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Balancing and Data Reconciliation of a coal fired boiler

Monitoring boiler efficiency

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Summary

1. The present report describes the modeling and data reconciliation of a pulverized coal fired boiler.

2. The model is based on a detailed mass, component and energy balance of main process units (air preheater, firebox, steam superheaters, economizer and steam coolers). The combustion chamber is modeled as a reaction invariant chemical reactor. The balancing model was complemented by user defined equations defining KPIs.

3. The following KPIs were calculated:

   - Efficiency of the boiler
   - Estimation of the coal consumption which is not measured
   - Fouling of heat transfer areas of all heat exchangers (steam superheaters, economizer, air preheater) in the form of HTC (Heat Transfer Coefficients)
   - Detailed mass and heat balance of the system including heat duties of all heat transfers
   - Information about leaks and the economizer bypass

4. The following results of calculation were discussed:

   - Precision of boiler's efficiency determination and possible improvement in this direction (key measured variables influencing the precision)
   - Precision of other KPI's
   - Possibilities and limitations of gross errors detection.

1. Introduction

Coal fired power stations are the most common plants which convert coal into electric energy and large power stations provide the majority of the world's electricity. Boilers which generate steam are complex systems which require adequate monitoring, control and maintenance.

This report describes modeling and data reconciliation of coal fired boilers in the program RECON. There are several challenging features which must not be neglected during this activity, for example

- The on-line measurement of the coal input is frequently not accurate enough for a direct determination of boiler's efficiency

- The quality of the coal is often not constant (the content of water, ash and other qualitative variables are variable or several kinds of coal can be blended)

- There can be significant leaks in a boiler causing a not required entry of air in a boiler

- Mass and energy balance of boilers requires mastering several unit operations, from chemical reactions in the combustion chamber to balancing high pressure steam, sometime in the supercritical state

- High temperatures (especially in the flue gas path) causing problems in temperature measurement due to the radiation)

- Different systems of units occurring in one task (generally the mass balance complemented by volume measurement of air and composition of flue gases in moles measured on the dry basis).

   Further will be modeled a typical medium size coal fired boiler with air preheat and steam superheaters. As there are two fuels (coal and a fuel gas), the solution can be also a prototype for gas fueled boilers (in general, gas fueled boilers are simpler than coal fired boilers, as concerns their modeling). Sometimes we can meet boilers with a steam reheat, but this is not a significant problem in modeling.

2. A pulverized coal fired boiler

2.1. System description

A pulverized coal fired boiler is a boiler that generates steam by burning pulverized coal that is blown in a mixture with the air to the combustion chamber (firebox). Pulverized coal fired boilers provide steam for producing about 50 % of the world's electric power supply. A typical boiler of such construction is shown in Fig. 2.1.

Coal is ground in the presence of the air and then is injected in the firebox. In the firebox there are furnace tubes connected with the steam drum. In this system water circulates, evaporates and steam is separated from water in the steam drum. Steam leaves the steam drum in a state which is very close to the saturated steam at pressure in the steam drum. The saturated steam is further superheated in three steam superheaters (SSH) in contact with hot flue gases. Between steam superheaters there are two steam coolers where steam is cooled by spraying the feed water to maintain steam temperature in an acceptable region. Flue gases also pass their energy to the feed water in the economizer. To control the exit flue gas temperature there is an unmeasured bypass of the economizer which is manually adjusted by operators.

The mineral part of the coal forms the bottom ash (slag), which is removed from the bottom of the firebox and the fly ash (further denoted simply as ash), which is separated and removed from the system in the economizer and finally in the electrostatic separator.

The air is brought to the boiler at an elevated pressure by a fan. Some air at the ambient temperature is used in coal mills. Most of the air is preheated in contact with flue gases. The preheated air is then used as an additional air in coal mills, as the air for burners and the rest as the tertiary air brought in the firebox.

There are several problems which can be observed in utilization of such boiler. Heat transfer surfaces in the boiler (steam superheaters and the economizer) can be fouled by the ash. Such deposits must be periodically removed by steam injection. In downstream parts of a boiler the pressure of flue gases is below the ambient, so that some suction of the ambient air can occur. Some types of air preheat heat exchangers are not completely tight so that the incoming air can mix with flue gases with negative effect on the overall boiler efficiency. All such problems should be monitored and solved.

2.2. Targets of monitoring

The following information is required:

- Efficiency of the boiler
- Estimation of the coal consumption which is not measured
- Fouling of heat transfer areas of all heat exchangers (steam superheaters, economizer, air preheater) in the form of HTC (Heat Transfer Coefficients)
- Detailed mass and heat balance of the system including heat duties of all heat transfers
- Information about leaks and the economizer bypass
- Data validation as concerns possible instrumentation errors and malfunction.

