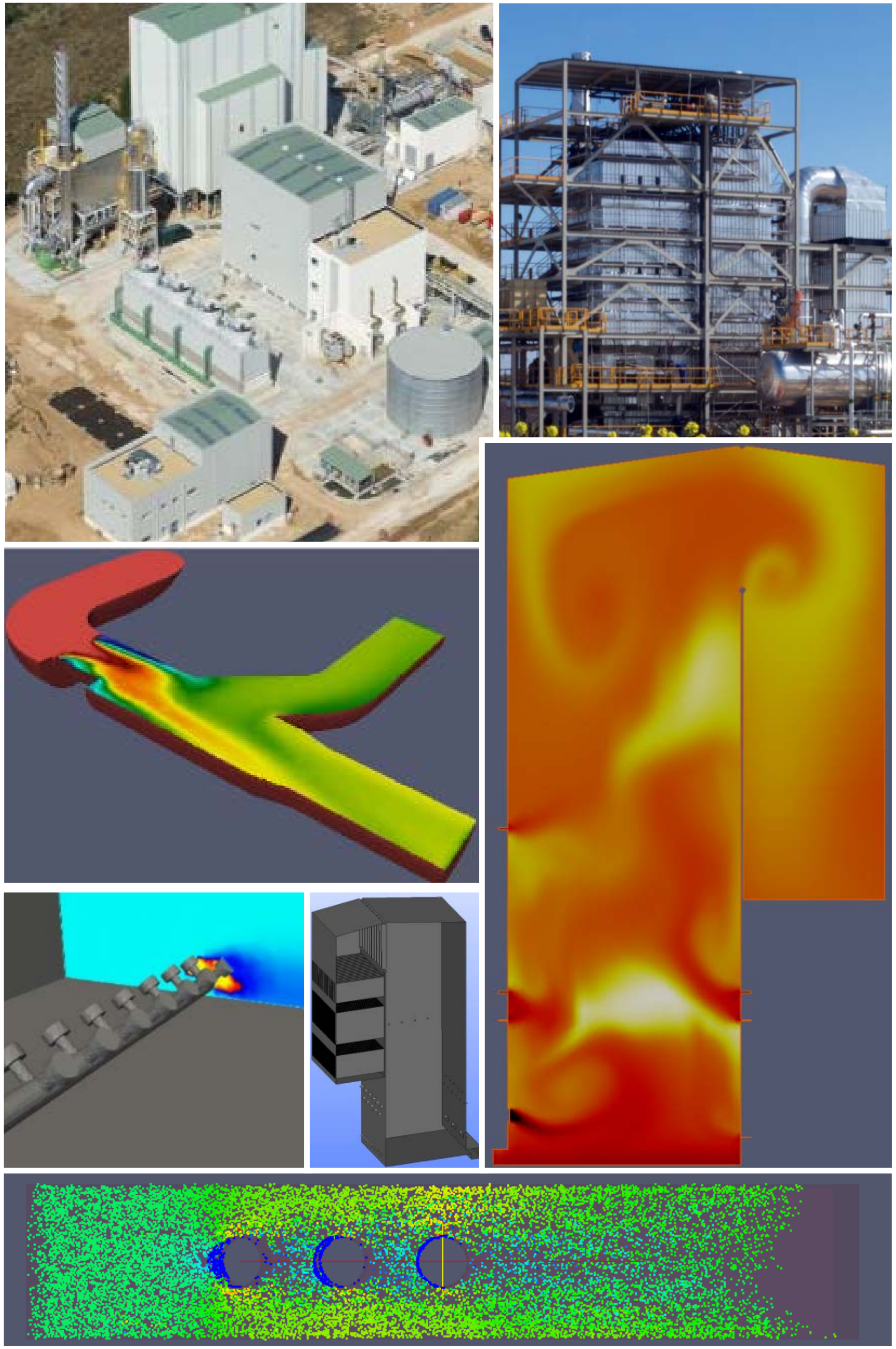


Gestamp
Energy Solutions

CFD R&D ACTIVITIES

"Modeling of fly ash deposition on olive waste fired boilers"

Miguel Díaz Troyano
General Manager

"Experimental and computational analysis of olive residues biomass-grates"

Pablo José Leal Forero
R&D Process Engineer

Code Saturne user meeting 2015
Thursday - April 2nd
EDF Lab Chatou

CODE SATURNE

Gestamp Energy Solutions

CODE SATURNE

Contents:

1. Company and activities

Gestamp Energy Solutions is defined as a Thermal Engineering Company. Within this scope, it is included the design and turnkey supply of:

