



# Welcome!

## Webinar #28: On Line & Off line Simulation of a Coal Plant

30 May 2018

### Agenda:

- \* Introduction
- \* Philosophy of Thermoflow
- \* Replicating an existing coal plant, STP-PCE
- \* Off-Line OD Simulation, STM / TFX-PCE
- \* On-Line OD Simulation, Elink, U-Link
- \* Data Reconciliation (DRS) and System Optimization (TOPS)
- \* Q & A Session

# Thermoflow Training and Support

- Standard Training
- On-site Training Course
- User's Meetings / Advanced Workshops
- Webinars when new version is released
- Help, Tutorials, PPT, Videos
- Technical Support

**→ Feature Awareness Webinars**

# Feature Awareness Webinars

- 1- Assemblies in TFX, June 2016
- 2- Scripts in Thermodflow programs, GTP-GTM-TFX
- 3- Multi Point Design in GTP-GTM
- 4- Reciprocating Engines in TFX
- 5- TIME in GTM
- 6- Matching ST Performance in STP
- 7- Modeling Solar Systems in TFX
- 8- Combining THERMOFLEX & Application-Specific Programs
- 9- Methods & Methodology in GT PRO & STEAM PRO
- 10- Supplementary Firing & Control Loops in GT PRO & GT MASTER
- 11- The Wind Turbine Feature in Thermoflex
- 12- Modelling GT's in Thermodflow program-1



## **13- Thermoflex for on line and off line performance monitoring**

- 14- Tflow 27, what's new
- 15- Modelling GT's in Thermodflow program-2
- 16- Multi Point Design in GTP-GTM
- 17- Total Plant Cost in TFX
- 18- Steam Turbine Tuning
- 19- User Defined Components in TFX
- 20- Cooling System Optimization

.....



## **28- OD Simulation of a Coal Plant**

# Simulation of an existing Plant: Philosophy of Thermoflow

- Clear Definition:    → What we want  
                              → What we can achieve
- Plant Engineers involvement @ the Development and Operation
- Plant operating regime & environment (regulation, prices, ...)
- Plant specific concerns
- Availability – Reliability comes first!!!
- Pay back?

 Realistic Expectations

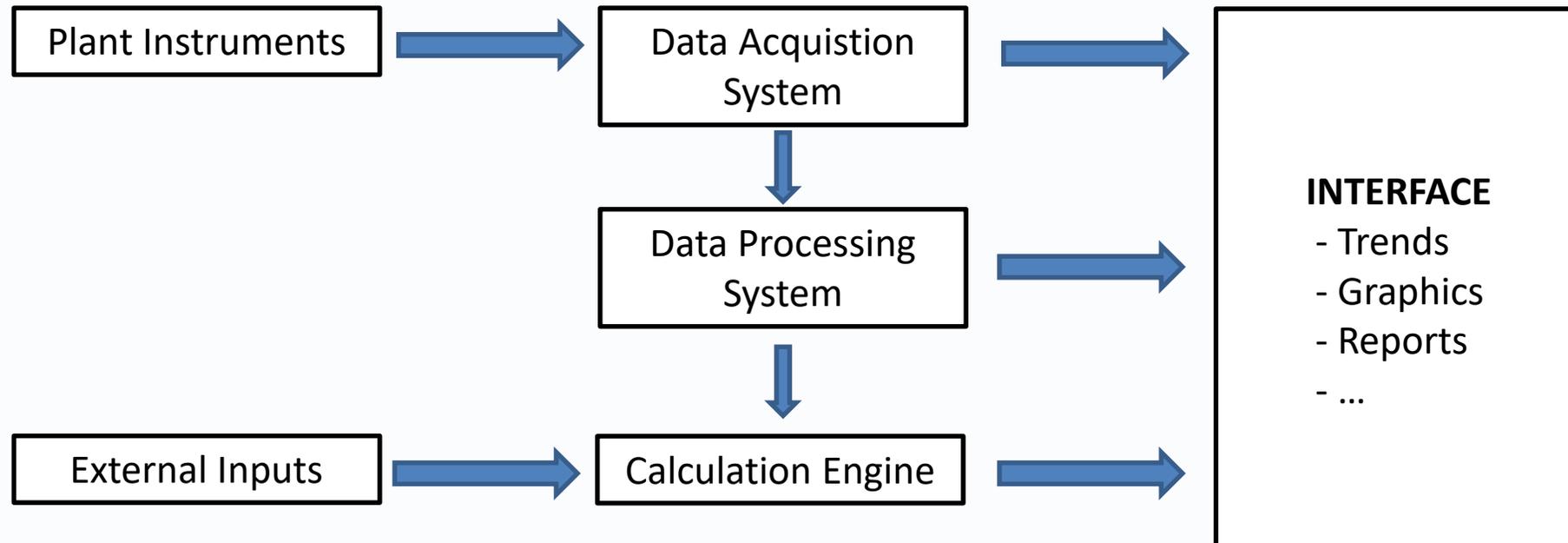
 Unique solution for each plant

# Monitoring an existing Plant: Options

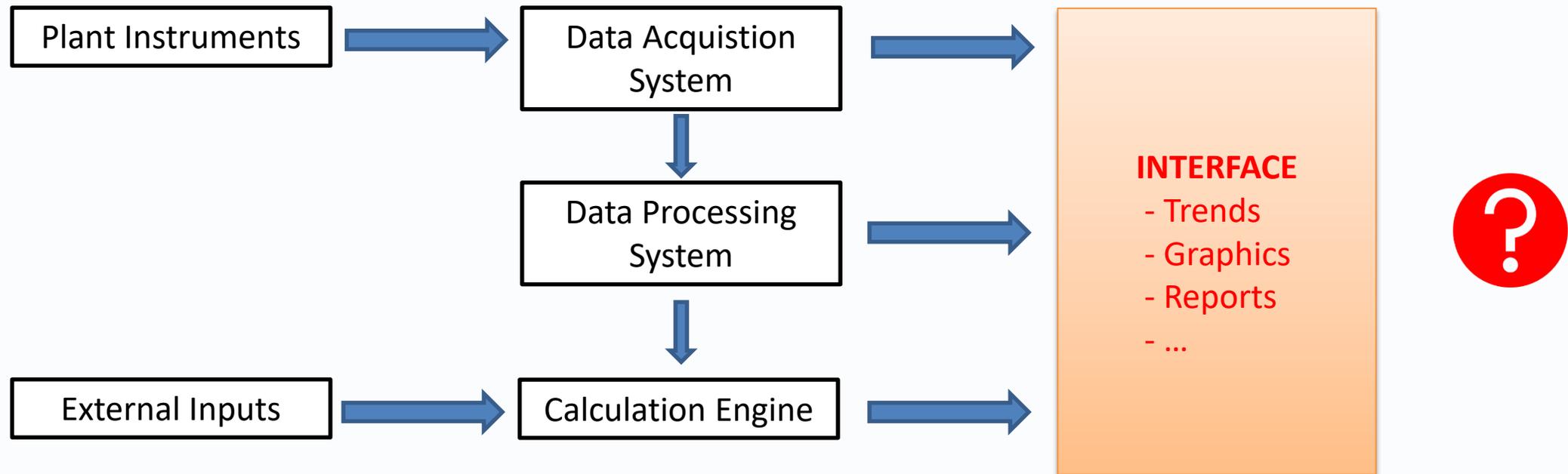
1. Data acquisition system + simple data processing → Trends
2. “ + use of correction curves
3. “ + Thermodynamic Model
4. “ + Detailed Engineered model → Thermoflow



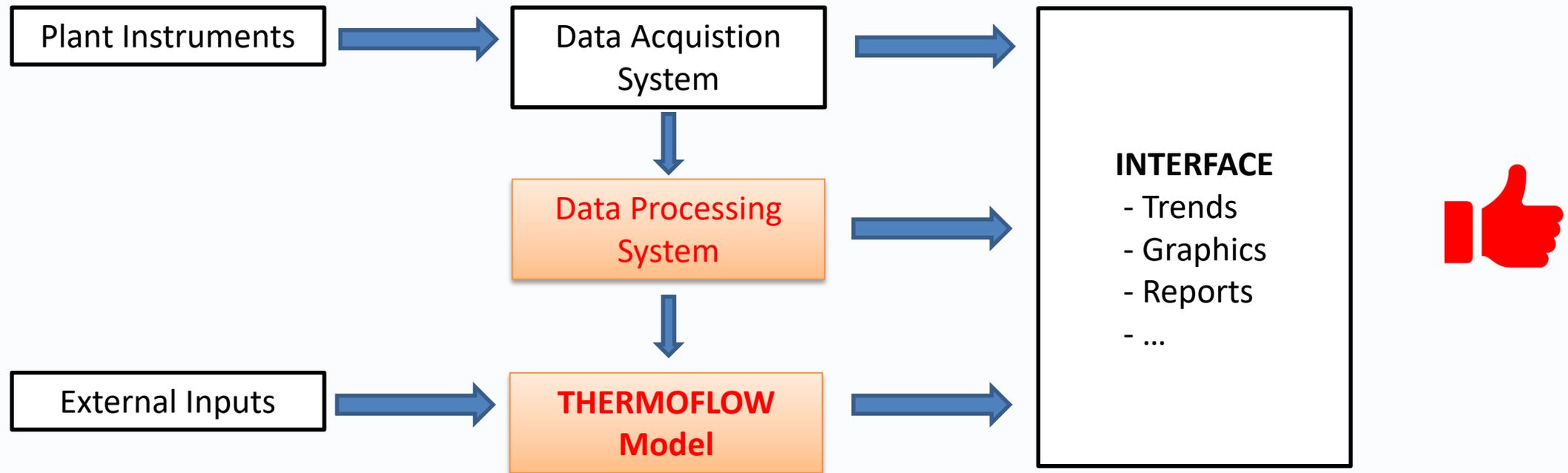
# Simulation of an existing Plant: Structure



# Simulation of an existing Plant: Focus?



# Simulation of an existing Plant: Focus?



## Simulation of an existing Coal Plant: Limitations

- Instrumentation available & accuracy
- Flow rates measurement: coal, air, gas, water-steam flows, CW flow
- Real Time Coal properties
- ST expansion on the wet region, steam properties
- Unburnt carbon in ash measurement
- Uncounted Boiler losses (Manufacturer Margin)
- Others: PA/SA distribution
  - Fly/Bottom Ash distribution
  - ...

# Simulation of an existing Plant in Thermoflow: Steps

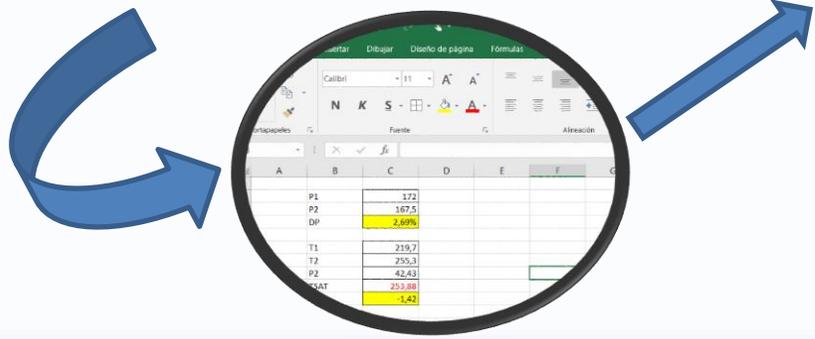
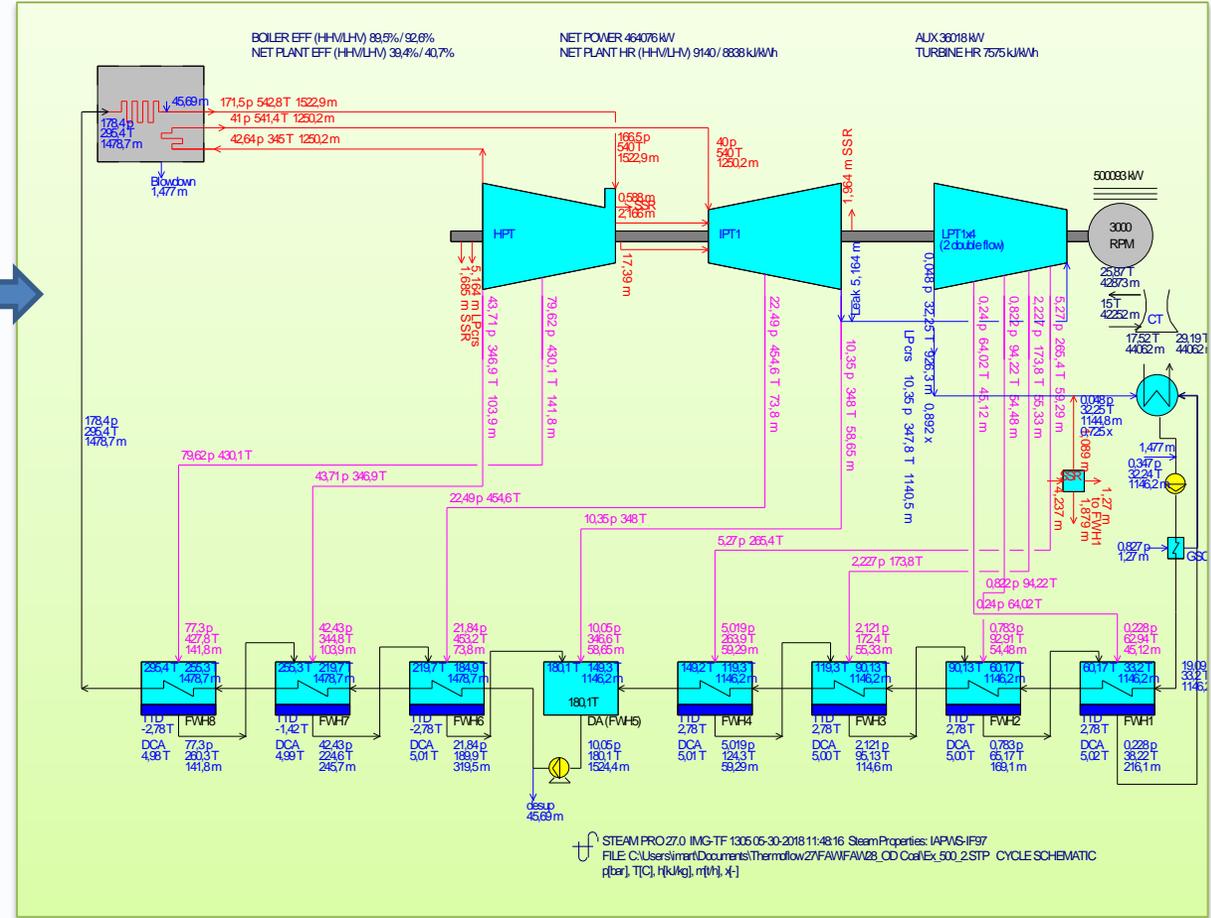
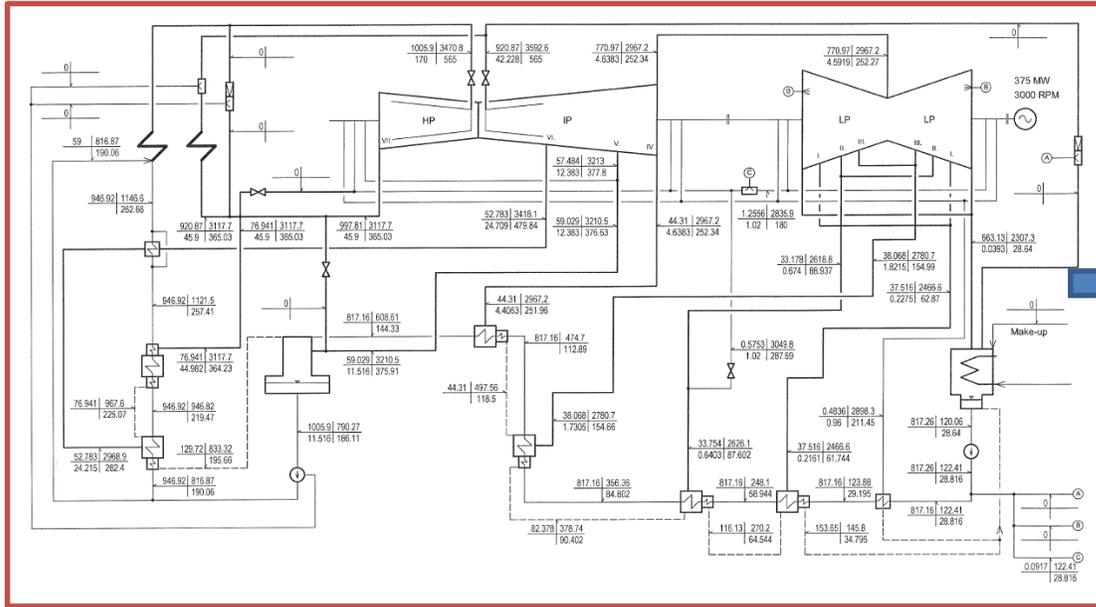
1. Replicating the Original HB → Steam Pro-PEACE
2. “As built” model in STM / TFX-PCE
3. Hardware in STM / TFX-PCE
4. Controls in STM / TFX-PCE
5. Degradation in STM / TFX-PCE: “Current Status” vs “Clean Status”
6. OD Simulation Off Line
7. OD Simulation On Line, Performance Monitoring

