Model-Free Closed Loop Ethanol Separation Real-time Optimisation

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Background

Clonbio’s biorefinery in Dunaföldvár, Hungary (operated by PannoniaBio) uses corn dry-fractionation and milling process to convert maize into renewable ethanol, high-protein animal feed, corn oil, and renewable biogas.

The main process steps used to make ethanol are shown in figure 1:

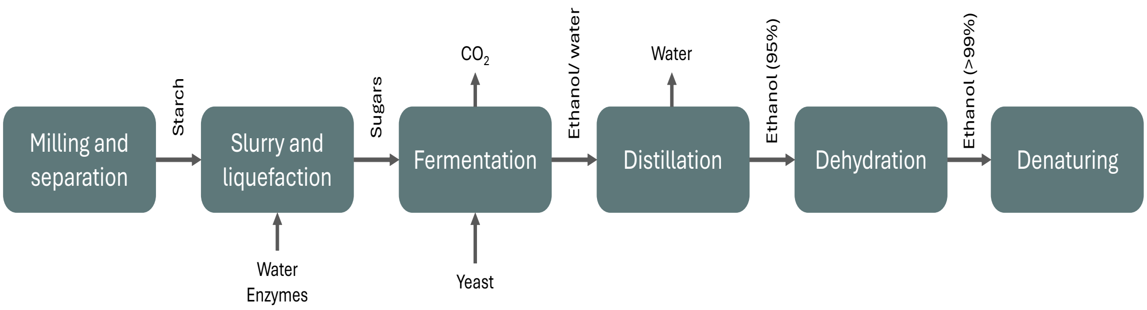


Figure 1 – Bioethanol Process Flow Scheme

Milling and Fractionation

- Milling: Incoming local corn is passed through mills and pulverized into a fine meal.
- Dry Fractionation: Corn kernels are separated into specific components (starch, fibre, germ, and protein) prior to fermentation.

Slurry and Liquefaction

- The starch-rich fraction is mixed with hot water and recycled process liquids to create a slurry.
- Heat and specific enzymes are introduced to break down complex starch molecules into simple sugars (glucose and dextrose)

Fermentation

- The simple sugar mixture (mash) is transferred to large vessels where yeast is added.
- The yeast consumes the sugars, converting them into ethanol and releasing carbon dioxide (CO_2).

Distillation

- The "beer" is pumped into multi-column distillation towers where it is separated into high purity ethanol (approximately 95% purity) and water.

Dehydration

- To make the ethanol suitable for fuel blending, remaining water must be removed.

- The 95% ethanol vapor is passed through molecular sieves, giving 99%+ pure (anhydrous) bioethanol.

Denaturing and Coproduct Processing

- Denaturing: A small amount of petrol is added to the pure ethanol to make it unfit for human consumption.
- Coproducts: The leftover mash/stillage (stillage, fibre, and germ) from the distillation columns is centrifuged, evaporated, and dried to produce nutrient-rich products. Residual fibres and waste streams are funnelled into on-site biogas facilities to generate renewable natural gas.

<u>Closed Loop Optimisation of Ethanol/ Water Separation</u>

The project at the PannoniaBio facility was on the Distillation section shown in figure 2.

