WASTE IS A RENEWABLE SOURCE OF ENERGY

Turnkey design & build and services

For:
- Household waste
- Commercial and industrial waste
- Biomass
- Fuels derived from waste

To produce:
- Recyclable materials
- Compost
- Energy (heat and electricity)
Dynamic Plant Simulator – a Virtual Reality Twin
to Model WtE Plant Behaviour and to Train Operators

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1. Digital development: a 21st century challenge

Digital development is a 21st century strategic axis regarding industrial performance enhancement in terms of productivity, energy efficiency and environmental impact, and is considered as the fourth industrial revolution.

![Figure 1: From 1.0 to 4.0 industry](image)
Therefore, it concerns all the energy sector actors and among them, Waste to Energy.

In that sector, the energy valorization of waste shall be efficient to complement sustainably other energetic sources and sorting. Consequently, improving energy recovery and lowering environmental footprint are fundamental and the digital development appears as the real keystone of this potential progress.

The digitalization enables to improve the performance throughout the plant life cycle by acting on both technology and human behavior at each key stage of the project: engineering, operation and maintenance:

- Engineering by improving internal performance, making communication and information faster inside a company, thanks to the Building Information Modelling (BIM) program for instance and/or allowing to optimize productivity scenarios
- Operation and maintenance performance, through designed tools to help operating the plant, such as predictive systems, or operator training tools.

In order to anticipate clients’ demands, CNIM has developed the *WtE Dynamic Plant Simulator*, a high-fidelity process digital twin, integrating Waste to Energy facility process and its Digital Control System (DCS).

![Dynamic plant simulator](image)

**Figure 2:** The WtE Dynamic Plant Simulator

## 2. Goals of the Dynamic Plant Simulator

Like a flight simulator in the aeronautic sector, the WtE Dynamic Plant Simulator (hereafter called DPS) enables to optimize human performances and predict the operation in various circumstances.

### 2.1. Why a Dynamic Plant Simulator?

By computing and integrating time-dependent variables and real features of the plant, the dynamic simulator provides a *full length movie of the possible states* of the power plant based on current and previous status, while a static simulator is just a *picture* of the power plant in a given steady condition. This full virtual approach of the plant operation provides three major benefits:

Firstly, this dynamic simulation offers new possibilities to optimize the plant process from the engineering phase (whether it is for a new plant or a retrofit) up to the commissioning in a safe, transparent and efficient way. When applied during the basic engineering phases of a project, the simulator allows more accuracy in equipment dimensioning, process optimization and removes some uncertainties especially in transient modes, which are more difficult to address by conventional static mode studies.
The simulator can also be used to check the adequacy between process behavior and a Digital Control System by:

- quantifying the effect of failures during Hazard and Operability studies (HAZOP),
- performing ‘what-if’ studies to ensure that the Plant can be operated safely, reliably and meets its performance expectations,
- performing dynamic Functional Acceptance Testing (FAT) of the Digital Control System, checking the efficiency of process control, safety equipment, etc., which makes the commissioning phase faster and safer.

Secondly, the simulator represents a gain for the plant staff. It is well known from operating companies that the skill of operators is one of the key factors in a plant overall performance and availability. All these companies perfectly know how hard it is to recruit experienced staff and/or to train non-experienced personnel in the Waste to Energy facilities, which is used to suffer from high turnover. Usually done with static demonstrations, PowerPoints, or coaching during commissioning, the operators’ training needed a more efficient and modern training support. Thanks to the simulator, operators and engineers learn more about the process and how to operate the plant and how to react in front of unexpected events smoothly, efficiently – in a single word: smartly – without any risk of causing damages on the real plant. It is a great advantage in their day-to-day job.

Thirdly, the simulator provides an efficient tool for the plant operation and behavior management. Indeed, used as a gap analyzer by comparing dynamically the real process data to the expected theoretical values, the DPS will allow the operators to point out unusual efficiency losses, and identify their sources. It provides high value information like level of cleanliness of various heat exchangers or about non-performing devices suggesting some preventive actions and/or advance maintenance. It also helps to evaluate the consequences of a non-conventional operation method, which can be applied in back-up mode, and/or the benefit of minor process changes to adapt the plant to new constraints throughout its lifetime.

The dynamic simulator offers a new tool of engineering optimization and risk management, human resources training and plant overall management. However, in order to fit these expectations, the dynamic simulator must be a realistic and adaptive tool.

