ProSimPlus Application Example

High temperature heat pump

Example purpose
This example presents the use of high temperature (HT) heat pump (HP) for industrial needs.

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Corresponding ProSimPlus file	*PSPS_EX_EN-High-Temperature-Heat-Pump.pmp3*

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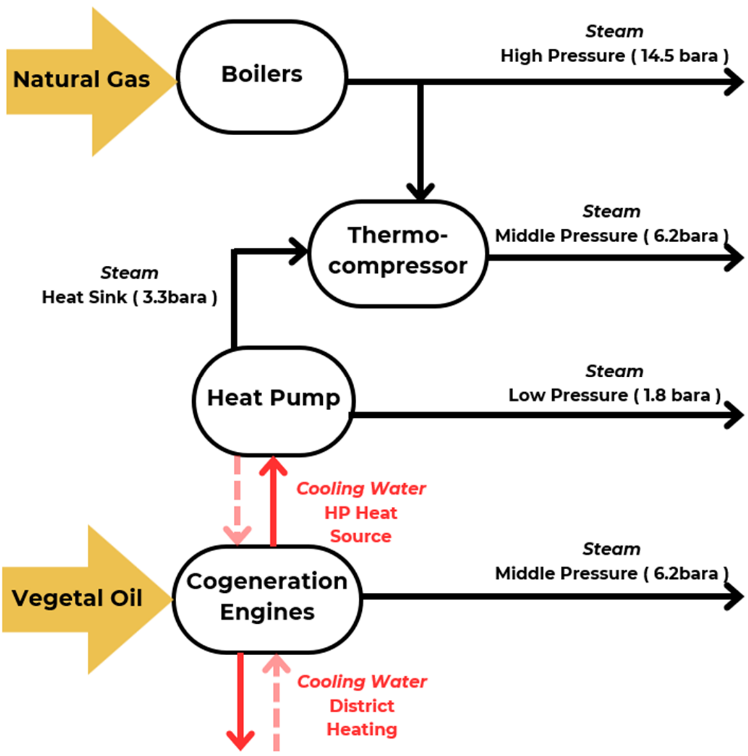
1. PROCESS MODELING

1.1. Process description

This example simulates a high temperature (HT) heat pump (HP) working with R1233zd. Temperature needs greater than 150°C can be obtained with high temperature heat pumps. Today, more HTHP are used in the industry, as a solution for recycling heat duty [ABR23], [BRU24], [ZUH24].