# Simulation of an existing Plant in Thermoflow: Steps

## *Example*

1. Design in 1999 → “Original Heat Balance”
2. Start Up in May 2002 → “As Built” HB and first “real data”
3. Last Overhaul in Sep 2016 → “Current Clean Status”
4. Now, May 2018 → “Current Status”

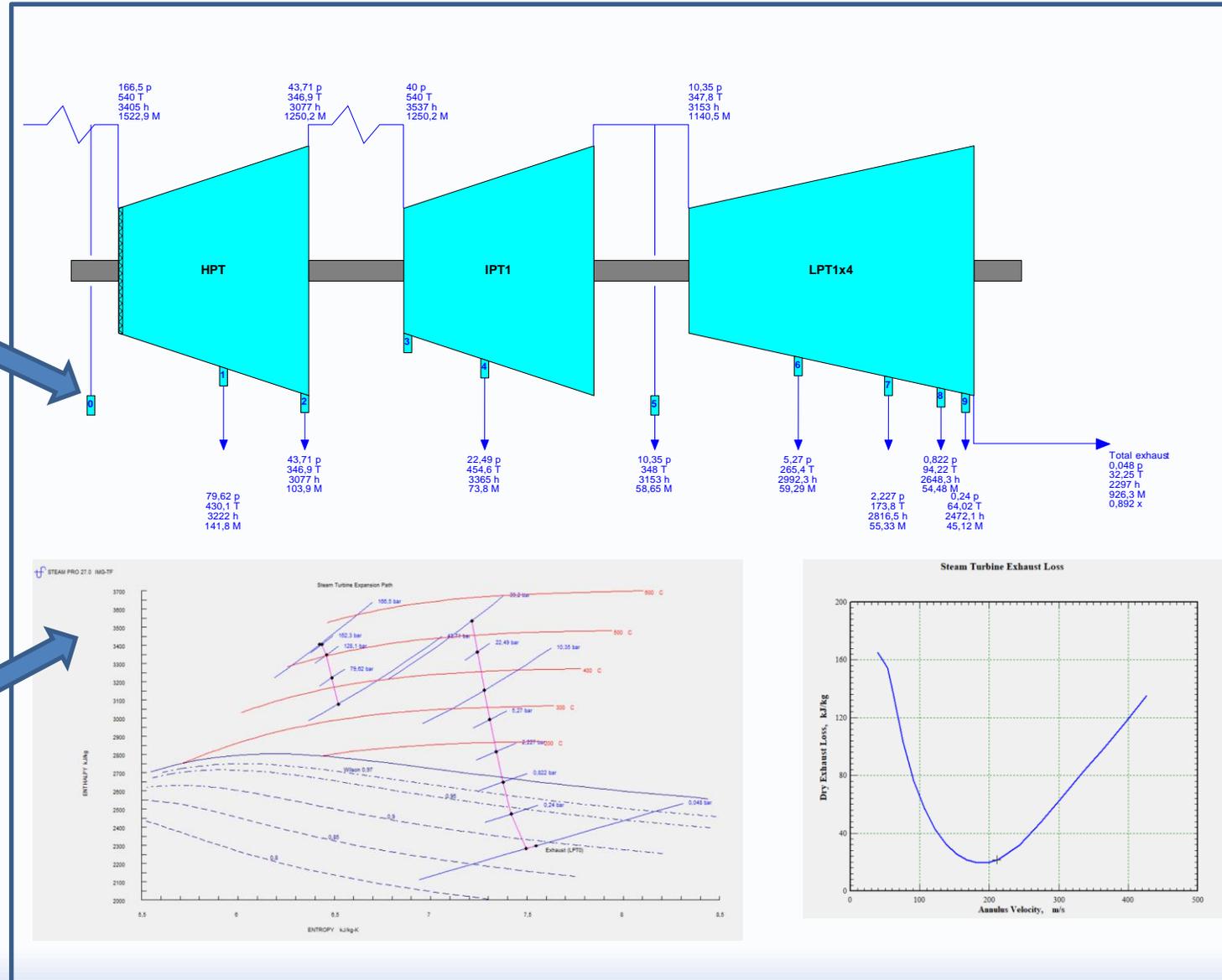
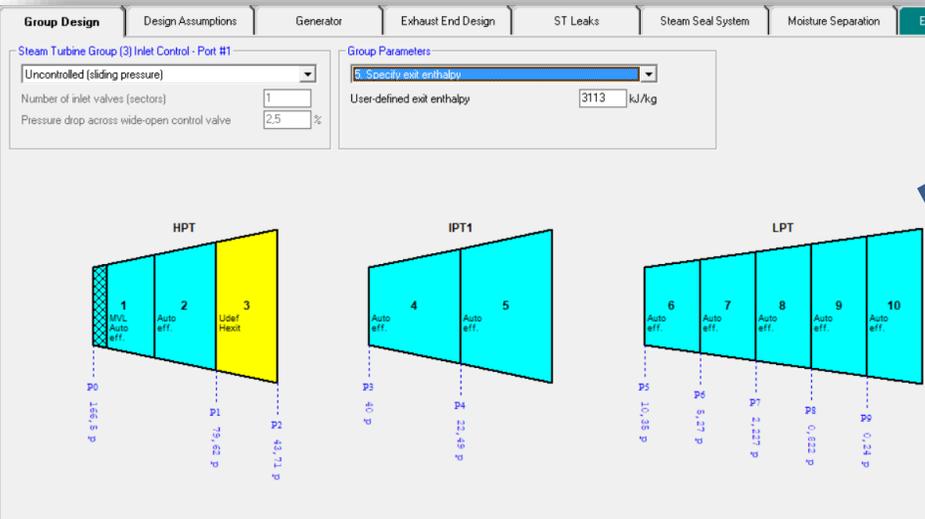
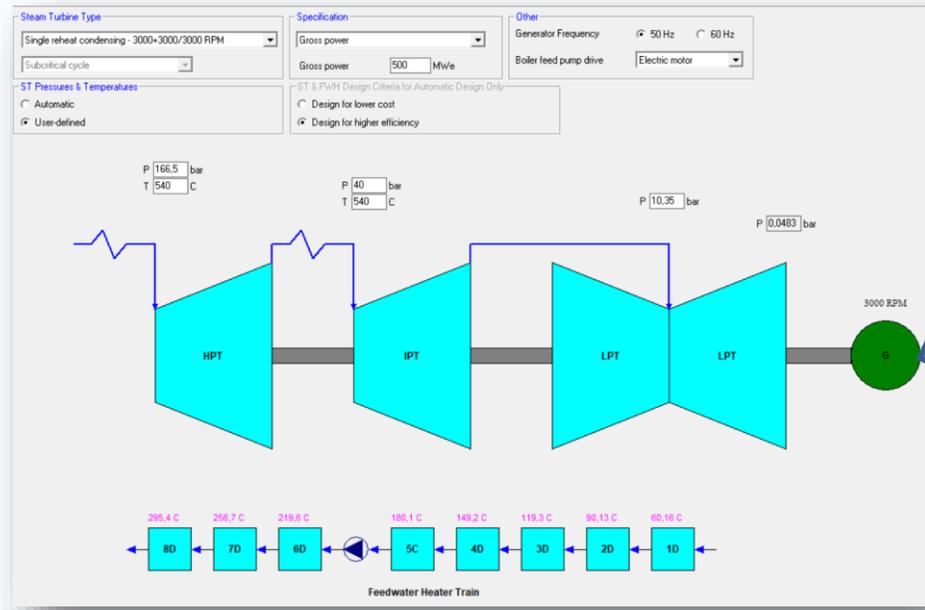
# Replicating an existing plant STP, Original HB, Steam Cycle

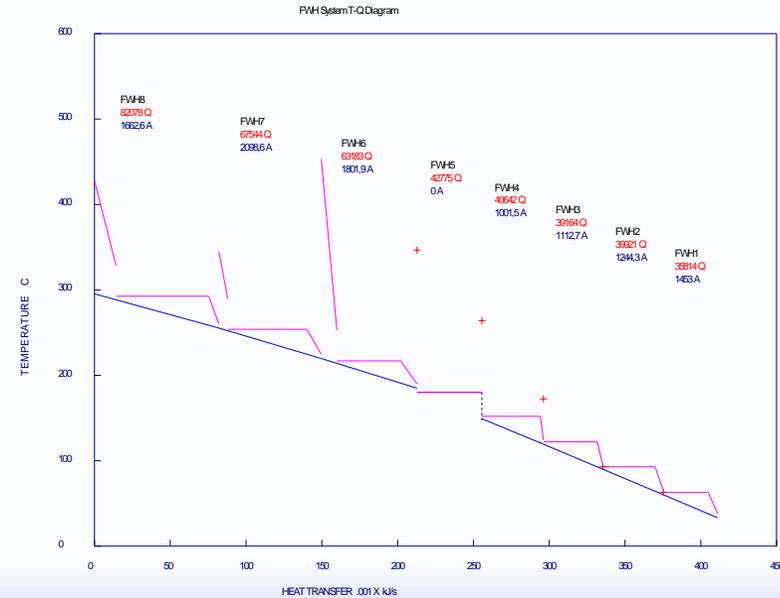
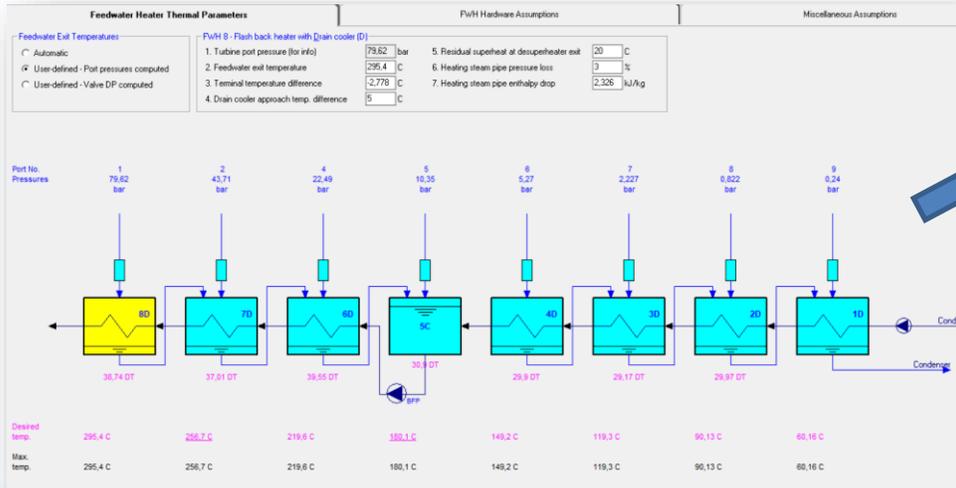
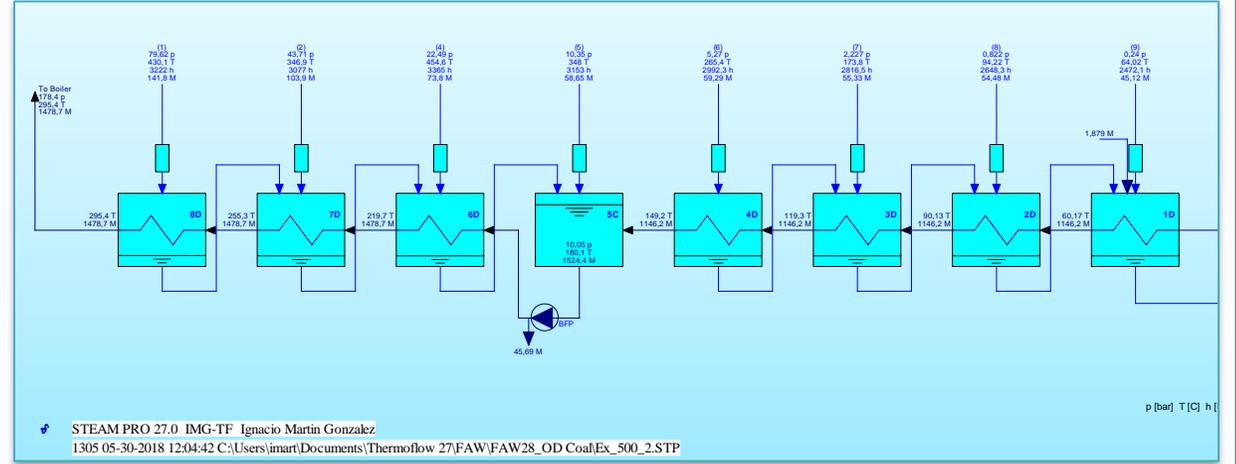
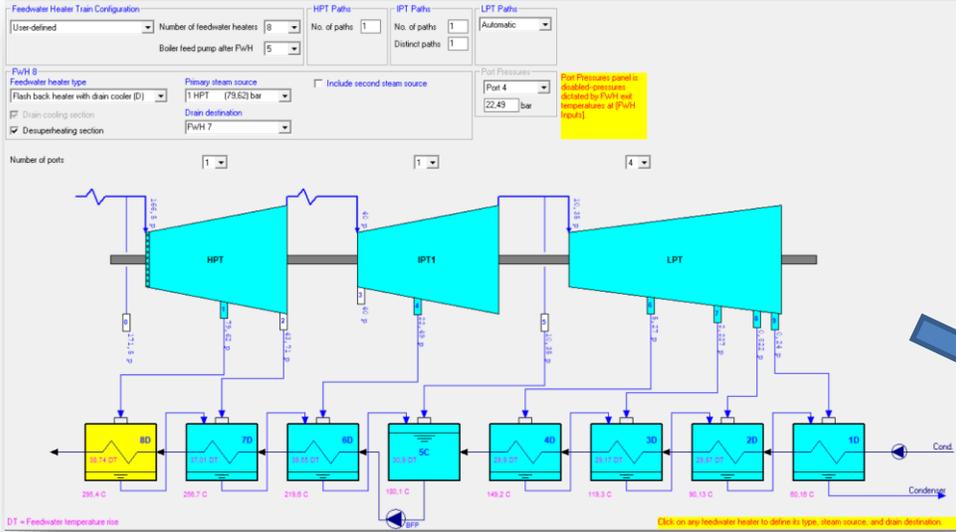


# Replicating an existing plant STP, Original HB, Steam Cycle

- Plant Criteria & Site Conditions
- Cycle type: Subcritical, Single Reheat Condensing
- Plant Size: HPT Flow, Gross Power, Net Power
- Steam Cycle conditions, Pressures & Temperatures
- Steam Turbine, Casing configuration, group efficiencies, leakage system, exhaust end-EL, losses
- FWH: number, type & connections
  - Thermal parameters, TTD, DCA, DP
  - Parallel trains
  - hardware definitions
- Cooling System: type, Condenser Pressure, CW DT, other parameters, hardware definitions
- Pipe pressure drops
- Boiler Feed Pump: electric motor or steam turbine
- Pumps, type, margins-curve, number operating & stand by
- Auxiliary Streams: aire preheater, jet ejector, auxiliary steam, steam to sootblowers, blowdown, desuperheating

# Replicating an existing plant STP, Original HB, ST





**Cooling System Main Inputs** | Display T-Q Diagram | Condenser | Natural Draft Cooling Tower | Condenser Misc. Assumptions | Steam Jet Air Ejector | Equipment Options

**Condenser Design Method** | Automatic

Condenser pressure: 0.0483 bar  
 Condenser pressure: 3.62 cm Hg  
 Condenser saturation temperature = 32.25 C

Hot CW approach to hotwell temperature = 3.051 C  
 Hot CW T = 29.16 C

Hotwell subcooling: 0 C  
 Water head to condensate outlet: 3.048 m

Cooling water temperature rise: 11.67 C  
 Cold CW T = 17.49 C

Return water approach to wet bulb: 6.667 C  
 T = 32.25 C

to FW

CT height to which CW is pumped: 9.144 m

Maximum salinity: 50000 ppm  
 Cycles of concentration: 1.5

Cooling Water: Fresh water / Seawater

Cooling Tower Air:  
 Specify wet bulb DT: 15 C  
 Specify L/G ratio: 1.25  
 RH @ wet CT exit: 100 %

**Cooling System Main Inputs** | Display T-Q Diagram | **Condenser** | Natural Draft Cooling Tower | Condenser Misc. Assumptions