### 2.2. Process wise realistic

The fidelity of the process and physical behavior are of major importance for the effectiveness of the dynamic plant simulator. In order to be process wise representative, the process model must include high fidelity data in terms of main engineering characteristics of purchased and home-designed items such as tanks, heat exchangers, valves, steam turbine, combustion grate, flue gas treatment, piping and physical process data such as elevations, dimension influencing the process. Also, real data sheet, heat and mass balance are used to model the plant.

Only very few components, which are fully automated and/or have no direct process impact like the waste handling crane are not fully modelled.
For some equipment (turbine for instance), data are not fully available due to data privacy from their supplier. In that case, the models are based on their thermodynamic properties adjusted by experience and real physical features observed during commissioning.

As the simulator effectiveness requires a full knowledge of the plant and its equipment features, the plant designer and process owner shall implement it.

2.3. Interface wise realistic

A flight simulator combines both realistic physics and time wise reactions, in order to provide the real feelings and reactions of a flight and a realistic cockpit representation, in order to put the pilot in the same working environment than in a real situation.

Also, for the DPS, realistic does not only mean providing a relevant plant process operation but also a supervision and a system, which will provide the feeling of real operation. Consequently, the DPS is structured around:

- a highly realistic dynamical process model which deals with physics, thermodynamic and chemistry and can be considered both as the heart and the brain of the DPS,
- the real Digital Control System (DCS), which will be implemented on site to get the proper plant's reactions and for the interface, the real genuine synoptic views of the plant.

The DCS logics and control loops are connected with the dynamic process model, including main sequences, interlocks, PID loops to control all the components (valves, fans, pumps, turbine) and ensure safety functions.
2.4. Adaptability

Different levels of flight simulators are available on the market. It can be a generic tool for various applications and/or a dedicated simulator for each plane.

Likewise, the DPS can be adapted to any WtE plant. Whether the plant includes several lines, steam export for district heating, special flue gas treatment, it can be modelled in detail.

For instance, the first full DPS has been developed and applied for an English facility that includes two lines of 60 t/h each and more recently for a plant based in the Middle East that includes one line of 140 t/h. Although ambient and operating conditions are different, we developed the two simulators following the same method, described in chapter 3.

2.5. Structure

The Digital Control System and the dynamic process model are linked and exchange data in real time by a communication protocol. The dynamic process model, replacing the real plant, is operated thanks to the DCS.

For the training simulator, we have implemented two communicative and linked supervisions:

- the operator interface, which contains all the actual plant control loops and logics,
- the trainer interface, which contains the same loops, but has more functionalities such as simulating malfunctions on equipment.

![Diagram of Simulator training architecture](image)

Trainee and Trainer are connected to the same dynamic process model and DCS. Thus, the operator and trainer will be able to see the effects of each other’s actions through a DCS user-friendly interface.

Performing a realistic and adaptive DPS requires the soft developers not only to get some knowledge and experience in Waste to Energy process and DCS implementation but also to get full access to process documents, designs, calculation notes and DCS soft and hardware. As process owner and integrator as well as DCS developer, CNIM has been able to develop the Dynamic Process Simulator efficiently and accurately.
3. Dynamic Plant Simulator development

After the development of a DPS proof of concept in 2017, we have implemented in 2018 an efficient method to develop the dynamic process model of the plant and to link to the plant’s DCS.

![Modelling method](image)

3.1. Data collection

At the early stage of a DPS project, we collect and compile into an exhaustive table all the process data and equipment characteristics required for the model:

- Data sheets provided by equipment supplier or by the company, provide all the information to be compiled into the process model;
- PID diagrams provide information about piping diameters, equipment relative locations,
- 3D Map extraction provides the heights and geometrical information of the different equipment,
- Heat and Mass Balance of the plant and Process Flow Diagrams (PFD) provide the main information about the plant’s state variables in different operating conditions (nominal, Maximum Continuous Rating, design, minimal and maximal load)

3.2. Data implementation

The dynamic process model is implemented with Apros software, provided by Fortum in collaboration with the VTT Technical Research Centre of Finland.

It is a dynamic simulation software for integrated process and thermal power plant automation design and engineering. It is based on mass, energy and momentum conservation equations and the integration of some basic geometrical aspect like elevation. It allows accurate real time simulation. The software highlights thermal hydraulic solvers and large component libraries.

Hence, a high-fidelity model of the plant is possible by structuring, programming and feeding dynamic simulation software with all the necessary plant data and the relevant details.