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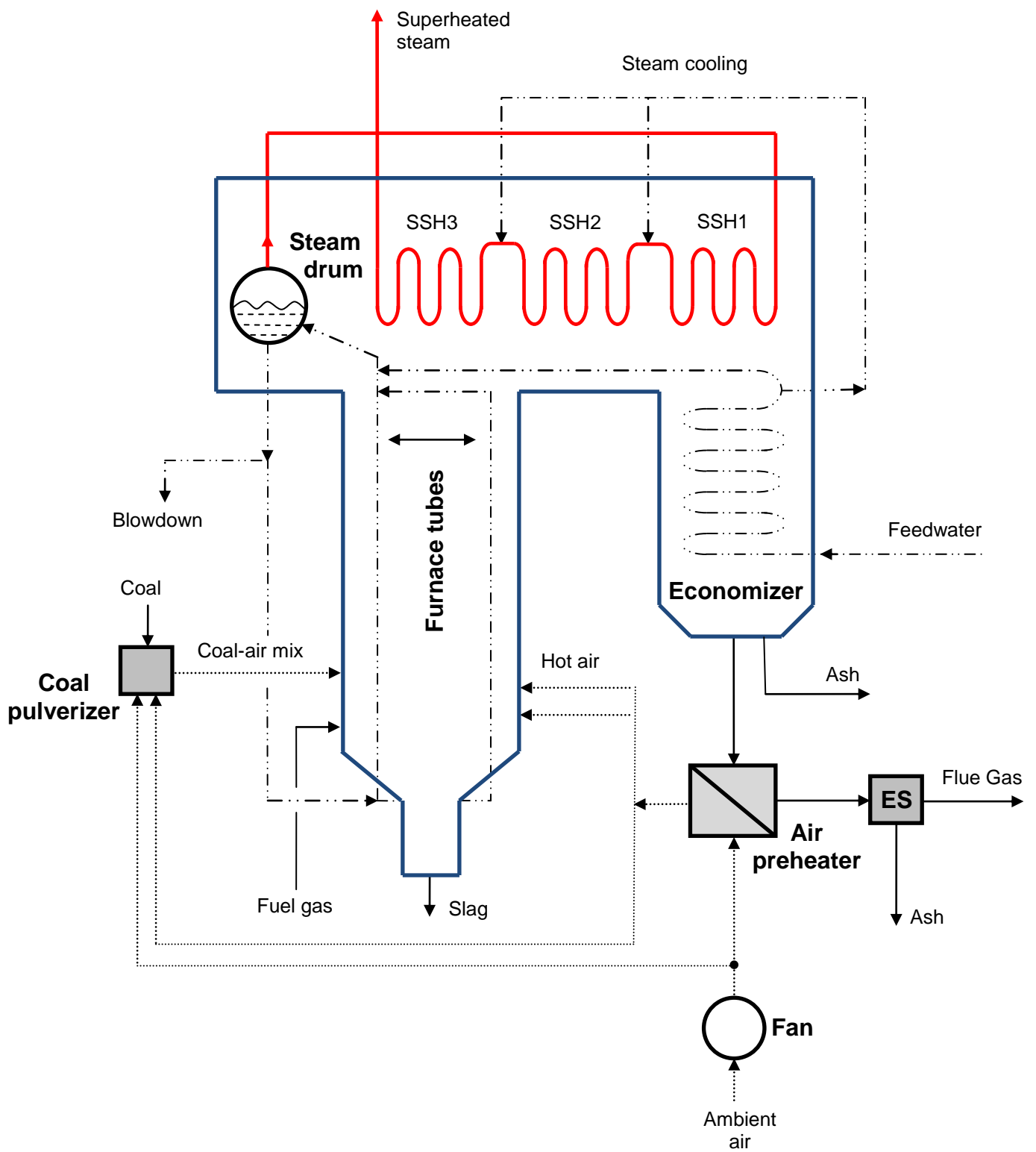
Fig. 2.1: A pulverized coal-fired boiler

2.3. Method of solution

There exits the international standards [1] which deals with acceptance test of boilers (new boilers or boilers after revamps) (see also the another similar standard [5] on this subject). The document [1] will be used as a basis in creating the model.

The most important is the determination of the boiler efficiency. There are 2 methods described in [1] which will be here a little bit simplified:

1. In the **direct method** the efficiency is defined as a ratio of the useful heat transferred to the water and steam in the boiler to the total energy brought to the system (mainly the low heating value of the fuel).

$$\eta_D = \frac{E_u}{E_{tot}}$$ (2-1)

where η_D boiler efficiency determined by the direct method

                 E_{tot} total energy brought in the boiler

                 E_u useful energy transferred to the feed water and steam

2. In the **indirect method** the efficiency is determined as

$$\eta_I = 1 - \frac{E_{loss}}{E_u + E_{loss}}$$ (2-2)

where η_I boiler efficiency determined by the indirect method

                 E_{loss} sum of all losses

Obviously

$$E_{tot} = E_u + E_{loss}$$ (2-3)

The advantage of the indirect method is that it does not require the knowledge of the feed of the fuel (which is frequently difficult to measure on-line). Moreover, the result of the indirect method is in most cases more precise than in the direct method.

Further we will use the indirect method. In our model the following assumptions will be accepted:

1. The useful heat transferred to the feed water and to the steam are heat fluxes in the

   - boiler (transformation of the feed water into a saturated steam)
   - 3 steam superheaters
   - economizer

2. The losses consist mostly of the apparent heat of the following streams:

- Slag
- 2 ash streams
- flue gas leaving the electrostatic separator
- heat loss from the whole boiler by convention and radiation. This loss is calculated as a constant from [1], Eq.(8.3-42), depending on the maximum design heat power of the boiler.

There were the following simplification done: the loss by incomplete combustion was neglected. The content of CO in flue gas is negligible from the balancing point of view (less than 100 ppm by volume). The information about the incompletely combusted flammable part of the coal presented in the ash was not available. Also the heat of the incoming air was not included in the efficiency calculation.

The indirect method of the efficiency determination requires the information about the apparent heat loss of streams leaving the boiler (slag, ash and flue gases). To calculate heat loss in these streams, the hypothetical coolers must be implemented in the balancing model (see Section 2.5). In these coolers all streams are cooled to the *reference temperature.* The reference temperature 25 ^{o}C was selected in this case.

The Blowdown requires some discussion. The Blowdown in our case is recycled via a feed water treatment plant, so that its energy is not lost. In the opposite case its energy should be added to other loss streams.

2.4. The balancing flowsheet

Before creating a complex flowsheet in RECON it is good to draw a simple flowsheet which can be used during the model building in RECON. Such a sketch is shown in Fig. 2.2.

The furnace part of the system is separated into 3 balancing nodes:

- *Combustion chamber* where the pulverized coal, fuel gas and air are mixed and burned. Leaving gases and ash create a mixture which leaves this node. There is no heat flux from this node and the calculated temperature in this node is the so-called *theoretical flame temperature*.
- *Flame* is the hypothetical node which serves for a heat transfer from the firebox to the water part of the boiler and from this node is also withdrawn the heat loss stream by convention and radiation.
- The *Boiler* node represents tubes in the firebox and the drum. It is supposed that steam leaving this node is saturated steam at the pressure in the drum. In reality this steam is wet.

It should be noted that this part of the model is idealized. In practice there is probably no theoretical flame temperature inside the firebox due to a continuous heat transfer to other parts of the boiler. Also the steam leaving the drum is not saturated. But all this has no significant effect on final results (boiler efficiency , etc.).