**Hardware Design Method**  
 Automatic  User-defined

Tube Material: Titanium  
 Tube Type: Seam welded

Apply fouling factor: 0.0002 m<sup>2</sup>·C/W  
 Apply cleanliness factor: 80 %

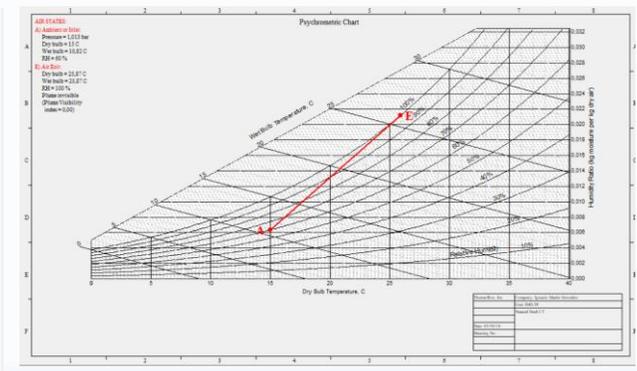
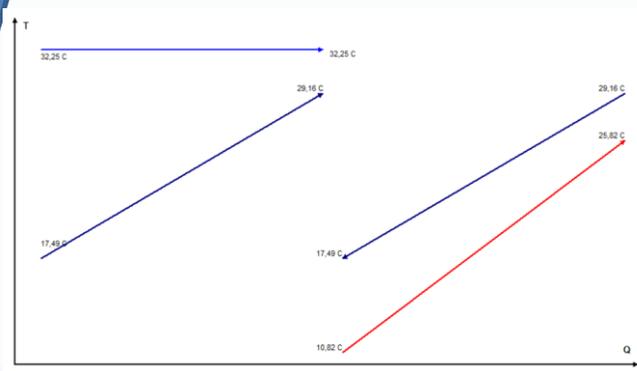
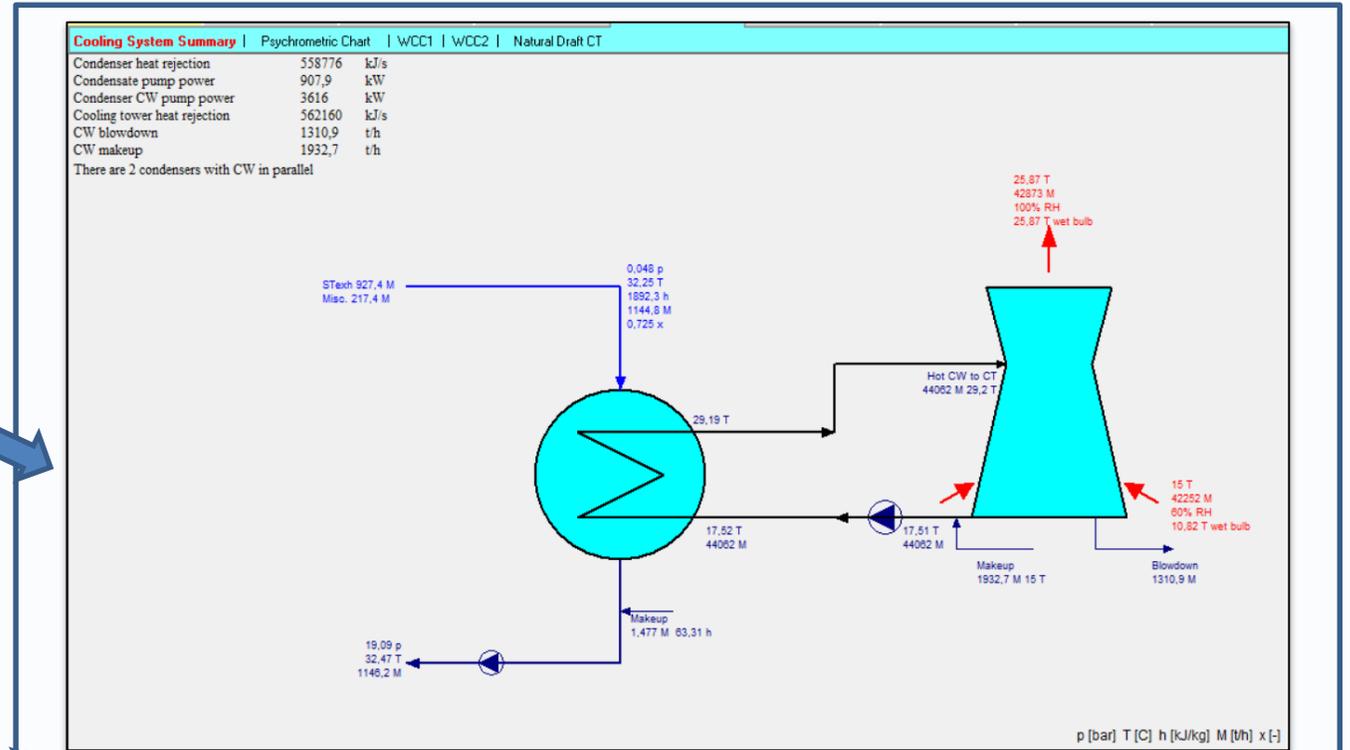
Tube outer diameter: 25.4 mm  
 Tube thickness: 0.5588 mm  
 Tube pitch/outside diameter: 1.6  
 Tube metal conductivity: 21.63 W/m·C  
 Tube water velocity: 2.186 m/s  
 Number of condenser passes: 2  
 Condenser external h.t.c. (D=auto): 0 W/m<sup>2</sup>·C  
 CW pressure drop correction factor: 1  
 Tube bundle h.t.c. / Single tube h.t.c.: 0.875

**Non-condensable Removal**  
 Mechanical vacuum pump  External mech. vacuum pump  
 Steam jet air ejector

Aspect ratio of uniformly-spaced tube bundle (Height/Width): 1  
 Condenser cross section / Uniformly-spaced tube bundle cross section: 1.56  
 Hotwell condensate storage requirement: 5 min

Mole percent (y) of non-condensable gases: 0 %  
 C in h.t.c. correction factor (H=1/(1+Cy)): 0.51

**Condenser Heat Transfer Calculation**  
 Hardware model  
 HEI method



## Replicating an existing plant STP: Boiler design

- Fuel type, fuel preparation
- Boiler Thermal: configuration, circulation, excess air, minor losses, blowdown
- Air Handling: PA-SA, Air Pre-heating, DP, fans
- Desuperheating
- Boiler sizing: Furnace exit T, SH load, RH load, Eco load
- Furnace parameters: unburnt carbon in ash
- Stack
- Convective HX DP and hardware definition

# Replicating an existing plant STP: Boiler design

No.	Parameter	Base	MTBU Barat		
			Min	Max	Average
1	Total Moisture (TM)	% AR	21.70	33.90	28.61
2	Proximate Analysis	% AR			
	- Innerent Moisture		9.30	21.20	16.04
	- Volatile Matter		30.22	56.33	33.45
	- Fixed Carbon		29.19	36.50	32.35

S/N	Name	Unit	Design Coal Type
1	Basic carbon collected [Car]	%	48.05
2	Basic hydrogen collected [Har]	%	3.51
3	Basic oxygen collected [Oar]	%	12.94
4	Basic nitrogen collected [Nar]	%	0.63
5	Basic sulfur collected [Sar]	%	0.67
6	Basic ash collected [Aar]	%	5.59
7	Whole water content [Mar]	%	28.61
8	Inherent Moisture [Mad]	%	16.04
9	Basic volatile collected [Var]	%	33.45
10	Received basis gross calorific [Qgr.ar]	kCal/kg	4632
11	As received basis calorific value [Qnet.ar]	kCal/kg	4271
12	Hardgrove grindability coefficient [HGI]		54

#### Ash components

S/N	Name	Unit	Design Coal
1	Silicon dioxide (SiO <sub>2</sub> )	%	52.96
2	Alumina (Al <sub>2</sub> O <sub>3</sub> )	%	19.72
3	Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> )	%	5.88
4	Titanium dioxide (TiO <sub>2</sub> )	%	0.64
5	Mangano-manganic oxide (Mn <sub>2</sub> O <sub>4</sub> )	%	0.11
6	Calcium oxide (CaO)	%	6.54
7	Magnesia (MgO)	%	3
8	Sodium oxide (Na <sub>2</sub> O)	%	3.31
9	Kali (K <sub>2</sub> O)		0.33
10	Phosphorus pentoxide (P <sub>2</sub> O <sub>5</sub> )		0.25
11	Sulfur trioxide (SO <sub>3</sub> )		6.12

Performance coal 100%B-MCR condition			
Boiler Parameters			
SH steam flow	v Dgr	t/h	440
SH steam temp.	Tgr	°C	540
SH steam outlet pressure	Pgr	MPa .g	13.8
Feed water temp.	Tgs	°C	249
Inlet Temp. at Air Heater	Ta	°C	35
Drum operation pressure	Pgt	MPa .g	15.05
RH steam flow	Dzr	t/h	359
RH steam outlet temp.	Tzr	°C	326
RH steam outlet pressure	Pzr	MPa .g	2.59
RH steam inlet pressure	Pjk	MPa .g	2.44
RH steam inlet temp.	Tjk	°C	540

Desuperheating type of SH: Spray water			
Primary stage	D1	t/h	14.76
Secondary stage	D2	t/h	7.92
Spray water temp.		°C	168
Desuperheating type of RH: Damper regulating			

Gas, air and steam temperature profile												
Item	Sym.	unit	Furnace	Cyclone	Enclosure	LTS	Platen SH	HTS	Cold RH	Platen RH	Eco.	Air Heater
Fluegas inlet temp.	T <sub>in</sub>	°C	/	883	882	669	/	829	857	/	532	305
Fluegas outlet temp.	T <sub>out</sub>	°C	/	883	/	531	/	669	534	/	305	149
Media inlet temp.	T <sub>in</sub>	°C	343	/	341	351	360	483	326	433	249	35
Media outlet temp.	t <sub>out</sub>	°C	343	/	352	373	500	540	435	540	322	263

# Replicating an existing plant STP: Boiler design

**Main** | Air Handling & Fuel Preparation | Thermodynamic Assumptions | Desuperheating | Steam/Water Air Heater | Fuel Heating | Flue Gas

Boiler Design:  Automatic,  User-defined

Max Boiler Efficiency:  100%,  HHV,  LHV

Number of Units in Plant: 1

Boiler Configuration:  Two pass,  Tower type

Evaporator Circulation:  Natural Circulation

Blowdown: 0.1%  
Boiler blowdown destination: [Discard]

Excess air: 20%  
Minor heat loss: 1.5%  
Min. flue gas exit temp.: 137.8 C

Furnace pressure: -0.622 millibar

Include ID fan:

Pensylvania Upper

Flue Gas Cooler

**Air Handling & Fuel Preparation**

Configuration:  Pulverizer mill - PA & SA heated separately,  Pulverizer mill - PA & SA heated together,  Beater mill - tempering air after FD fan,  Beater mill - tempering air after air heater,  Simplified - PA & SA heated separately,  Simplified - PA & SA heated together,  No air heating

Flue Gas Air Heater Type:  Rotary,  Tubular

Mill Capacity: Number operating: 4, Number standby: 1, Capacity margin: 15%

Pulverizer Nameplate Conditions: HGI: 50, Fineness: 70%, Moisture: 8%, Specific power: 22.05 kWh/tonne

Fuel fineness is derived as % of passing 200 mesh (74 microns)

Mill exit temperature: 82.22 C

% of as-received fuel moisture evaporated: 65%

Mill exit gauge pressure: 99.63 millibar

Pulverized fuel fineness: 70%

Furnace P = -0.622 millibar

SA burner dP: 12.45 millibar

An-received fuel moisture = 2.1%  
Fuel HGI = 96

Inlet air/fuel mass ratio: 1.75  
Power consumption converted into heat: 90%  
Pressure drop in mill: 24.31 millibar

FD fan isentropic eff.: 87%  
FD fan mech./elec. eff.: 90%

Secondary air: Primary air

PA fan isentropic eff.: 87%  
PA fan mech./elec. eff.: 90%

Secondary air outlet: 273.3 C  
Primary air outlet: 204.4 C  
Tempering air

**Main** | Furnace & Radiant Elements | Air Heaters/FG Cooler | Convective Elements | Stack | Equipment Options

Dependent parameter in furnace design: **SH load in furnace**

Click on a heat exchanger to drag to a new location. You may also directly edit heat exchanger loads where an input box is provided.

Radiant flux past screen: 20%  
Furnace exit temp.: 1204.4 C

Zone	Path	Load
8		
9		
10		
11	CS1	Load 50%
12	CR1	Load 50%
13	CS3	Load 0%
14	CR3	Load 0%
15		
16		
17	CEV	Load 100%
18	ECD2	Load 0%
19	ECO1	Load 100%

Aperture height to width ratio: 0.65  
Depth to width ratio: 1  
Height to width ratio: 3.48

Downpass depth (L) to furnace depth (D): 0.85

**Heat Transfer Parameters**

Waterwall surface emissivity: 0.8  
Convective h.t.c. correction factor: 1  
Waterwall radiant flux correction factor: 1  
Superheater radiant flux correction factor: 0.75  
Reheater radiant flux correction factor: 0.75  
2nd reheater radiant flux correction factor: 0.75

**Particulate Matter**

Soot emissivity exponent correction factor: 1  
Carbon to soot conversion rate: 0.3%  
Ash emissivity exponent correction factor: 1  
Ash particle mean diameter: 10.16 micron  
Fly ash recirculation ratio: 1  
Fly ash as percentage of total ash: 80%  
Bottom ash temperature reduction: 0 C  
Specific ash handling power: 44.09 kWh/tonne

**Unburnt Carbon**

Unburnt Carbon as % of Carbon in Fuel:   
Unburnt carbon loss with ash: 0.25%  
Distribution of unburnt carbon in fly ash and bottom ash: 1  
Unburnt Carbon as % of Ash:   
Unburnt carbon in fly ash: 3.236%  
Unburnt carbon in bottom ash: 3.236%

**Radiating Beam Length**

Evaluated by furnace dimension:  User-defined  
Mean beam length / "standard" value: 0.9  
Mean beam length: 11.92 m

**Waterwall Thermal Resistances**

Wall thermal conductivity @ 260C: 46.73 W/m-C  
Wall thermal conductivity slope: -0.0249 W/m-C<sup>2</sup>  
Wall thickness: 12.7 mm  
Water-side fouling factor: 0.0002 m<sup>2</sup>C/W  
Gas-side fouling factor: 0.0062 m<sup>2</sup>C/W

**Primary Waterwall Protection**

None  Pin-stud SiC refractory  SiC tiles  
Primary protection coverage: 0%  
Primary coverage thermal resistance: 0 m<sup>2</sup>C/W  
No additional resistance.

