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Modeling a 3-zone Feedwater Heater

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Summary

1. The present report describes modeling of a 3-zone Feedwater Heater.
2. The model is based on a detailed mass and energy balance complemented by user defined equations defining KPIs.
3. The following KPIs were calculated:
 - TTD – Terminal Temperature Difference
 - DCA – Drain Cooler Approach
 - HTCs – Heat Transfer Coefficients in individual zones
4. The following results of calculation were discussed:
 - Precision (uncertainty) of the desuperheating zone heat duty
 - Precision (uncertainty) of the desuperheating zone heat transfer coefficient.

1. Introduction

Feedwater heaters (FWH) are used in conventional and nuclear plants to preheat boiler feed water. The source of heat is the extraction steam from turbines. The main objectives are to

- improve the thermodynamic efficiency of the steam cycle (so called Carnotization of the cycle)
- lower the thermal shock to the boiler when feedwater enters the boiler
- disburden the LP turbine load.

This report describes modeling and KPI monitoring of a 3-zone feedwater heaters in the program RECON. There are several important subjects which must be mastered in this direction, mainly

- There are a lot of unmeasured streams in the system (uncontrolled extractions, stream parameters, ...) so that a detailed mass and energy balance model must be set up to observe all important parameters
- Thermodynamic analysis of 3-zone Feedwater heaters
- Performance monitoring based on TTD and DCA values.
- Monitoring heat transfer in 3 heat exchangers.

Further it will be modeled a typical large size feedwater heater which is an auxiliary of a condensation turbine.

2. A 3-zone Feedwater Heater (FWH)

2.1. FWH description

Arrangement of a typical feedwater heater, which will be further modeled, is shown in the Fig. 2.1.

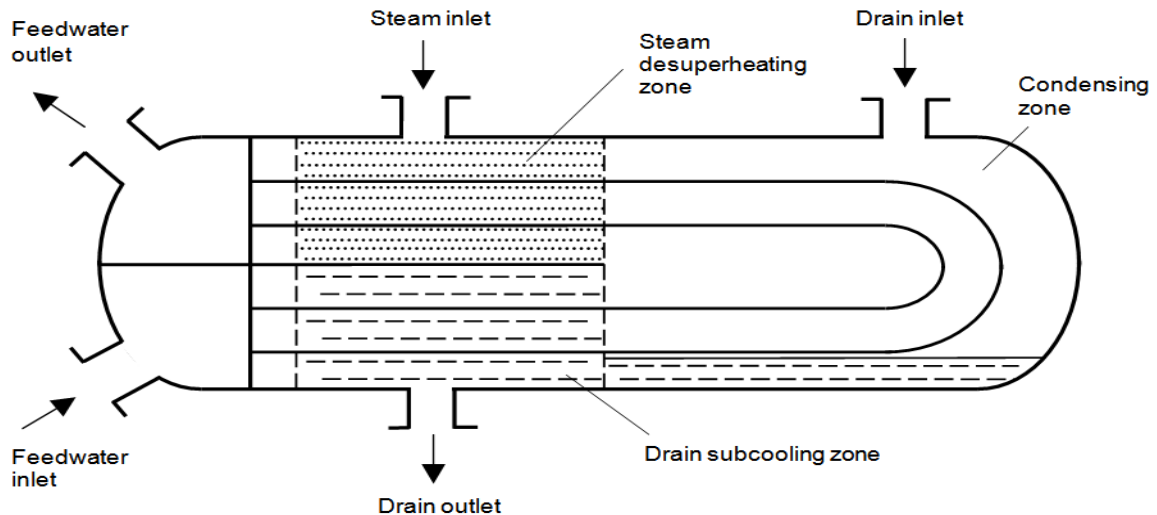


Fig. 2.1: Typical schematic arrangement of a 3-zone feedwater heater

A FWH is usually a shell and tube heat exchanger (condenser) where cold feed water in the tube space of FWH is heated by a contact with superheated steam which is consecutively cooled to the saturation temperature, condenses and the condensate is later subcooled by the fresh feed water.

The FWH consists of 3 zones (sections):

- The steam desuperheating section where the superheated steam is cooled in a contact with dry tubes of the U-tube bundle to the saturation temperature.
- The condensing zone where steam condenses in a contact with tubes. Some FWHs have also inlet of a condensate (drain) from a neighbor FWH. As this drain has higher pressure than is in the condensing zone, it flashes and releases some additional saturated steam.
- The subcooling zone which is flooded by the condensate, where subcooling occurs. Condensate leaves FWH at the bottom (drain).

All zones are equipped with baffles to promote heat transfer. There is therefore some pressure loss, especially in the desuperheating zone, which causes decrease of pressure (and also the saturation temperature) in the condensing zone. The pressure in the condensing zone is important for the performance analysis of FWHs and further will be supposed that this pressure is either measured or can be estimated from parameters of the extraction steam.