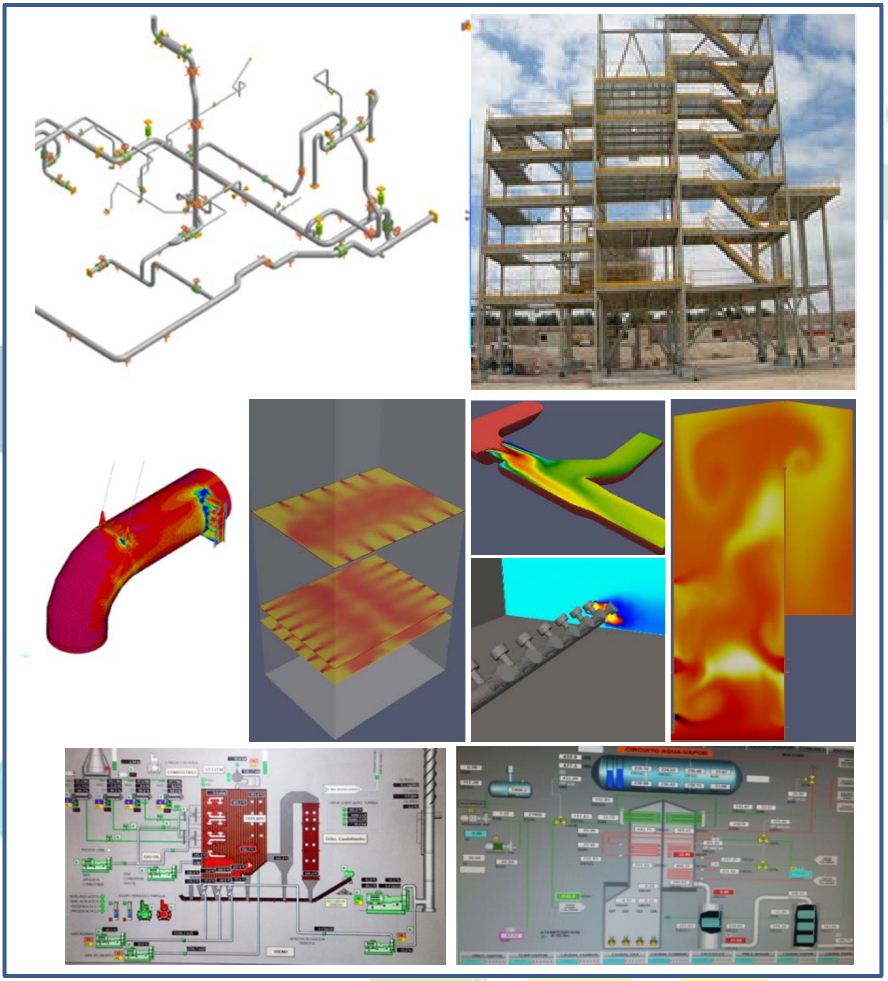
- Electric power generation plants:
  - ✓ Conventional fuels.
  - ✓ Biomass.
  - ✓ Solid urban wastes.
- Hybrid biomass/solar plants and solar/cogeneration plants.
- Compact Electric Biomass Power Plants (BIOBLOCK®).
- Steam Boilers:
  - ✓ Conventional fuels.
  - ✓ Biomass.
  - ✓ Solid Urban wastes incinerators.
  - ✓ Recovery. (HRSG)
- Piping, supports and stress on pipes and ducts.
- Thermal equipment:
  - ✓ Shell and tube heat exchangers.
  - ✓ Condensators.
  - ✓ Pre-heaters (high and low pressure).
  - ✓ Reboilers.
  - ✓ Economizators, evaporators and superheaters for CSP.
- Mechanical design, development and construction of components for chemical industry, petrochemical and food industry. (columns, reactors, steam accumulators etc.)

1. Company and activities

Gestamp Energy Solutions is defined as a Thermal Engineering Company. Within this scope, it is included the design and turnkey supply of: (continue)

- Services y aftersales:
  - ✓ Combustion specialized consulting.
  - ✓ Boiler transformation to other fuels.
  - ✓ Boilers revamping y transformations.
  - ✓ Energy plant process automation: combustion and boilers in general. Logics definitions and integration.
  - ✓ Boilers and other installations energy efficiency.
  - ✓ Co-combustion.

- Maintenance and exploitation of combustion powered generation plants and CSP.
- Design and calculation of industrial metallic structures.
- Finite element calculations, studies and simulations (stress and heat transfer) as well as Computational Fluid Dynamic (flux distribution, heat exchange, combustion processes etc.)



2. The use of *Code Saturne* at Gestamp Energy Solutions

Gestamp Energy Solutions is being using Open-Source software since 2012 in a *practical* application of CFD to all the engineering stages of GES's product line in horizontal integration.

Open Source Software
(Linux-based)

- **Geometry:** Salome-Meca geometry module, either by parametric generation or imported geometries from development department.
- **Meshes:** Salome-Meca meshing module.
- **CFD code:** Code Saturne.
- **Post processing:** Paraview.

Uses of Code Saturne at Gestamp Energy Solutions:

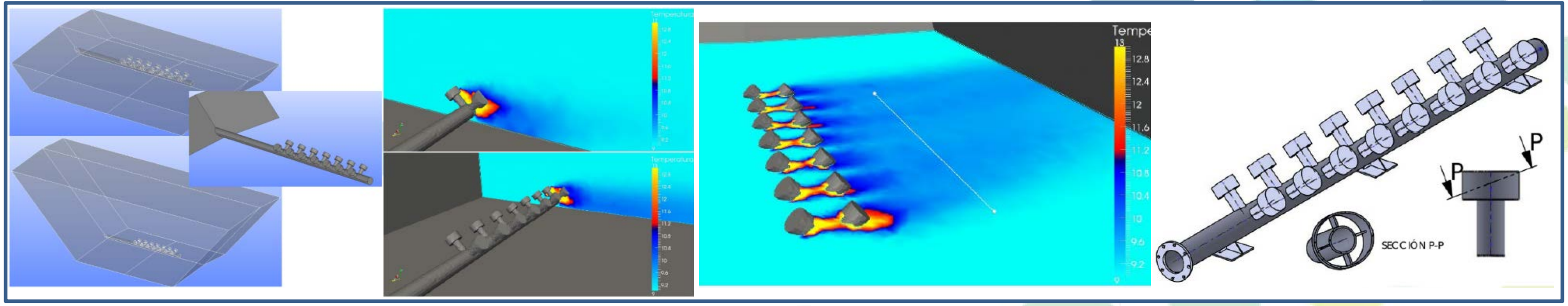
- **Preliminary engineering:**
  - Rough design of flow-related equipment.
  - Assessment to techno-economical evaluation processes.
- **Engineering support:**
  - Mechanical designs where required and flows distribution, head losses, and thermal/combustion processes are present.
- **Operational analysis:**
  - Modeling of observed physical phenomena of existing facilities (reverse-engineering), for improvements in later designs or performances in operation.
- **Research and development activities:**
  - Evaluation of modifications on existing equipment designs based on experiences.
  - Improvements on engineering services as an additional value (service differentiation).

