symposium on Combustion

One GrateCFD work was presented at 37th International Symposium on Combustion, 29 July - 3 August, Dublin, Ireland:
Jingyuan Zhang, Tian Li, Terese Løvås. Simulating thermochemical conversion of thermally thick wood particles with an Eulerian-Lagrangian method.

GrateCFD at EUBCE 2018

One GrateCFD connected work was presented at EUBCE 2018 in Copenhagen, Denmark, 14-17 May 2018:
Geir Skjevrak, Liang Wang, Tore Filbakk, Øyvind Skreiberg, Henrik Kofoed Nielsen, Johan E. Hustad. Effects of Fuel Additives on Quality of Agricultural Wastes Pellets.

GrateCFD in Energy & Fuels

A GrateCFD connected work entitled "Investigation on Ash Slagging Characteristics during Combustion of Biomass Pellets and Effect of Additives" was published in Energy & Fuels. The abstract is given below.

"This study reports a systematic investigation into ash slagging behavior during combustion of barley straw and barley husk pellets with or without additives in a residential pellet burner. The slagging tendencies of the pellets were evaluated based on the amount, chemistry, mineralogy, and morphology of inlet ash formed as slag and sintering degrees of residual ash. The barley straw and husk pellets showed high slagging tendencies with 39 and 54 wt % ingoing ash formed as slag. Analyses using X-ray fluorescence and scanning electron microcopy combined with energy-dispersive X-ray spectroscopy revealed high concentrations of K, Si, and Ca but a minor amount of P in barley straw slag. The slag mainly contained melted potassium silicates directly observed by X-ray diffraction. For the barley husk, high ash slagging tendency was observed and mainly attributed to the formation and melting of potassium phosphates, potassium silicates, and complex mixtures of the two mineral phases. Addition of marble sludge completely eliminated ash slagging during combustion of barley straw and husk pellets because it led to the formation of high temperature melting calcium potassium phosphates, calcium rich potassium silicates, and oxides. Addition of calcium lignosulfonate showed a less pronounced ability to mitigate ash slagging issues during pellet combustion, although it promoted the formation of calcium-rich silicates and phosphates (both with high-melting points) in barley straw and husk ash, respectively. This process was accompanied by considerable reduction in the amount and sintering degree of the formed barley straw and husk slag."

GrateCFD at 6th Sino-Australian Symposium on Advanced Coal and Biomass Utilisation Technologies

One GrateCFD connected work was presented at 6th Sino-Australian Symposium on Advanced Coal and Biomass Utilisation Technologies, 4-8 December 2017, Perth, Australia:
Liang Wang, Geir Skjevrak, Øyvind Skreiberg, HongWei Wu, Henrik Kofoed Nielsen, Johan E. Hustad. Investigation on Ash Slagging Characteristics during Combustion of Biomass Pellets and Effect of Additives.

GrateCFD in Progress in Energy and Combustion Science

A comprehensive review paper with the WoodCFD PhD candidate Inge Haberle as first author has been published in Progress in Energy and Combustion Science:
Inge Haberle, Øyvind Skreiberg, Joanna Lazar, Nils Erland L. Haugen. Numerical models for thermochemical degradation of thermally thick woody biomass, and their application in domestic wood heating appliances and grate furnaces. Progress in Energy and Combustion Science 63(November 2017):204-252. The abstract is given below.

"This paper reviews the current state-of-the-art of numerical models used for thermochemical degradation and combustion of thermally thick woody biomass particles. The focus is on the theory of drying, devolatilization and char conversion with respect to their implementation in numerical simulation tools. An introduction to wood chemistry, as well as the physical characteristics of wood, is also given in order to facilitate the discussion of simplifying assumptions in current models. Current research on single, densified or non-compressed, wood particle modeling is presented, and modeling approaches are compared. The different modeling approaches are categorized by the dimensionality of the model (1D, 2D or 3D), and the one-dimensional models are separated into mesh-based and interface-based models. Additionally, the applicability of the models for wood stoves is discussed, and an overview of the existing literature on numerical simulations of small-scale wood stoves and domestic boilers is given. Furthermore, current bed modeling approaches in large-scale grate furnaces are

presented and compared against single particle models."