2.2. Temperature profiles in a FWH

Temperature profiles in a FWH are shown in the next Fig. 2.2

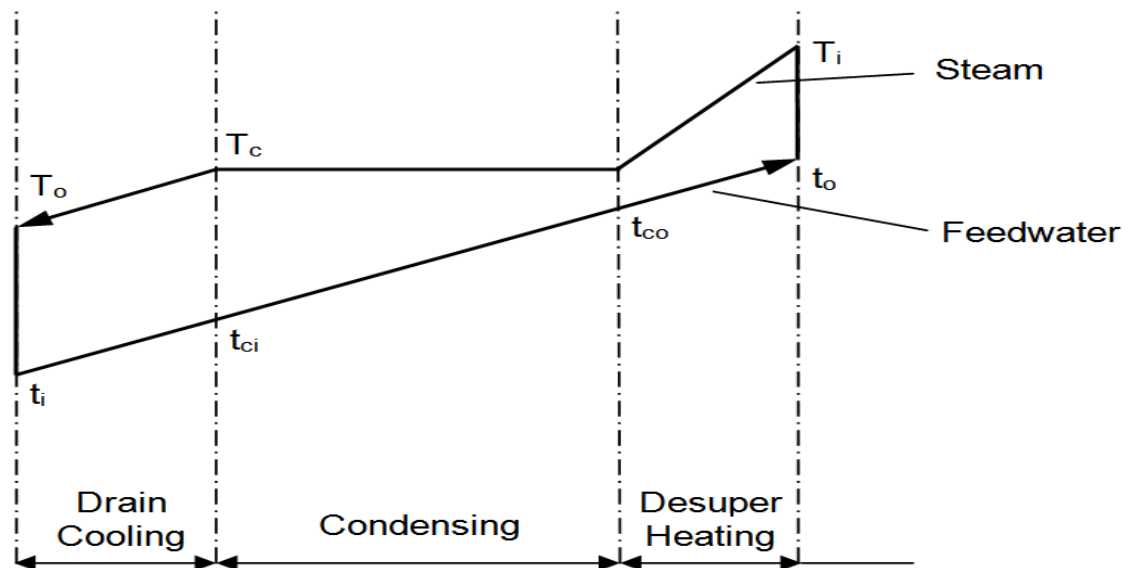


Fig. 2.2: Temperature profiles in a FWH

In practice, in modern power plants all input and output temperatures (indices i and o) are measured. Further there is usually measured pressure in the shell side of the condensing zone. This pressure then defines the saturation temperature T_c because the saturation conditions can be supposed in the condensing zone.

$$T_c = T_{\text{sat}}(P_c) \quad (2-1)$$

where P_c is the pressure in the shell side of the condensing zone.

The remaining temperatures can be calculated on the basis of mass and heat balances.

2.3. Method of solution

At the beginning a mass and heat balance of the FWH must be set up. While this can be a problem for a separated FWH, in a real flowsheet of a power plant there should not be significant problems. Especially, flows of the condensate and the drain from the neighboring FWH are known from the mass and heat balance of the whole steam cycle. Moreover, modeling of equilibrium between water and steam in the condensing zone will add another equation (see later).

The performance of FWHs is in practice frequently characterized by two simple characteristic temperature differences – TTD and DCA:

TTD (Terminal Temperature Difference)

$$TTD = T_c - t_o \quad (2-2)$$

DCA (Drain Cooler Approach)

$$DCA = T_o - t_i \quad (2-3)$$

While the DCA must be always positive, TTD can be both positive or negative, depending on steam superheating.

The other (more important) characteristics of 3-zone FWHs are heat transfer coefficients (HTCs) in the individual zones.

Heat transfer in heat exchangers is usually defined by the following equation:

$$Q = U A dT \quad (2-4)$$

Where

- Q = heat flux
- U HTC
- A heat transfer area
- dT mean temperature difference.

In FWHs the heat transfer area of individual zones is not easy to determine. Moreover, the borders between individual zones need not be fixed, depending on load, FWH degradation, etc. Anyway, it is sufficient to identify the product

$$HTCA = U A \quad (2-5)$$

The Equation (2-4) then reads

$$Q = HTCA dT \quad (2-6)$$

where the heat transfer area is hidden.

Another problem is a definition of dT. An analytical solution for a single phase flow in simple heat exchangers is available but the situation in practice is frequently more difficult. The most frequent model is the Logarithmic Mean Temperature Difference (LMTD), which is the optimal solution for countercurrent heat exchangers. The following equations (2-7) and (2-8) hold for the subcooling zone.

$$\text{LMTD} = \frac{(T_o - t_i) - (T_c - t_{ci})}{\ln \frac{T_o - t_i}{T_c - t_{ci}}} \quad (2-7)$$

In the case of FWH the situation is quite simple for the condensing zone where the use of LMTD is justified. On the other hand side, the remaining two zones have very complicated flow patterns. We still think that the LMTD is applicable even in this case.