3. *Code Saturne* references at Gestamp Energy Solutions

Some of the most representatives works performed in Code Saturne:

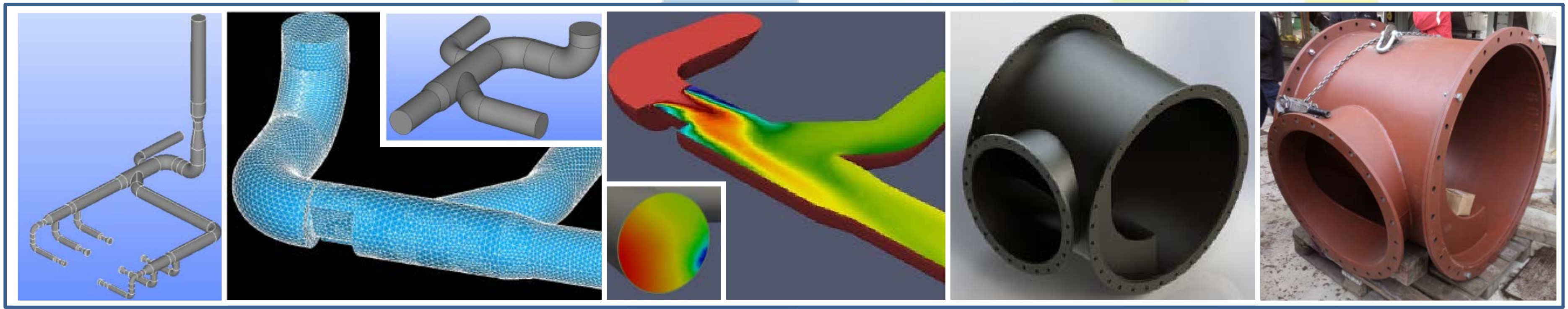
- **Dilution process analysis of a Biomass Plant submarine outfall in river Tacuarembó (Uruguay)**

  Outfall analysis focused on the temperature dilution with its equipment design for the Environmental Agency of Uruguay as a part of the Environmental Authorization for a Biomass Plant.



- **Air-recirculated flue gases mixing system for a Biomass plant:**

  Optimization and modification of the recirculating flue gases system of an existing Gestamp Biomass plant for the reduction on the pressure losses and increase of the process stability.

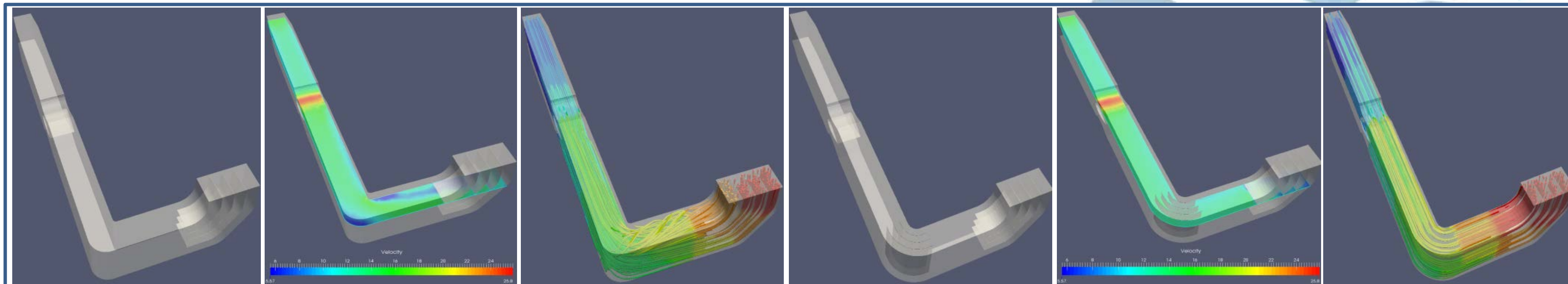


3. *Code Saturne* references at Gestamp Energy Solutions

Some of the most representatives works performed in Code Saturne (continued):

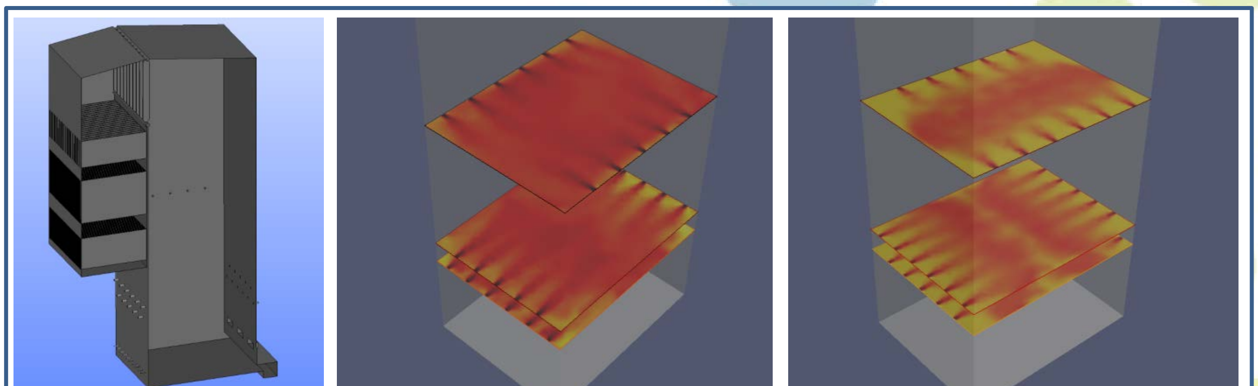
- **Vibration analysis in a gas-burner combustion air duct**

  Turbulence analysis for an air duct and comparative evaluation of suggested optimized solution.