GrateCFD in EERA Bioenergy Newsletter

An article entitled "Computational Fluid Dynamics for improving micro- to large-scale woody biomass and municipal solid waste combustion units" presented GrateCFD as well as WoodCFD (Clean and efficient wood stoves through improved batch combustion models and CFD modelling approaches) in an EERA (European Energy Research Alliance) Bioenergy newsletter.

GrateCFD publications

Øyvind Skreiberg, Tian Li, Liang Wang, Mette Bugge, Terese Løvås. An evaluation of effects of fuel parameters and flue gas recirculation on NOx emissions through detailed chemical kinetics simulations. Abstract accepted for presentation at ICheaP14, 26-29 May 2019, Bologna, Italy.

J. R. Aarnes, T. Jin, C. Mao, N. E. L. Haugen, K. Luo, H Andersson. Treatment of solid objects in the Pencil Code using an immersed boundary method and overset grids. Accepted for publication in Geophysical & Astrophysical Fluid Dynamics.

Øyvind Skreiberg, Tian Li, Elettra Vantaggiato, Liang Wang, Mette Bugge, Terese Løvås (2018). An evaluation of effects of operational parameters on NOx emissions through detailed chemical kinetics simulations. 10th International Conference on Applied Energy, 22-25 August 2018, Hong Kong, China.

Fredrik Buvarp (2018). Experimental development of combustion models. SINTEF Summer Job Project report. Main supervisor: Per Carlsson, Co-supervisors: Mette Bugge, Judit Sandquist

Jingyuan Zhang, Tian Li, Terese Løvås (2018). Simulating thermochemical conversion of thermally thick wood particles with an Eulerian-Lagrangian method. 37th International Symposium on Combustion, 29 July - 3 August, Dublin, Ireland.

Nguyen Cong Thanh (2018). A thermogravimetric and kinetic study on devolatilization of biomass. NTNU Master thesis. Main supervisor: Terese Løvås, Co-supervisor: Liang Wang

Elettra Vantaggiato (2018). Reduced chemical model development for grate fired biomass application. NTNU Project thesis. Main supervisor: Terese Løvås, Co-supervisor: Tian Li

Geir Skjevrak, Liang Wang, Tore Filbakk, Øyvind Skreiberg, Henrik Kofoed Nielsen, Johan E. Hustad (2018). Effects of Fuel Additives on Quality of Agricultural Wastes Pellets. 26th EUBCE, 14-17 May 2018, Copenhagen, Denmark.

Liang Wang, Geir Skjevrak, Øyvind Skreiberg, Hongwei Wu, Henrik Kofoed Nielsen, Johan E. Hustad (2018). Investigation on Ash Slagging Characteristics during Combustion of Biomass Pellets and Effect of Additives. Energy & Fuels 32(4):4442-4452.

Liang Wang, Geir Skjevrak, Øyvind Skreiberg, Hongwei Wu, Henrik Kofoed Nielsen, Johan E. Hustad (2017). Investigation on Ash Slagging Characteristics during Combustion of Biomass Pellets and Effect of Additives. 6th Sino-Australian Symposium on Advanced Coal and Biomass Utilisation Technologies, 4-8 December 2017, Perth, Australia.

Inge Haberle, Øyvind Skreiberg, Joanna Lazar, Nils Erland L. Haugen (2017). Numerical models for thermochemical degradation of thermally thick woody biomass, and their application in domestic wood heating appliances and grate furnaces. Progress in Energy and Combustion Science 63:204-252.

Øyvind Skreiberg (2017). Computational Fluid Dynamics for improving micro- to large-scale woody biomass and municipal solid waste combustion units. EERA Bioenergy Newsletter 2017 (7), p. 5.

Øyvind Skreiberg (2017). Modellering og numeriske simuleringer for økt bærekraft (in Norwegian). SINTEF blog article.

Other news

WtE 2030 in good progress

The competence building project WtE 2030 that in May had its kick-off meeting in Trondheim is in good progress. It is as GrateCFD funded by the Research Council of Norway and industry partners. It strengthens the research efforts within the Waste-to-Energy area, and it is a complementary project to GrateCFD. Both projects have several industry partners in common. WtE2030 will run for three years, 2018-20. For more info about the project: www.sintef.no/projectweb/wte_2030/

IEA Task 32 Biomass Combustion and Co-firing

The first IEA Bioenergy Task 32 meeting of the year was arranged in May in Copenhagen, Denmark, in connection with the EUBCE 2018 conference. The meeting was combined with a field trip to the Amagerværket CHP plant.