**Secondary Waterwall Protection**

Secondary coverage by Inconel: 0%

**Forced Circulation**

Pump head: 1.379 bar  
Circulation ratio: 10

**Miscellaneous Furnace**

Heat transfer non-uniformity correction factor: 0.85  
Fuel chlorine converted to HCl: 80%  
Fuel delivery energy included in heat balance: 80%  
Fuel mercury leaving with flue gas: 80%  
Flue gas SO2 to SO3 conversion rate: 0.5%

Desired Furnace Thermal Load Fractions:  
Fraction of EV load in water wall: 1  
Fraction of SH load in furnace: 0.3167  
Fraction of RH load in furnace: 0

SH/RH Steam Flow Sequence:  
Superheaters: CS1->RSH->CS2->CS3  
Reheaters: CR1->RR1->CR2->CR3

Convective Heat Exchanger Design:  
3. User-defined, water/steam DP by user

Parallel HX Configuration:  
 HX tube length equal to downpass depth  
 HX bundle width equal to downpass width

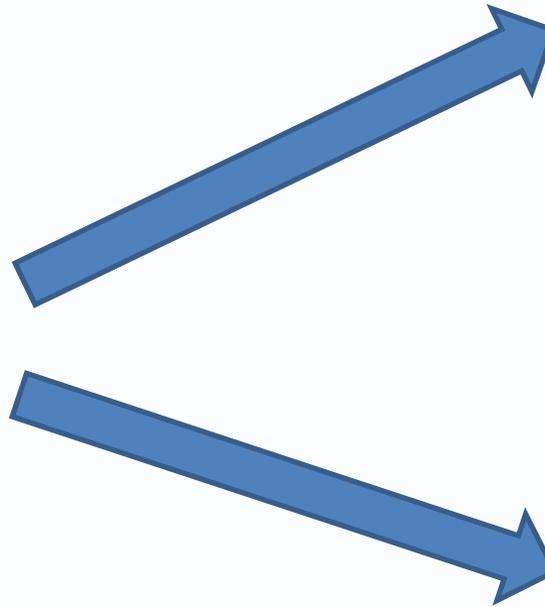
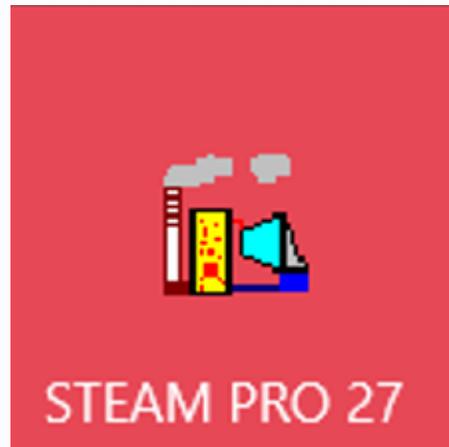
## Replicating an existing plant STP: Environment

- NO<sub>x</sub>: SCR-SNCR
- Particles: Fabric Filter-ESP
- Sulfur: FGD wet/dry
- Mercury: activated carbon injection

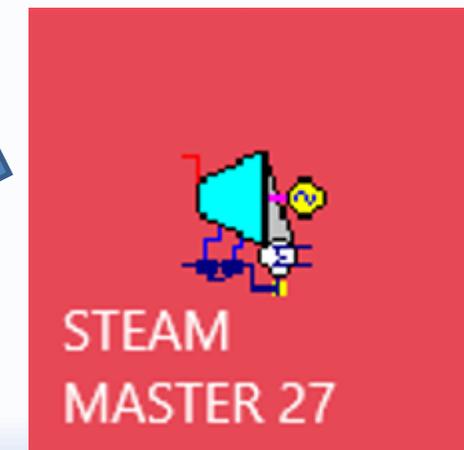
## Replicating an existing plant STP: Auxiliary Power

- Pumps
- Fans
- Fuel Delivery, Ash Handling
- Emission Control equipment
- Transformer Losses
- Other PEACE
- Miscellaneous

# From Design to Off Design



or



## **When in Off Design mode, STM or TFX**

- Tune the Hardware
- Set the Controls
- Introduce Degradation

## Tuning the Design in STM / TFX: **Hardware**

- Pipes
- FW Heaters
- Condenser / Cooling Tower
- ST: Inlet Nozzle Area
- Furnace Dimensions
- Boiler Convective HX
- Air Heaters
- Stack

# Tuning the Design in STM / TFX: Hardware

**FWH**

Select heater	Feedwater Heater Type: Drain cooler	Tube material: Carbon Steel
1. Total number of tubes	2460	
2. Length of tube per pass	12.24 m	
3. Tube outer diameter	19.05 mm	
4. Tube wall thickness	2.108 mm	
5. Tube pitch / tube outer diameter	1.45	
6. Number of passes	2	
7. Total heat transfer area	1801.9 m <sup>2</sup>	
8. Desuperheater area / total heat transfer area	8.675 %	
9. Desuperheater heat transfer area	156.3 m <sup>2</sup>	
10. Drain cooler area / total heat transfer area	32.58 %	
11. Drain cooler heat transfer area	587 m <sup>2</sup>	
12. Desuperheater crossflow multiplier	0.33	
13. Desuperheater baffle spacing	0.6184 m	
14. Desuperheater crossflow area	0.1431 m <sup>2</sup>	
15. Drain cooler crossflow multiplier	0.5	
16. Drain cooler baffle spacing	0.9276 m	
17. Drain cooler crossflow area	0.3251 m <sup>2</sup>	
18. Desuperheating zone overall h.t.c. CF	1	
19. Drain cooling zone overall h.t.c. CF	1	
20. Condensing zone overall h.t.c. CF	1	

**Condenser**

Other Inputs	Performance Method
Tube Material	Titanium
Tube Type	Seam welded
Apply fouling factor	0.0002 m <sup>2</sup> -C/W
Apply cleanliness factor	80 %
Tube outer diameter	25.4 mm
Tube thickness	0.5588 mm
Tube pitch/outside diameter	1.6
Tube length	14.14 m
Number of tubes	11682
Condenser surface area	13185 m <sup>2</sup>
Number of condenser passes	2
Tube metal conductivity	21.63 W/m-C

**Pipes**

Pipe pressure drop & enthalpy loss calculation

Use PEACE mode

Pressure Drop Calculation

Use hardware-determined pressure drop

Resistance coefficient: 282.6 m<sup>-4</sup>

Pressure drop as percent of exit pressure (DP/P): 3 %

Heat Loss Calculation

Specify enthalpy loss

Enthalpy loss: 2.326 kJ/kg

Material: P-22

Number of pipe runs: 1

Overall length of pipe run: 146.3 m

Number of legs in pipe run: 1

Equivalent length of pipe run: 215.4 m

Elevation at start of pipe run: 0 m

Elevation at end of pipe run: 0 m

Number of additional velocity head losses: 0

Absolute roughness: 0 m

**Convective HX**

Main Inputs	Hardware	Other Inputs
Fin-tube type	TP 409, #7	Tube material: T91, #4
Tube length	10.1 m	Tube outer diameter: 63.5 mm
Transverse width	15.12 m	Tube wall thickness: 6.045 mm
# of tube rows (longitudinal)	36	Fin thickness: 1.905 mm
# of tubes per row (transverse)	48	Fin spacing: 3.556 mm
# of rows per water side flow pass	6	# of fins: 183.1 per meter
Longitudinal row pitch, Pl	76.2 mm	Fin height: 0 mm
Transverse tube pitch, Pt	314.9 mm	HX total outside area: 3482 m <sup>2</sup>

**Furnace**

Zone

EC01

Aperture height: 9.945 m

Furnace depth: 15.3 m

Furnace height: 53.24 m

Furnace width: 15.3 m

**Stack**

Specification	Stack
Stack height (H)	121.9 m
Steel liner diameter (D)	6.09 m
Steel liner thickness	9.525 mm
Stack breaching height (Hb)	9.135 m
Concrete shell outside diameter (Ds)	11.68 m
Concrete shell average thickness	355.6 mm

# Tuning the Design in STM / TFX: Hardware

## Steam Pro

Main Inputs | Hardware | Other Inputs | CS2  
 Fin-tube type: Bare - no fins | Tube arrangement: In line | Fin material: TP 409, #7 | Tube material: T91, #4 | Use different material for fins and tubes:

Longitudinal row pitch, Pl: 76,2 mm  
 Transverse tube pitch, Pt: 309,1 mm  
 Define tube length/HX width: [dropdown]  
 Tube length/HX width: 0,65  
 Tube length: 8,126 m

Tube outer diameter: 63,5 mm  
 Tube wall thickness: 6,045 mm  
 Fin thickness: 1,905 mm  
 Fin spacing: 3,556 mm  
 # of fins: 183,1 per meter  
 Fin height: 0 mm

Segment width: 7,938 mm  
 # of segments: 0  
 Un-cut height/fin height: 0,2

For illustration only. Actual number of tubes and number of rows to be calculated.

## Steam Master

Boiler Main Inputs | Boiler Furnace Hardware | Desuperheating | Boiler Operating Parameters | Component Hardware | Steam Air Heater | Fuel Heating  
 Main Inputs | Hardware | Other Inputs | CS2  
 Fin-tube type: Bare - no fins | Tube arrangement: In line | Fin material: TP 409, #7 | Tube material: T91, #4 | Use different material for fins and tubes:

Tube length: 10,1 m  
 Transverse width: 15,12 m  
 # of tube rows (longitudinal): 36  
 # of tubes per row (transverse): 48  
 # of rows per water side flow pass: 6  
 Longitudinal row pitch, Pl: 76,2 mm  
 Transverse tube pitch, Pt: 314,9 mm

Tube outer diameter: 63,5 mm  
 Tube wall thickness: 6,045 mm  
 Fin thickness: 1,905 mm  
 Fin spacing: 3,556 mm  
 # of fins: 183,1 per meter  
 Fin height: 0 mm  
 HX total outside area: 3482 m<sup>2</sup>

Segment width: 7,938 mm  
 # of segments: 0  
 Un-cut height/fin height: 0,2

View derived quantities

## Tuning the Design in STM / TFX: **Controls**

- Plant
- ST
- Boiler
- FWH
- Condenser

# Tuning the Design in STM / TFX: Controls

STEAM MASTER 27.0 - C:\Users\imart\Documents\Thermoflow 27\FAW\FAW28\_OD Coal\Ex\_500\_3c.STM

File View Options Window New Session Help

Main Inputs Plant Criteria Steam Turbine Process Feedwater System Boiler Environment Nuclear Cycle Cooling System Pumps Desalination Site Major Equipment Pipes, Pumps, etc. Economics Re-design in ST PRO COMPUTE

Ambient temperature: 15 C  
 Ambient pressure: 1,013 bar  
 Ambient humidity: 60 %  
 Ambient wet bulb: 10,82 C  
 Site CW temperature: 15 C  
 Makeup temperature: 15 C  
 Design point excess air: 20 %

**Plant Control Mode**

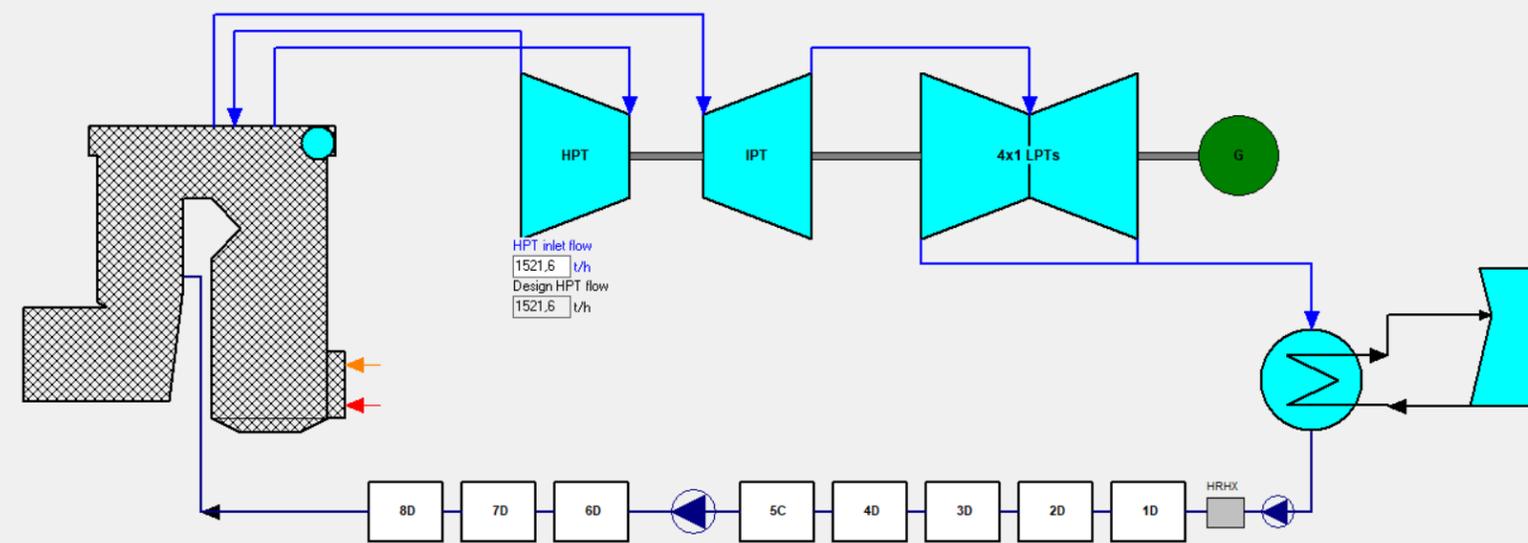
- Fuel heat input %
- Air and fuel flows
- HPT steam flow**
- ST generator power
- Plant net output
- ST & condenser (TFX link)
- Steam turbine only (TFX link)
- Cycle w/o boiler (TFX link)

**Boiler Model**: Fixed hardware

**Mode**

- ST MASTER only
- ST MASTER & PEACE

**Plant Controls**



HPT inlet flow: 1521.6 t/h  
 Design HPT flow: 1521.6 t/h

Boiler controlled by excess air  
 Set through design point excess air and excess air curve  
 Boiler controlled by Eco exit O2-%  
 Desired O2-%: 3,35 %  
 dry-basis

Guidance

# Tuning the Design in STM / TFX: Controls

## Boiler Controls

**Boiler Model**

Fixed hardware

Fixed hardware

Grey box

Boiler Main Inputs | Boiler Furnace Hardware | **Desuperheating** | Boiler Operating Parameters | Component Hardware | Steam Air Heater | Fuel He

Water/Steam Circuit

- Superheater
- Reheater
- LP Reheater

Desuperheating Water Source

- Superheater: Boiler feed pump
- Reheater: Boiler feed pump
- LP reheater: Boiler feed pump

Desuperheating Flow

- Superheater desuperheating flow as % of HP flow: 3
- Reheater desuperheating flow as % of HP flow: 0
- LP reheater desuperheating flow as % of HP flow: 0

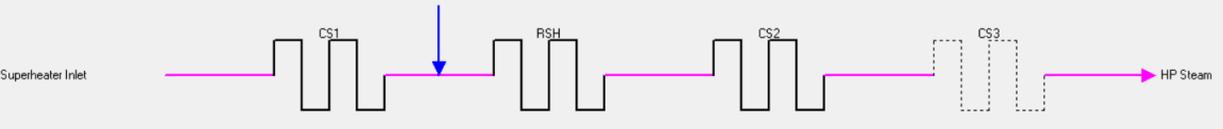
Desuperheating Model

- Control steam setpoint temperature
- Specify desuperheating flow

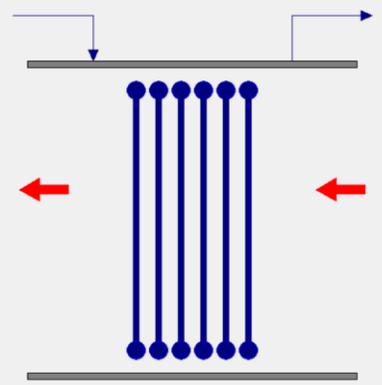
Min. superheat after desuperheating location: 15 C

- Desuperheat before CS1
- Desuperheat before RSH
- Desuperheat before CS2
- Desuperheat before CS3

Distribution of desuperheating flow: 100 %



- Boiler controlled by excess air  
Set through design point excess air and excess air curve
- Boiler controlled by Eco exit O2-%  
Desired O2-%: 3,35 %  
 dry-basis



Economiser

- Steaming Control**
  - No steaming control
  - On - pressurize to control exit subcooling
  - On - recirculate to control exit subcooling
- Water Recirculation to Control**
  - No water recirculation
  - Gas exit temperature
  - Metal temperature
  - Water inlet temperature
  - Water exit temperature
  - Gas approach to dew point
  - Gas approach to sulfur dew point
  - Inlet water approach to dew point
  - Inlet water approach to sulfur dew point
- Water Bypass to Control**
  - No water bypass
  - Gas exit temperature
  - Metal temperature
  - Water exit temperature
  - Gas approach to dew point
  - Gas approach to sulfur dew point
- Gas Bypass to Control**
  - No gas bypass
  - Gas exit temperature



# Tuning the Design in STM / TFX: Controls

## FWH Controls

Control mode

Fixed hardware

Fixed hardware

Approximate TTD method

### FWH 6 - Drain cooler

Maximum set point heating pressure 32,76 bar

Local feedwater bypass 0 %

Drain leak mass flow 0 t/h

Drain destination FWH5

Drain leak destination Ambient

OK Cancel

HP Feedwater Bypass Control		LP Feedwater Bypass Control	
Bypass flow rate	0 %	Bypass flow rate	0 %
Bypass begins at inlet of heater	6	Bypass begins at inlet of heater	1
Bypass merges with exit of heater	8	Bypass merges with exit of heater	4

# Tuning the Design in STM / TFX: Controls

**Cooling System Main Inputs**

Cooling System Optimisation:

Cooling Water Flow:  User-defined  Computed from pump capacity and flow resistance

Condenser Pressure Limited by:  Coolant flow  No. of operating CT cells

CT Cooling Water Distribution:  All cells  Operating cells

Minimum condenser pressure:  bar  
Maximum condenser pressure:  bar

Fan power CF =

Number of existing cells: 1- speed  2- speed   
Number of operating cells: Full speed  Half  Zero

Sizing air flow per cell = 609,9 m<sup>3</sup>/s  
Full speed cell air flow/sizing:  %  
Half speed cell air flow/sizing:  %  
Zero speed cell air flow/sizing:  %

Cooling tower inlet air:

Ambient dry bulb 15 C  
Ambient wet bulb 10,82 C  
Ambient RH 60 %

Nominal CW flow per condenser: 45093 t/h  
Desired CW flow as % of nominal:  %

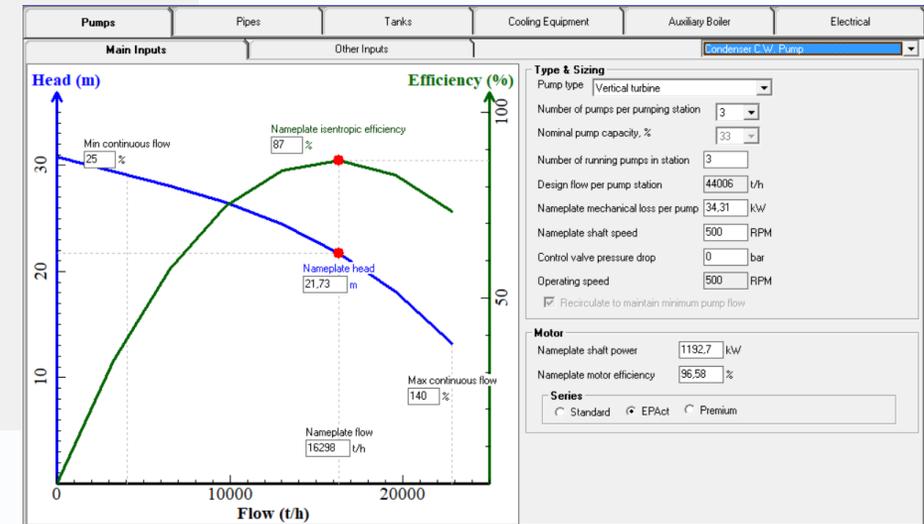
Hotwell subcooling:  C  
Water head to condensate outlet:  m

to FWH  Cooling tower is shut down

Cooling Water:  Fresh water  Sea water

Cycles of concentration:   
CT minimum basin temperature:  C

**Cooling System Controls**



## Tuning the Design in STM / TFX: **Degradation**

- ST: Efficiency Degradation
- FWH: Blocked Tubes, Fouling, Leaks
- Condenser: Cleanliness Factor, Air intake
- Boiler: HX Fouling
- Others

## OD Simulation **Off Line**

- Typical Correction curves (Elink)
- Other correction curves (steam out, steam to sootblowing, desuperheating, ...)
- Effect of Operation alternatives
  - Bypass FWH
  - CW Pumps / CT-ACC cells on
  - Excess Air-Unburnt Carbon in Ash
  - Steam Air pre heating
- Effect of Degradation
  - FWH blocked tubes
  - AH leakage / Dirtytness
  - Boiler fouling
  - Condenser fouling

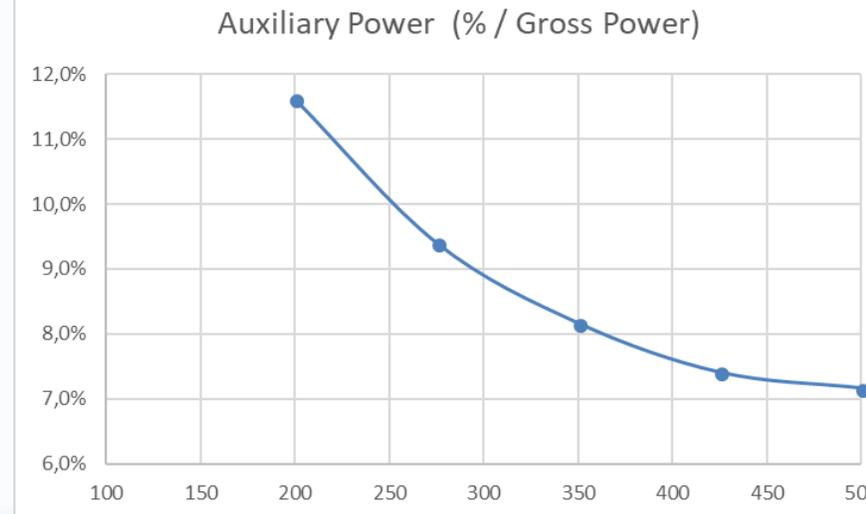
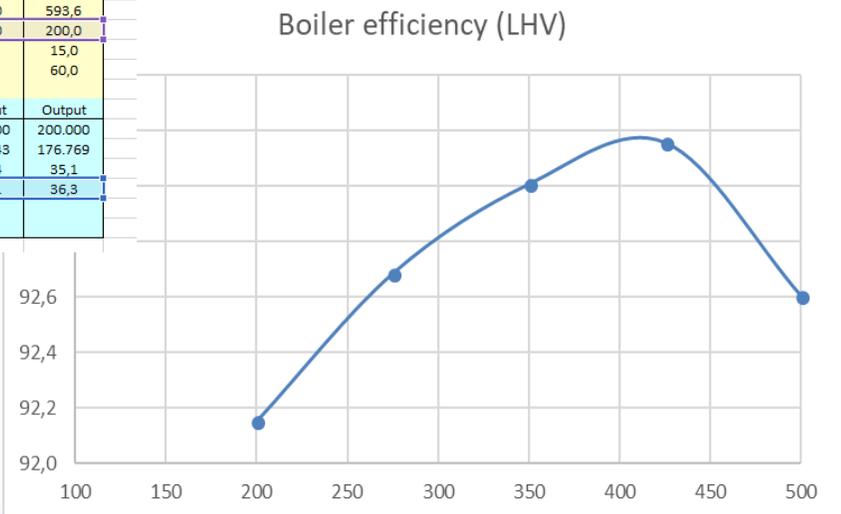
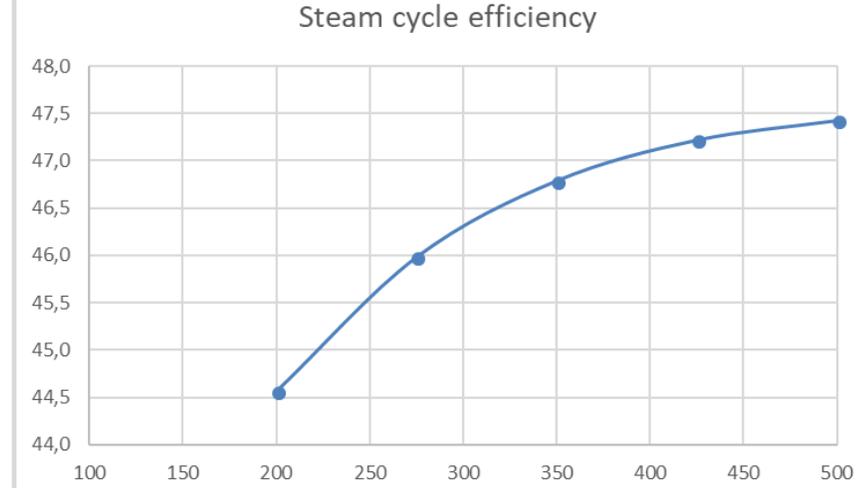
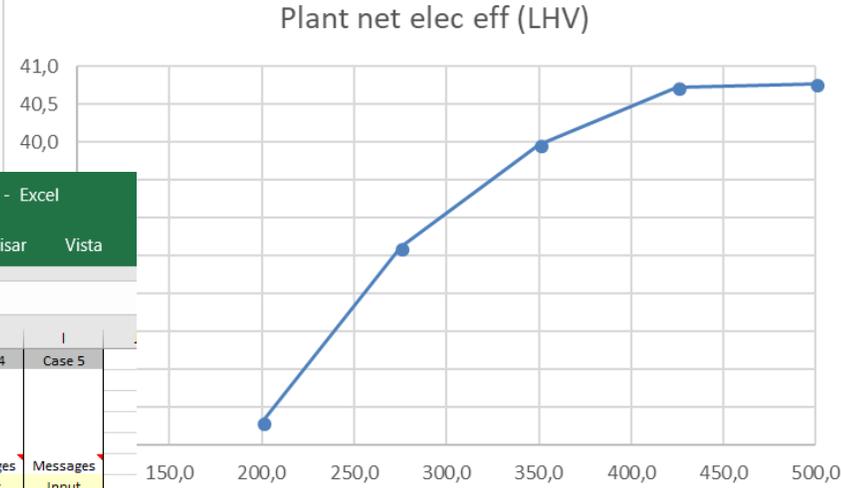
## Part Load Curves

Autoguardado TFELINKx1 - Excel

Archivo Inicio Insertar Dibujar Diseño de página Fórmulas Datos Revisar Vista

Gráfico 1

	B	C	D	E	F	G	H	I
	ELINK 27.0 (Save-ALL)		Base Case	Case 1	Case 2	Case 3	Case 4	Case 5
1	Copyright (c) 1999 - 2017							
2	Base Case:							
3	C:\learn\mark\Documents\Thermoflow							
4	Computation	Message ->	Messages	Messages	Messages	Messages	Messages	Messages
5		Units	Input	Input	Input	Input	Input	Input
6	<b>INPUT VARIABLE DESCRIPTION</b>							
7	Plant control mode (choose first): 0=fuel heat		0	3	3	3	3	3
8	input percentage, 1=air+fuel flows, 2=HPT		1522,0	1522,2	1279,3	1035,6	809,0	593,6
9	steamflow, 3=ST generator power, 4=Plant net		499,9	500,0	425,0	350,0	275,0	200,0
10	power		15,0	15,0	15,0	15,0	15,0	15,0
11	Desired HPT inlet steam flow rate	t/h	60,0	60,0	60,0	60,0	60,0	60,0
12	Desired ST generator power	MWe						
13	Ambient temperature	C						
14	Ambient relative humidity	%						
15	<b>OUTPUT VARIABLE DESCRIPTION</b>	Units	Output	Output	Output	Output	Output	Output
16	Plant gross output	kW	499.930	500.000	425.000	350.000	275.000	200.000
17	Plant net output	kW	464.090	464.156	393.496	321.409	249.143	176.769
18	Plant net elec eff (HHV)	%	39,42	39,43	39,38	38,64	37,34	35,1
19	Plant net elec eff (LHV)	%	40,77	40,77	40,73	39,96	38,61	36,3

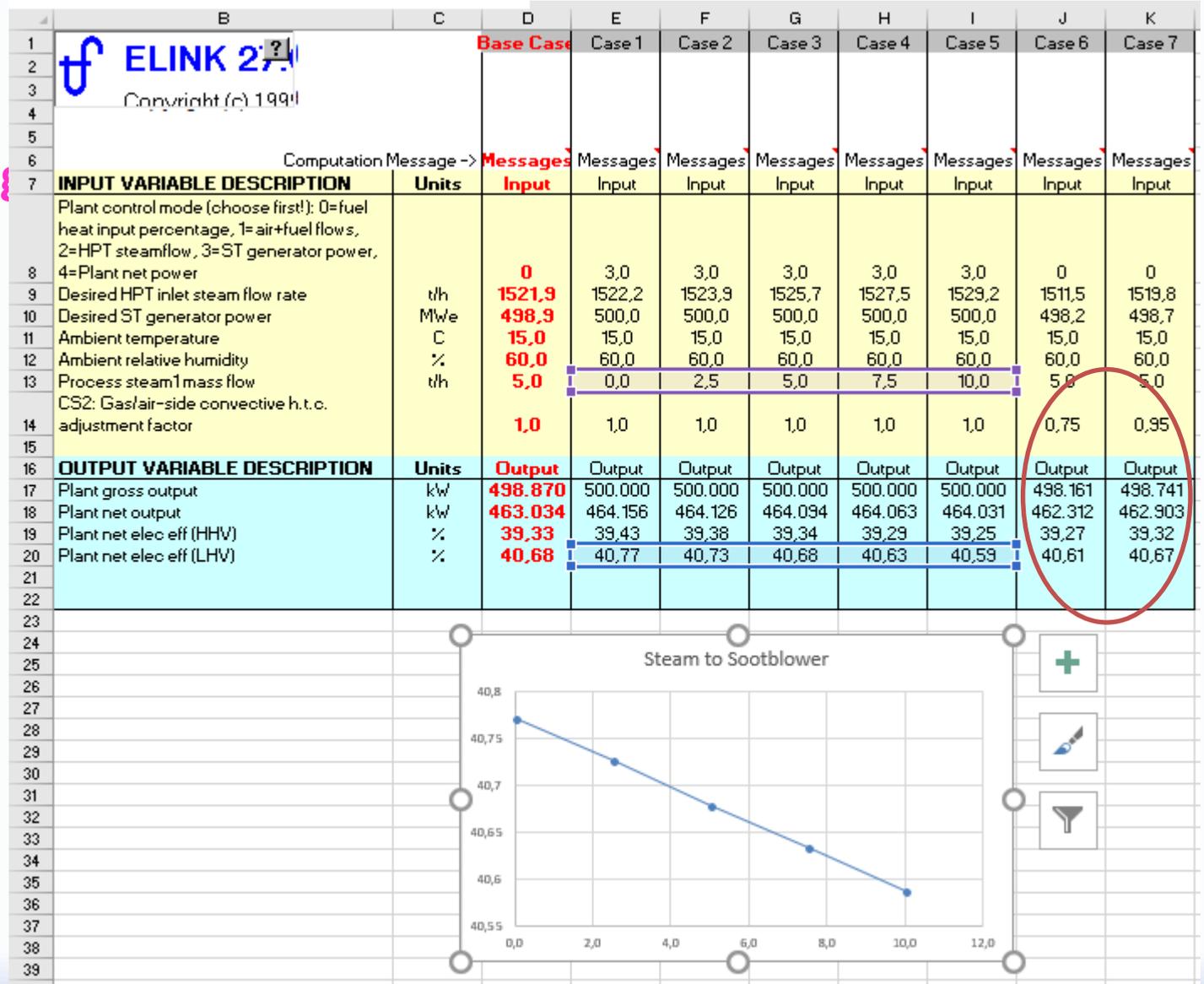


# OD Simulation Off Line, STM

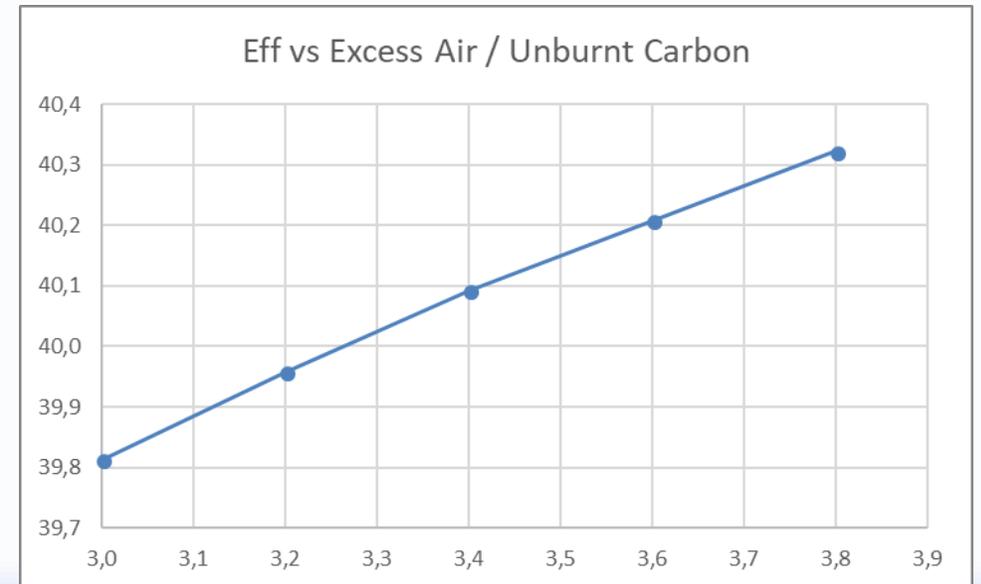
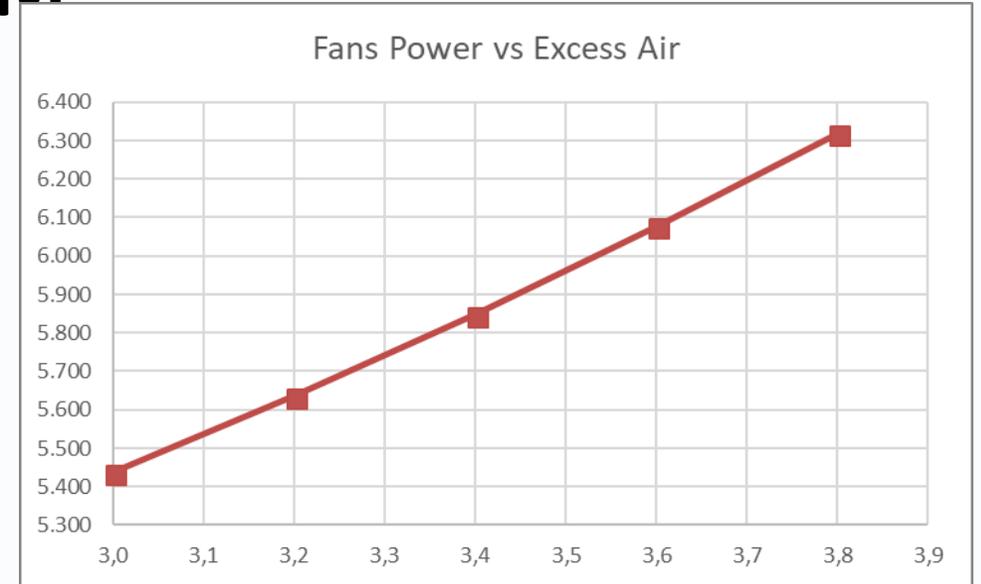
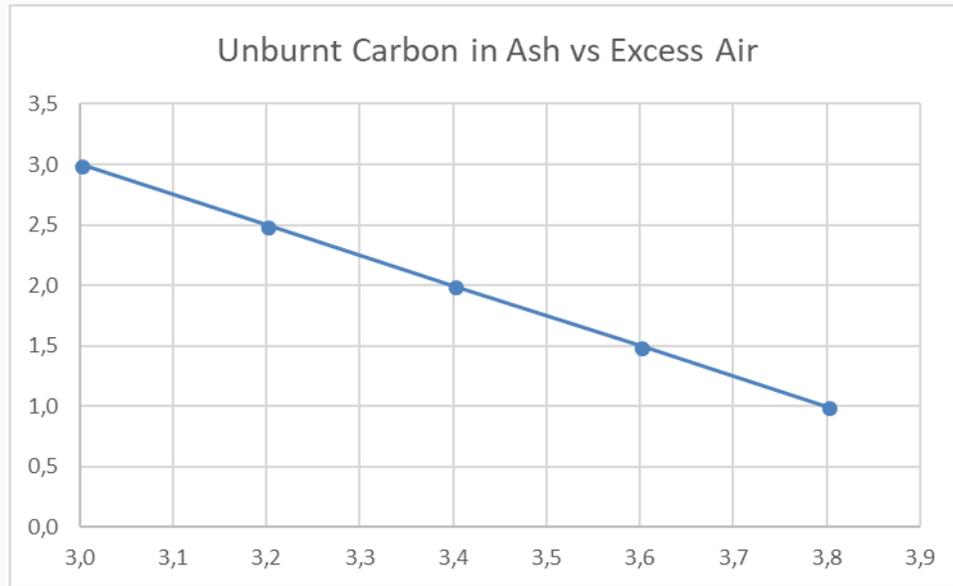
## Steam to Sootblowers vs HX cleaning