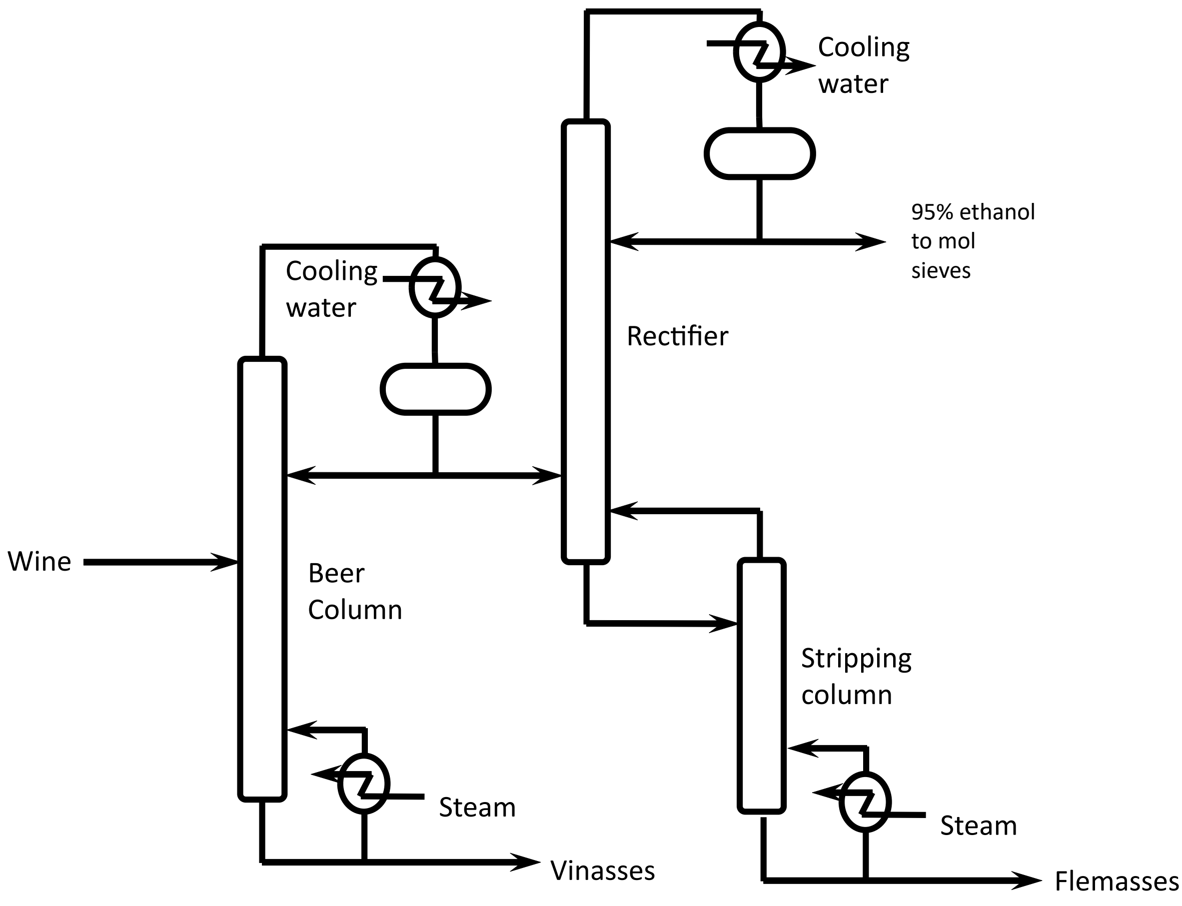


Figure 2 – Distillation Section

The distillation section separates ethanol and water before the ethanol passes to the molecular sieves for final water removal. Reboiler steam flows on the beer column and stripping section are adjusted by column temperature controllers. These temperatures impact ethanol losses in the bottom products on the columns.

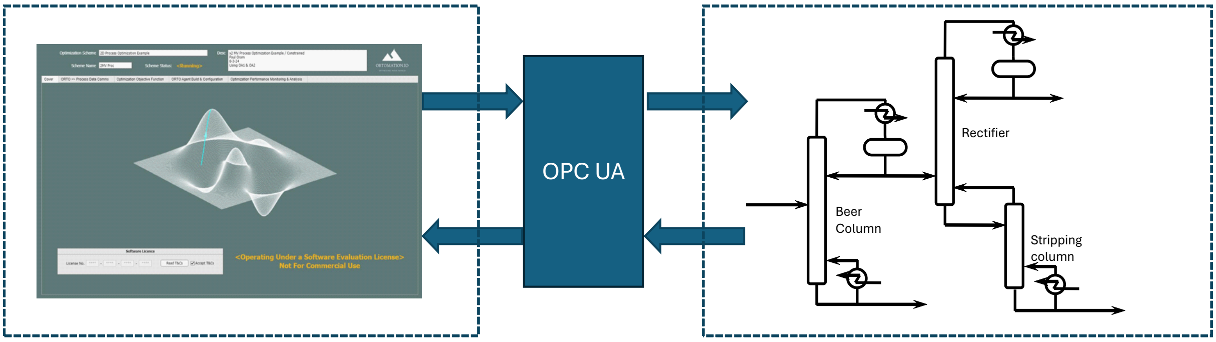
Since ethanol and water form an azeotrope, the ethanol concentration in the top product of the rectifier can only achieve 95% and the operating goal is to minimize steam use whilst meeting product limits on the bottom products of the beer column and stripping column.