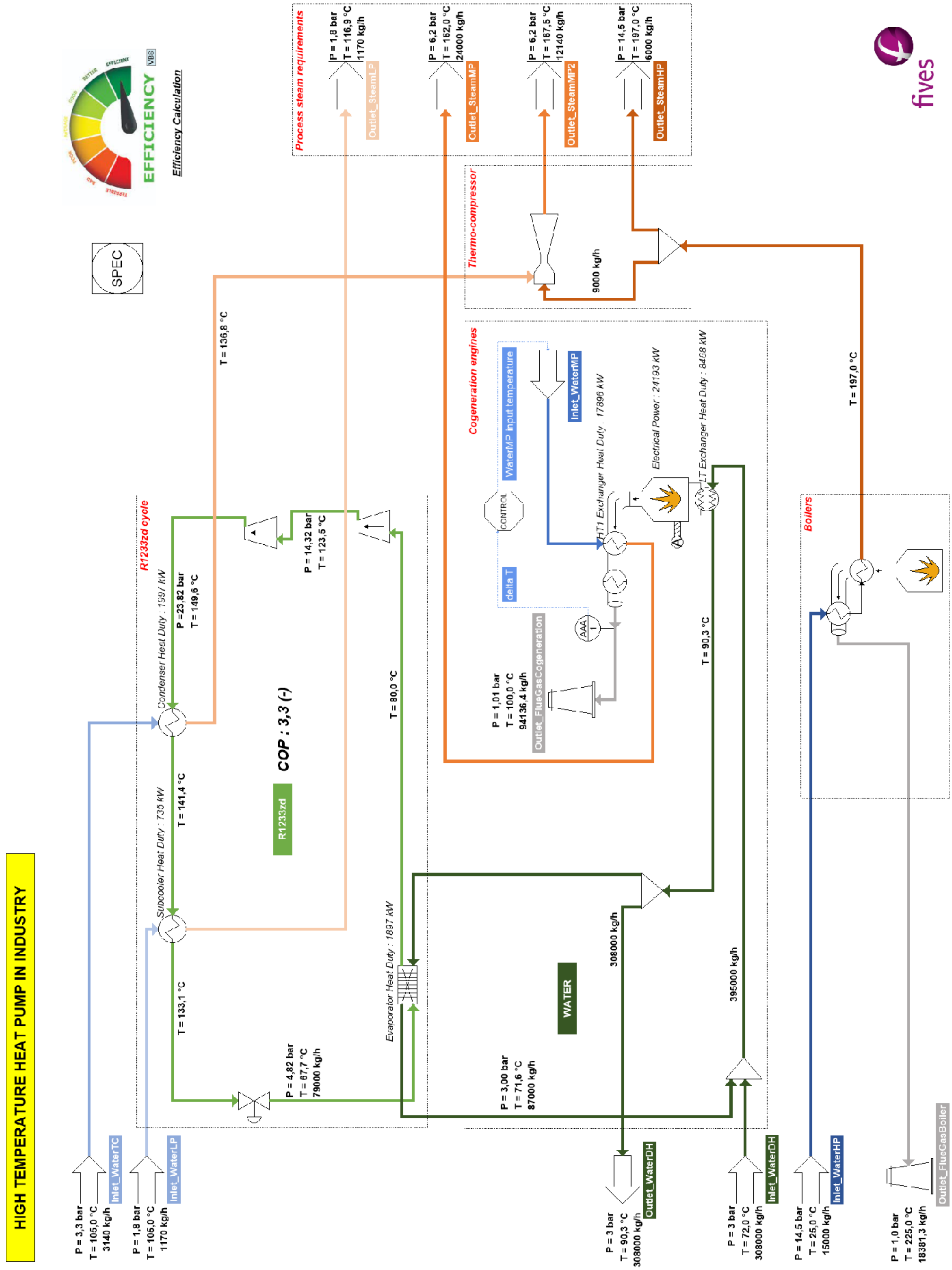
This example is based on the data from a European project "PUSH2HEAT". This project studied a paper factory "*Cartiera di Guarcino*" located in Italy. Different needs in steam at different pressure levels are required by the factory. Different units produce steam:

- 3 cogeneration engines, fed with vegetal oil (palm oil) and animal fat, produce saturated steam at 6.2 bara and electricity. Almost all the electricity produced is self-consumed (the excess is sent to the local electricity network). The most part of the steam needed is produced with these engines.
- 2 gas boilers produce steam at high pressure (HP) level (14.5 bara)
- A high temperature heat pump (HTHP) produces 1170 kg/h of low-pressure (LP) steam (1.8 bara) and 3140 kg/h of steam at 3.3 bara. This steam is sent to a thermo-compressor where it is mixed with a portion of the high-pressure steam to form mid-pressure (MP) steam (6.2 bara)
- Cogeneration engines are cooled with a water loop refrigeration. Water enters in the engine at *ca.* 70°C and is released at 90°C. This hot water is used for 2 purposes: a first part is used for the building heating and a second part is used as the heat pump heat source.



Block diagram of the installation

1.2. Simulation flowsheet



1.3. Components

The components considered in the simulation are listed in the table below, as well as their chemical formula and their CAS numbers[1]. The properties of pure substances are taken from the standard ProSim database.

Component	Chemical formula	CAS Number(1)
Water	H_2O	7732-18-5
R1233zd	$C_3H_2ClF_3$	102687-65-0
Carbon monoxide	CO	630-08-0
Oxygen	O_2	7782-44-7
Nitrogen	N_2	7727-37-9
Carbon dioxide	CO_2	124-38-9
Hydrogen Sulphide	H_2S	7783-06-4
Sulphur dioxide	SO_2	7446-09-5
Sulphur trioxide	SO_3	7446-11-9
Nitric oxide	NO	10102-43-9
Hydrogen	H_2	1333-74-0
Ammonia	NH_3	7664-41-7
Methane	CH_4	74-82-8

1.4. Thermodynamic model

Three thermodynamic "calculators" are defined in this simulation:

- « Water »: this calculator only contains the water component. Hence it uses the “pure water” thermodynamic model. It is used to represent the cooling water and the steam of the process.
- « R1233zd »: this calculator only has the refrigerant “R1233zd”. It is directly loaded from the refrigerant fluid database of ProSimPlus.
- « Fumes-Biogas »: this calculator contains the following components: CO, O_2, N_2, CO_2, H_2S, SO_2, SO_3, NO, H_2O, H_2, NH_3, CH_4. It is used to simulate the fumes from combustion. This calculator (components and thermodynamic model) is generated automatically using the “Combustion” reactor.