- **Analysis of the air injection in a biomass oven**

  Adequate over-fire injection analysis of secondary air in existing biomass boilers ovens in terms of velocity and distribution for an optimal combustion process.



4. R&D

Gestamp Energy Solutions performs an intense R&D activity based on the following concepts:

- An open mind is base for business and products improvements required by the actual competitive industrial environment.
- Investments in terms of resources, time and formation for an adequate comprehension of the tools is required for a successful R&D activity.
- Applicability-focused results: The averaged equilibrium theory-reality-practicality provides the most adequate solution for a required issue in an industrial day-by-day reality.

Most relevant ongoing R&D works:

- **Modeling of biomass boilers burning olive residues:**

  Developing of an accurate, realizable and practical full-scale CFD model for grate-firing biomass boilers burning olive residues for engineering purposes which involves two independent (yet related) works, also focused to be the PhD dissertation of the authors:

  - Experimental and computational analysis of olive residues biomass-fired grates.
  - Modeling fly ashes particle deposition on olive waste fired boiler.

- **BiOxySorb:** "Economic Low Carbon Power Production and Emissions Controls for future and Flexible Biomass Co-Fired power stations."

  Among others, the BiOxySorb project implies the technical-ecnomical evaluation of the biomass (2nd generation fuel) co-combustion processes in a large scale (20MWt) boiler (supplied by GES in 2011) under air and oxy-fuel firing conditions with an investigation on burnouts, emissions (HCl, SO_2, SO_3 and Hg) and full cycle impact.

5. Experimental and computational analysis of olive residues biomass-fired grates

Introduction:

Spain is one of the biggest olive oil producers in the world, and this industry generates diverse oil residues (one of the most frequent is the so-called "orujillo") which is used in biomass boilers to its valorization through the steam production for electricity generation (with common power ranges from 2 MWe to 25 MWe) is highly extended.

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, although this can be avoided by means of:

- Conservative design values in both heat exchanging surfaces and boiler geometry according to flying ashes composition.
- Grate operation cautions.
- Improves in 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 boiler, modeling is poorly developed despite the aroused interest.

Gestamp Energy Solutions has developed **<u>five</u>** turnkey projects of grate-firing biomass boilers burning olive residues in the past years in Spain with powers ranges from 5 to 15 MW_e.

5. Experimental and computational analysis of olive residues biomass-fired grates

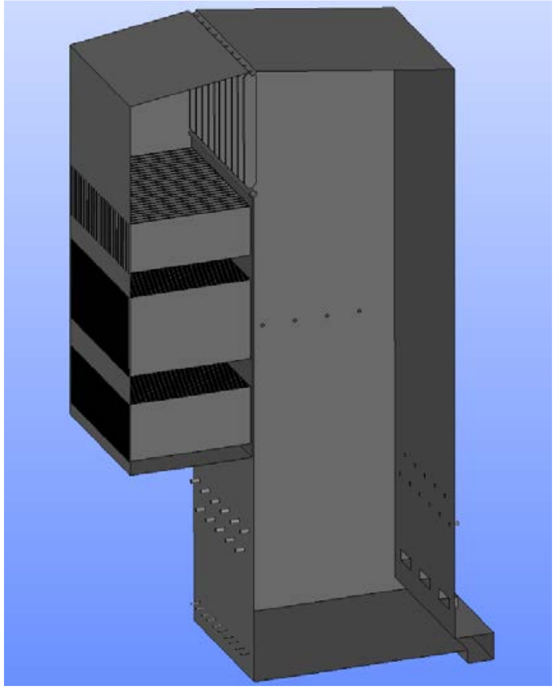
➢ Objective:

Develop and validate a feasible olive residues combustion model in grates for Code Saturne simulation thus allowing:

- ✓ Biomass boiler design optimization in engineering stages according to the olive wastes nature and particularities
- ✓ Boiler performance prediction considering combustion products and particles in order to maximize facilities dispatchability.

➢ Generic guidelines:

1. Develop a combustion model algorithm based on the particular olive waste composition and state-of-the-art combustion mechanisms for *Code Saturne*.
   - Gaseous species generation, either typical and specifically product of olive wastes.
   - Particle generation (flying ashes) with variable composition.
2. Integration of the combustion algorithm with *Code Saturne* radiation, turbulence and reaction models.
3. Real-scale validation of the model in existing and operating **Gestamp Renewables** boilers.



5. Experimental and computational analysis of olive residues biomass-fired grates

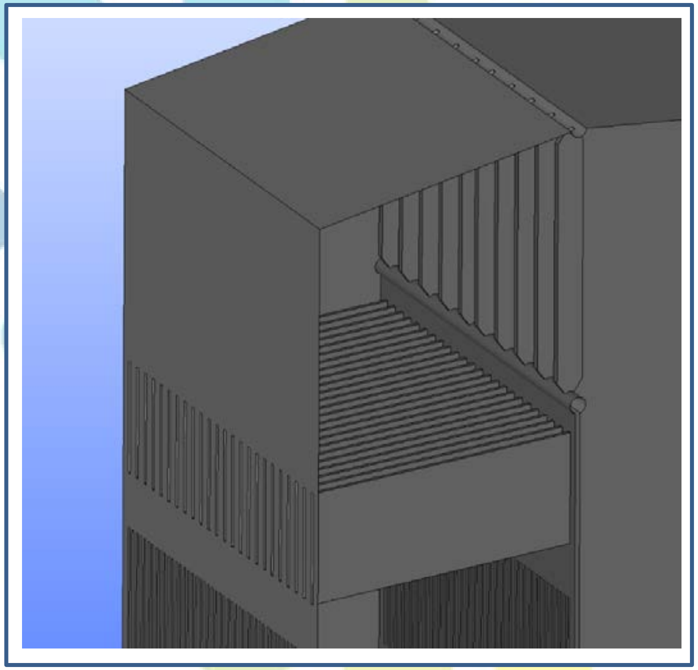
➢ Physical modeling :