Case 1 to 5: Steam mf to Sootblowers, 0 to 10 t/h

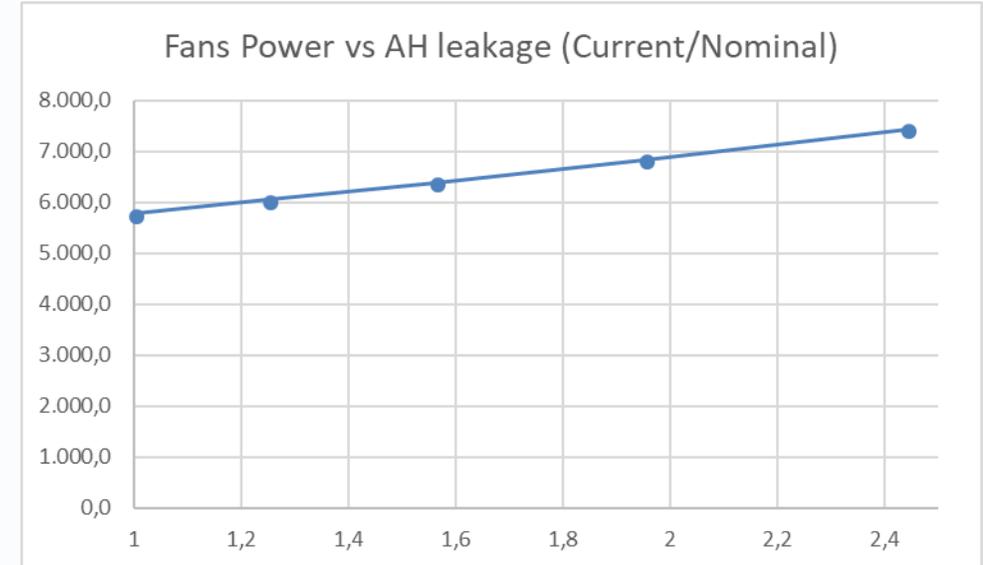
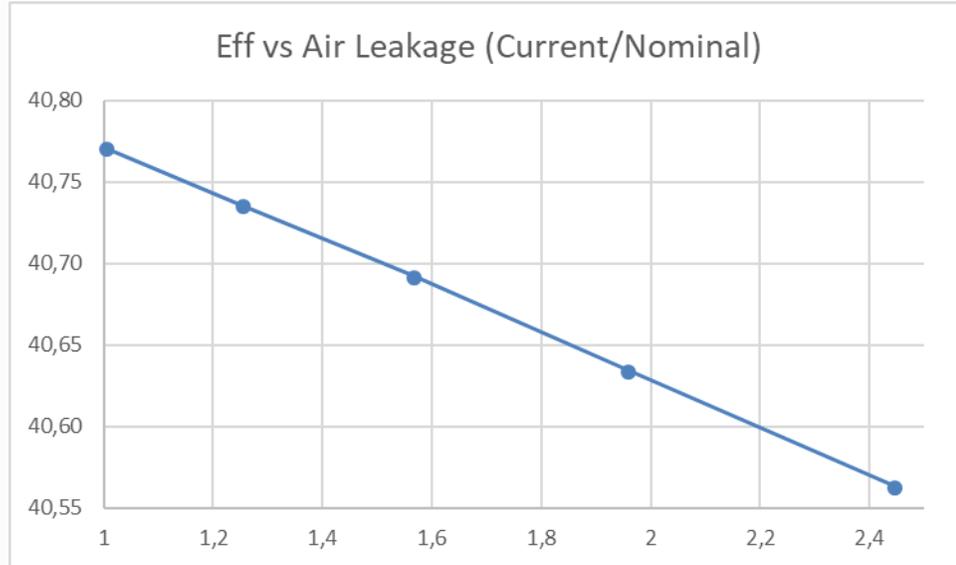
Cases 6 & 7: Effect of cleaning SH2, HTC adjustment factor 0,75→0,95



## Excess Air / Unburnt Carbon in Ash

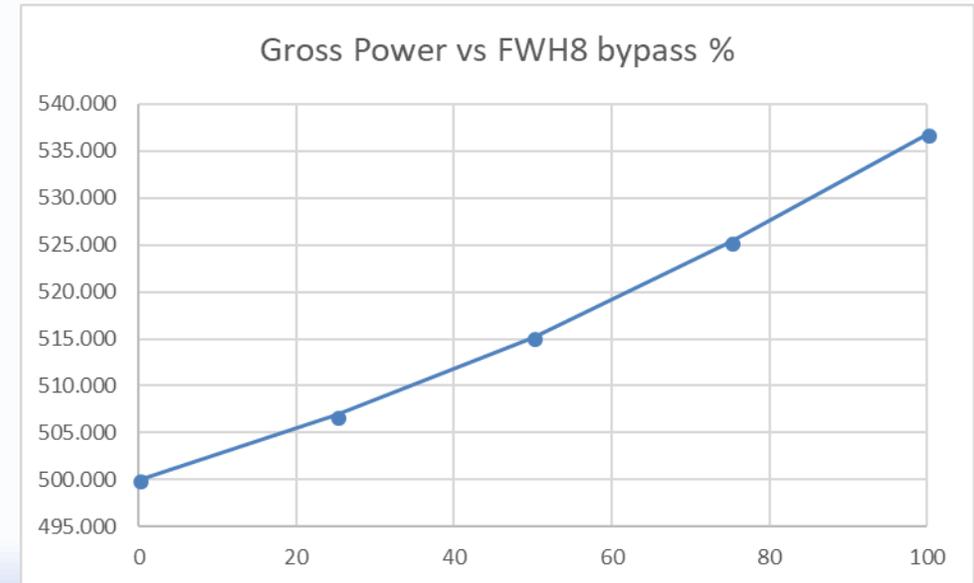
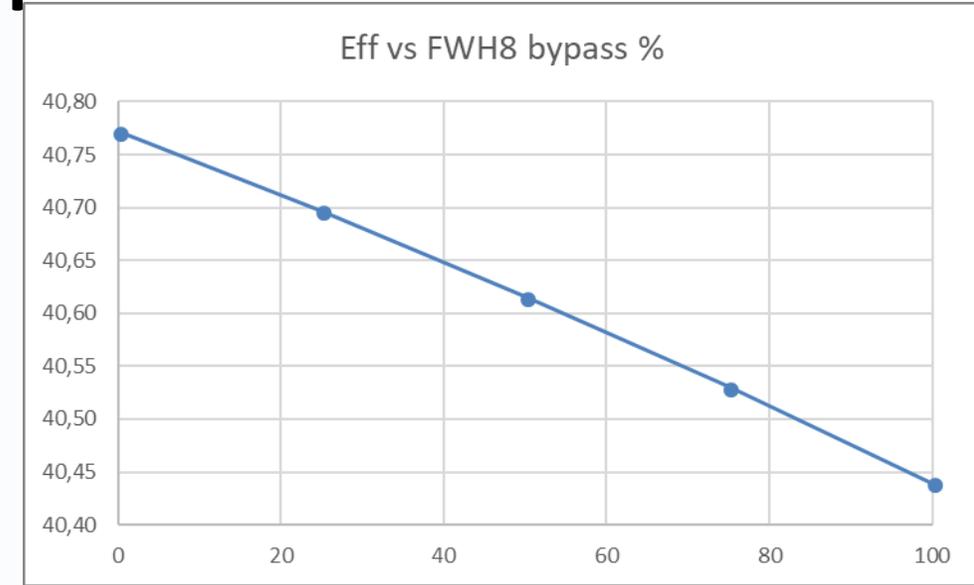
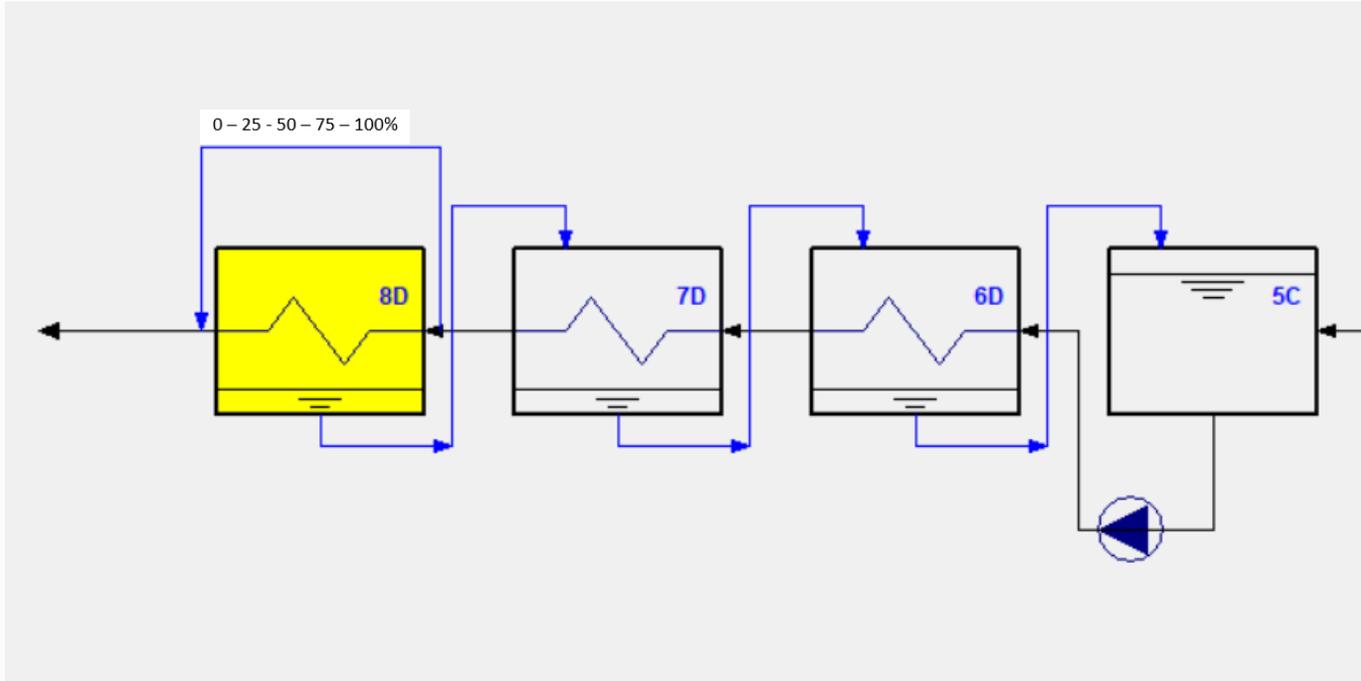


## Air Heater Leakage / DP



# OD Simulation Off Line, STM

## FWH Bypass



# OD Simulation **On Line**, Performance Monitoring

- Tune Thermoflex+PEACE Model
- Connect to the DCS (Elink - ULink)
- Select Inputs & Outputs to be considered as Inputs / Outputs
- Select Inputs & Outputs to be reconciled
- Calculate degradation parameters
- Enter external inputs
- Set and Admin. the User Interface

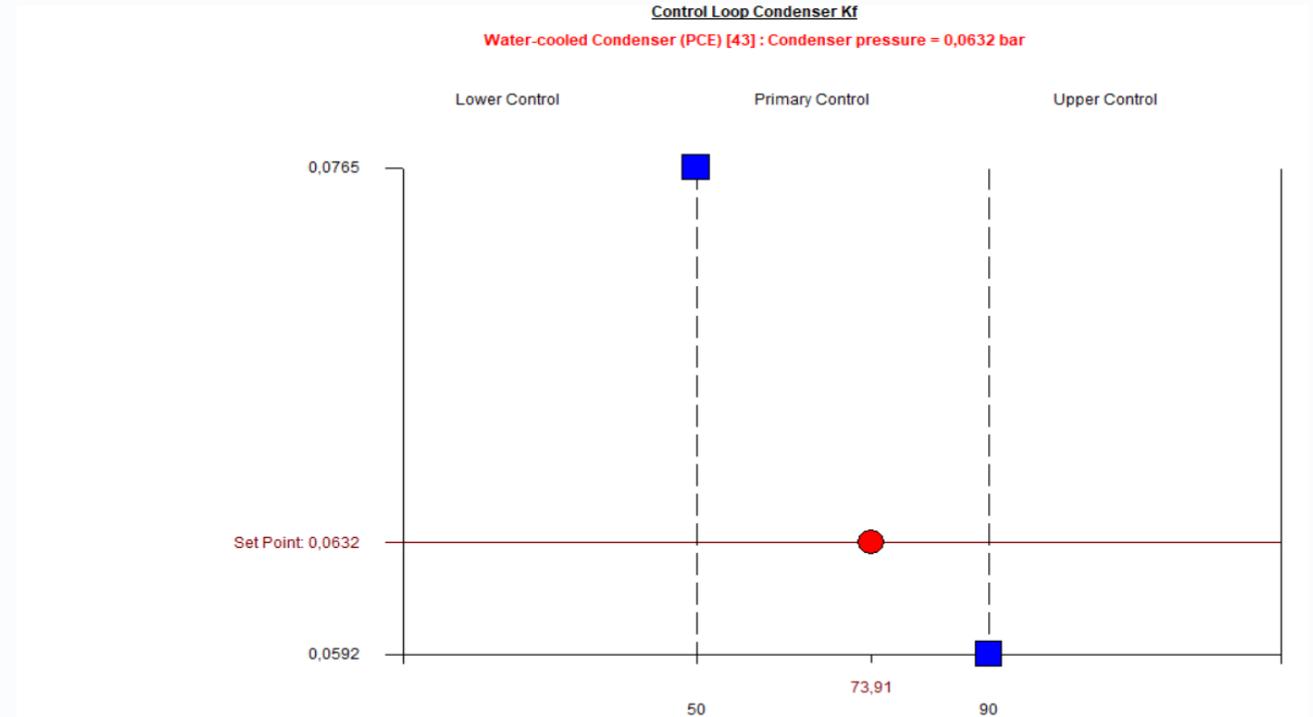
 ***See Webinar n. 13, June 2017***

## Condenser Fouling

@ Current Conditions (Ambient, Load, CW Pumps, ...):

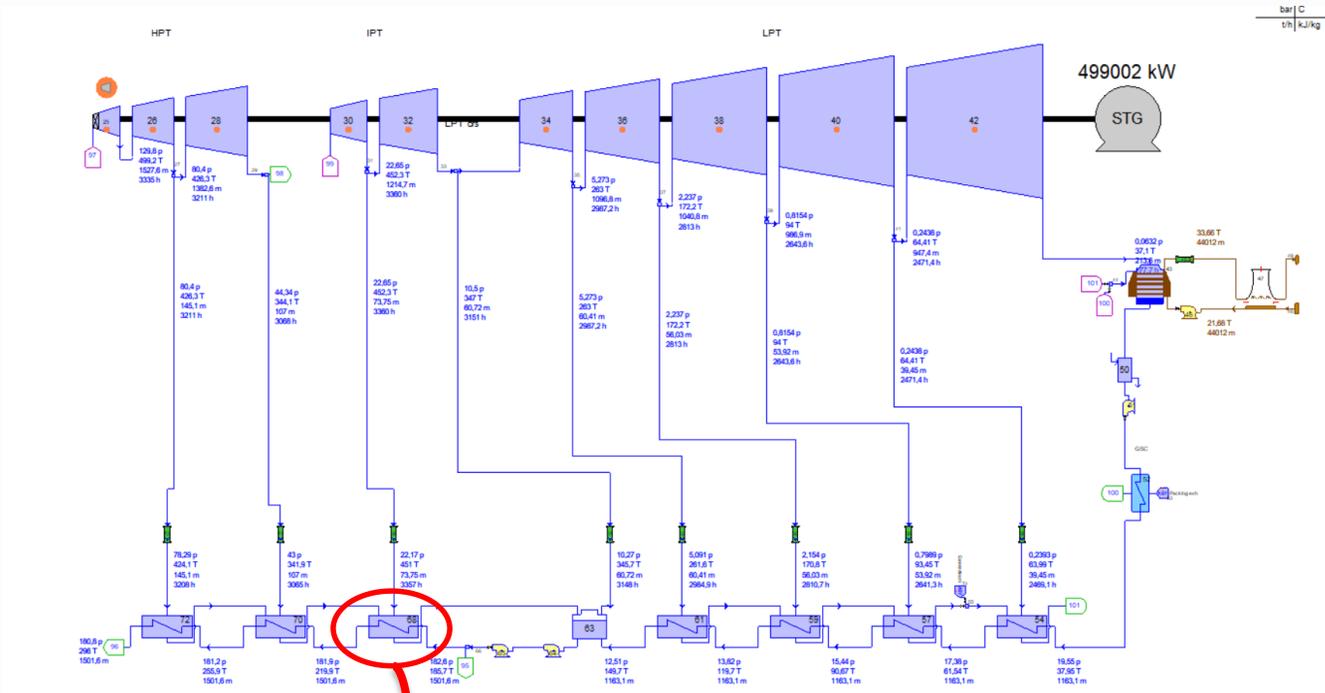
Expected from TFX  
Measured

<i>Cond P mbar</i>	<i>Cleanliness Factor</i>
61,4	80%
63,2	???