The thermodynamic models used are documented in the thermodynamic help accessible from the calculator definition window.

[1] *CAS Registry Numbers® are the intellectual property of the American Chemical Society and are used by ProSim SA with the express permission of ACS. CAS Registry Numbers® have not been verified by ACS and may be inaccurate.*

1.5. Operating conditions

- ✓ Feed

Name	Inlet_WaterLP	Inlet_WaterTC	Inlet_WaterMP	Inlet_WaterHP	Inlet_WaterDH
Partial Mass Flowrate (kg/h)					
Water	1170	3140	22500	15000	308000
Temperature (°C)	105	105	7.5	25	72
Pressure (bara)	1.8	3.3	6.2	14.5	3

- ✓ Heat pump
  - o Heat exchangers

Name	Subcooler	Condenser	Evaporator
Exchanger type	Counter current or multipasses	Counter current or multipasses	Counter current or multipasses
Specification type	Cold stream	Cold stream	Cold stream
Constraint	Superheated over its dew point temperature	Superheated over its dew point temperature	Outlet temperature
Temperature (°C)	0	0	80

- o Compressors

Name	C1	C2
Supplied specification	Supplied	Supplied
Exhaust pression (bara)	14.32	23.82
Isentropic efficiency	0.8	0.8
Mechanical efficiency	1	1
Electrical efficiency	1	1

- o Expansion valve

Constraint type	Pressure specification
Pressure specification	Supplied
Pressure (bara)	4.82
Pressure drops (bara)	0

- ✓ Cogeneration process
    - o Cogeneration engines

Combustion	
Combustive	
Type	Air
Constraint	% mass content of O_2 in fumes on combustion outlet
O_2 in fumes (%)	2
Inlet pressure (atm)	1
Inlet temperature (°C)	80
Fuel (liquid/solid) on dry	
% mass C	45.42
% mass H	6.35
% mass O	47.63
% mass N	0.47
% mass S	0.13
Inlet pressure (atm)	1
LHV	Estimated

The fuel compositions (palm oil) are taken from the literature [ABI23].

The stoichiometric coefficients of the combustion reactions are obtained by clicking the button “Calculate the stoichiometric coefficients of conventional reactions”.

Note: The "Load the compounds of fumes" button of the module enables the user to load the fumes calculator and define this calculator as the boiler calculator. A new "Fumes-Biogas" calculator is then added to the list of calculators.

Heat exchanger LT	
Inlet temperature of cooling fluid to the engine (Outlet LT) (°C)	72
Outlet temperature of cooling fluid from the engine (Inlet LT) (°C)	92
Cooling fluid	Water

Heat exchanger HT1	
Exchanger type	Pure counter current
Calculation mode	Pinch model
Pinch value (K)	70

Constraint	
Constraint type	HT power imposed
Constraint on outlet temperature of HT1 utility	Outlet temperature of utility fluid
Outlet temperature (°C)	162

Yield calculation	
LE yield (low enthalpy) (%)	10
LT yield (%)	14
Electric yield (%)	40

- Stream splitter

Supplied specification	Mass flowrates
Automatically calculated stream	C20 (Outlet_WaterDH)
C19 mass flowrate (HeatSource evaporator) (kg/h)	87000

✓ Boilers

Combustion	
Combustive	
Type	Air
Constraint	% mass content of O_2 in fumes on combustion outlet
O_2 in fumes (%)	2
Inlet pressure (atm)	1
Fue (gas) / advanced description	
Type	Molar/Volume
Methane content (%)	84.6
Ethylene content (%)	0
Ethane content (%)	6.4
Propylene content (%)	0
Propane content (%)	5.3
Butane content (%)	1.4
CO_2 content (%)	1.3
CO content (%)	0
H_2 content (%)	0
N_2 content (%)	1
H_2S content (%)	0
Inlet pressure (atm)	1

The fuel compositions (natural gas) are taken from the literature [FAR16].