Flue gases and ash are then in a less or more countercurrent contact with steam in 3 steam superheaters and later with the feed water in the economizer. The economizer can be bypassed on the flue gas side to control the exit flue gas temperature. There are also 2 steam coolers on the steam path where the steam is cooled by spraying a part of the feed water in the steam.
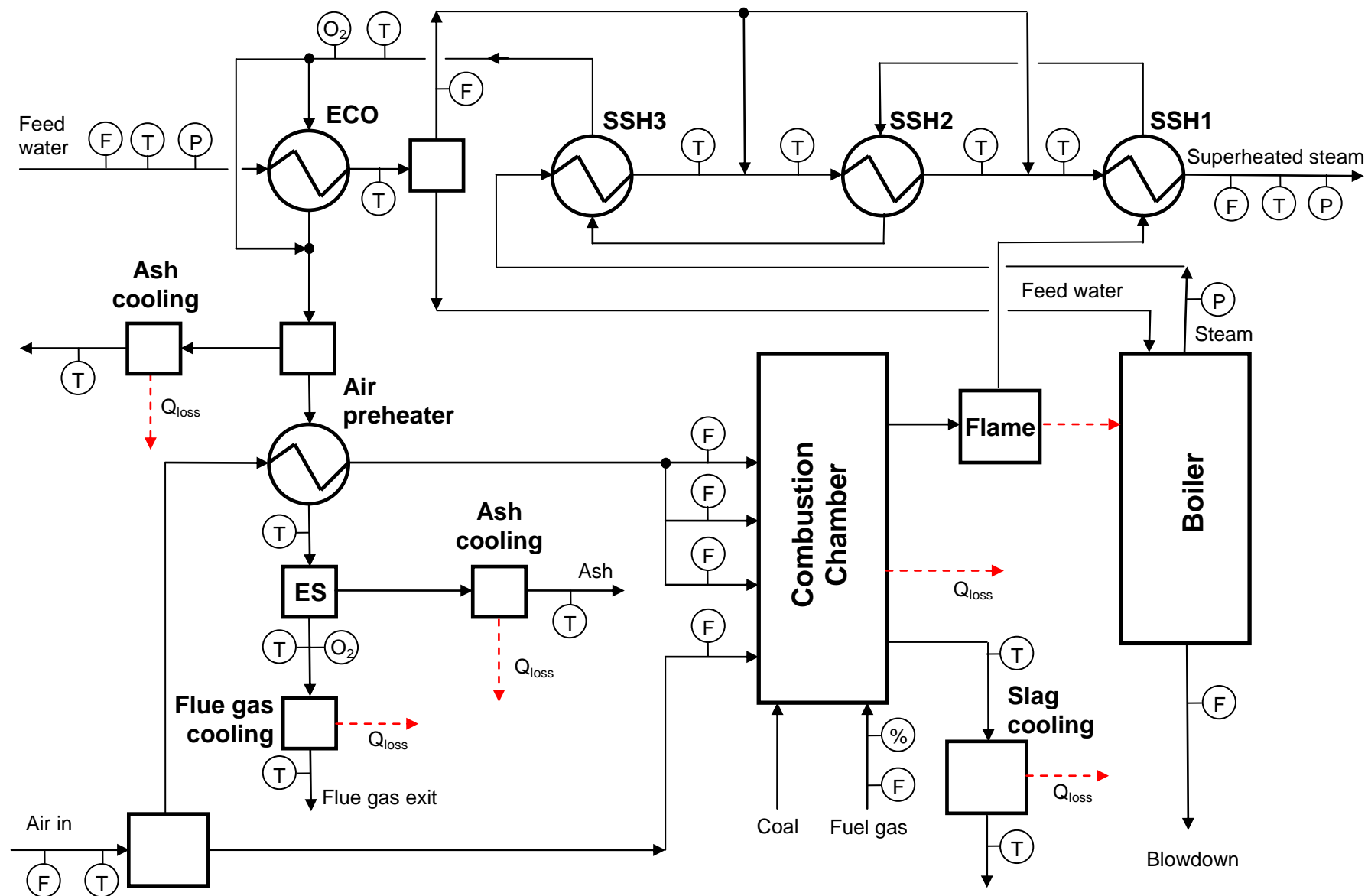
Fig. 2.2: A pulverized coal-fired boiler – a balancing flowsheet

The slag and the ash are removed from the system from the firebox and in the economizer and the electrostatic separator. On these places are installed hypothetical coolers which will be later needed for calculating heat losses. A similar hypothetical cooler is placed at the end of the flue gas path to calculate the flue gas heat loss.

There is a lot of instrumentation shown on the flowsheet. This is important for observability and redundancy of the model. Let's discuss some important observations:

- Important is the fact that the coal input is not measured so that the indirect method of the efficiency determination must be used.

- There is the complete temperature measurement on the steam path. This makes possible to calculate the enthalpy balance around all superheaters, economizer and also around steam coolers.

- The balance around steam coolers makes possible to calculate the amount of the feed water entering steam coolers. As the overall amount of the feed water to steam coolers is directly measured, there is one degree of redundancy.

- There exist some thermometers in the flue gas path in the boiler but due to high temperatures they are unreliable due to radiation. The first thermometer which can be trusted is at the flue gas inlet to the economizer.

- There are 2 analyzers of oxygen, the first at the inlet to the economizer and the second at the outlet of the electrostatic separator.

- There is redundancy on the air path where all flows are measured

2.5. Modeling in RECON

2.5.1 Basic considerations

The boiler flowsheet in RECON is shown in Fig. 2.5. The system of units is shown in Fig. 2.3.

Fig. 2.3: Definition of physical units

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As the most of measured flow variables is in tons per hour, the mass balance was selected as a basis of calculation. The system of pressure measurement MPag requires definition of the atmospheric pressure which is 0.101325 MPa. The energy unit is GJ and the power unit is GJ/HR. The more common power unit in the Power industry - MW - must be re-calculated if it is used.

The list of 11 components occurring in our problem is shown on the next panel.

List of task's components

	ID	Description	Database of	
	H2OV	steam	Steam	
	H2OL	water	Water	
	O2	oxygen	Oxygen	
	N2	nitrogen	Nitrogen	
	AR	argon	Argon	
	CO2	CO2	Carbon dioxide	
	AH	ash	Ash	
	SO2	SO2	Sulfur dioxide	
▶	COAL	softcoal	Soft coal aver	
	CH4	methane	Methane	
	CO	CO	Carbon monoxide	