The temperature difference can be calculated also as the arithmetic average of temperature differences at exchanger's ends.

For example, in the case of the subcooling zone the temperature difference can be calculated as follows:

$$dT = \frac{(T_o - t_i) + (T_c - t_{ci})}{2} \quad (2-8)$$

To summarize, for subcooling and desuperheating zones both LMTD and arithmetic average temperature difference are available and easily applicable in Recon models. It should be noted that the arithmetic average method is more suitable from the numerical point of view. Also, from the Eq. (2-7) it is clear that LMTD is not defined for equal temperature differences at both sides of a heat exchanger (numerical problems can occur even in the vicinity of such case). In this case the LMTD in Recon is replaced by the arithmetic average.

2.4. Modeling the FWH in Recon

2.4.1 Basic considerations

A detailed balancing flowsheet of a FWH is shown in Fig. 2.3 (compare with Fig. 2.1.).

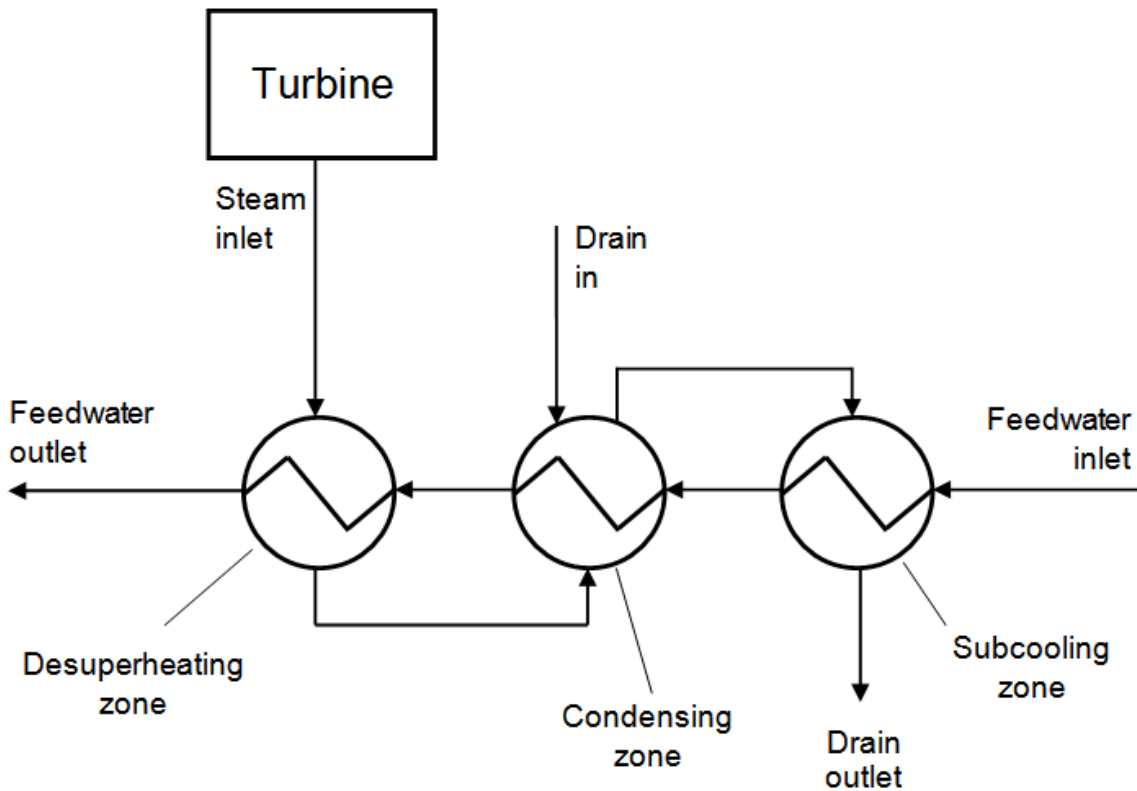


Fig. 2.3: Feedwater Heater – a balancing flowsheet.

The flowsheet created in Recon is shown in the next Fig. 2.4 where is also shown the instrumentation used in the model configuration.