The entire plant is divided in major Equipment (Primary and secondary combustion air lines, boiler, turbine, condensate, combustion chamber, flue gas treatment, burners, air cooled condensers, common water and steam package). Each Major Equipment includes a set of components. Each component is modelled in the dynamic simulation as per design data (or per as built data depending on the project phase) and is connected as per PID diagrams taking into account components’ data sheets, heat and mass balance of the Air Flue Gas (AFG) and Water Steam (WS) parts, and integrates also some chemical and electrical features.
Figure 6: Process of a waste to energy power plant, major modelled equipment
The data collection, optimization and rationalization is of main importance before compiling into the dynamic process model for the entire plant. Then, the few boundary conditions (primary air inlet, the secondary air inlet, the stack outlet, and the waste feed) are set. Once implemented, the process model is validated by running the Maximum Continuous Rating (MCR) condition. At that stage, the main physical reactions and main equipment of the plant runs realistically on the DPS.

We describe hereafter some specific model loops to illustrate the above principle:

**Combustion air**

The main air line composed of Primary Air, Secondary Air and Extraction Air, is modelled in detail (fans, control valves, ducting, heat exchangers, flow element …). We set an atmospheric boundary condition in pressure and temperature. By running the dynamic process model, the other process value along the air line of the model are calculated.

**Combustion/pollutant**

The waste fuel feeding is set as a boundary condition. It is defined as a particulate of waste solid fuel characterized by its average C.H.O.N.S, ash, volatile matter composition, moisture percentage and its Lower Heating Value. The model integrates also a two-stage carbon combustion model with CO/CO₂ ratio and two types of volatiles matter: neutral and fuel volatiles. To be even more accurate and realistic the combustion fuel model integrates also some random variations around its setting.

As modelling the waste handling crane has not been considered as a benefit for the DPS, the waste flow rate is introduced in the model by a control valve.

This simulated waste inlet and the preheated air are mixing in the combustion calculation node (point) representing the waste grate, inducing the combustion reaction:

As shown in Figure 7, the solver offers a complete combustion model in which are integrated air (blue line), flue gas (orange) but also interaction with water/steam loop (blue line). The Air Flue Gas composition and thermal heat flux provided by the combustion are computed depending on the fuel composition and characteristics defined in the model properties.

The DPS integrates SOₓ, HCl, NOₓ pollutants for a better process training on pollutant control. Due to the complexity of their chemical reactions, no model is available to predict and integrate the variability of their concentration in flue gas over time. Consequently, we have implemented in the model their usual values and fluctuation based on real plant data and we have correlated them with relevant process factor such as oxygen concentration, temperature…

Then we have implemented our own chemistry transfer functions to simulate the efficiency of the SNCR for NOₓ reduction by Urea injection and the efficiency of the VapoLAB dry Flue gas treatment by lime, active carbon and steam injection for SOₓ, HCl reduction.
Boiler and water/steam lines

The heat flux produced by combustion is transferred to the Water and Steam loop through heating surfaces and heat exchangers. The heat exchangers models includes convection, radiation and conduction heat transfer sub-models and characterized by several data such as number of tubes, diameter, material, length, heat exchange convective and radiative coefficients, exchanger type…). Figure 7 shows in red the model of the boiler exchangers passes. Hence, thermal energy is transferred from flue gas to water, the dynamic model is accurate enough to establish on his own the induced natural circulation in the first, second, and vaporizer passes.

The compliance of the modelled components with their real data is of major importance for the relevance of the dynamic process model. For example, when modelling the boiler superheaters, we tried to simplify the right and left side heat exchangers in a single heat exchanger, with the cumulative number of tubes. Then we figured out that the inertia of the temperatures was not accurate enough when cooling down the boiler because a single heat exchanger does not react like two left and right parallel heat exchangers. We came back to a two-side separate model to run efficiently.

Turbine

Our dynamic process model includes the simulation of the turbine. The realistic and detailed process model of the turbine can be implemented including several bleeds. Depending on the turbine pressure control valve setting, the steam flow induces rotation.
of the turbine blades and shaft, and the model calculates the electricity production. We also simulated the electricity consumption of the plant according to these electrical main components.

![Figure 8: Turbine modelling](image)

### 3.3. Digital control system

The DCS is the plant interface for the operator. According to DCS data, the operator modifies some settings to achieve process changes.

The DCS developed for the plant is adapted to the dynamic process model by interchanging the physical inputs and outputs -meant to be connected on the real plant- by the virtual inputs and outputs of the dynamic process model.

To control the model, we keep all the sequences, interlocks and loops developed for the plant DCS, in order to have the same behavior between our DPS and the real plant.

The latest DPS has been implemented using our DCS system (developed on Valmet Metso soft and hardware), but our dynamic process model can be interfaced with all the well-known DCS brands (e.g. ABB, Siemens…).