Soft coal aver: Composition

	Element	x	Auxiliary	
▶	C	70.67		
	H	5.9		
	N	0.95		
	O	20.5		
	S	1.98		

Fig. 2.4: Configuration of components

The enthalpy calculations require thermodynamic properties of components and every component must be therefore linked with the corresponding item in the RECON's database of physical properties (column "Database of …"). This database contains more than 400 pure components and users can also define new pure components and also empirical components like coal. The composition and other properties of empirical components can be defined by the RECON's administrator only in the Administration – Physical properties data. The example of an average soft coal properties is shown in the next panel:
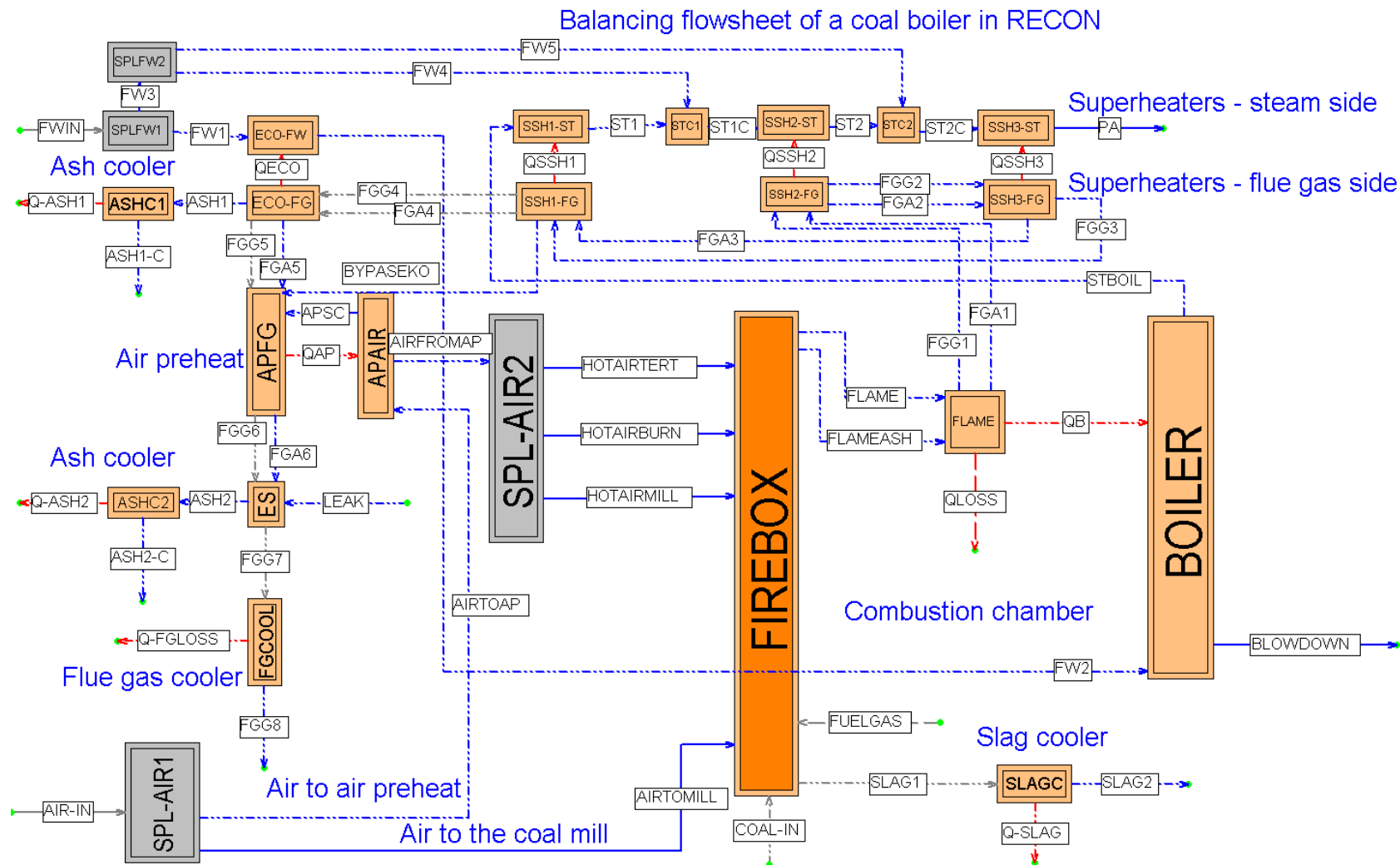
Fig. 2.5: Balancing flowsheet of the boiler in RECON. Abbreviations: FGA – flue gas ash; FGG – flue gas gas; Q – heat flux; SPL – splitter; SSH – steam superheater; ST – steam; STC – steam cooler.

Name	CAS	Type	MW
Soft coal aver		Empirical	100

Name	CAS	Type	MW
Soft coal aver		Empirical	100
Steam	7732185	Chemical	18,016
Styrene	100425	Chemical	104,15
Sulfur	7704349	Chemical	32,064
Sulfur dioxide	7446095	Chemical	64,066
Sulfur trioxide	7446119	Chemical	80,066
Sulfuric acid	7664939	Chemical	98,078
Terphenyl (m-)	92068	Chemical	230,309
Tetradecane (n-)	629594	Chemical	198,38
Tetradecene (1-)	1120361	Chemical	196,379
Tetraethylene glycol	112607	Chemical	194,2
Tetrahydrofuran	109999	Chemical	72,12
Tetrachloroethane (1,1,1,2	630206	Chemical	167,85
Tetrachloroethane (1,1,2,2	79345	Chemical	167,85
Tetrachloroethylene	127184	Chemical	165,83
Tetramethylbutane (2,2,3,3	594821	Chemical	114,233
Tetramethylhexane (2,2,3,3	13475815	Chemical	142,287
Tetramethylhexane (2,2,5,5	1071814	Chemical	142,287
Tetramethylpentane (2,2,3,	7154792	Chemical	128,26
Tetramethylpentane (2,2,3,	1186534	Chemical	128,26
Tetramethylpentane (2,2,4,	1070877	Chemical	128,26
Tetramethylpentane (2,3,3,	16747389	Chemical	128,26
Thiophene	110021	Chemical	84,13

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Composition

Element	Mass %
H	5,9

Element	Mass %
C	70,67
H	5,9
N	0,95
O	20,5
S	1,98

Units: Mass %

Sum	100

API parameters
Units: 1, K, cSt

Sp.gravity	
MeABP	
KV100	
KV210	

Formation heat
Units: kJ/kmol

Form.heat	-333868

☑ From lower comb.heat
Units: kJ/kg

Heat (lower)	27097

Fig. 2.5: Definition of composition of the flammable part of a soft coal

It is supposed that a coal is composed of 3 components: water, ash and the flammable part which is marked in the database as "Soft coal aver". It is supposed that the flammable part consists of carbon, hydrogen, nitrogen, oxygen and sulphur. While pure components are usually characterized by their heats of formation, in the case of coal the Low Heating Value (heat of combustion when water in flue gases is in vapor state) is more common (LHV can be calculated from the heat of formation and vice versa). The coal composition can be either some average or can be imported on-line from some data source. Of other components we mention Ash, the fictive element representing the mineral part of the coal (atomic weight 100).

A special discussion requires the component water (H_2O). There are two places in the model where water behaves in a different way. In the pure water path (feed water, boiler proper and steam) thermodynamic properties of water are modeled according to the IAPWS IF-97 method [2]. A different situation is in the air – coal and the flue gas path. Water enters the firebox mostly in the form of a coal moisture and partially also as an air humidity and water is also created during combustion from hydrogen presented in the flammable part of coal. Application of the IAPWS method is not possible in this case as water is here in complex mixtures. The proper way of modeling is to view water as two components – liquid water (presented in the coal) and gaseous water (presented in the incoming air and also in flue gases). The enthalpy of the water vapor in flue gases is calculated from the model of ideal gas as the temperature on the flue gas path is high and pressure is low [3].

