Thermolib
User Story

# Inspire and ABB develop Market Driven Waste-to-Energy Production with Thermolib Toolbox

Developers at ABB, a global leader in power and automation technologies, Inspire AG and the Institute for Machine Tools and Manufacturing (IWF) at ETH Zurich combined efforts to build a control system for waste-to-energy power plants.

Waste-to-energy (WtE) power plants use the thermal energy from waste incineration to produce electricity, thus contributing stability to the electrical grid by compensating load peaks and frequency shifts. A major challenge in such power plants is that waste material is highly inhomogeneous which leads to a greatly variable heating value and thus increases the uncertainty power plant controllers have to deal with.

## Challenge

Since composition of waste material cannot be predicted beforehand, the chosen method for the controller was model predictive control (MPC) combined with reinforcement learning methods used in the field of artificial intelligence. Before being deployed, the controller will have to learn how to react from thousands of possible scenarios. It was already clear at the beginning of the project that model-based design will be used. This imposed a set of challenges for the project:

- The developers required a control system that can handle the highly variable environment in waste incineration.
- They also needed a realistic model of the waste power plant, which will have to simulate the thermodynamic process of waste burning, along with the highly random composition of waste. Measured data were already available from a real waste-to-energy power plant in Turgi, Switzerland. The model will have to be verified against this data.
- The gap between complex control methods such as MPC and complex thermodynamic simulations was to be closed.

## Solution

Simulink®, already known and used by ABB developers, lent itself well as a development environment for process simulation. However, the thermodynamic models of the waste burning process that were so far developed and implemented by ABB turned out to be too complex for the application intended by this project.

This led the developers to the Thermolib toolbox. Relatively quickly, they were able to develop a Simulink® model of the power plant, despite not having an extensive background in thermodynamics. Since most major components were readily available, the process engineers were able to focus on expressing the relevant aspects of a thermal power plant. The model was then successfully verified against the measured data from the real power plant.

The Thermolib toolbox also allowed them to model the inhomogeneous composition of waste. Waste is mostly composed of carbon, water, hydrogen and other

Waste incineration plant

### Challenge

- Control system to handle highly variable environment.
- Realistic model of the waste-to-energy power plant.
- Bridge gap between complex controller and complex thermodynamic simulations.

### Solution

- Develop strategic control policies based on artificial intelligence learning algorithms.
- Use Thermolib toolbox to create a model of waste incineration plants and simulate the inhomogeneous composition of waste.
- Create a toolbox to connect the Python controller to the Thermolib model.

### Results

- Sped up development of a highly stable process model.
- Accurately modeled waste composition and combustion.
- Bridged the gap between MATLAB®/Simulink® and Python.
- Created a highly adaptable control system.

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"Power plant simulation with Thermolib reduces the effort to set up realistic, plant-specific simulations in order to test and continuously improve controllers with the simulation-in-the-loop approach."

*Christian Baltensperger, ABB Switzerland Ltd., Power Systems*

"Using the Thermolib toolbox enables us to develop model predictive controllers for complex systems, such as thermal power plants. It brings together extended control methods like planning under uncertainty and learning from the field of artificial intelligence and thermodynamic simulations."

*Dr. Bastian Migge, ETH Zurich, Institute of Machine Tools and Manufacturing*

elements. By extending the Thermolib media database to include carbon, and rewiring the source blocks to generate random compositions, they were able to model a random source of waste.

The highly random composition of waste material creates a relatively unknown environment in waste incineration. The system can be described as partially observable: it is not completely known which state the system is in (because the waste composition is unknown) but the controller does have control over what to do next. This is a problem commonly encountered in robotics, so the developers used a framework employed in that area: partially observable Markov decision processes (POMDP). The POMDP framework is used to develop control laws for systems where the states are not completely observable but where the controller does have control over state transitions. The controller, instead of applying a statically given control law, tries to guess which state it is in and adapts to the system by continuously evaluating the effect of control actions. In the case of a large waste power plant, it is trained via thousands of simulations to cover many possible scenarios – a time consuming undertaking. This further enforced the need for a fast and stable thermodynamic model of the power plant.

Finally, to bridge the gap between the controller (Python, C & C++) and the simulation (Simulink®), IWF developed a toolbox that connects both environments. They were able to train their controllers on the Thermolib model by running a large number of possible scenarios.

## Results

### Sped up development of a highly stable process model.

By using the Thermolib toolbox, the process engineers did not have to delve into the details of thermodynamic behavior, and were instead able to shift focus to setting up a correct and verified model of the waste-burning power plant. This sped up the development time significantly.

### Accurately modeled waste composition and combustion.

Using the Thermolib media database and the random number generators in Simulink®, the developers were able to simulate both the highly variable composition of waste and the consequently variable thermal combustion.

### Bridged the gap between MATLAB®/Simulink® and Python.

The created toolbox connects readily available tools in languages such as Python or C with process models developed in Simulink®/Thermolib. This opens the door to develop further sophisticated controllers.

### Created a highly adaptable control system.

Adapting the optimal control laws to new market situations is time consuming. Teaching the controller using the Thermolib process model via thousands of simulations led to creating a highly adaptable control system.

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