Project Execution

Upon approval of ORTOmation's proposal by the operating company, project execution commenced following these steps:

1. Software Installation

The ORTOmation software, ORTO™, was installed server connected to the DCS. The connection to the measurement system and regulatory controls was built using OPC UA, as depicted in figure 3.



ORTO™ Application (OPC Client)

Distillation Section

Figure 3 – OPC Communications

2. Training

Training covering how an optimization scheme is built, commissioned and then monitored using ORTO™ was provided to the operating company team via Microsoft Teams. The training took roughly 3 hours.

Later in the project, the training was repeated for a newly hired control engineer.

3. Optimization Scheme Definition and Build

The operating company team and ORTOmation had carried out some initial discussions prior to ORTOmation submitting the proposal. A further, more in-depth discussion was held to define the optimisation objective function:

1. **The operation and economics of the distillation columns:**
   The overall objective was to minimise steam use in the Beer Column and the Stripping Column. Minimizing steam reduces fuel consumed by the om-site boiler, thereby reducing variable costs.
2. **Manipulated variables to be used by the optimizer:**
   a. Steam flow to the Beer column.
   b. Steam flow to the Stripping column.
   c. Ethanol product quality.
3. **Constraints that needed to be adhered to by the optimiser:**
   a. The qualities of the beer column bottom product and stripper column bottom product (ethanol content).
   b. Hydraulic capacity constraints.
   c. Steam reboiler condensate pressure limits.

d. Controller stability.

4. **Optimizer pause flags:**

   It was decided that the optimizer should pause if:

   a. The manipulated controllers were not in the correct mode i.e. to receive a remote SP.
   b. Reboiler pressures are too high or valve positions are constraining.
   c. Reboiler availabilities as determined by interlocks.

Table 1 below summarises the final optimization objective function design.

4. <u>ORTO Scheme Build and Operator interface</u>

A full read / write OPC tag list was defined, including a communications watchdog. Communications were configured and tested at a system integrator's facility in Dublin, using a control system / VM, replicating that on the site.

A simple operator interface was also built, as shown in figure 4, and then embedded in the main beer column operator graphic.

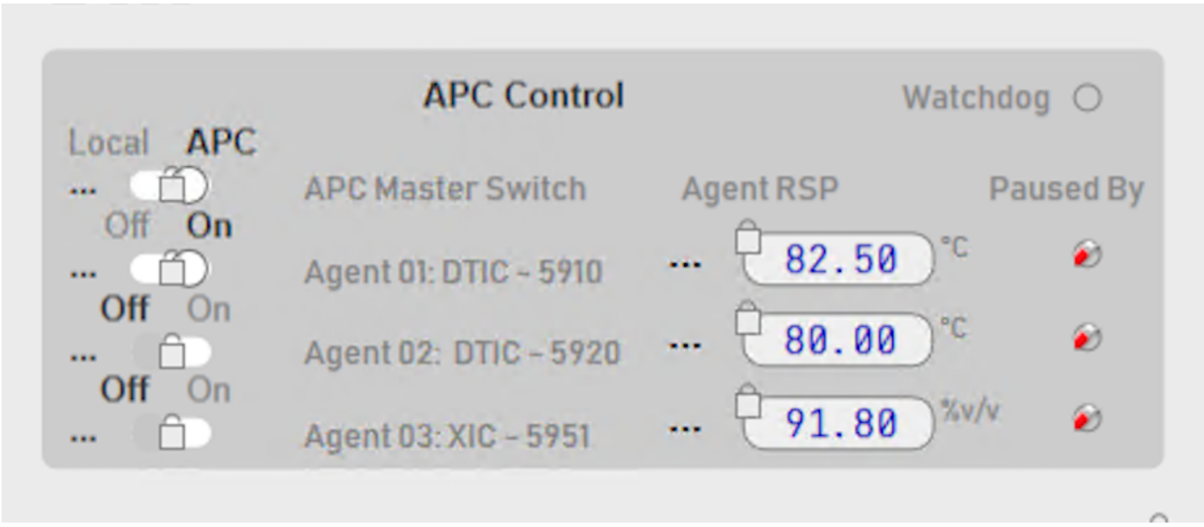


Figure 4 – ORTO Operator UI

All software then underwent a full two-day FAT, again at the system integrator's offices, with ORTOmation present.

On site, the optimisation objective function was then configured in the ORTO software and the three agents required for the three MVs were built.