In the flowsheet we will frequently use so-called *dependent streams*. This means that the composition of a dependent stream is the same as the composition of the so-called *master stream.* This hold for all air streams and also for most of flue gas streams. This makes the model configuration less tedious and resulting models are simpler. In the following parts of this chapter a reader should refer to the RECON flowsheet in Fig. 2.5.

2.5.2 Modeling the combustion chamber

Further we will look at the combustion chamber including heat transfer to the boiler proper (nodes FIREBOX, FLAME and BOILER). The reaction part of the combustion chamber (node FIREBOX) is modeled as a so-called *Reaction invariant chemical reactor*. The configuration panel of the firebox is shown in the next figure.

Node: FIREBOX

Stream	Function	Temperature	Pressure	Wetness
iAIRTOMILL	AIR	AMBIENTAI		
iCOAL-IN	COAL	T25		
iFUELGAS	IG(T)	T25		
iHOTAIRBURN	AIR	AIREXAP		
iHOTAIRMILL	AIR	AIREXAP		
iHOTAIRTERT	AIR	AIREXAP		
oFLAME	IG(T)	TFLAME		
oFLAMEASH	ASH	TFLAME		
oSLAG1	ASH	TSLAG		

Fig. 2.6: The configuration of the firebox

There are 4 streams of air entering the FIREBOX (AIRTOMILL, HOTAIRBURN, HOTAIRMILL and HOTAIRTERT). The fuel streams are COAL-IN and FUELGAS). Outputs are SLAG1 and FLAME (representing gaseous part of flue gases) and FLAMEASH representing the flying ash. The separation of flue gases into two streams is inevitable as it is not possible to incorporate solid ash into the gaseous part which is treated as an ideal gas. This fact will be seen in the whole flue gas path till the electrostatic separator where the flying ash is separated definitely.

The functions for calculating enthalpies for air, ash and coal are simple polynoms as functions of temperature. The IG(T) function calculates enthalpy of gases available in the RECON's database of physical properties.

The invariant balance option (the checkbox in the panel) means that there are needed no reactions in the model. The balance is reconciled on the basis of conservation of chemical element in the FIREBOX node. The heat of combustion is calculated from heats of combustion of streams connected with the firebox. In this process also the evaporation of coal moisture is respected.

The temperature TFLAME represents the theoretical flame temperature calculated from the energy balance of the firebox. It is the main result of this calculation (even though there exists no such real temperature in the boiler). The next balancing node belonging to the firebox area is the FLAME node. Its purpose is to represent a heat exchange between the flame and water in tubes of the boiler proper.

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Fig. 2.6: The configuration of the FLAME node

The temperature TFLUEGAS represents the temperature of the flue gas leaving the firebox. This is calculated from the flame temperature and the heat transferred to the boiler proper. There is also a small heat loss calculated according to the standard [1]. The temperature at the exit of the firebox is important for monitoring the firebox function and can indicate improper function of the firebox caused for example by fouling of the firebox by slag.

Fig. 2.7: The configuration of the BOILER node

The boiler proper (steam generator) energy balance is modeled with the aid of the IAPWS IF-97 enthalpy model. It is supposed that the enthalpy of the feed water is defined by its temperature and the pressure (heat function H2OL(T,P). The output streams (BLOWDOWN and STBOIL) are water and steam saturated at the boiler pressure.

2.5.3 Modeling the flue gas path

As was mentioned previously, the gas path consists of two parallel steams – gas and ash. There are 3 steam superheaters, 2 steam coolers, 1 economizer, 1 air preheater and 1 electrostatic separator on this path. It should be noted that on the flue gas path there are used no temperature measurements between the firebox and the economizer. All temperatures are unmeasured and are calculated from the enthalpy balance of the steam path. Example of configuration of a steam superheater is shown in the Fig. 2.8.

Node: SSH3-FG

ID	Description
SSH3-FG	steam superheater SSH3

Geodesic height [M]		Node pres.

☐ Reaction heat - from database of properties

Non-energy streams incident with node

Stream	Function	Temperature
iFGA2	ASH	TFUELGAS2
iFGG2	IG(T)	TFUELGAS2
oFGA3	ASH	TFUELGAS3
oFGG3	IG(T)	TFUELGAS3

Fig. 2.8: The configuration of the steam superheater SSH3, the flue gas side

Important is the measurement of O_2 concentrations on the path which is essential for closing the component balance of the system. The O_2 concentrations measurements are important also for detection and quantification of leaks (suction of an ambient air to the system). This problem is significant especially at the end of the flue gas path where the suction is maximal (air preheater, electrostatic separator).

In our system the O_2 concentration is measured at 2 places: At the inlet to the economizer and at the outlet of the electrostatic separator. Here is one important problem which is typical for flue gas analyzers: their units of measurement are mostly molar (or volume) per cents. At the same time their values are referred to the dry gas (water is removed from the gas before it is brought to the analyzer). RECON makes possible to cope with this problem by changing composition units for selected streams.

Stream : FGG7

From node: **ES**
To node: **FGCOOL**

Material flow: wt

Stream	Description
FGG7	flue gas from ES

Concentrations: mol(dry)

Component	Description
H2OV	steam
H2OL	water
O2	oxygen

Fig. 2.9: The configuration of the flue gas from the electrostatic separator

It can be seen that even if the overall balance is in weight units, the composition of streams can be set in molar per cent on a dry basis.

There should be noted also other features on the flue gas path (see Fig. 2.5). The stream BYPASSECO is used for control of the flue gas temperature at the exit. The control valve is set manually and the bypass flow is not measured. But this flow can be calculated from the overall energy balance. The stream which should also be

monitored is the air shortcut from the air side to the flue gas side of the air preheater (stream APSC). The flow of this shortcut can be calculated from the heat and component balance.

2.5.4 Modeling the water and the steam path

This part of our model is very standard based on the IAPWS IF-97 model. The only component present here is H_2O. As an example can serve the steam side of the first steam cooler STC1.

Node: STC1

ID	Description
STC1	spray 1

Geodesic height [M]   Node pres.

☐ Reaction heat - from database of properties

Non-energy streams incident with node

Stream	Function	Temperature	Pressure	
iSPRAY1	H2OL(T,P)	01X01T006	01X01P004	
iST1	H2OV(T,P)	01X01T022	01X01P017	
oST1C	H2OV(T,P)	01X01T023	01X01P017	

Fig. 2.9: The configuration of the steam cooler

The mass and energy balance on the water and steam path is important as it fixes the flue gas balance where are no flowmeters and some thermometers are not reliable.