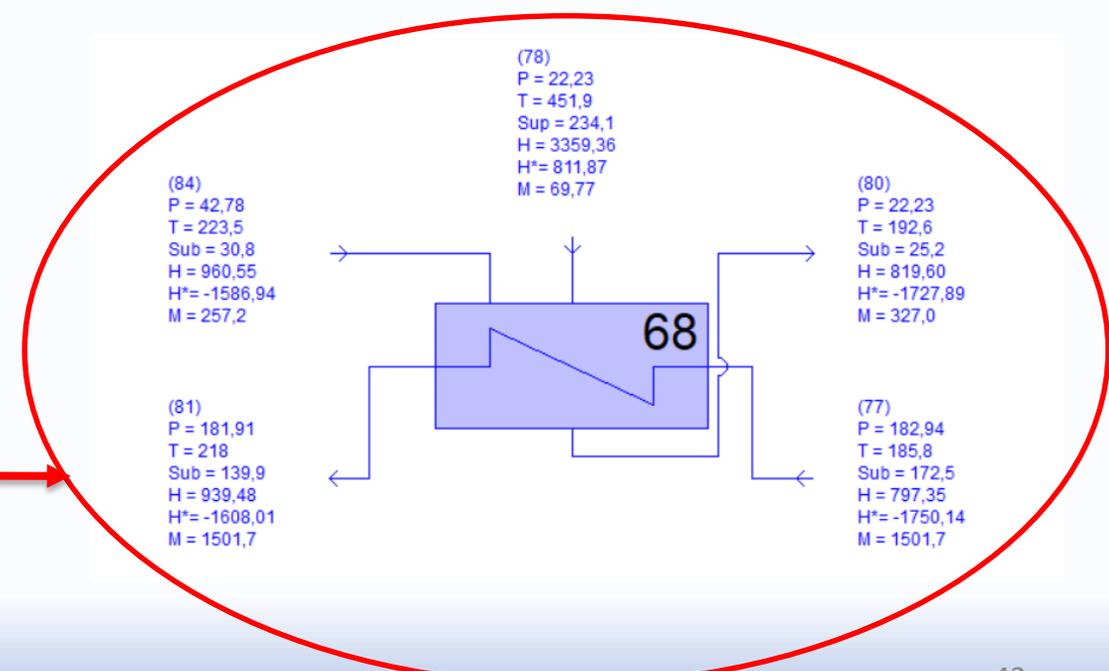


Water-cooled Condenser (PCE) [43] Cleanliness factor	%	<b>73,91</b>	80,0	73,91
Boiler Assembly: Furnace w/ Pulverizer [1] Steam production rate	t/h	<b>1500</b>	1500	1500
<b>OUTPUT VARIABLE DESCRIPTION</b>	<b>Units</b>	<b>Output</b>	Output	Output
Gross power	kW	<b>499.005</b>	499.906	499.005
Net power	kW	<b>462.868</b>	463.765	462.868
Net electric efficiency(LHV)	%	<b>40,13</b>	40,21	40,13
Water-cooled Condenser (PCE) [43] Condenser pressure	bar	<b>0,0632</b>	0,0614	0,0632

## FWH blocked tubes / fouling



2	Feedwater Heater (PCE) [68] Total number of tubes		2458	2458	1917
6	Feedwater Heater (PCE) [68] Condensing zone overall h.t.c. correction factor		0,95	1,0	0,9375
1					
2	<b>OUTPUT VARIABLE DESCRIPTION</b>	<b>Units</b>	<b>Output</b>	Output	Output
7	Feedwater Heater (PCE) [68] Feedwater temperature rise (overall)	C	34,2	34,55	32,15
8	81 - Feedwater outlet of Feedwater Heater (PCE) [68] -> Feedwater inlet of Feedwater Heater (PCE) [70] Temperature	C	219,9	220,3	218,0
9					



## OD Simulation On-Line, other TF tools

- DRS: Data Reconciliation System
- TOPS: Optimizer

# Computation Tools

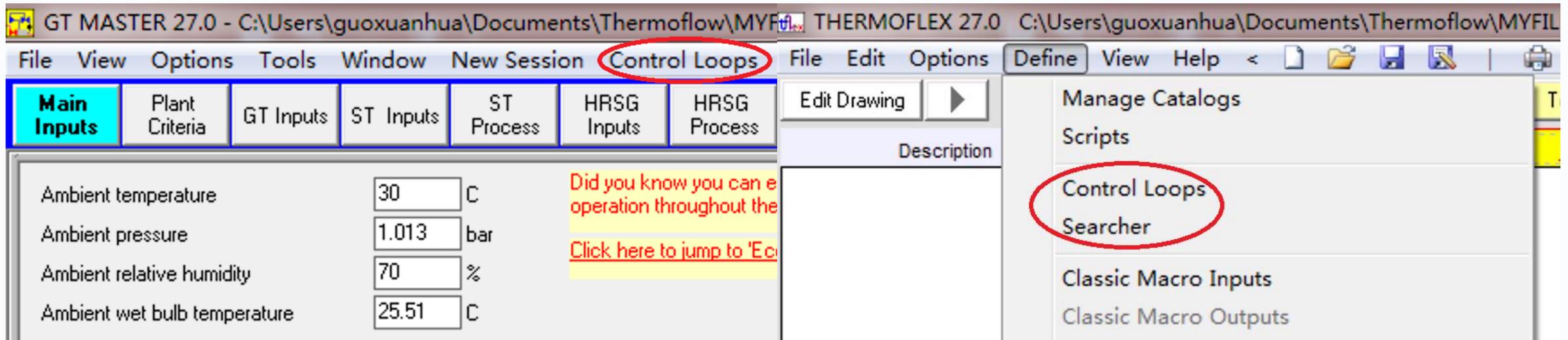
**Introduce four types of computation tool:**

- \* Control Loops
- \* Searcher
- \* Data Reconciliation System (DRS)
- \* Thermoflow's Optimization System(TOPS)

These tools must be used together with our programs such as GT Master, Thermoflex etc.

# Where to find these tools?

- \* Control Loops (GT Master, Thermoflex)
- \* Searcher (Thermoflex)



The screenshot displays two windows from the Thermoflow software. The left window is titled "GT MASTER 27.0" and shows a menu bar with "Control Loops" circled in red. Below the menu bar is a tabbed interface with "Main Inputs" selected. The "Main Inputs" tab contains a table of ambient conditions:

Parameter	Value	Unit
Ambient temperature	30	C
Ambient pressure	1.013	bar
Ambient relative humidity	70	%
Ambient wet bulb temperature	25.51	C

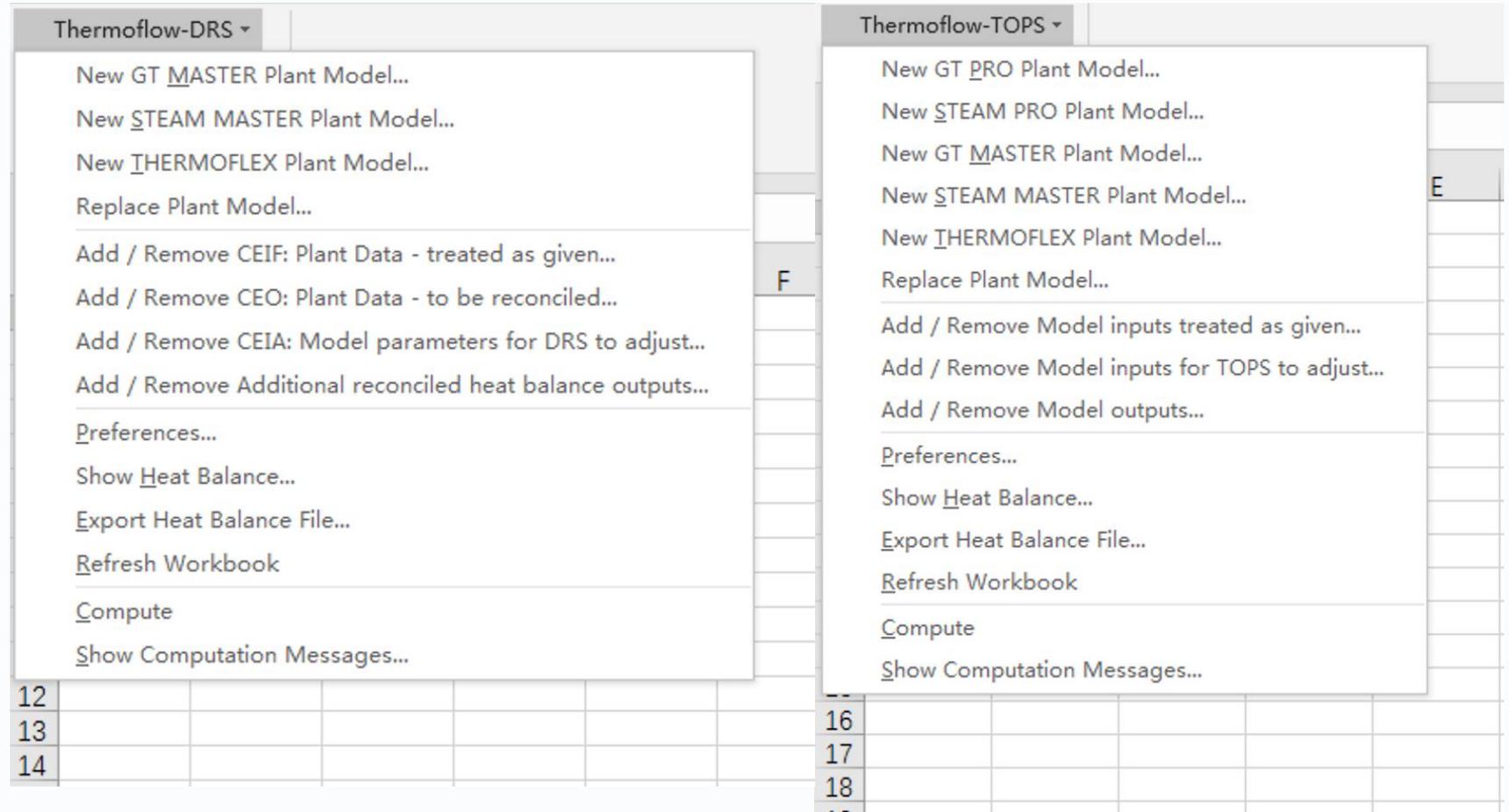
To the right of the table, there is a red text box with the message: "Did you know you can e operation throughout the" and a yellow highlighted link: "Click here to jump to 'Ec".

The right window is titled "THERMOFLEX 27.0" and shows a menu bar with "Define" selected. Below the menu bar is a list of tools, with "Control Loops" and "Searcher" circled in red.

# Where to find these tools?

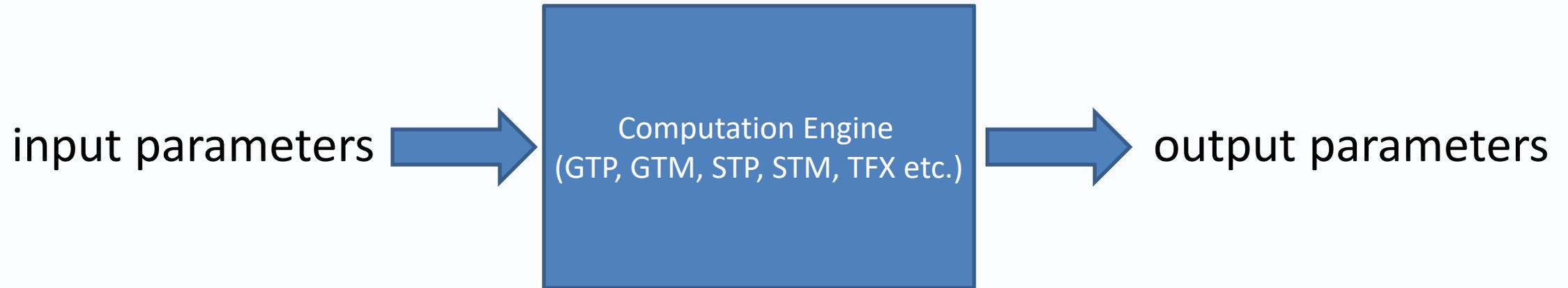
\* DRS (Excel Addin)

\* TOPS (Excel Addin)



The image shows two side-by-side screenshots of an Excel spreadsheet. The left screenshot displays the 'Thermoflow-DRS' menu, and the right screenshot displays the 'Thermoflow-TOPS' menu. Both menus are open, showing a list of options. The 'Thermoflow-DRS' menu includes options like 'New GT MASTER Plant Model...', 'New STEAM MASTER Plant Model...', 'New THERMOFLEX Plant Model...', 'Replace Plant Model...', 'Add / Remove CEIF: Plant Data - treated as given...', 'Add / Remove CEO: Plant Data - to be reconciled...', 'Add / Remove CEIA: Model parameters for DRS to adjust...', 'Add / Remove Additional reconciled heat balance outputs...', 'Preferences...', 'Show Heat Balance...', 'Export Heat Balance File...', 'Refresh Workbook', 'Compute', and 'Show Computation Messages...'. The 'Thermoflow-TOPS' menu includes options like 'New GT PRO Plant Model...', 'New STEAM PRO Plant Model...', 'New GT MASTER Plant Model...', 'New STEAM MASTER Plant Model...', 'New THERMOFLEX Plant Model...', 'Replace Plant Model...', 'Add / Remove Model inputs treated as given...', 'Add / Remove Model inputs for TOPS to adjust...', 'Add / Remove Model outputs...', 'Preferences...', 'Show Heat Balance...', 'Export Heat Balance File...', 'Refresh Workbook', 'Compute', and 'Show Computation Messages...'. The background shows an Excel grid with columns labeled 'F' and 'E', and rows labeled '12', '13', '14', '16', '17', '18'.

## To be adjusted & to be matched



E.g. To achieve a certain net power in GTM, we adjust GT load percentage.  
We can use trial method manually, but it's tedious/time-consuming.  
Control loops is automatical trial method, save your time!

# Control Loops Interface in GTM

GT MASTER 27.0 - Control Loop Menu

Control loop:  Enabled  Disabled Toggle lower window display OK

**Current Control Loop Configurations**

**Set Point => Plant net output** Tolerance  %  
 Desired value  [kW]

**Primary control => GT load percentage** from  to  [%]

**Upper control => None** from  to

**Lower control => None** from  to

**Select Set Point or Control Variables**

**Set Point variables**

Plant operating variables  Process streams  HRSG massflow additions/extractions

None  
 Plant gross output  
 Plant net output  
 Steam turbine generator output  
 Plant gross heat rate  
 Plant net heat rate  
 Plant gross electric eff  
 Plant net electric eff  
 Gas turbine gross output  
 PURPA efficiency

Click on the list box to select Set Point variable. GT MASTER will iterate on Primary Control variable, and Upper or Lower Control variable if necessary, to achieve the desired set point value.