Internal heat exchanger	
Configuration	
Exchanger type	Pure counter current
Calculation mode	Pinch model
Pinch value (K)	200

Constraint	
Constraint	Useful power imposed
Utility constraint	Outlet temperature of utility
Outlet temperature (°C)	197

- ✓ Thermo-compressor unit
  - o Vapor ejector

Pb/Pe ratio	0.9
Primary nozzle isentropic efficiency	0.9
Secondary fluid expansion zone isentropic efficiency	1
Calculation mode	Mixing chamber with constant section
Diffuser isentropic efficiency	0.9

  - o Stream splitter

Supplied specification	Mass flowrates
Automatically calculated stream	C5 (Outlet_SteamHP)
C9 mass flowrate (inlet thermo-compressor) (kg/h)	9000

1.6. Initialization

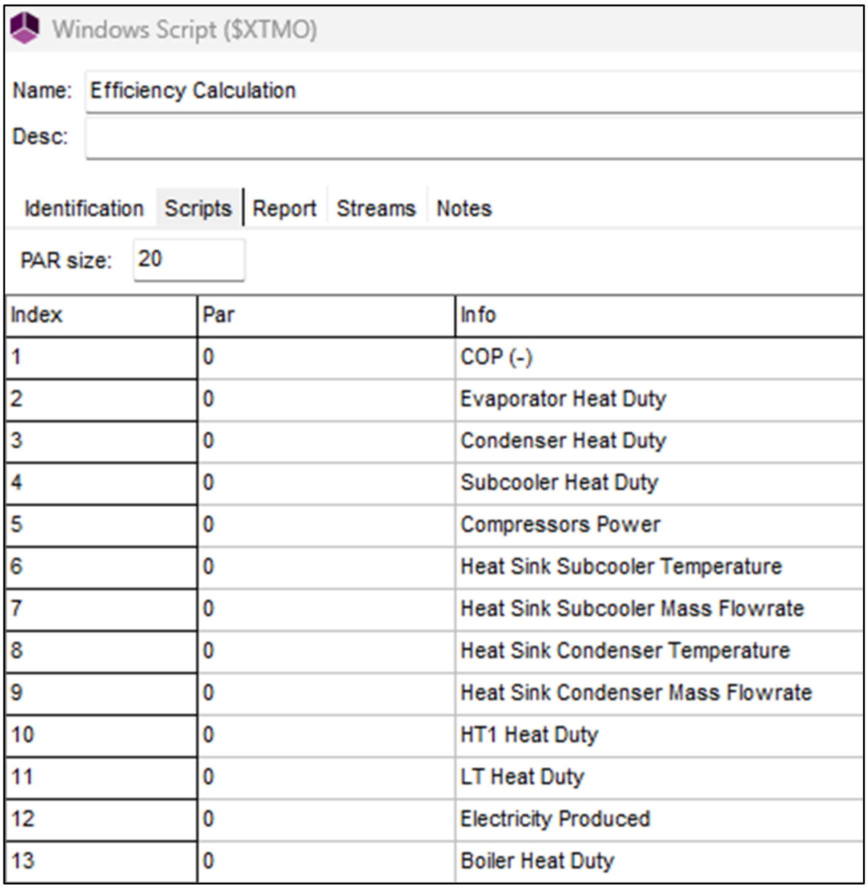
The calculation sequence is automatically determined by ProSimPlus. Two tear streams are detected: « C27 » stream (evaporator inlet) from the HP loop and « C19 » stream (evaporator inlet) from the cogeneration engine waterloop. The following initial valuesfor these streams are used in the simulation:

Stream	C27	C19
Partial mass flowrate (kg/h)		
R1233zd	79000	0
Water	0	87000
Temperature (°C)	67.7	92
Pressure (bara)	-	3
Vapor fraction	0.585	-

2. RESULTS

2.1. Mass and energy Balance

The “Efficiency Calculation” windows script module, used in the flowsheet, summarize the overall performance of the process.