A grate model - furnace coupled modeling strategy will be used as it is commonly used for these studies according to the state-of-the-art models:

- Kær, S.; "Numerical modeling of straw-fired grate boiler" – Fuel, 83, 1183-1190, 2004.
- Yin, C.; Rosendahl, L.; Kær, S.; "Grate firing of biomass for heat and power production" – Progress in Energy and combustion science, 34, 725-754, 2008
- Yin, C.; Rosendahl, L.; Kær, S.; Clausen, S.; Hvid, S.; Hille, T., "Mathematical modeling and experimental study of biomass combustion in a Thermal 108 MW Grate-Fired boiler"- Energy and Fuels, 22, 1380-1390, 2008.

By means of Code Saturne turbulence equations, thermal models, combustion and Lagrangian particle tracking modules together with expressly developed subroutines two different zones will be considered:

- The *Olive Wastes Grate* model (OWG model), where chemical reactions related with the fuel will be modeled in order to provide gas-phase reactions and flying ashes particles resulting compositions.
- Furnace, where both the gas-phase reactions and gas flow turbulence equations are solved together with the included thermal mechanisms. This furnace implies geometrical simplifications as slab-type / porous approximation heating surfaces.

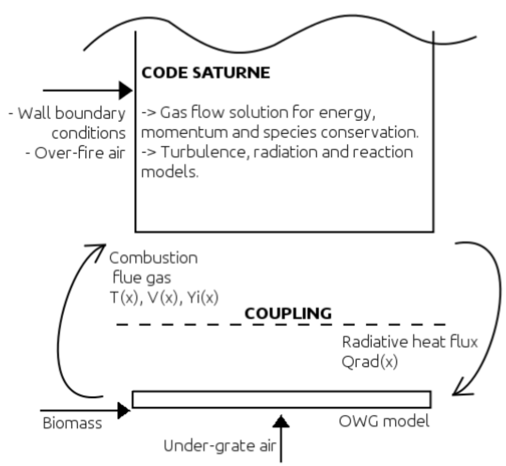


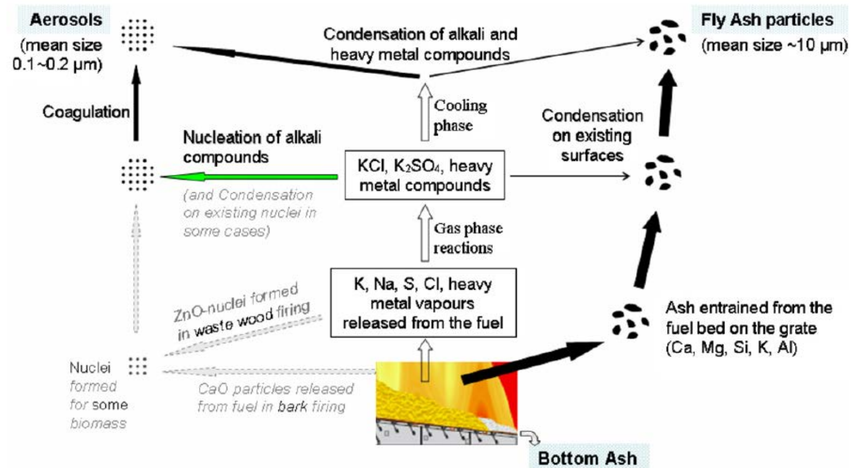
5. Experimental and computational analysis of olive residues biomass-fired grates

- **Physical modeling, modeling strategy:**

Aforementioned two zones corresponds to two different processes which are strongly coupled and then sequentially solved, as follows:

- **Step 1:** Based on biomass data, a primary air injection and an initial radiative flux, the OWG model routine is initially solved so initial temperature, velocity, fuel gas and particles composition profiles are obtained.
- **Step 2:** According to the OWM model output values treated as part of the furnace domain overall inlet conditions, CFD modeling of both the gas mixing and a homogeneous approach with moisture combustion is performed so that radiative flux onto grate is obtained.
- **Step 3:** Furnace domain CFD 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.