<table>
<tr><td colspan="2">Optimization Variable (OV) Calculation:</td></tr>
<tr><td>(FT5910Apv+FT5920pv)/FT5910pv

Calculated in the control system and then read in by the ORTO software.</td><td>The overall objective is to minimise the steam use on the beer column and the stripper column divided by the total feed flow to the beer column.</td></tr>
<tr><td colspan="2">Manipulation Variables (MVs)</td></tr>
<tr><td>Beer column temperature (DC5910sp)
Stripping column temperature (DC5920sp)
Ethanol product quality (XC5951sp)</td><td>To adjust reboiler steam flow and rectifier reflux.</td></tr>
<tr><td colspan="2">Constraint Logic Expressions</td></tr>
<tr><td>C1 applied to beer column temperature control ORTO agent:
(PT5910pv>0.6) | (ETH5910pv>0.1) | abs(TT5910pv-DTC5910rb)>1 | (DTC5910output<=DTC5910opmin)

C2 applied to stripping column temperature control ORTO agent:
(PT5920pv>0.68) | (ETH5920pv>3) |abs(TT5920pv-DTC5920rb)>1 | (DTC5920output<=DTC5920opmin)

C3 applied to stripping column reflux ORTO agent:
(XT5951pv<=91.2) | (FT5942pv<=18) | (FIC5942output<=FIC5942opmin)</td><td>C1 switches ON if beer column:
Reboiler condensate pressure is above an acceptable operating pressure range
OR
Ethanol losses in the beer column bottom product is above a desired limit
OR
Control stability is outside constraints
OR
Temperature controller output is at or below the operator set output low limit

C2 switches ON if stripping column:
Reboiler condensate pressure is above an acceptable operating pressure range
OR
Ethanol losses in the stripping column bottom product is above than requirements
OR
Control stability is outside constraints
OR
Temperature controller output is at or below the operator set output low limit

C3 switches on if stripping column:
Ethanol purity goes below a minimum specification
OR
Reflux flow is driven below a minimum value</td></tr>
</table>

<table>
<tr><td></td><td>OR
Reflux controller output is at or below the operator set output low limit</td></tr>
<tr><td colspan="2">Pause Logic Expressions:</td></tr>
<tr><td>*P1 applied to beer column temperature control ORTO agent:*
(DTC5910mode~=1) | (MVHealthStatus~=0) | (EV5910A4st~=1) | (EV5910A5st~=0) | (PT5910Apv>1.07)

P2 applied to stripping column temperature control ORTO agent:
(DTC5920mode~=1) | (MVHealthStatus~=0)

P3 applied to stripping column reflux ORTO agent:
(FIC5942mode~=1) | (MVHealthStatus~=0) | (RefluxActive~=1) | (RectActive~=0)</td><td>P1 switches ON if beer column:
Temperature controller not in remote cascade mode
OR
MC health status (calculated in the control system) is bad
OR
Reboiler is not in correct operating mode
OR
Rebolier pressure too high

P2 switches ON if stripping column:
Temperature controller not in remote cascade mode
OR
MC health status (calculated in the control system) is bad

P3 switches on if stripping column:
Reflux controller not in remote cascade mode
OR
MC health status (calculated in the control system) is bad
OR
Reflux regulatory control scheme is not switched for ORTO optimisation</td></tr>
</table>

Table 1 – Distillation Section Optimization Scheme - Objective Function Design

5. ORTO Scheme Commissioning

Commissioning was completed incrementally because:

1. A cautious approach was adopted whereby ORTO agents were commissioned one at a time.
2. Re-engineering of the configuration of the ethanol purity controller which was incomplete when ORTO commissioning started.
3. Process issues with the operation of the Stripping Column following start-up.

The Beer Column temperature control ORTO agent was commissioned first. It remains running 100% of the time.

The stripping column ORTO agent was then commissioned but process issues have since led to its intermittent use.

Lastly, following the reflux control scheme reconfiguration, the stripping column reflux ORTO agent was commissioned, and fine tuning continues to maximise its uptime.

6. Monitor and Analyse Scheme Performance

ORTO™ analysis tools were used to monitor performance and make gradual adjustments to limits and tuning parameters. Data was exported every 24 hours from the ORTO™ software to allow for deeper off-line analysis. Data from ORTO™ was ingested by the Seeq data analytics tools to support analysis and monitoring by site engineers.