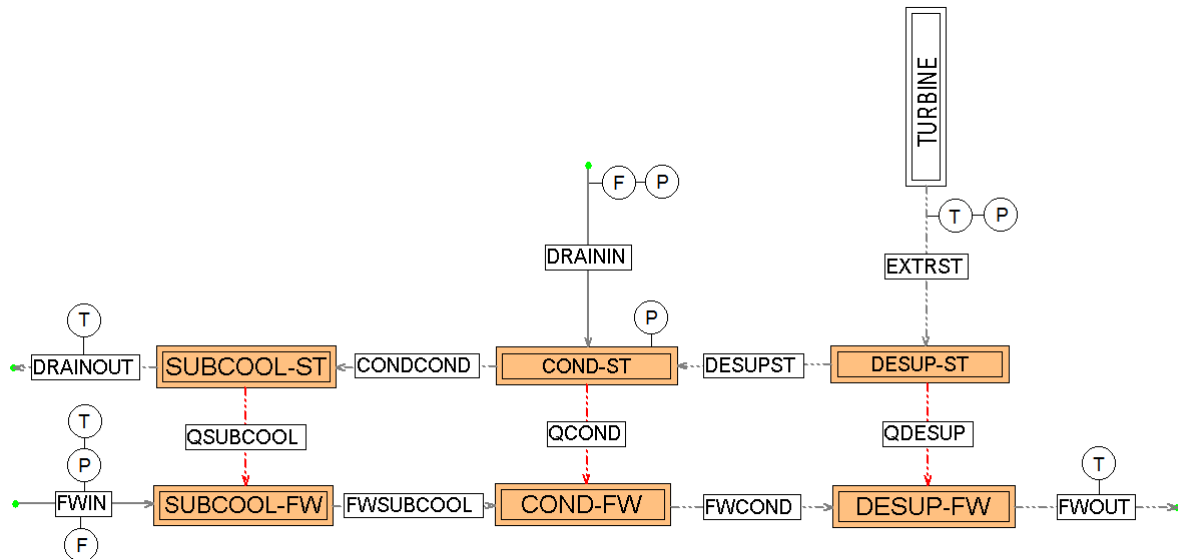


Fig. 2.4: Feedwater Heater – a balancing flowsheet in Recon.

It is supposed that flows of entering feedwater (FWIN) and the drain from the neighboring FWH (DRAININ) are known. In practice these flows are not measured but are known from the overall balance of the feedwater preheat train. The measured temperatures concern inlet and outlet streams of the FWH (extraction steam, drain input and output and feedwater). In practice these values are usually available.

Pressures of the feedwater are sometimes unmeasured but can be estimated (the influence of a variable pressure on feedwater enthalpy is only marginal).

Aside of mass streams there are also energy streams QSUBCOOL, QCOND and QDESUP representing heat duties (fluxes) in individual zones.

2.4.2 Modeling heat nodes

The configuration of mass and energy balances is illustrated on an example of steam side of the desuperheater DESUP-ST, see the next Fig. 2.5.

Node: DESUP-ST

ID: DESUP-ST Description: desuperheater steam space

Geodesic height [M]: Node pres.:

Reaction heat - from database of properties Invariant balance

Sort of calculations:

- Balancing
- Hydraulic node
- Heat node
- Reaction node

Non-energy streams incident with node

Stream	Function	Temperature	Pressure	Wetness
iEXTRST	H2OV(T,P)	EXTRST	EXTRST	
oDESUPST	H2O(P,X)		COND	steam

Reactions in no

Fig. 2.5: Configuration the DESUP-ST node

There are 2 mass streams incident with this node. The enthalpy of the inlet extraction steam EXTRST is calculated by function H2OV(T,P) (superheated vapor defined by temperature and pressure). The outlet stream DESUPST is modeled by function H2O(P,X) (saturated steam at pressure in the condensing zone).

2.4.3 Modeling Key Performance Indicators of the FWH

The performance of the whole FWH is usually characterized by TTD and DCA, the individual zones are characterized by heat transfer coefficients (HTC). In our model we will use HTCA – a product of HTC and the heat transfer area, see Eq. (2-5).

At the beginning there is the calculation of the condensing steam saturated temperature, see Eq. (2-1). This temperature is configured in the editor of User Defined Equations – Model supplements.

User-defined model equations

Standard functions					Logical expressions		Independent variables		Calculated variables		
In	log	sqr			{	}	Mass flow	Temperature	Stream: Enthalpy	Heat duty	Strapping table
exp	10^	*2	abs	sng	.AND.		Concentration	Pressure	Stream: Density	Heat transfer	Density table
7	8	9	(	)	.OR.		Compound: Molar weight	Steam wetness	Stream: Molar weight	Sat. steam: Temperature	Viscosity table
4	5	6	+	-	.LT.	.GT.	Heat flow	Pipe roughness	Stream: Entropy	Sat. steam: Pressure	Auxiliary properties
1	2	3	*	/	.LE.	.GE.		Auxiliary		Reaction extent	
0	.		^		.NE.	.EQ.	User equation			LMTD	

