Code_Saturne User's Meeting 2016

USE OF *Code_Saturne* FOR POWER PLANTS ENGINEERING

R&D ongoing works at Gestamp Biomass Solutions

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Context

Nowadays, biomass boilers are an alternative energy source because their diverse fuels sources and dispatchability allows remarkable profits with a reduced environmental and social impact so that these facilities are in vigorous growth and either biomass boiler designs and tools for performing their characterization and optimization are highly demanded.

On the other hand, Spain is the biggest olive oil producer in the world, and this industry generates diverse oil residues (mainly called "orujillo"), which use in biomass boilers to its valorization through the steam production for electricity generation (power ranges from 2 MWe to 25 MWe) is highly extended. In Spain, olive residues fired biomass plants generate more than 126 MWe with a biomass consumption of more than 800 tons per year.

Due to the fuel characteristics, these boilers must stop for maintenance operations (cleaning operations of fouling deposits on tube banks or biomass vaults on the grate), reducing the dispatchability. This uses to be avoided by means of conservative design values in heat exchanging surfaces and boiler geometry according to flying ashes composition, grate operation, internal flow distribution, exchanged heat and foreseen fuel nature variation.

CFD modeling allows to perform overall behavior models for a specific fuel as it determines the fuel design, but for olive wastes boilers, modelization is poorly developed despite the aroused interest.

PhD research: Modeling fly ash particles deposition on olive waste fired boiler

Introduction:

This work aims to find an useful, accurate and reliable tool for boiler design engineers who need to predict fouling problems in boilers firing troublesome biomasses. Deposition (slagging and fouling) and corrosion are one of the major problems in the design and operation of a combustion system. The particulate matter formed during solid fuel combustion (also known as flying ash particles, FAPs) may be deposited on furnace walls and heat-exchanger tubes, which will reduce the heat transfer and could give rise to corrosion problems.

Biomass-fired furnaces, in particular those burning a high Cl and alkali content (Na+K) in fuel (e.g. olive waste fired furnaces), are often reported to suffer from severe deposition and corrosion problems, compared to conventional coal-fired boilers. (Figure a)

Physical modeling:

The model will be based on a Turbulent, Eulerian-Lagrangian model of the flow with one-way coupling. Deposition and fouling should be a standalone choice, independent from the existing pulverized coal firing mode on *Code_Saturne* selection. Once the particle reaches to the near wall boundary layer ($y^+<100$), the model initiates a stochastic transportation that predicts if the particle enters (injection), maintains certain residence time (diffusion) or changes trajectory leaving the nearest layer ($y^+<10$) (ejection). Up to here, this model (Guingo-Minier[1]) is used. Afterwards, a new set of programs in C+ and fortran is implemented with the deposition criteria of [1], in such a way that the code of the existing CFD is not altered. The sequence of iteration on each near wall particle is shown in Figure b.

Besides the inertial impaction of the high range of particle size (2-250 µm) and low range particles (0,2-10 µm), a new particle class of 0,5 µm for defining aerosol particles of KCl (alkali salt condensation) will be implemented[2].

Condensation of low melting point salts (KCl and sulphates) is the major source of fouling on the clean surfaces of tubes. Salts vapor condensation and submicron FAPs by diffusion and thermophoresis are the initial mechanisms of fouling as it creates the first layer of fouling (see white layer fig.c) over which further FAPs will be deposited.

A User Subroutine is used for calculating the critical viscosity C_v[3] as a function of the chemical composition of FAPs.[2]. The critical temperature T_{cv} is also determined and will be the limit below which the probability of adherence will be η_{stick} =1. This will always determine that a FAP touching the tube surface will be deposited and not rebounded off.

Probability of salt condensation deposition will depend on the particle temperature and tube surface temperature[2]. Tube surface temperature will increase as the layer of deposit grows up. So in each iteration after deposition of one particle, a new thickness of the cell boundary face will be calculated, in such a way that boundary face temperature will be updated under the running of the model.