Results

A short review of improvements was conducted after the first two agents were commissioned was carried out. Data from the ORTO™ analysis tools are shown below in figure 5.

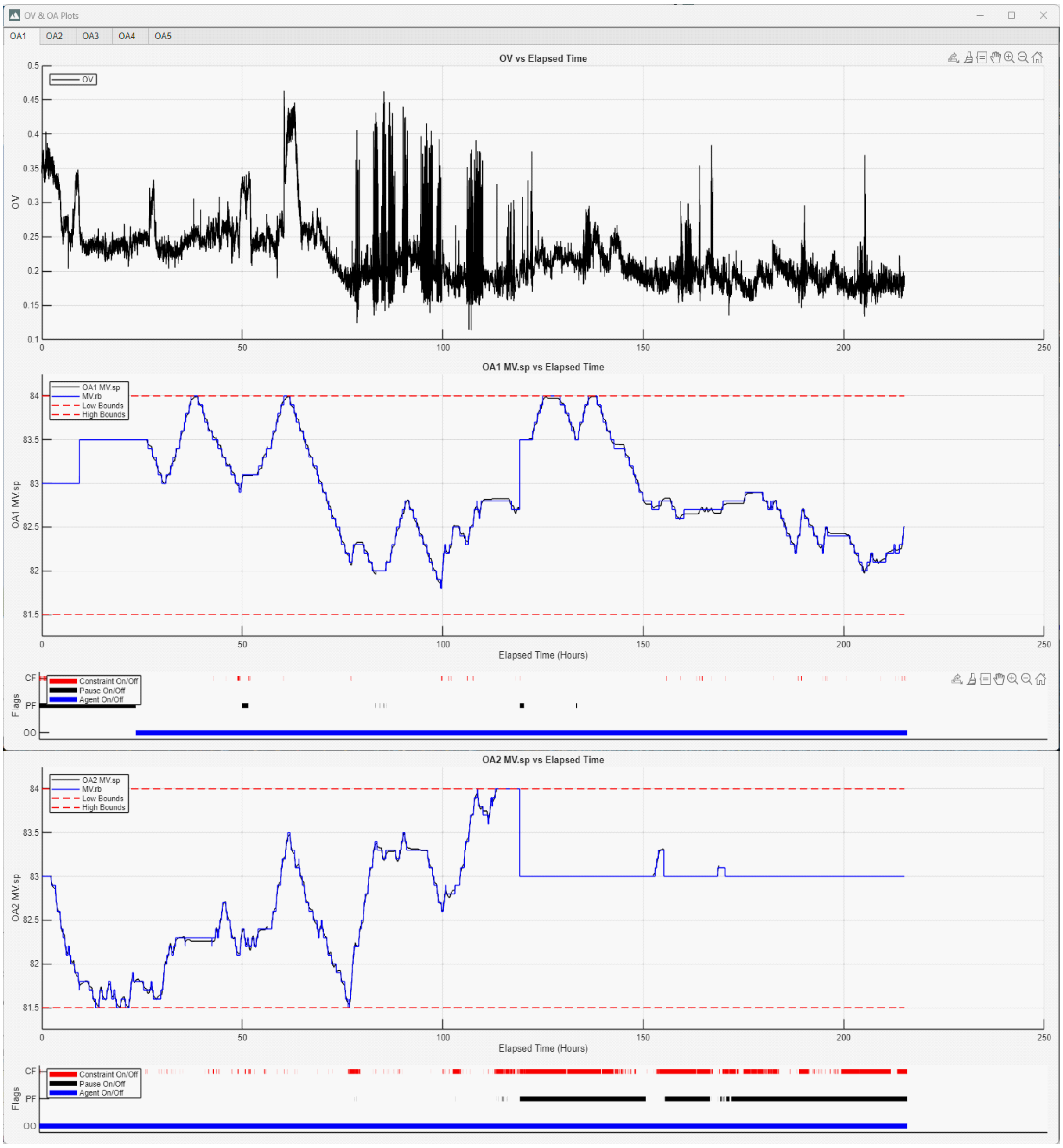


Figure 5 – Performance After Initial Commissioning

Key points:

- Significant steam flow reductions were achieved initially.
- Good ease of use comments were received from the site engineers and operators.
- Constraints and pause flags worked as expected (as shown by red and black bars at the bottom of the trends.
- After 120 hours, the agent adjusting the stripping column steam flow was turned off due to process issues.