Equations	Working area	<input checked="" type="checkbox"/> Use in model?						
DCA HTCACOND HTCADESUP HTCASUBCOOL LMTDCOND LMTDDESUP LMTDSUBCOOL SATURTCOND TTD	<table border="1"> <thead> <tr> <th>Equation</th> <th>Description</th> </tr> </thead> <tbody> <tr> <td>SATURTCOND</td> <td>saturated temperature in condensing zone</td> </tr> </tbody> </table>	Equation	Description	SATURTCOND	saturated temperature in condensing zone	<table border="1"> <thead> <tr> <th>Checking</th> </tr> </thead> <tbody> <tr> <td><input checked="" type="checkbox"/> </td> </tr> </tbody> </table>	Checking	<input checked="" type="checkbox"/>
Equation	Description							
SATURTCOND	saturated temperature in condensing zone							
Checking								
<input checked="" type="checkbox"/>								
	<table border="1"> <thead> <tr> <th>Equation proper</th> <th>Resulting value</th> </tr> </thead> <tbody> <tr> <td>[T<CONDSATUR>]-[ST<COND>]</td> <td></td> </tr> </tbody> </table>	Equation proper	Resulting value	[T<CONDSATUR>]-[ST<COND>]				
Equation proper	Resulting value							
[T<CONDSATUR>]-[ST<COND>]								

Fig. 2.6: Definition of the saturated temperature in the condensing zone

The saturated temperature CONDSATUR is calculated by function [ST<COND>] where COND is the pressure in the condensing zone. The ST<> function is invoked by the button *Sat.steam Temperature* on the panel.

TTD and DCA are defined also by User Defined Equations. The example of TTD (see Eq. (2-2) is shown in the next Fig. 2.7.

Equations	Working area	<input checked="" type="checkbox"/> Use in model?				
DCA HTCACOND HTCADESUP HTCASUBCOOL LMTDCOND LMTDDESUP LMTDSUBCOOL SATURTCOND TTD	<table border="1"> <thead> <tr> <th>Equation</th> <th>Description</th> </tr> </thead> <tbody> <tr> <td>TTD</td> <td>Terminal Temperature Difference</td> </tr> </tbody> </table>	Equation	Description	TTD	Terminal Temperature Difference	
Equation	Description					
TTD	Terminal Temperature Difference					
	<table border="1"> <thead> <tr> <th>Equation proper</th> </tr> </thead> <tbody> <tr> <td>[V<TTD>]-([T<CONDSATUR>]-[T<FWOUT>])</td> </tr> </tbody> </table>	Equation proper	[V<TTD>]-([T<CONDSATUR>]-[T<FWOUT>])			
Equation proper						
[V<TTD>]-([T<CONDSATUR>]-[T<FWOUT>])						

Fig. 2.7: Definition of the Terminal Temperature Difference

Also HTCA's are defined with the aid of User Defined Equations, the example of desuperheater's HTCA follows:

Equations	Working area	<input checked="" type="checkbox"/> Use in model?				
DCA HTCACOND HTCADESUP HTCASUBCOOL LMTDCOND LMTDDESUP	<table border="1"> <thead> <tr> <th>Equation</th> <th>Description</th> </tr> </thead> <tbody> <tr> <td>HTCADESUP</td> <td>HTCA desuperheating zone</td> </tr> </tbody> </table>	Equation	Description	HTCADESUP	HTCA desuperheating zone	
Equation	Description					
HTCADESUP	HTCA desuperheating zone					
	<table border="1"> <thead> <tr> <th>Equation proper</th> </tr> </thead> <tbody> <tr> <td>[S<QDESUP>]-[V<HTCADESUP>]*[V<LMTDDESUP>]</td> </tr> </tbody> </table>	Equation proper	[S<QDESUP>]-[V<HTCADESUP>]*[V<LMTDDESUP>]			
Equation proper						
[S<QDESUP>]-[V<HTCADESUP>]*[V<LMTDDESUP>]						

Fig. 2.8: Definition of the desuperheater's HTCA

The Equation defining HTCA (see Eq (2-7)) is in the implicit form. The temperature difference LMTDDESUP is the auxiliary variable defined by the following user defined equation:

User-defined model equations

Standard functions					Logical expressions		Independent variables		Calculated variables		
In	log	sqr			{	}	Mass flow	Temperature	Stream: Enthalpy	Heat duty	Strapping table
exp	10^	^2	abs	sng	.AND.		Concentration	Pressure	Stream: Density	Heat transfer	Density table
7	8	9	(	)	.OR.		Compound: Molar weight	Steam wetness	Stream: Molar weight	Sat. steam: Temperature	Viscosity table
4	5	6	+	-	.LT.	.GT.	Heat flow	Pipe roughness	Stream: Entropy	Sat. steam: Pressure	Auxiliary properties
1	2	3	*	/	.LE.	.GE.		Auxiliary		Reaction extent	
0	.		^		.NE.	.EQ.	User equation			LMTD	

Equations **Working area** Use in model?

Equation	Description	Checking	Resulting value
LMTDDESUP	LMTD desuperheating zone	<input checked="" type="checkbox"/>	
Equation proper			
[V<LMTDDESUP>]-[LMTD<EXTRST:CONDSATUR:FWCOND:FWOUT>]			

Fig. 2.9: Definition of the LMTD for the desuperheater.

The LMTD function [LMTD<EXTRST:CONDSATUR:FWCOND:FWOUT>] is invoked by the LMTD button on the panel.