Windows Script ($XTMO)

Name: Efficiency Calculation

Desc:

Identification Scripts Report Streams Notes

PAR size: 20

Index	Par	Info
1	0	COP (-)
2	0	Evaporator Heat Duty
3	0	Condenser Heat Duty
4	0	Subcooler Heat Duty
5	0	Compressors Power
6	0	Heat Sink Subcooler Temperature
7	0	Heat Sink Subcooler Mass Flowrate
8	0	Heat Sink Condenser Temperature
9	0	Heat Sink Condenser Mass Flowrate
10	0	HT1 Heat Duty
11	0	LT Heat Duty
12	0	Electricity Produced
13	0	Boiler Heat Duty

The following script is used to present the various equipment power values, to calculate the coefficient of performance (COP), and to remind the heat pump data. The results are printed in the “Report” tab of the “Efficiency Calculation” module:

```
'-------------------------------------------------------------------------------'
' CALL OF PREDEFINED SCRIPT
'-------------------------------------------------------------------------------'
ExecuteGlobal CreateObject("Scripting.FileSystemObject").OpenTextFile(Project.ApplicationPath &
"Scripts\IncludeScript.vbs", 1).ReadAll()
IncludeScript "StreamProperties.vbs"
IncludeScript "UnitConversion.vbs"
IncludeScript "FormatDouble.vbs"

Function OnCalculation()

'---------------------------------------------------------------------------------'
' CALCULATION OF COEFFICIENT OF PERFORMANCE OF HEAT PUMP
'---------------------------------------------------------------------------------'

  Evaporator_HeatDuty = Project.Modules("Evaporator").HeatDuty
  Condenser_HeatDuty = Project.Modules("Condenser").HeatDuty
  Subcooler_HeatDuty = Project.Modules("Subcooler").HeatDuty
  Compressors_Power = Project.Modules("C1").TotalUsefulPower + Project.Modules("C2").TotalUsefulPower

  Heatsink_Subcooler_Temperature = Project.Modules("Subcooler").OutputStream(2).Temperature
  Heatsink_Subcooler_MassFlowrate = Project.Modules("Subcooler").OutputStream(2).MassFlowrate

  Heatsink_Condenser_Temperature = Project.Modules("Condenser").OutputStream(2).Temperature
  Heatsink_Condenser_MassFlowrate = Project.Modules("Condenser").OutputStream(2).MassFlowrate

  COP = (Condenser_HeatDuty + Subcooler_HeatDuty) / Compressors_Power

  Module.parameter(1) = COP
  Module.parameter(2) = ProSimToReport("Power", Evaporator_HeatDuty)
  Module.parameter(3) = ProSimToReport("Power", Condenser_HeatDuty)
  Module.parameter(4) = ProSimToReport("Power", Subcooler_HeatDuty)
  Module.parameter(5) = ProSimToReport("Power", Compressors_Power)

  Module.parameter(6) = ProSimToReport("Temperature", Heatsink_Subcooler_Temperature)
  Module.parameter(7) = ProSimToReport("Mass flow rate", Heatsink_Subcooler_MassFlowrate)

  Module.parameter(8) = ProSimToReport("Temperature", Heatsink_Condenser_Temperature)
  Module.parameter(9) = ProSimToReport("Mass flow rate", Heatsink_Condenser_MassFlowrate)

'---------------------------------------------------------------------------------'
' CALCULATION COGENERATION ENGINES PERFORMANCES
'---------------------------------------------------------------------------------'

  HT1_ExchangerHeatDuty = abs(Project.Modules("CogenerationEngines").HT1ExchangerHeatDuty)
  LT_ExchangerHeatDuty = abs(Project.Modules("CogenerationEngines").LTExchangerHeatDuty)
  ElectricalPower = abs(Project.Modules("CogenerationEngines").ElectricalPowerProduced)

  Module.parameter(10) = ProSimToReport("Power", HT1_ExchangerHeatDuty)
  Module.parameter(11) = ProSimToReport("Power", LT_ExchangerHeatDuty)
  Module.parameter(12) = ProSimToReport("Power", ElectricalPower)

'---------------------------------------------------------------------------------'
' CALCULATION COGENERATION ENGINES PERFORMANCES
'---------------------------------------------------------------------------------'

  Boiler_ExchangerHeatDuty = abs(Project.Modules("Boilers").InternalExchangerHeatDuty)

  Module.parameter(13) = ProSimToReport("Power", Boiler_ExchangerHeatDuty)
 OnCalculation = true

End Function
```



```
Sub OnPrintResults()
'-------------------------------------------------------------------------------
' PRINT RESULTS
'-------------------------------------------------------------------------------
  Module.PrintReport "Heat Pump Performance" & VbLf

  Module.PrintReport "Power consumption and heat duty" & VbLf

  Module.PrintReport "   Evaporator heat duty        = " & FormatNumber(Module.parameter(2), 0) &
ReportUnit("Power")
  Module.PrintReport "   Condenser heat duty         = " & FormatNumber(Module.parameter(3), 0) &
ReportUnit("Power")
  Module.PrintReport "   Subcooler heat duty         = " & FormatNumber(Module.parameter(4), 0) &
ReportUnit("Power")
  Module.PrintReport "   Compressors power           = " & FormatNumber(Module.parameter(5), 0) &
ReportUnit("Power")

  Module.PrintReport "   COP                         = " & FormatNumber(Module.parameter(1),1) & " (-)"
& VbLf

  Module.PrintReport "Heat sink paramaters " & VbLf

  Module.PrintReport "   Steam temperature"
  Module.PrintReport "     Sublcooler Outlet         = " & FormatNumber(Module.parameter(6), 0) &
ReportUnit("Temperature")
  Module.PrintReport "     Condenser Outlet          = " & FormatNumber(Module.parameter(8), 0) &
ReportUnit("Temperature") & VbLf

  Module.PrintReport "   Steam mass flowrate"
  Module.PrintReport "     Sublcooler Outlet         = " & FormatNumber(Module.parameter(7), 0) &
ReportUnit("Mass flow rate")
  Module.PrintReport "     Condenser Outlet          = " & FormatNumber(Module.parameter(9), 0) &
ReportUnit("Mass flow rate") & VbLf

  Module.PrintReport "Cogeneration Engines Performance" & VbLf

  Module.PrintReport "   HT1 Exchanger heat duty     = " & FormatNumber(Module.parameter(10), 0) &
ReportUnit("Power")
  Module.PrintReport "   LT Exchanger heat duty      = " & FormatNumber(Module.parameter(11), 0) &
ReportUnit("Power")
  Module.PrintReport "   Electrical power generated  = " & FormatNumber(Module.parameter(12), 0) &
ReportUnit("Power") & VbLf

  Module.PrintReport "Boilers Performance" & VbLf

  Module.PrintReport "   Boiler power                = " & FormatNumber(Module.parameter(13), 0) &
ReportUnit("Power")
End Sub
```