2018 is the last year of the current triennium, and plans for activities in the next triennium (2019-2021) have been made, yet to be finalized.

The second Task 32 meeting was arranged in San Francisco in November in connection with the IEA

Bioenergy end of triennium conference. There the proposed activities for the next triennium were further discussed, and based on this the final plans for the next triennium will made.
However, there will be significant focus on biomass combustion in grate-fired units.
In the current triennium, relevant deliverables are:
- Aerosols from biomass combustion
- Particle emission measurement techniques
- State of the art on innovative CHP concepts (ongoing)
- Strategic study for renewable heat (ongoing)
- Workshop on Solid Recovered Fuels
- Workshop on Biomass Combustion Generated Nanoparticles
- Workshop on New Emission Measurement Methods

For information about IEA Bioenergy Task 32 activities, see the webpage and newsletters, and for IEA Bioenergy news, see this newsletter. Øyvind Skreiberg from SINTEF Energy Research is the Norwegian participant in IEA Bioenergy Task 32.

EERA Bioenergy – SP5 Stationary Bioenergy

The effort this year has been focused on revising the SP focus and the description of work, and this work is now soon finalized. A Strategic Research and Innovation Agenda (SRIA) has been made for the whole EERA Bioenergy, to be finalized this year. For more info on EERA Bioenergy, visit the brand new website, and see the newsletters. Berta Matas Güell from SINTEF Energy Research is leading SP5 Stationary Bioenergy in EERA Bioenergy.

RHC technology platform

The activity level of the RHC platform picked up after a period where new financing solutions were sought and the originally planned strategy documents had been delivered. The "new" European Technology and **Innovation** Platform on Renewable Heating & Cooling (RHC-ETIP) brings together stakeholders from the biomass, geothermal and solar thermal sector - including related industries such as District Heating and Cooling, Thermal Energy Storage, Hybrid Systems and Heat Pumps - to define a common Research, Development and Innovation strategy for increasing the use of renewable energy technologies for heating and cooling.
Previously concrete work has been carried out by the Biomass Panel in the RHC-ETIP connected to giving input to the SET-plan issues paper on renewable fuels and bioenergy, as well as work connected to the Implementation of the biomass technology roadmap of the Biomass Panel. The aim of the latter was to update the progress in R&I priorities identified by the Biomass technology roadmap. This work continues through different efforts. Øyvind Skreiberg from SINTEF Energy Research is a member of the Biomass Panel Steering Committee and has been the leader of Issue group 2: Residential/small scale heating devices and building integration.
For the next three years there will be a special focus on work to be carried out in horizontal working groups (HWG) that will focus on contributing to 1) vision, 2) research and innovation priorities and 3) deployment and innovation strategy documents. Øyvind Skreiberg will chair the HWG 100% Renewable Buildings, where a large number of members from the different RHC-ETIP panels already have expressed their interest in contributing to the HWG. Other working groups have been established on 100% Renewable Districts, 100% Renewable Cities and 100% Renewable Industry.
As a continuation of the SET-plan work, workgroups were established to provide specific input to the SET-plan work, e.g. Action 5 Energy Efficiency in Buildings with the sub-action 5.2 Heating and Cooling Technologies for Buildings and Action 8 Renewable Fuels and Bioenergy. Two meetings connected to Action 5 have been arranged in 2018 to provide input to this implementation plan. The work has now been finalized and an endorsed implementation plan is now ready. Øyvind Skreiberg has been involved in the Action 5 work, representing the Biomass Panel. For Action 8, an endorsed implementation plan has now been ready for a while.
See the RHC-ETIP newsletters for other news.

Links (click on the links or logos to get there)

StableWood
SKOG22
Energi21
Renewable Heating and Cooling ETIP
EERA Bioenergy
IEA Task32 Biomass Combustion and Cofiring

SINTEF


NTNU


LOGE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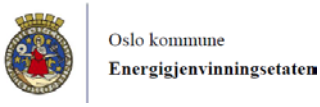
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