3. Results of modeling

Input data of the task are presented in the Appendix 1, complete results of calculation are in the Appendix 2 (RECON's output file). It is supposed that the reader is familiar with basics of Data Reconciliation in the extent of report [4]. Here are some excerpts of main results:

In the input data it is worth mentioning the uncertainties of measured variables. The uncertainties of measured flows were supposed to be 2 % of measured values and temperature's uncertainties were supposed to be 2 °C.

The iterative calculation proper required 3 iterations. The calculation lasted 0.3 second on a standard desktop PC. The main global characteristics are

G L O B A L D A T A

Number of nodes	7
Number of heat nodes	6
Number of streams	12
Number of energy streams	3
Number of components	1
Number of temperatures	8
Number of pressures	4
Number of auxiliaries	8
Number of measured variables	11
Number of adjusted variables	0
Number of non-measured variables	21
Number of observed variables	21
Number of non-observed variables	0
Number of free variables	0
Number of equations (incl. UDE)	21
Number of independent equations	21
Number of user-defined equations (UDE)	9
Degree of redundancy	0
Mean residue of equations	6.0412E-09
Qmin	0
Qcrit	0
Status (Qmin/Qcrit)	0

There is no redundancy in this task, just solution of a system of 21 equations in 21 unknown variables. No data validation and no gross errors can be detected.

There are several important KPIs which belong to auxiliary variables (TTD, DCA and HTCA). For information there are also temperature differences LMTDs.

A U X I L I A R I E S

Name	Type	Inp.value	Rec.value	Abs.error
DCA	NO	3.900	3.900	2.828
HTCACOND	NO	4168891.129	4136670.915	679761.487
HTCADESUP	NO	326315.384	323455.477	57472.358
HTCASUBCOOL	NO	1192145.222	1186238.525	347172.538
LMTDCOND	NO	16.782	16.755	1.901
LMTDDESUP	NO	29.959	29.906	3.052

```

LMTDSUBCOOL    NO          13.776          13.784          3.781
TTD            NO          3.136           3.136           2.026
(NO = Nonmeasured Observable variable, Inp.value = first guess, Abs.error
= uncertainty)

```

TTD, DCA and LMTDs are in centigrades, HTCAs are in W/°C.

Heat duties of heat exchangers are in the next table:

E N E R G Y S T R E A M S

Name	Type	Inp.value	Rec.value	Abs.error	
QCOND	NO	251.862	249.515	21.644	GJ/H
QDESUP	NO	35.194	34.824	3.495	GJ/H
QSUBCOOL	NO	59.124	58.864	3.801	GJ/H

We can ask a question, which variables are influencing the uncertainty of important variables? The next tables present shares of important variables on the variance of the heat flux QDESUP and HTCA of the desuperheater HTCADESUP (the vector of shares):

REPORT ABOUT PROPAGATION OF ERRORS

Type Variable

HF QDESUP

THE VARIANCE OF GIVEN VARIABLE IS CAUSED MAINLY BY:

Type Variable	Share
MF FWIN	6 %
T EXTRST	4 %
T FWIN	42 %
T FWOUT	47 %
Sum	98 %

Type Variable

V HTCADESUP

THE VARIANCE OF GIVEN VARIABLE IS CAUSED MAINLY BY:

Type Variable	Share
T FWIN	9 %
T FWOUT	88 %
Sum	97 %

Legend:

MF Mass flow
T Temperature

The vector of Shares informs how much the individual primary variables influence the Efficiency's variance. In the case of the heat duty QDESUP it is clear that there are 2 variables which together represent 89 % of the QDESUP variance:

Temperature FWIN (feed water inlet)
Temperature FWOUT (feed water outlet)

These variables represent the bottleneck of this heat duty precision. These instruments should be therefore carefully maintained. It should be noted that the uncertainties of temperatures were set as 2 °C.

Literature

- [1] ANSI/ASME PTC 12.1 -2000 (R2005): Closed Feedwater Heaters
- [2] IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam. International Association for the Properties of Water and Steam. ASME PRESS, NY 1998
- [3] Gay R.R., Palmer C.A., Erbes M.R.: Power Plant Performance Monitoring. Tech Books International, New Delhi 2006
- [4] Process data validation in practice. Applications from chemical, oil, mineral and power industries. Report CPT 229-07. Usti nad Labem 2007

Appendix 1: RECON's input data

RECON 11.1.6-Pro [CHemPlant]
 Task: FWH-3PARTS (3 sectional feed water heater)

GLOBAL DATA

Number of nodes	7
Number of heat nodes	6
Number of streams	12
Number of energy streams	3
Number of components	1
Number of temperatures	8
Number of pressures	4
Number of auxiliaries	8