Control Loop Results

**Control loop set point => Plant net output** Close

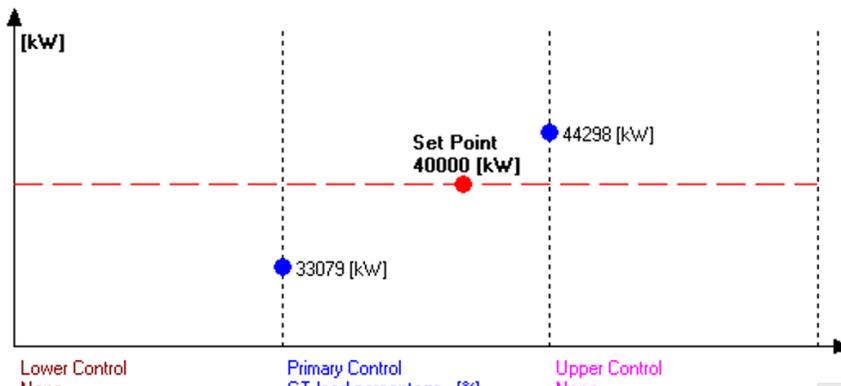
Desired =  [kW] Tolerance  %  
 Actual =  [kW]

**Primary Control (ON) => GT load percentage** =  [%]

Upper Control (OFF) => None =

Lower Control (OFF) => None =

[The control loop set point has been achieved by activating your Primary Control alone.](#)

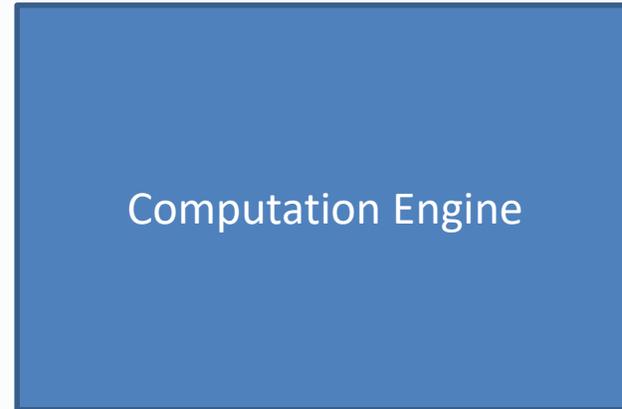


Print

At one time, there is only one input parameter to be adjusted although you may pick up to three inputs in control loops.

# How to choose computation tools

Adjust One  
Input Parameter



Match One  
Output Parameter

Control Loops

# How to start work with data reconciliation

Imagine that you get hundreds of gauge measurements from DCS.

A small part of these measurements are inaccurate.

But you don't know which ones are faulty.

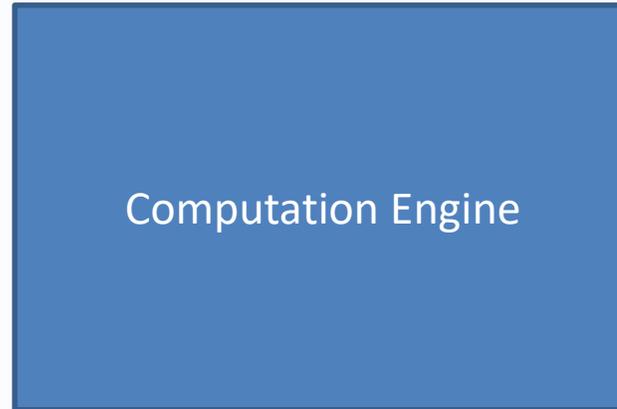
Theoretically every measurement is suspicious.

How to start your work since you trust none of them?

**We don't trust any individual measurement, but we trust the whole of them, so we'll match many parameters simultaneously.**

# How to choose computation tools

Adjust Many  
Input Parameters



Match Many  
Output Parameters

DRS

# DRS background

DRS is useful in online/offline monitoring for data reconciliation.

Measurements always include uncertainty caused by random and systematic errors. In operating power plants various levels of effort are dedicated to accurately measuring the quantities used to monitor and control the plant. **The DRS uses a model-based approach to help isolate faulty sensors, quantify the accuracy of other measurements, and fill-in unmeasured quantities.**

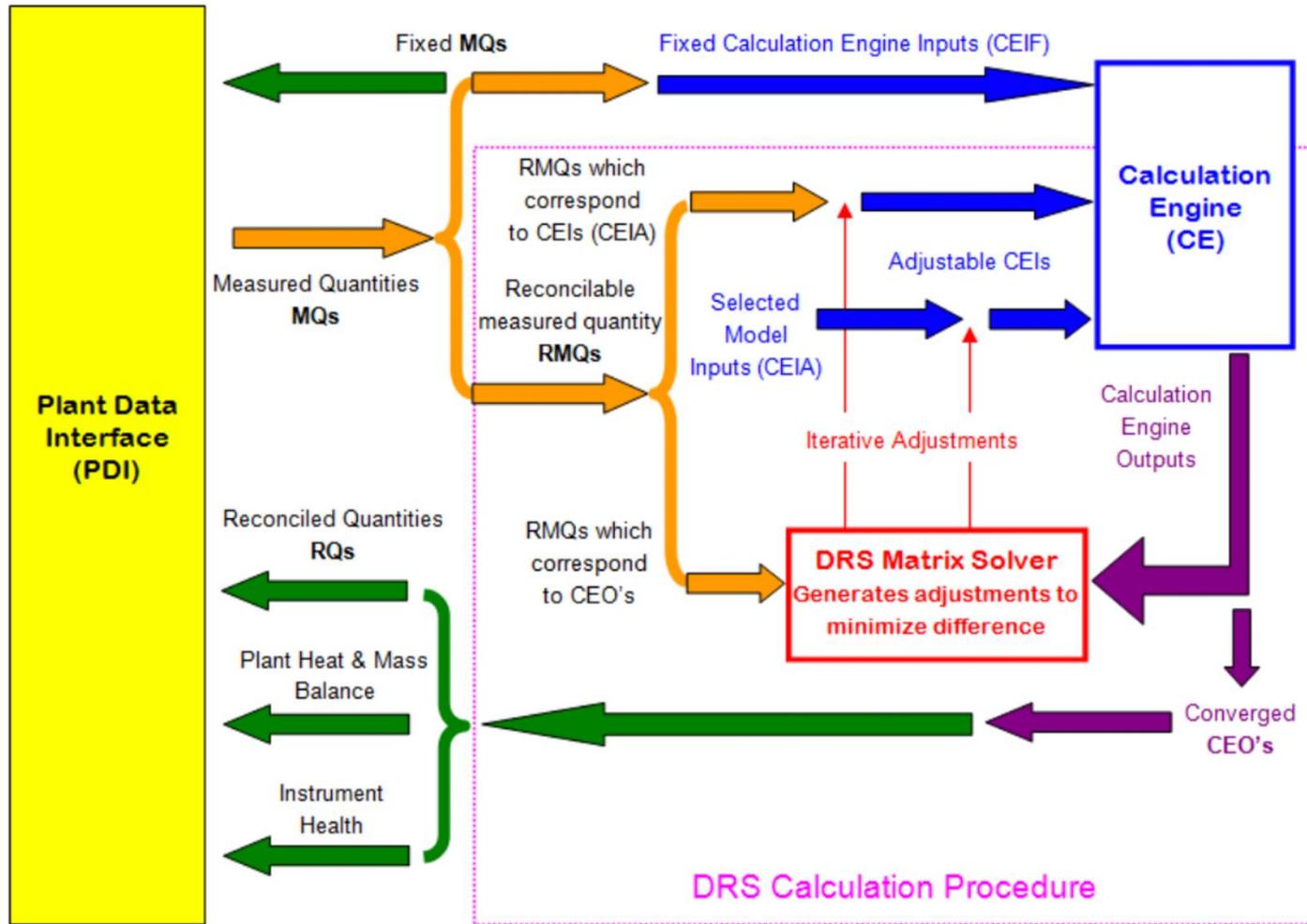
# Least square method

Minimize the sum of the squares of the weighted error signals. The error signals are defined as the difference between the MQs and the corresponding CEOs at the current nominal point.

Full Name	Abbreviation	Description
Calculation Engine	CE	The calculation engine is any one of ThermoFlow's GT PRO, GT MASTER, STEAM PRO, STEAM MASTER, or THERMOFLEX modeling programs. It uses a base model file together with input parameters to compute model output parameters.
Measured Quantity	MQ	Data values measured by plant sensors, or imputed from measured values.
Reconciled Quantity	RQ	Reconciled quantities are outputs from the computation engine. Each RQ has an equivalent MQ, for example generator power is both a measurement value and a computation result. The DRS final step produces the complete set of RQs.
Calculation Engine Input	CEI	Parameter that is an input to the program that the interactive user normally enters to make a calculation. Examples include site ambient temperature, duct burner fuel flow, cooling water source temperature, condenser cooling water flow, etc.
Calculation Engine Output	CEO	Parameter that is a computed result from the program that the interactive user typically finds in the text and graphics displays following computation. Examples for a gas turbine are generator power, fuel flow, exhaust flow and exhaust temperature.
Fixed Calculation Engine Input	CEIF	This is a particular type of CEI. It comes directly from the measurements and is not adjusted by the DRS. Any CEI can be included in this category. Part of DRS configuration is to judiciously select which MQs to include in the CEIF category. Typically, ambient temperature is one of the MQs on the CEIF list.
Adjustable Calculation Engine Input	CEIA	This is a particular type of CEI. It is a model input that is adjusted by the DRS as it tries to minimize the difference between the measurement values and the model output values. Some CEIAs correspond directly to measured quantities. Other CEIAs, such as condenser fouling factor, or steam turbine efficiency, do not correspond to physical measurements. These are model parameters chosen during DRS configuration and assigned nominal starting values by default.

Table 3-1 Summary of DRS terminology

# DRS Process



# DRS example

There are four DRS example files in the sample directory.  
Show (DRS4)RHTGTCC.xls

# How to choose computation tools

Adjust One  
Input Parameter

A solid blue rectangular box with a thin white border, containing the text 'Computation Engine' in white.

Computation Engine

Find One Extreme  
Output Parameter

No idea of the value in advance

Searcher

# Searcher interface

Searcher (1 of 1)

**Define Searcher** | Define Output

Searcher(1) New

Enable Searcher Remove

**Target**

Select Net electric efficiency(LHV) 42.55 %

Search for minimum      Tolerance 0 fraction

Search for maximum

**Adjuster**

Select STAssembly[1]: ST Group [3]: Design point Inlet pressure (upstream of any stop or control valves) 35.53 bar

Adjuster Type:  Continuous      Initial number of steps 10

Discrete      Increment 1

Range:      Minimum 20 bar      Maximum 40 bar

Starting Point: Range minimum

Search Method:  Try all cases

Find solution closest to starting point

OK Cancel

# How to choose computation tools

Adjust **Many** Parameters

A solid blue rectangular box with the text 'Computation Engine' centered inside in white.

Computation Engine

Find One Extreme Parameter  
No idea of the value in advance

TOPS

# TOPS example

Full Name	Abbreviation	Description
Objective Function	OBJ	This is the function to optimize. It may simply be an output value computed by the core program, or it can be a function of one or more program outputs and other input values you define and declare.
Calculation Engine	CE	The calculation engine is any one of Thermoflow's GT PRO, GT MASTER, STEAM PRO, STEAM MASTER, or THERMOFLEX modeling programs. It uses a base model file together with input parameters to compute model output parameters.
Calculation Engine Output	CEO	Parameter that is a computed result from the program that the interactive user typically finds in the text and graphics displays following computation. Examples for a gas turbine are generator power, fuel flow, exhaust flow and exhaust temperature.
Calculation Engine Input	CEI	Parameter that is an input to the program that the interactive user normally enters to make a calculation. Examples include site ambient temperature, duct burner fuel flow, cooling water source temperature, condenser cooling water flow, steam turbine section efficiency degradation, etc.
Fixed Calculation Engine Input	CEIF	This is a particular type of CEI. For each TOPS run these inputs are unchanged. They come from user input directly. Any CEI can be included in this category. Typically, boundary conditions like ambient conditions and cooling water temperature are in this category. Additionally, any fixed constraints like steam flow to process are on the CEIF list.
Adjustable Calculation Engine Input	CEIA	This is a particular type of CEI. It is a model input that is adjusted by TOPS as it searches for an optimum in the objective function. The number of independent CEIAs defines the degrees of freedom in the system. There must be at least one CEIA, but there may be many depending on the nature of the model and objective function.

Table 3-1 Summary of TOPS Terminology

# TOPS example

There are two TOPS example files in the sample directory.

Show (TOPS2)CCGTLoadOptimization.xls

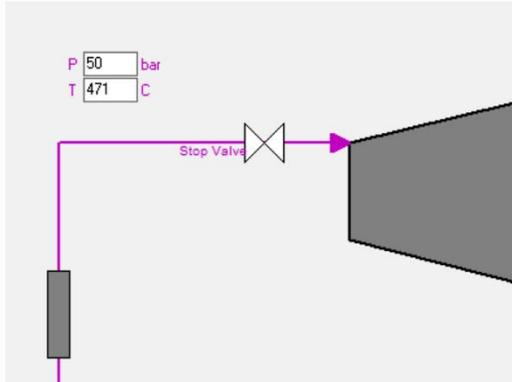
If you run TOPS for design models of our programs, you optimize the design;

If you run TOPS for OFF-design models of our programs, you optimize the operating for existing power plants.

# TOPS example

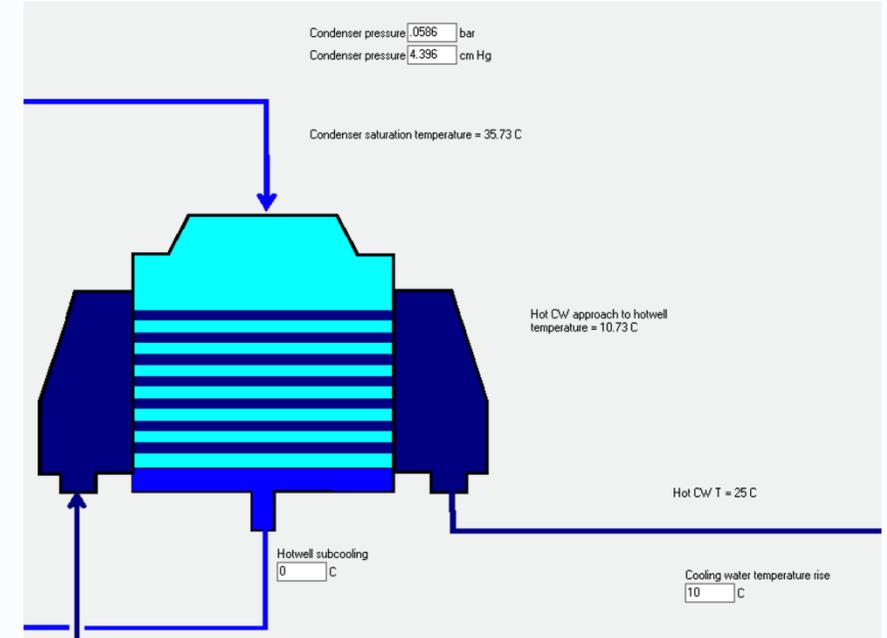
<b>Optimum Equipment Load Levels Versus Power Price</b>						
<b>Power Price, \$/MWhr</b>	<b>15</b>	<b>25</b>	<b>35</b>	<b>55</b>	<b>75</b>	<b>175</b>
Gas Turbine Load, %	30	100	100	100	100	100
Chiller Load, %	0	0	88	100	100	100
Duct Burner Load, %	0	0	92%	100	100	100
Steam Injection Level, %	0	0	0	0	0	0
Cooling Tower Utilization, %	100	100	100	100	100	100
Circ pump Utilization, %	33	100	100	100	100	100
Net Power, MW	22.1	55.1	68.4	69.6	69.6	69.6
Net Electric Efficiency, %	34.9	45.7	44.3	44.1	44.1	44.1
Operating Profit, \$/hr	-506	-219	350	1,737	3,130	10,093

# TOPS vs Elink(Multiple design)



If you want to optimize 10 parameters simultaneously and each parameter has 5 trials.

$$5^{10} = 9,765,625 \text{ combinations!}$$



With Elink, if your PC computes one combination within 10 seconds, it will cost you 3 years to find the optimized solution! With TOPS you can find it within minutes!

# Computation Tools Summary

- 1) Both control loops and searcher are “1 adjustable vs 1 target” tools. When you want to match the target value in advance please use control loops otherwise use searcher to find the unknown extreme value.
- 2) DRS is “N vs N” tool, much powerful than 1 vs 1 control loops when matching output values.
- 3) TOPS is “N vs 1” tool, much powerful than searcher when finding one extreme/optimized value.

# **DRS and TOPS for online/offline simulation**

Our customers may build up online/offline monitoring system with accurate hardware model plus DRS & TOPS modules.

In this way, they will master the real status of existing plants and get operating optimization suggestions.

## Q & A Session

- Please forward your questions on the WebEx Chat
- Further questions by email to: [info@thermoflow.com](mailto:info@thermoflow.com)
  
- PP Presentation will be available on the Website / Tutorials
- Video will be available on the Service Center

# Thank you!

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