2.5.5 User defined equations

There are two kinds of user defined equation. The equations used in data pre-processing pre-calculate some variables to get acceptable inputs. In this model there is just one equation of this kind. The blowdown measurement is not reliable and so the blowdown is pre-calculated as 0.6 % of the feed water flow. This is acceptable as the blowdown flow is controlled by a small orifice and is stable.

The other user defined equations complete the model formed by RECON automatically on the basis of the flowsheet configured. The following auxiliary variables were calculated:

- Distribution of ash among slag in the firebox and the fly ash separated in the economizer and the electrostatic separator. This distribution is fixed on the basis of previous experience

- Mean temperature difference in heat exchangers. The character of the flow in heat exchangers is not completely known. The mean temperature difference was calculated as the arithmetic average of temperature differences at both ends of a heat exchanger. In all cases the countercurrent flow was supposed

- Heat Transfer Coefficients (HTC) were calculated from the heat flux, mean temperature difference and the heat transfer area

- Temperature in the boiler as the saturated steam temperature belonging to the pressure at the exit of the boiler

- There is a shortcut of air in the air preheater (Ljungstrom exchanger). To set up the model, the mean temperature of this shortcut is needed. Here is supposed that this temperature is the arithmetic average of air temperature in the inlet and the outlet streams of the air preheater.

3. Results of data reconciliation

Complete results of calculation are in the Appendix 1 (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:

The iterative calculation required 4 iterations. The calculation lasted 2 second on a standard desktop PC. The main global characteristics are

```
G L O B A L   D A T A

 Number of nodes                                24
 Number of heat nodes                           20
 Number of streams                              58
 Number of energy streams                       11
 Number of components                           11
 Number of heat functions                        4
 Number of temperatures                         21
 Number of pressures                             4
 Number of auxiliaries                          13
 Number of react.nodes                           1

 Number of measured variables                   27
 Number of adjusted variables                   27
 Number of non-measured variables               99
 Number of observed variables                   99
 Number of non-observed variables                0
 Number of free variables                        0
 Number of equations (incl. UDE)               133
 Number of independent equations               104
 Number of user-defined equations (UDE)         17

 Degree of redundancy                            5

 Mean residue of equations            1,6478E-07
 Qmin                                 2,7978E+00
 Qcrit                                1,1100E+01
 Status (Qmin/Qcrit)                     0,252058
```

The Status of data quality (see the last row) is well below the critical value 1, so that no gross error was detected. The degree of redundancy is 5. RECON generated 29 dependent equations which is quite high number. This is caused by not unified system of units in this task (mass and molar concentrations, concentrations based on dry gas composition). Anyway, the existence of dependent equations has no effect on the final result as the dependent equations are eliminated during the solution.

Probably the most important KPI result is the efficiency of the boiler. The main result is:

BOILER EFFICIENCY = 90.99 ± 0.27 %

The relative maximum error is about 0.3 % of the boiler efficiency value. This is typical for the indirect method of the efficiency determination. The confidence interval contains both random and systematic errors so that in practice (with stable systematic errors) substantially smaller changes in the efficiency can be monitored and detected.

We can ask question, which variables are influencing the precision the boiler efficiency. The next table presents shares of important variables on variance the boiler efficiency.

```
REPORT ABOUT PROPAGATION OF ERRORS
 =================================

 Type Variable
 -------------
  V   EFFICIENCY

 THE VARIANCE OF GIVEN VARIABLE IS CAUSED MAINLY BY:

 Type Variable                Share
 ----------------------------------
  MF  AIR-IN                    4 %
  T   01X01T023                 3 %
  T   01X01T025                 3 %
  T   01X01TIA131              25 %
  V   [C<FGG7:O2>]             59 %

  Sum                          93 %
```

The Share informs how much the individual primary variables influence the Efficiency's variance. The other variables influence the efficiency by less than 2 %. It is clear that there are 2 variables which together represent 84 % of the Efficiency's variance:

- Temperature 01X01TIA131 (flue gas exit from the electrostatic separator)
- C<FGG7:O2> (oxygen concentration at the exit of the electrostatic separator)

These variables represent the bottleneck of Efficiency's precision. These instruments should be therefore carefully maintained.

Some other calculated KPIs are in the next table:

Name	Type	Inp.value	Rec.value	Abs.error
HTCECO	NO	67,128	65,656	8,208
HTCSSH1	NO	85,622	86,543	8,328
HTCSSH2	NO	30,710	30,975	3,987
HTCSSH3	NO	48,779	50,207	9,082
Q-LOSS	NO	28,835	28,715	1,310
Q-USEFULL	NO	289,893	290,142	10,351

The heat transfer coefficients (HTC) are estimated with tolerance about ± 10 – 20 % (column Abs.error.)

Heat fluxes 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	
Q-ASH1	NO	0,125	0,125	5,98E-3	GJ/HR
Q-ASH2	NO	0,741	0,738	0,033	GJ/HR
Q-FGLOSS	NO	24,534	24,416	1,264	GJ/HR
Q-SLAG	NO	0,555	0,556	0,021	GJ/HR
QAP	NO	41,477	41,656	2,902	GJ/HR
QB	NO	167,994	168,465	6,421	GJ/HR
QECO	NO	23,320	22,623	3,515	GJ/HR
QLOSS	F	2,880	2,880		GJ/HR
QSSH1	NO	42,038	41,912	2,953	GJ/HR
QSSH2	NO	28,654	28,785	3,884	GJ/HR
QSSH3	NO	27,888	28,356	4,829	GJ/HR

Typical output table of stream parameters is

```
Stream: FGG4  (From node SSH1-FG -> To node ECO-FG)
    M = 29.001 KG/KMOL

No. Name       Type     Inp.value     Rec.value      Abs.error
---------------------------------------------------------------
    Flowrate   NO        126,292       125,308         14,879  T/HR
 3  O2         MC          2,792         2,857          0,490  %mol(dry)
 4  N2         NO         80,002        79,998          0,053  %mol(dry)
 5  AR         NO          0,950         0,950        6,02E-4  %mol(dry)
 6  CO2        NO         16,052        16,027          0,432  %mol(dry)
 8  SO2        NO          0,160         0,160        4,34E-3  %mol(dry)
11  CO         NO        8,07E-3       8,06E-3        8,81E-4  %mol(dry)

 1  H2OV       NO          9,339         8,997          0,207  %wt
 3  O2         NO          2,624         2,695          0,473  %wt
 4  N2         NO         65,831        66,081          0,217  %wt
 5  AR         NO          1,115         1,120        3,71E-3  %wt
 6  CO2        NO         20,752        20,799          0,479  %wt
 8  SO2        NO          0,301         0,301        7,02E-3  %wt
11  CO         NO        6,64E-3       6,65E-3        7,21E-4  %wt
```

This stream is the flue gas (gas without ash) going from the superheater SSH1 to the economizer. At this place is the measurement if the O_2 concentration which is measured in molar per cents based on the dry gas. Both systems of units are available for this stream.