Longer Term Analysis

After all three agents were commissioned, a PannoniaBio engineer analysed the improvements in operation using Seeq data analytics tools, as shown in figure 6.

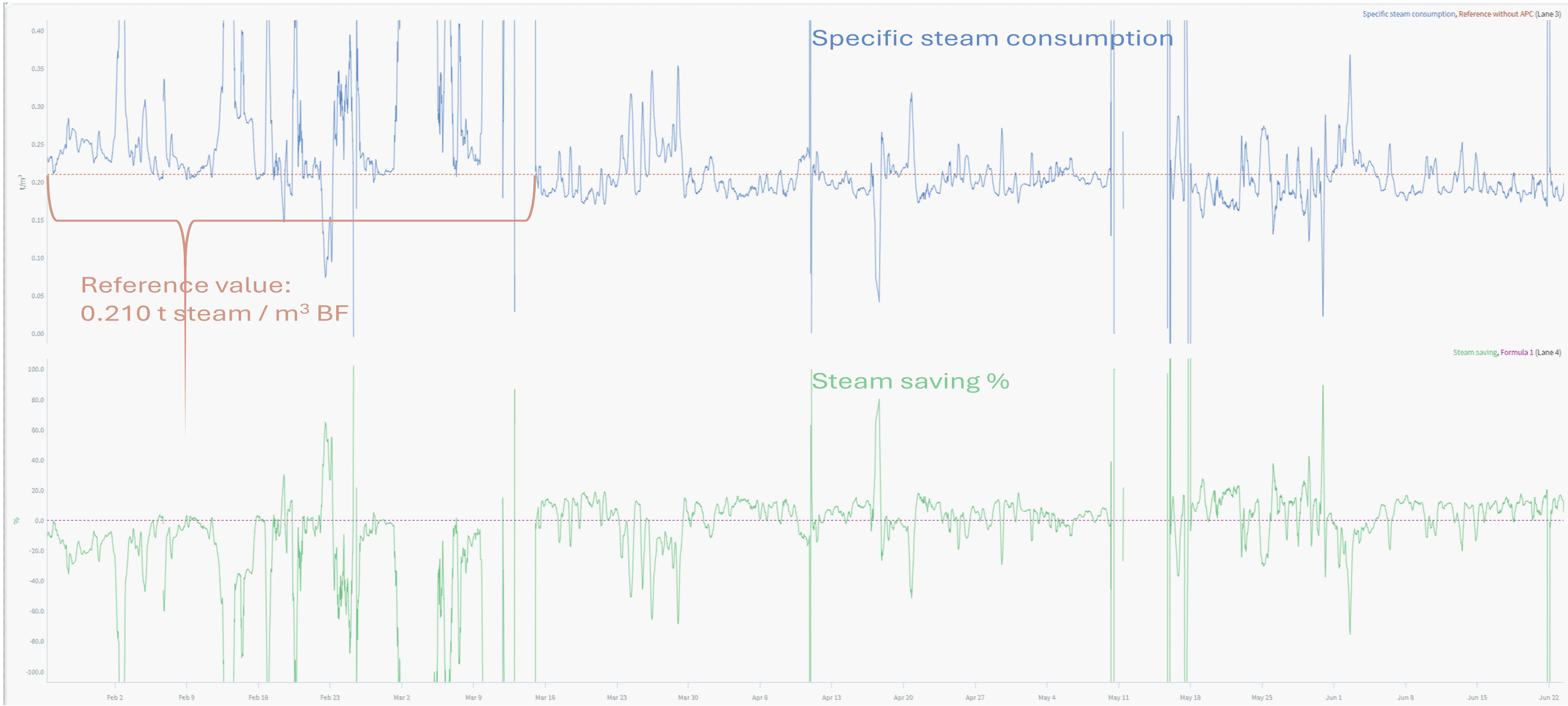


Figure 6 – Performance Trends

In figure 6, the top trend is steam use per m^3 of feed ("specific steam consumption") and analysis of performance before the ORTO™ agents were commissioned is determined.

Further analysis determined steam savings over three months after commissioning of the ORTO™ agents and is shown in Figure 7. Note, before data was biased to compare ORTO performance to the 'best' achieved under operator control.