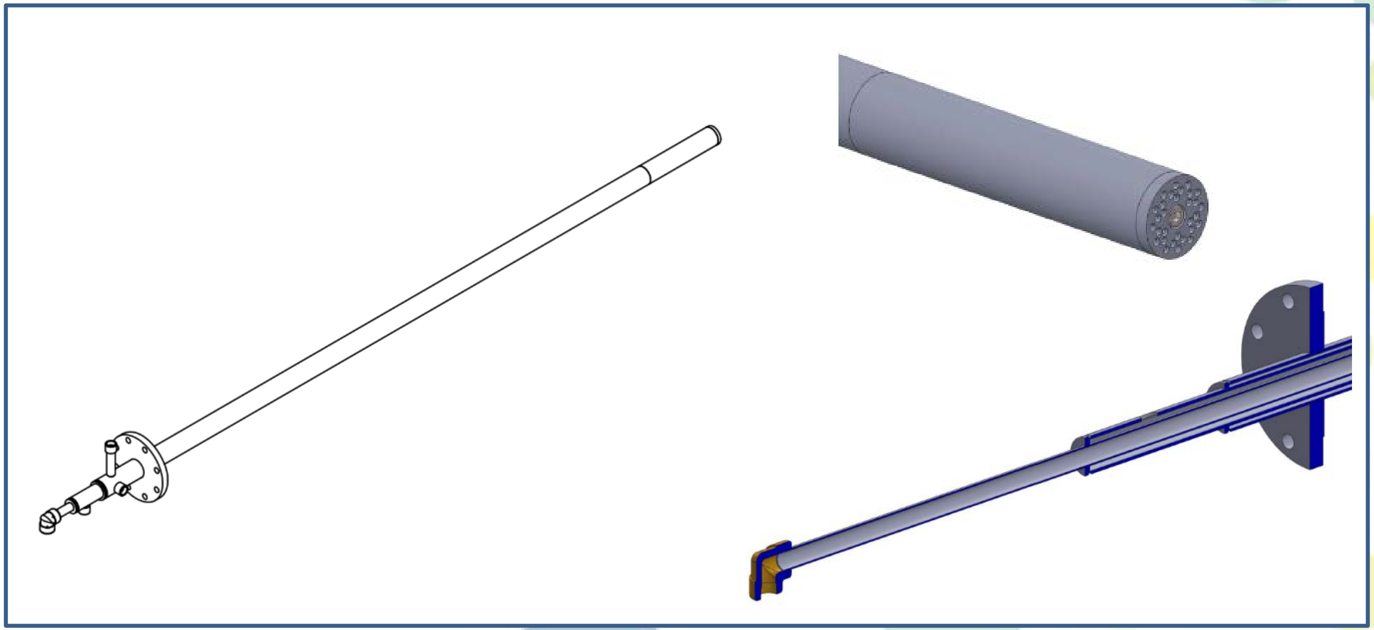


5. Experimental and computational analysis of olive residues biomass-fired grates

Physical modeling, validation process:

The OWG model will be validated in existing and operating **Gestamp Renewables** biomass power plants burning olive residues (8-15MWe) by means of on-site measurement (H_2O, CO_2, CO and particles) and model species prediction at measured points.

A temperature-controlled measurement probe will be specifically designed for model validation purposes. It will be able to extract fuel gases and particles in boiler existing nozzles and control surface temperature for ashes deposition.



Gestamp Energy Solutions

CODE SATURNE

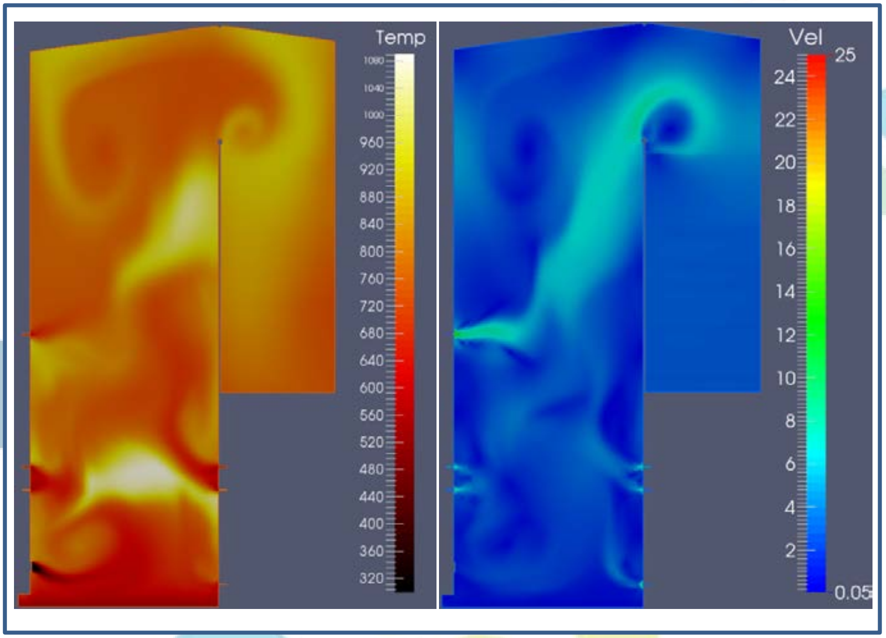
5. Experimental and computational analysis of olive residues biomass-fired grates

Physical modeling, development tests:

A simplified grate-firing 50MW$_t$ biomass boiler model of an existing facility has been developed in order to evaluate performances and capabilities of the available Code Saturne biomass combustion mechanisms as well as to allow the identification of the involved variables.

The following consideration has been taken to perform this model:

- Quasi-bi-dimensional domain (reduced computational resource), adapting radiative, combustion and flow parameters for representative results purposes.
- Multi-domain simulation (7 domains) connected by face-joinning.
- Tube banks modeled as head losses domains without heat exchange, adjusting values up to expected pressure drops.
- Pulverized fuel combustion model adapted to biomass, frozen field generated with Eulerian pulverized fuel combustion with moisture.
- Wood fuel (poplar) discretized in terms of granulometry and compositions into several geometrical inlets according to approximated fuel compositions in real operating facilities (different fuels).



- **Preliminary results** shows a good approximation in terms of temperature profile and velocities according to observed fouling tendency in the real boiler. Identification and investigation on the available combustion mechanism is being analyzed for later integration in OWG model.