2.2. Process Performance

Simulation result	Notation	Heat pump
Evaporator heat duty (kW)	A	1894
Subcooler heat duty (kW)	B	735
Condenser heat duty (kW)	C	1997
Compressor power (kW)	D	838
COP (-)	E $\left(=\frac{B+C}{D}\right)$	3.3
Condenser temperature reached (°C)	F	136.8
Subcooler temperature reached (°C)	G	117
Condenser mass flowrate (kg/h)	H	3140
Subcooler mass flowrate (kg/h)	I	1170

The simulations data obtained are consistent with the results values of the European project "PUSH2HEAT": the HP powers and the COP obtained by simulation fit with the published results.

3. References

[ABI23] Abioye, K. J., Harun, N. Y., Umar, H. A., & Kolawole, A. H. (2023). Study of physicochemical properties of palm oil decanter cake for potential Syngas generation. *Chemical Engineering Transactions*, *99*, 709–714. https://www.researchgate.net/publication/374867940

[ABR23] Abrami, G., Toppi, T., POLIMI, BONO, & ENERTIME. (2023). *Demonstration site at CDG - system design* (By POLIMI).

[BRU24] Bruyère, B., CETIAT, & ALLICE. (2024). *Etat de l'art des PAC THT – Volet 2* (p. 66). https://www.alliance-allice.com/fr/travaux-collectifs viewed on 25/06/2025.

[FAR16] Faramawy, S., Zaki, T., & A.A.-E. Sakr. (2016). Natural gas origin, composition, and processing: A review. In *Journal of Natural Gas Science and Engineering* (Vol. 34, pp. 34–54). http://dx.doi.org/10.1016/j.jngse.2016.06.030

[ZUH24] Zühlsdorf, B., Nekså, P., & Elmegaard, B. (2024). 4th High-temperature Heat Pump Symposium: Book of Presentations. DTU Mechanical Engineering.