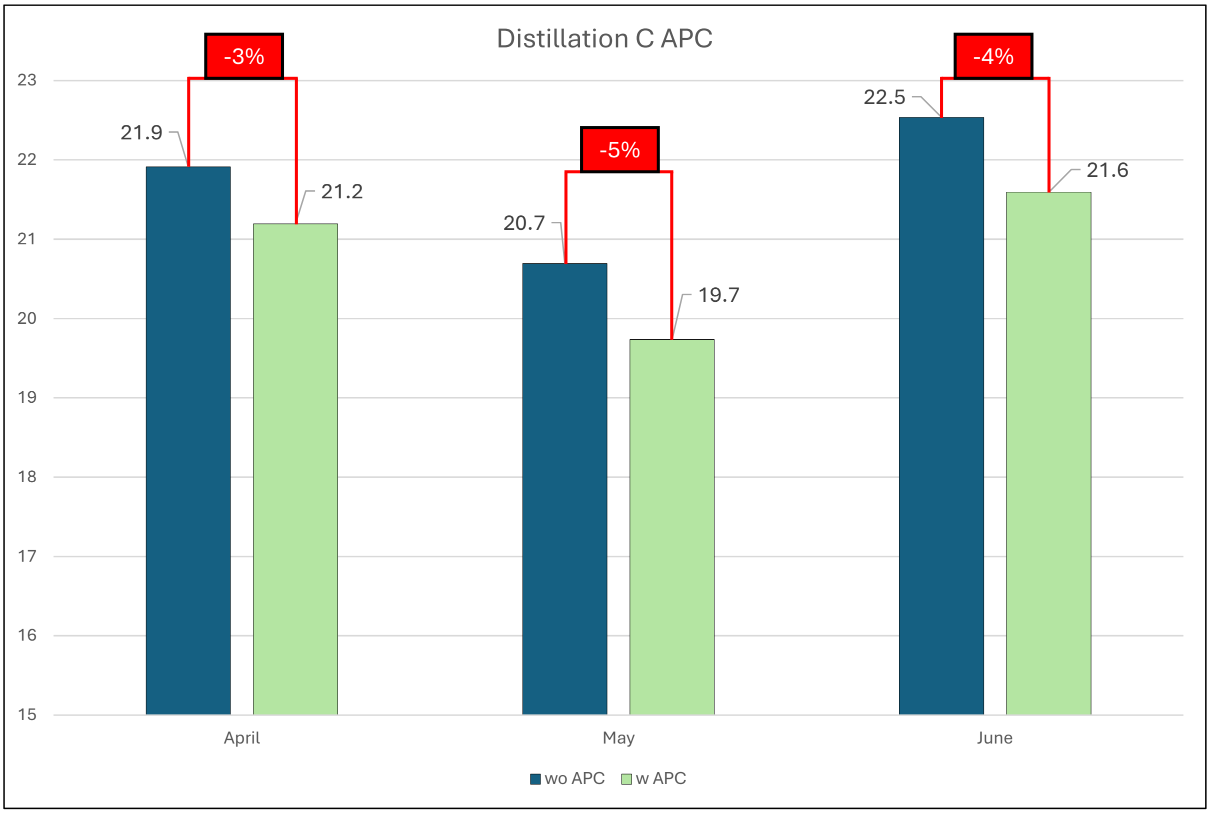


Figure 7 – Monthly Steam Savings

Total steam savings were calculated as shown below in Table 2.

Month	Steam Savings, Tonnes
April	517
May	690
June	678
Total	1885

Table 2 – Monthly Steam Savings

An annual total would be approximately 5.6 kTe.

Ancillary Benefits

Review of the trends of specific steam usage in Figure 5, shows that after the ORTO™ agents were commissioned the variation in operation reduced. Analysis shows

	Standard deviation, tonne/m^3	% reduction
Reference period	0.101	
April	0.061	40
May	0.047	53
June	0.073	28

Increased variability:

- Increases the likelihood of excursions which require intervention by operators, interlocks or other safety systems
- Increases the wear of mechanical equipment such as valves, pumps, etc

Reduced variability should therefore lead to lower maintenance costs and losses due to excursions.

Benefits Summary

ORTOmation and PannanioBio collaborated successfully to implement a self-learning closed loop optimiser on the ethanol/water separation section of the bioethanol site in Hungary. The optimizer ran effectively, adjusting distillation column operations for several months and reduced steam usage by between 3 and 5%, when compared to the best operator performance.

Further savings will be achieved through further tuning of the agents and resolution of stripping column operational issues, affecting its stability.