5. Experimental and computational analysis of olive residues biomass-fired grates

➢ Physical modeling, development tests:

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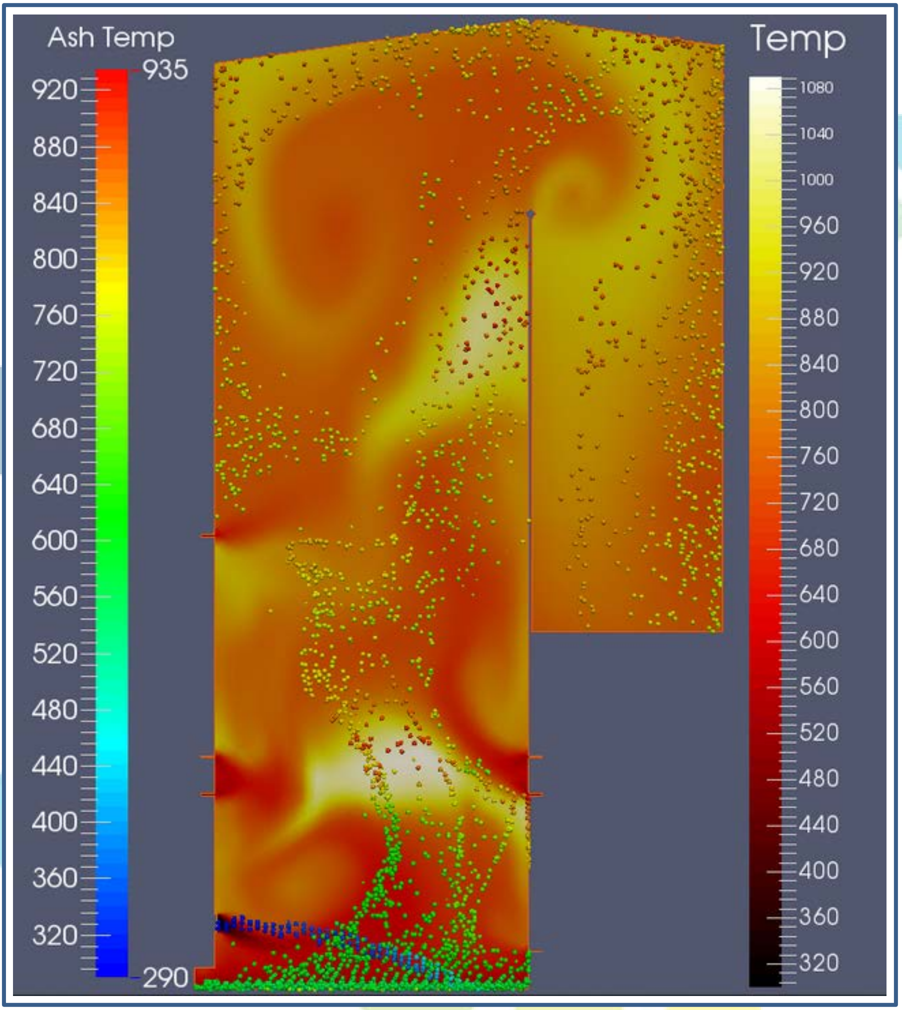
- Pulverized fuel combustion model adapted to biomass, frozen field generated with Eulerian pulverized fuel combustion with moisture.
- Wood fuel (poplar) discretized in terms of granulometry and compositions into several geometrical inlets according to approximated fuel compositions in real operating facilities (different fuels).
- Lagrangian multiphase particle tracking based on the pulverized fuel combustion of the homogeneus approach with moisture simulation, considering different granulometries injections, also shows a good approximation according to the expected results in real scale boiler.



6. Modeling fly ashes particle deposition on olive waste fired boiler

➢ Introduction:

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 may be deposited on furnace walls and heat-exchanger tubes, which will reduce the heat transfer and could give rise to corrosion problem.

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.

6. Modeling fly ashes particle deposition on olive waste fired boiler

➢ Physical modeling, general guidelines:

A new approach shall be implemented, following the model of C. Yin, L. A. Rosendhal, S. K. Kaer. (Dedicated models for grate-firing biomass. Technical report, Aalborg University, 2007)

Deposition mechanisms now are:

- ✓ Flying ashes particles (FAPs), by inertial, turbulent and thermophoretic mechanisms (2-250 μm)
- ✓ KCl vapor particles, by diffusion, turbulent and thermophoretic mechanisms (0.5 μm).

So, totally 4 different mechanisms are involved :

1. Condensation of alkali salts on surfaces
2. Thermophoresis (associated to small particles, low inertia)
3. Difusion (mechanical deposition associated to small particles)
4. Impaction (mechanical deposition associated to big particles, high inertia)

A User Subroutine is used for calculating the Critical Viscosity Cv as a function of the chemical composition of FAPs following works preformed by M. Seggiani and G. Panoncchia (Univ. of Pisa)

The critical temperature Tcv is also determined and will be the limit below which the probability of adherence will be ηstick =1.

This will always determine that a FAP touching the tube surface will be deposited and not rebounded off.

6. Modeling fly ashes particle deposition on olive waste fired boiler

➢ **Physical modeling, condensation of salts:**

A new approach shall be implemented, following the model of C. Yin, L. A. Rosendhal.

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. It creates the first layer of fouling over which further FAPs will be deposited.

Sticky probability shall depend also on wall temperature and potasium salt KCl melt fraction (fmelt)

6. Modeling fly ashes particle deposition on olive waste fired boiler

Physical modeling, condensation of salts:

$$\eta_{\text{stick}} = \underbrace{p(T_{\text{p}})}_{\text{particles}} + \underbrace{(1 - p(T_{\text{p}}))\, p(T_{\text{w}})}_{\text{deposit surface}}$$

…being:

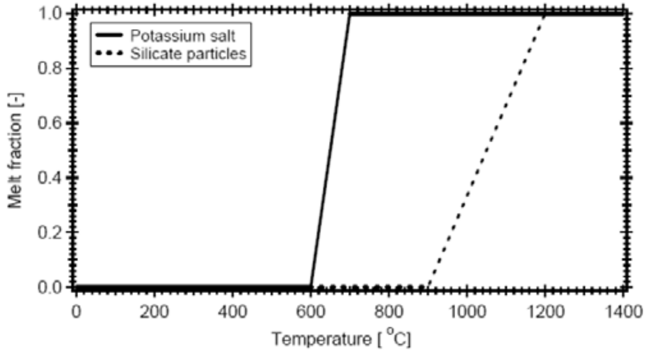
$$p(T_{\text{p}}) = \begin{cases} 0 & \text{if } T_{\text{p}} < T_{stick1} \\ 1 - \dfrac{T_{stick2} - T_{\text{p}}}{T_{stick2} - T_{stick1}} & \text{if } T_{stick1} < T_p < T_{stick2} \\ 1 & \text{if } T_{\text{p}} > T_{stick2} \end{cases} \qquad p(T_{\text{w}}) = \begin{cases} 0 & \text{if } f_{\text{melt}}(T, Y_i) < 0.1 \\ \dfrac{f_{\text{melt}} - 0.1}{0.6} & \text{if } 0.1 < f_{\text{melt}} < (T, Y_i) < 0.7 \\ 1 & \text{if } f_{\text{melt}}(T, Y_i) > 0.7 \end{cases}$$

$$f_{\text{melt}}(T, X) = f_{\text{melt,KCl}}(T) \cdot Y_{\text{KCl-deposit}} + f_{\text{melt,silicate}}(T) \cdot Y_{\text{ash-deposit}}$$

$Y_{\text{KCl-deposit}}$, $Y_{\text{ash-deposit}}$: mass fraction of KCl & silicates in deposit; $Y_{\text{KCl-deposit}} + Y_{\text{ash-deposit}} = 1$;

$f_{\text{melt,KCl}}(T)$, $f_{\text{melt,silicate}}(T)$: the temperature-dependency

…can be determined from the following figure:



6. Modeling fly ashes particle deposition on olive waste fired boiler

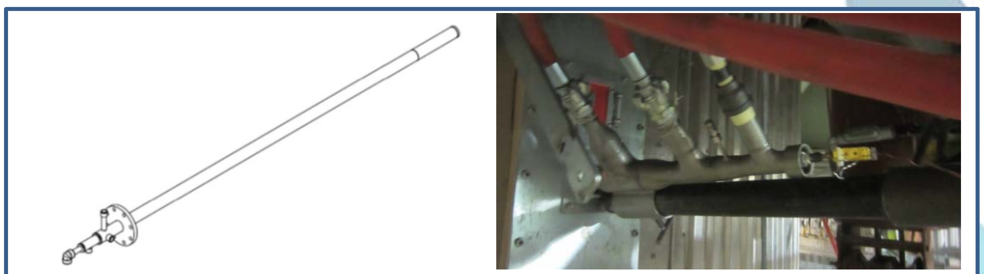
Physical modeling, strategy:

- Existing standard Langevin model plus a Guingo-Minier submodel.
- 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.
- Thermophoretic force shall be included in the model.
- Deposit shedding will be also included in the model. Only natural shedding (erosion and gravity) will be considered, excluding external or artificial ones (e.g. soot blowing and thermal shocks).

6. Modeling fly ashes particle deposition on olive waste fired boiler

➢ Physical modeling, experimental validation:

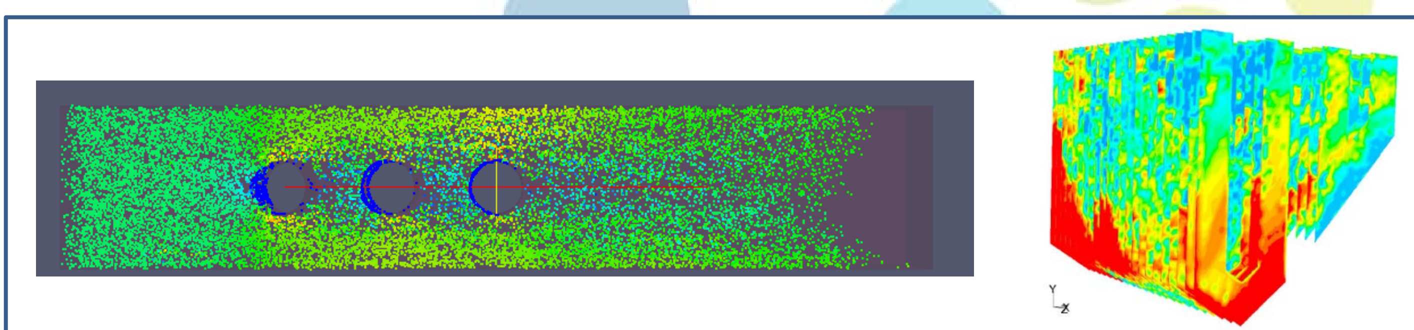
Models will be tested with data acquisition at site, in existing power station boilers of Gestamp Renewables (8-15 MWe) burning olive oil waste. Deposition probes with (air-water) controlled metal temperature will be used.



Results will be presented for a small set of 3 or 4 tubes with a high mesh density. After that, an industrial model will be constructed and tested, with simplified geometries for computational power saving.

This full-size model shall have plain surfaces instead of membrane walls profiles for economy in computing resources. Tube coils shall be simplified by plain slabs for the same purpose.

Results will be compared to real deposits obtained by the test probe at a controlled tube metal temperature.



7. Goals of the works

➢ Main goal of the works

- Find an useful, accurate and reliable tool for boilers design engineers who need to predict fouling problems in boilers firing troublesome biomasses.
- Once the work is finished, this effort will be profitable and useful for future *Code Saturne* users.

THANKS FOR YOUR ATTENTION

Polígono Industrial Salinas de Levante
C/ Doctor Pariente, Naves 22-24
11500 – El Puerto de Santa María,
Cádiz (SPAIN)
Tlf: (+34) 956 871 066
Fax: (+34) 956 860 379

Miguel Díaz Troyano
General Manager

miguel.diaz@gestampren.com

Pablo José Leal Forero
R&D Process Engineer

pablo.leal@gestampren.com