![Figure 9: Digital control system boiler view](image)
3.4. Coupling the DCS and the dynamic process model

Communication

DCS and the dynamic process model are connected together thanks to an industrial standard communication protocol with a Client – Server structure. It enables to define easily the exchanged between variables. The Client connects to the server and gives or receives information to/from it. One variable from the Client is associated to a variable from the server through an exchange table in the form of an xml file.

Depending on the variable type (Sensor, speed set point, valve position), the dynamic model writes or reads values from the DCS. For instance, sensors only need communication from the dynamic model to the DCS, while a pump speed set point needs to be both read and written from the model to the DCS depending on the simulation state (Running, paused, reset, see next point Simulation management).

Simulation control

The dynamic plant simulator, contrary to a real plant, can be controlled through time. One can pause the physical reactions, go back to a previous digital plant state (called Initial Condition), only by clicking on one button (refer to Figure 9).

Simulation phases management

We defined three main phases during a simulation: the running phase, the pause phase, and the reset phase.

When the simulation is running, the exchange between the DCS and the dynamic process model are the same as in the real plant:

The different sensors values are written to the DCS and the controlling equipment get their information from the DCS.

When loading a new initial condition, the dynamic process model re-writes all the values to the DCS: Sensor values, Controller outputs to their initial position/settings depending on the defined state.

This ensures full synchronization between DCS and dynamic process model.
When the simulation is on pause, all the controller values are forced to their last value, so that they will not be able to change. This prevents from getting synchronization issues between the model and the DCS.

4. Results

The DPS covers the whole plant process, including Air Flue Gas, Water Steam, electric production, condenser and chemical reactions and is entirely linked to the DCS. Our DPS reproduces the plant operation from the cold start up (cold status) up to the maximum load condition (hot status). As in a real plant, stable phases can run automatically and some particular transient phases need human manual intervention (i.e. purging, venting…). It is the reason why in the Dynamic Plant Simulator, the transition from cold status to hot status currently needs to be activated by two separate sequences.

4.1. Utilization

At development stage, when presenting the Beta version of our DPS applied for training session, our Client Viridor mentioned, The level of sophistication in the software is very high and there is confidence that the finished product will mimic the characteristics of an actual Energy Recovery Facility (ERF). Alarms and trips (if unattended) based on real time experience, will make this simulator a valuable training tool. It will allow trainees to familiarize themselves with the actual mimics on site, the alarms and faults. It will develop further the confidence and understanding to operate Viridor’s ERF in a safe and optimum level.

We are applying the Dynamic Plant Simulator since early 2019 to train operators on DCS interface and process. This new, easy, interactive, and user-friendly tool has been welcomed by operators who have clearly shown a better understanding and pro-active attitude during their training sessions. Even if it is yet too early to confirm the effect on the future plant operation, we expect the success of this new training method to be positive in the plant handover and operation.

We started to apply the dynamic process model for designing and optimizing specific plant operations and/or devices such as steam tanks to guarantee 24/7 continuous steam export over specific plant failure mode. We are currently extending the simulator to several other applications such as:

- HAZOP scenarios validation
- Various plant process and safety checks
- DCS Factory Acceptance Test (FAT)
- Extend DCS’s FAT to dynamic test to preset time dependent variables such as PID loops parameters for control valves and actuators, temporizations and save time and uncertainty during the various commissioning phases.
4.2. Application Availability

Today the Dynamic Plant Simulator is available under two major versions:

1. The Digital Operator Training (DOT) DPS based on a standard plant dynamic model with a standard DCS interface looking like the Client’s future plant and DCS. This tool is available to train the operators on plant operation & process.

2. The Digital Twin DPS based on the Client’s plant dynamic model and Client DCS interface. In addition of training purposes, the Digital Twin Dynamic Plant Simulator allows our Client to compare in real time its current plant performance with the optimized one, to easily identify weakness or wrong operation, make troubleshooting analysis and to evaluate preventively the effect of corrective actions or back-up operation mode. With our assistance, the impact of process improvement throughout the plant’s lifetime can also be evaluated.

5. Further development

By acting on clients’ digital and human resources development, this DPS whether applied as a training software or as a digital twin, offers to our clients the opportunity to run their plants in an optimum way. Our goal for the upcoming years is to push further the added value of this simulator.

In a short-term future, we plan to link the Digital Twin to the 3D plant model, making the simulator a fully immersive tool allowing checking the whole process and engineering before having even dug the first foundation of the real plant.

The Dynamic Plant Simulator will improve the performance of Waste to Energy Facilities.

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