COMPONENTS

ID	Description	Database of properties

H2O		

NODES

ID	Description	Remark

ENVIRON	Environment	unbalanced
COND-FW	condensing zone - feed water si	
COND-ST	condenser steam space	
DESUP-FW	desuperheater Feed Water side	
DESUP-ST	desuperheater steam space	
SUBCOOL-FW	subcooler Feed Water space	
SUBCOOL-ST	subcooler steam side	
TURBINE	turbine extraction segment	unbalanced

STREAMS

ID	From node	To node	Description

CONDCOND	COND-ST	SUBCOOL-ST	condensate from condensing zone
DESUPST	DESUP-ST	COND-ST	steam from desuperheater
DRAININ	ENVIRON	COND-ST	drain from the previous heater
DRAINOUT	SUBCOOL-ST	ENVIRON	drain out
EXTRST	TURBINE	DESUP-ST	extraction steam
FWCOND	COND-FW	DESUP-FW	Feed Water from condenser
FWIN	ENVIRON	SUBCOOL-FW	feed water inlet
FWOUT	DESUP-FW	ENVIRON	Feed Water outlet
FWSUBCOOL	SUBCOOL-FW	COND-FW	Feed Water from sucooler
QCOND	COND-ST	COND-FW	heat flux condenser
QDESUP	DESUP-ST	DESUP-FW	heat flux desuperheater
QSUBCOOL	SUBCOOL-ST	SUBCOOL-FW	heat flux subcooler

MATERIAL STREAMS

ID	Type	Value	Max.error

CONDCOND	N	334.4571	T/H
DESUPST	N	139.4571	T/H
DRAININ	M	195.0000	2.0000% T/H
DRAINOUT	N	334.4571	T/H
EXTRST	N	139.4571	T/H
FWCOND	N	2023.2000	T/H
FWIN	M	2023.2000	2.0000% T/H
FWOUT	N	2023.2000	T/H
FWSUBCOOL	N	2023.2000	T/H

ENERGY STREAMS [GJ/H]

ID	Type	Value	Max.error

QCOND	N	251.8621
QDESUP	N	35.1945
QSUBCOOL	N	59.1237

T E M P E R A T U R E S [C]

ID	Type	Value	Max.error
CONDSATUR	N	271.2358	
DRAININ	M	274.9000	2.0000
DRAINOUT	M	235.1000	2.0000
EXTRST	M	349.0000	2.0000
FWCOND	N	264.4097	
FWIN	M	231.2000	2.0000
FWOUT	M	268.1000	2.0000
FWSUB	N	237.6904	

P R E S S U R E S [BAR]

ID	Type	Value	Max.error
COND	M	56.1000	0.5000%
DRAININ	M	85.0000	0.5000%
EXTRST	M	60.0000	1.0000%
FWIN	M	302.0000	0.5000%

W E T N E S S E S [%]

ID	Type	Value	Max.error
steam	F	0.000E+0	
water	F	100.0000	

A U X I L I A R I E S

ID	Type	Value	Max.error
DCA	N	3.9000	
HTCACOND	N	4168891.1293	
HTCADESUP	N	326315.3845	
HTCASUBCOOL	N	1192145.2221	
LMTDCOND	N	16.7818	
LMTDDESUP	N	29.9595	
LMTDSUBCOOL	N	13.7762	
TTD	N	3.1358	

H E A T N O D E S

ID	Stream	Function	Temperature	Pressure	Wetness
COND-FW	FWSUBCOOL	H2O(L,T,P)	FWSUB	FWIN	
	FWCOND	H2O(L,T,P)	FWCOND	FWIN	
COND-ST	DRAININ	H2O(P,X)		DRAININ	water
	DESUPST	H2O(P,X)		COND	steam
	CONDCOND	H2O(P,X)		COND	water
DESUP-FW	FWCOND	H2O(L,T,P)	FWCOND	FWIN	
	FWOUT	H2O(L,T,P)	FWOUT	FWIN	
DESUP-ST	EXTRST	H2O(V,T,P)	EXTRST	EXTRST	
	DESUPST	H2O(P,X)		COND	steam
SUBCOOL-FW	FWIN	H2O(L,T,P)	FWIN	FWIN	
	FWSUBCOOL	H2O(L,T,P)	FWSUB	FWIN	
SUBCOOL-ST	CONDCOND	H2O(P,X)		COND	water
	DRAINOUT	H2O(L,T,P)	DRAINOUT	COND	