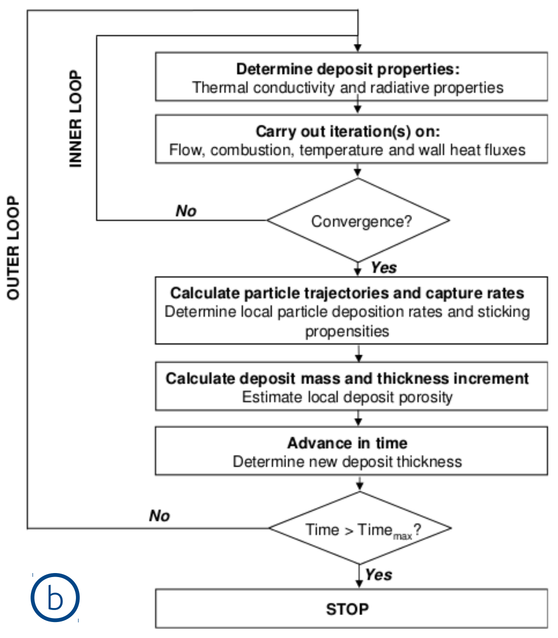
Experimental validation:

Models will be tested with data adquisition at site, in existing power station boilers of **Gestamp Renewables**' (8-15 MWe) burning olive oil waste. Deposition probes with (air-water) controlled metal temperature will be used (figure d).

Status:

The new deposition model is being programmed in the *Code_Saturne* Lagrangian module with a brand-new Lagrangian model *"iphyla = 3"* based on the aforementioned mechanisms and coded within the *Code_Saturne* kernel so that different functions and subroutines are being modified and/or updated according to the scheme shown in figure e.

Up to now the new compilations of the modified code show promising results (figure f).



Determine deposit properties:
Thermal conductivity and radiative properties

Carry out iteration(s) on:
Flow, combustion, temperature and wall heat fluxes

Convergence?

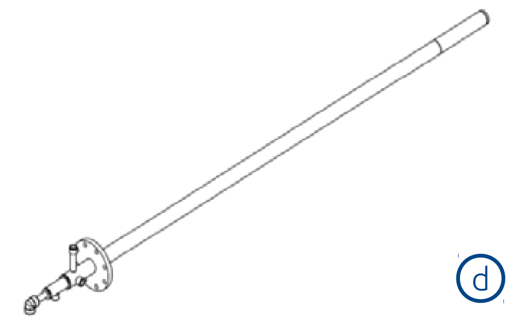
Calculate particle trajectories and capture rates
Determine local particle deposition rates and sticking propensities

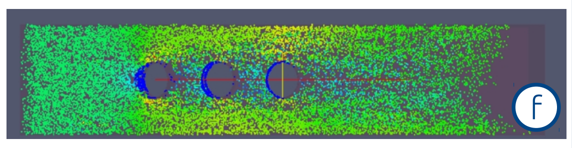
Calculate deposit mass and thickness increment
Estimate local deposit porosity

Advance in time
Determine new deposit thickness

Time > $Time_{max}$?

STOP





Fortran code:

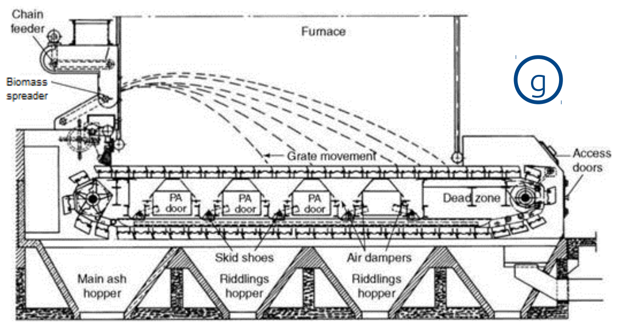
- *Lagran.f90:* New variables declarations and calculations,"*jvisp*" for particle viscosity depending on additional parameters calculations or "*iTempWall*"for an overwritten wall temperature based on the boundary conditions and the accumulated deposition effect, "*iThickness*" for total deposition thickness and "*iMassdep*" for total deposition mass.
- *Lagopt.f90*: Modifications for new variables included in other subroutines.
- *Lagune.f90*: Modification for new variable calculations in time.
- *Lagent.f90*: Modifications for new Lagrangian variables calculations in time.
- *Lagcar.f90*: Links for new variables dependences on existing particles variables.
- *Lagphy.f90*: Modification for new Lagrangian variables calculations in time.
- *Lagvis.f90*: Brand-new subroutine for the particle critical viscosity calculation.