Another question is the "How well are results protected against gross measurement errors?". This depends on redundancy of measurements. The best measure of redundancy is the adjustability redundant variables. Adjustabilities greater than 0.1 are shown in the next table (for variables with adjustabilities lesser than 0.1 gross errors will probably remain undetected). The column Threshold value shows how large must a gross error be to be detected with probability 90 %. For example, the error of the feed water (variable MF FWIN) must be at least 15.992 T/HR to be detected with probability 90 %.

```
R E D U N D A N T   M E A S U R E M E N T S


 Type Variable        Adjustability     Threshold value  Unit    Description
-------------------------------------------------------------------------
  MF   AIR-IN           0,645620            62,426  T/HR    Air input

  MF   FWIN             0,323534            15,922  T/HR    Feed water input

  MF   HOTAIRTERT       0,387152            36,809  T/HR    Tertiary air input

  MF   PA               0,353783            16,084  T/HR    Steam export

  T    01X01T023        0,427280            48,245  C       Steam from spray 1

  T    01X01T025        0,401387            57,184  C       Steam from spray 2

  T    01X01TIA131      0,119248            12,831  C       Flue gas from ES


Legend: MF – mass flow; T – temperature.
```

Literature

[1]   EN 12952-15:2003: Water-tube boilers and auxiliary installations – Part 15: Acceptance tests.

[2]   IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam. International Association for the Properties of Water and Steam. 2007

[3]   API: API Data Book. 7th edition. API 2005

[4]   Process data validation in practice. Applications from chemical, oil, mineral and power industries. Report CPT 229-07. Usti nad Labem 2007

[5]   ASME Power Test Code 4.1: Steam Generating Units 1964. Reapproved 1979

Appendix 1: RECON's output file

```
RECON 11.1.2-Pro  [CHemPlant]
 Task: COAL_BOILLER (detailed coal boiler balance)

 Balance: [21.01.2011 08:00; 21.01.2011 09:00)

 I T E R A T I O N S


 Iter         Qeq             Qx              Qy              Qmin
 ----------------------------------------------------------------
 START    3,4606E+04
    1      8,7922E+01      4,8248E-01      2,3182E+03      2,6510E+00
    2      5,6261E+00      1,8147E-01      1,1041E+03      2,7978E+00
    3      9,9636E-05      2,3733E-04      1,4098E+00      2,7978E+00
    4      1,6478E-07      1,2936E-07      1,4179E-03      2,7978E+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                            24
 Number of heat nodes                       20
 Number of streams                          58
 Number of energy streams                   11
 Number of components                       11
 Number of heat functions                    4
 Number of temperatures                     21
 Number of pressures                         4
 Number of auxiliaries                      13
 Number of react. nodes                      1

 Number of measured variables               27
 Number of adjusted variables               27
 Number of non-measured variables           99
 Number of observed variables               99
 Number of non-observed variables            0
 Number of free variables                    0
 Number of equations (incl. UDE)           133
 Number of independent equations           104
 Number of user-defined equations (UDE)     17

 Degree of redundancy                        5

 Mean residue of equations           1,6478E-07
 Qmin                                2,7978E+00
 Qcrit                               1,1100E+01
 Status (Qmin/Qcrit)                    0,252058


 S T R E A M S

 Stream: AIR-IN  (From node ENVIRON -> To node SPL-AIR1)
     M = 28.966 KG/KMOL

 No. Name        Type      Inp.value       Rec.value       Abs.error
 ----------------------------------------------------------------
     Flowrate    MC         140,945         141,985           9,990  T/HR
  3 O2           F           23,200          23,200                  %wt
  4 N2           F           75,470          75,470                  %wt
  5 AR           F            1,280           1,280                  %wt
  6 CO2          F            0,050           0,050                  %wt

 Stream: AIRFROMAP  (From node APAIR -> To node SPL-AIR2)
     M = 28.966 KG/KMOL; Master stream = AIR-IN

 No. Name        Type      Inp.value       Rec.value       Abs.error
 ----------------------------------------------------------------
     Flowrate    NO         129,884         130,273           5,731  T/HR
  3 O2           F           23,200          23,200                  %wt
  4 N2           F           75,470          75,470                  %wt
```

```
        5 AR          F         1,280        1,280                    %wt
        6 CO2         F         0,050        0,050                    %wt

    Stream: AIRTOAP  (From node SPL-AIR1 -> To node APAIR)
        M = 28.966 KG/KMOL; Master stream = AIR-IN

    No. Name         Type      Inp.value    Rec.value    Abs.error
    --------------------------------------------------------------------
          Flowrate   NO        140,876      140,047        9,996   T/HR
        3 O2         F          23,200       23,200                    %wt
        4 N2         F          75,470       75,470                    %wt
        5 AR         F           1,280        1,280                    %wt
        6 CO2        F           0,050        0,050                    %wt

    Stream: AIRTOMILL  (From node SPL-AIR1 -> To node FIREBOX)
        M = 28.966 KG/KMOL; Master stream = AIR-IN

    No. Name         Type      Inp.value    Rec.value    Abs.error
    --------------------------------------------------------------------
          Flowrate   MC          1,943        1,937        0,389   T/HR
        3 O2         F          23,200       23,200                    %wt
        4 N2         F          75,470       75,470                    %wt
        5 AR         F           1,280        1,280                    %wt
        6 CO2        F           0,050        0,050                    %wt

    Stream: APSC  (From node APAIR -> To node APFG)
        M = 28.966 KG/KMOL; Master stream = AIR-IN

    No. Name         Type      Inp.value    Rec.value    Abs.error
    --------------------------------------------------------------------
          Flowrate   NO         10,992        9,774        9,307   T/HR
        3 O2         F          23,200       23,200                    %wt
        4 N2         F          75,470       75,470                    %wt
        5 AR         F           1,280        1,280                    %wt
        6 CO2        F           0,050        0,050                    %wt

    Stream: ASH1  (From node ECO-FG -> To node ASHC1)
        M = 100 KG/KMOL; Master stream = FGA4

    No. Name         Type      Inp.value    Rec.value    Abs.error
    --------------------------------------------------------------------
          Flowrate   NO          0,403        0,403        0,015   T/HR
        7 AH         F         100,000      100,000                    %wt

    Stream: ASH1-C  (From node ASHC1 -> To node ENVIRON)
        M = 100 KG/KMOL; Master stream = FGA4

    No. Name         Type      Inp.value    Rec.value    Abs.error
    --------------------------------------------------------------------
          Flowrate   NO          0,403        0,403        0,015   T/HR
        7 AH         F         100,000      100,000                    %wt

    Stream: ASH2  (From node ES -> To node ASHC2)
        M = 100 KG/KMOL; Master stream = FGA4

    No. Name         Type      Inp.value    Rec.value    Abs.error
    --------------------------------------------------------------------
          Flowrate   NO          6,843        6,853        0,262   T/HR
        7 AH         F         100,000      100,000                    %wt

    Stream: ASH2-C  (From node ASHC2 -> To node ENVIRON)
        M = 100 KG/KMOL; Master stream = FGA4

    No. Name         Type      Inp.value    Rec.value    Abs.error
    --------------------------------------------------------------------
          Flowrate   NO          6,843        6,853        0,262   T/HR
        7 AH         F         100,000      100,000                    %wt

    Stream: BLOWDOWN  (From node BOILER -> To node ENVIRON)
        M = 18.015 KG/KMOL; Master stream = FWIN

    No. Name         Type      Inp.value    Rec.value    Abs.error
    --------------------------------------------------------------------
          Flowrate   MC          0,711        0,711        0,036   T/HR
        2 H2OL       F         100,000      100,000                    %wt

    Stream: BYPASSECO  (From node SSH1-FG -> To node APFG)
        M = 29.001 KG/KMOL; Master stream = FGG4
```