U S E R E Q U A T I O N S

ID	Description Programmatic code	Remark
DCA	Drain Cooler Approach [V<DCA>]-([T<DRAINOUT>]-[T<FWIN>])	Model
HTCACOND	HTCA condensing zone [S<QCOND>]-[V<HTCACOND>]*[V<LMTDCOND>]	Model
HTCADESUP	HTCA desuperheating zone [S<QDESUP>]-[V<HTCADESUP>]*[V<LMTDDESUP>]	Model
HTCASUBCOOL	HTCA subcooler [S<QSUBCOOL>]-[V<HTCASUBCOOL>]*[V<LMTDSUBCOOL>]	Model
LMTDCOND	LMTD condensing zone [V<LMTDCOND>]-[LMTD<CONDSATUR:CONDSATUR:FWSUB:FWCOND>]	Model
LMTDDESUP	LMTD desuperheating zone [V<LMTDDESUP>]-[LMTD<EXTRST:CONDSATUR:FWCOND:FWOUT>]	Model
LMTDSUBCOOL	LMTD subcooling zone [V<LMTDSUBCOOL>]-[LMTD<CONDSATUR:DRAINOUT:FWIN:FWSUB>]	Model
SATURTCOND	saturated temperature in condensing zone [T<CONDSATUR>]-[ST<COND>]	Model
TTD	Terminal Temperature Difference [V<TTD>]-([T<CONDSATUR>]-[T<FWOUT>])	Model

Appendix 2: RECON's output file

RECON 11.1.6-Pro [ChemPlant]

Task: FWH-3PARTS (3 sectional feed water heater)

Balance: [29.10.2013 10:00; 29.10.2013 11:00]

I T E R A T I O N S

Iter	Qeq	Qx	Qy	Qmin
START	3.9382E+04			
1	4.1897E+01	0.0000E+00	3.1653E+04	0.0000E+00
2	8.8289E-05	0.0000E+00	2.8344E+00	0.0000E+00
3	6.0412E-09	0.0000E+00	3.5774E-05	0.0000E+00

Legend:

Qeq mean residual of equations

Qx mean increment of measured variables in iteration

Qy mean increment of non-measured variables in iteration

Qmin least-square function

G L O B A L D A T A

Number of nodes	7
Number of heat nodes	6
Number of streams	12
Number of energy streams	3
Number of components	1
Number of temperatures	8
Number of pressures	4
Number of auxiliaries	8
Number of measured variables	11
Number of adjusted variables	0
Number of non-measured variables	21
Number of observed variables	21
Number of non-observed variables	0
Number of free variables	0
Number of equations (incl. UDE)	21
Number of independent equations	21
Number of user-defined equations (UDE)	9
Degree of redundancy	0
Mean residue of equations	6.0412E-09
Qmin	0
Qcrit	0
Status (Qmin/Qcrit)	0

S T R E A M S

Name	Type	Inp.value	Rec.value	Abs.error	
CONDCOND	NO	334.457	332.988	13.935	T/H
DESUPST	NO	139.457	137.988	13.559	T/H
DRAININ	MN	195.000	195.000	3.900	T/H
DRAINOUT	NO	334.457	332.988	13.935	T/H
EXTRST	NO	139.457	137.988	13.559	T/H
FWCOND	NO	2023.200	2023.200	40.464	T/H
FWIN	MN	2023.200	2023.200	40.464	T/H
FWOUT	NO	2023.200	2023.200	40.464	T/H
FWSUBCOOL	NO	2023.200	2023.200	40.464	T/H

E N E R G Y S T R E A M S

Name	Type	Inp.value	Rec.value	Abs.error	
QCOND	NO	251.862	249.515	21.644	GJ/H
QDESUP	NO	35.194	34.824	3.495	GJ/H
QSUBCOOL	NO	59.124	58.864	3.801	GJ/H

T E M P E R A T U R E S

Name	Type	Inp.value	Rec.value	Abs.error	
CONDSATUR	NO	271.236	271.236	0.321	C
DRAININ	MN	274.900	274.900	2.000	C
DRAINOUT	MN	235.100	235.100	2.000	C
EXTRST	MN	349.000	349.000	2.000	C
FWCOND	NO	264.410	264.449	1.780	C
FWIN	MN	231.200	231.200	2.000	C
FWOUT	MN	268.100	268.100	2.000	C
FWSUB	NO	237.690	237.662	1.851	C

P R E S S U R E S

Name	Type	Inp.value	Rec.value	Abs.error	
COND	MN	56.100	56.100	0.281	BAR
DRAININ	MN	85.000	85.000	0.425	BAR
EXTRST	MN	60.000	60.000	0.600	BAR
FWIN	MN	302.000	302.000	1.510	BAR

W E T N E S S E S

Name	Type	Inp.value	Rec.value	Abs.error	
steam	F	0.00E+0	0.00E+0		%
water	F	100.000	100.000		%

A U X I L I A R I E S

Name	Type	Inp.value	Rec.value	Abs.error	
DCA	NO	3.900	3.900	2.828	
HTCACOND	NO	4168891.129	4136670.915	679761.487	
HTCADESUP	NO	326315.384	323455.477	57472.358	
HTCASUBCOOL	NO	1192145.222	1186238.525	347172.538	
LMTDCOND	NO	16.782	16.755	1.901	
LMTDDESUP	NO	29.959	29.906	3.052	
LMTDSUBCOOL	NO	13.776	13.784	3.781	
TTD	NO	3.136	3.136	2.026	

End of results

Calculations lasted 00:00:0.301
 Report created 12.11.2013 12:20:07