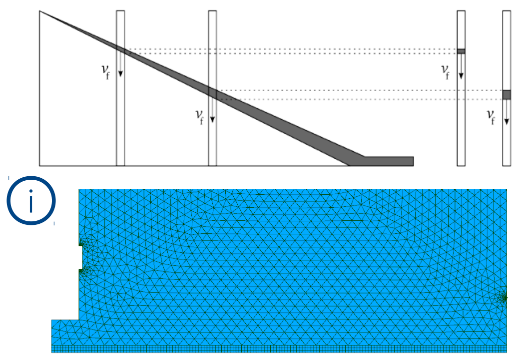
e

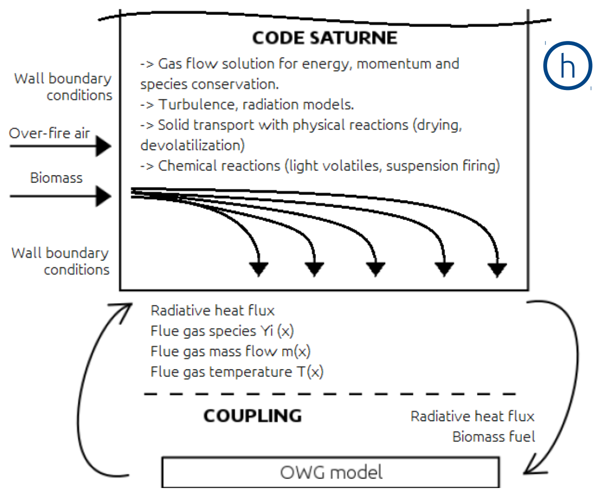
C++ code:

- *cs_lagr_tracking.h*: Modified for particle interaction with the boundary conditions analyses.
- *cs_gui_particles.h*: Modified for allowing introduction of new model parameters with the XML file.

PhD research: Experimental and computational analysis of olive residues biomass-fired grates







CODE SATURNE
-> Gas flow solution for energy, momentum and species conservation.
-> Turbulence, radiation models.
-> Solid transport with physical reactions (drying, devolatilization)
-> Chemical reactions (light volatiles, suspension firing)

Radiative heat flux
Flue gas species Yi (x)
Flue gas mass flow m(x)
Flue gas temperature T(x)

COUPLING

Radiative heat flux
Biomass fuel

OWG model

j

- Gas phase equations

$$\frac{\partial(\varepsilon_b\cdot\rho_g)}{\partial t}+\frac{\partial(\varepsilon_b\cdot\rho_g\cdot\upsilon_g)}{\partial y}=r_{dry}+r_{pyr}+r_{char}$$

$$\frac{\partial(\varepsilon_b\cdot\rho_g\cdot Y_{g,i})}{\partial t}+\frac{\partial(\varepsilon_b\cdot\rho_g\cdot\upsilon_g\cdot Y_{g,i})}{\partial y}=\frac{\partial}{\partial y}\left(\varepsilon_b\cdot\rho_g\cdot D_{g,i}\cdot\frac{\partial Y_{g,i}}{\partial y}\right)+r_i+\varepsilon_b\sum_j r_{i,j}\text{...per "i" gaseous specie}$$

$$\frac{\partial(\varepsilon_b\cdot\rho_g\cdot h_g)}{\partial t}+\frac{\partial(\varepsilon_b\cdot\rho_g\cdot\upsilon_g\cdot h_g)}{\partial y}=\frac{\partial}{\partial y}\left(\frac{\varepsilon_b\cdot\lambda_g}{C_{p,g}}\cdot\frac{\partial h_g}{\partial y}\right)+h_c\cdot A_p\cdot(T_s-T_g)+(r_{dry}+r_{pyr}+r_{char})\cdot h_s-\varepsilon_b\cdot\sum_{j\in G}\Delta h_j\cdot r_j-4\varepsilon_b\lambda_w\cdot\frac{T_g-T_{amb}}{d^2_{in,r}\cdot\ln\left(\frac{d_{out,r}}{d_{in,r}}\right)}$$

- Solid phase equations

$$\frac{\partial((1-\varepsilon_b)\cdot\rho_s)}{\partial t}=-r_{dry}-r_{pyr}-r_{char}$$

$$\frac{\partial((1-\varepsilon_b)\cdot\rho_s\cdot h_s)}{\partial t}=\frac{\partial}{\partial y}\left((1-\varepsilon_b)\cdot\frac{\lambda_s}{C_{p,s}}\cdot\frac{\partial h_s}{\partial y}\right)+h_c\cdot A_p\cdot(T_g-T_s)+r_{char}\cdot\Delta h_{char}+r_{dry}\cdot\Delta h_{vap}-(r_{dry}+r_{pyr}+r_{char})\cdot h_s-\varepsilon_b\cdot\sum_{j\in G}\Delta h_j\cdot r_j-4(1-\varepsilon_b)\lambda_w\cdot\frac{T_s-T_{amb}}{d^2_{in,r}\cdot\ln\left(\frac{d_{out,r}}{d_{in,r}}\right)}$$

- Process rates

$$\begin{cases} r_{dry}=2{,}822\cdot10^{(-4)}\cdot e^{\left(\frac{-10584}{T_s}\right)}\cdot(1-\varepsilon_b)\cdot\rho_s\cdot Y_{H_2O,s} \\ r_{pyr,i}=1{,}56\cdot10^{10}\cdot\exp\left(\frac{-16600}{T_S}\right)\cdot(1-\varepsilon_b)\cdot\rho_S\cdot Y_i\text{...per "i" solid specie} \\ \text{Combution rates: solid and gas phase reactions}\end{cases}$$

- Additional equations for physical and chemical properties for solid fuel in packed beds combustion.

Objective:

Developing and validation (in existing power station boilers of **Gestamp Renewables**) of a feasible olive residue combustion model for industrial grates and its routines for *Code_Saturne*, thus allowing biomass boiler design optimization in engineering stages according to the olive waste nature and particularities. This combustion model will allow a boiler performance prediction considering the combustion products and particles so that the dispatchability can be maximized.

Background:

CFD packages does not directly support several specific and required models for the grate models so user-defined routines must be defined. The existing models[4] are related with the degree of approximation to the processes in the fuel layer as several products leave the fuel bed and enter into the freeboard together with an energy supply. None of the background approaches include an integration with an spreader-type feeding system (See figure g) and only some of them are capable of predicting behavior thus defining the model approach as it is following explained.

Methodology:

The work will be focused on the numerical modeling of the grate combustion as a stand-alone packed bed numerical model[5] with integration with both combustion and lagrangian particle transport modules in the freeboard.

Two zones will be considered (see figure h):

- *Olive-waste grate model (OWG)*: Physical/chemical reactions related with the olive-waste fuel and its composition defined and modeled providing gas-phase reactions and flying ashes particles compositions. Some of the OWG model details are following explained:
  - Fuel is ignited from the top layer
  - A thin vertical slice of the bed at a certain position is folowed as it moves on the grate towards the ash pit with a known velocity v_G, the reaction front travels down from the top of the column. (see figure i)
  - The transient solution of a one-dimensional reactor can be related with the corresponding position of the grate by a simple relation and the operation is represented by a transient 1-D simulation with the following assumptions:
    - The entire bed is treated as a plug-flow, justified only when cross-flow gradients are neligible, especially when the heat flux due to thermal conduction is much smaller than the convective heat flux.
    - Some assumptions for the fuel mixing are considered by introducing some empirical mixing coefficients although are neligible in all existing one-dimensional models.
- *Furnace (freeboard)*: Gas-phase reactions and gas flow equations are solved with existent thermal mechanisms and particle combustion/transport of *Code_Saturne*.

Considering the aforementioned zones, the sequential solution process will be:

- Based on biomass/primary air injection/initial radiative flux, the OWG model routine is initially solved so temperature/velocity/flue gas/particles composition profiles is obtained. (see governing equations on figure j)
- OWM model output are treated as part of the freeboard inlet conditions, CFD modeling of gas mixing and heterogeneous/homogeneous combustion/particle transport is performed so that a radiative/biomass mass flux onto grate is obtained.
- Freeboard results are used recursively in steps 1 and 2 until no significant changes between outgoing radiative heat flux from OWG model and incoming from the furnace CFD model are observed.

Status: In development.

References

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[5]. Kær, S. , "Numerical modeling of straw-fired grate boiler"- Fuel, 83, 1183-1190, 2004.

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