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```
No. Name         Type     Inp.value     Rec.value     Abs.error
-----------------------------------------------------------------
    Flowrate     NO          24,457        25,853        14,103   T/HR
  3 O2           MC           2,792         2,857         0,490   %mol(dry)
  4 N2           NO          80,002        79,998         0,053   %mol(dry)
  5 AR           NO           0,950         0,950       6,02E-4   %mol(dry)
  6 CO2          NO          16,052        16,027         0,432   %mol(dry)
  8 SO2          NO           0,160         0,160       4,34E-3   %mol(dry)
 11 CO           NO         8,07E-3       8,06E-3       8,81E-4   %mol(dry)

  1 H2OV         NO           9,339         8,997         0,207   %wt
  3 O2           NO           2,624         2,695         0,473   %wt
  4 N2           NO          65,831        66,081         0,217   %wt
  5 AR           NO           1,115         1,120       3,71E-3   %wt
  6 CO2          NO          20,752        20,799         0,479   %wt
  8 SO2          NO           0,301         0,301       7,02E-3   %wt
 11 CO           NO         6,64E-3       6,65E-3       7,21E-4   %wt
```

Stream: COAL-IN (From node ENVIRON -> To node FIREBOX)
    M = 46.384 KG/KMOL

```
No. Name         Type     Inp.value     Rec.value     Abs.error
-----------------------------------------------------------------
    Flowrate     NO          26,206        26,244         1,005   T/HR
  2 H2OL         F           25,400        25,400                 %wt
  7 AH           F           30,720        30,720                 %wt
  9 COAL         F           43,880        43,880                 %wt
```

Stream: FGA1 (From node FLAME -> To node SSH2-FG)
    M = 100 KG/KMOL; Master stream = FGA4

```
No. Name         Type     Inp.value     Rec.value     Abs.error
-----------------------------------------------------------------
    Flowrate     NO           7,245         7,256         0,278   T/HR
  7 AH           F          100,000       100,000                 %wt
```

Stream: FGA2 (From node SSH2-FG -> To node SSH3-FG)
    M = 100 KG/KMOL; Master stream = FGA4

```
No. Name         Type     Inp.value     Rec.value     Abs.error
-----------------------------------------------------------------
    Flowrate     NO           7,245         7,256         0,278   T/HR
  7 AH           F          100,000       100,000                 %wt
```

Stream: FGA3 (From node SSH3-FG -> To node SSH1-FG)
    M = 100 KG/KMOL; Master stream = FGA4

```
No. Name         Type     Inp.value     Rec.value     Abs.error
-----------------------------------------------------------------
    Flowrate     NO           7,245         7,256         0,278   T/HR
  7 AH           F          100,000       100,000                 %wt
```

Stream: FGA4 (From node SSH1-FG -> To node ECO-FG)
    M = 100 KG/KMOL

```
No. Name         Type     Inp.value     Rec.value     Abs.error
-----------------------------------------------------------------
    Flowrate     NO           7,245         7,256         0,278   T/HR
  7 AH           F          100,000       100,000                 %wt
```

Stream: FGA5 (From node ECO-FG -> To node APFG)
    M = 100 KG/KMOL; Master stream = FGA4

```
No. Name         Type     Inp.value     Rec.value     Abs.error
-----------------------------------------------------------------
    Flowrate     NO           6,843         6,853         0,262   T/HR
  7 AH           F          100,000       100,000                 %wt
```

Stream: FGA6 (From node APFG -> To node ES)
    M = 100 KG/KMOL; Master stream = FGA4

```
No. Name         Type     Inp.value     Rec.value     Abs.error
-----------------------------------------------------------------
    Flowrate     NO           6,843         6,853         0,262   T/HR
  7 AH           F          100,000       100,000                 %wt
```

Stream: FGG1 (From node FLAME -> To node SSH2-FG)

```
      M = 29.001 KG/KMOL; Master stream = FGG4

No. Name        Type      Inp.value    Rec.value    Abs.error
----------------------------------------------------------------
     Flowrate   NO        150,748      151,161        6,288   T/HR
 3 O2           MC          2,792        2,857        0,490   %mol(dry)
 4 N2           NO         80,002       79,998        0,053   %mol(dry)
 5 AR           NO          0,950        0,950       6,02E-4  %mol(dry)
 6 CO2          NO         16,052       16,027        0,432   %mol(dry)
 8 SO2          NO          0,160        0,160       4,34E-3  %mol(dry)
11 CO           NO         8,07E-3      8,06E-3      8,81E-4  %mol(dry)

 1 H2OV         NO          9,339        8,997        0,207   %wt
 3 O2           NO          2,624        2,695        0,473   %wt
 4 N2           NO         65,831       66,081        0,217   %wt
 5 AR           NO          1,115        1,120       3,71E-3  %wt
 6 CO2          NO         20,752       20,799        0,479   %wt
 8 SO2          NO          0,301        0,301       7,02E-3  %wt
11 CO           NO         6,64E-3      6,65E-3      7,21E-4  %wt

Stream: FGG2   (From node SSH2-FG -> To node SSH3-FG)
      M = 29.001 KG/KMOL; Master stream = FGG4

No. Name        Type      Inp.value    Rec.value    Abs.error
----------------------------------------------------------------
     Flowrate   NO        150,748      151,161        6,288   T/HR
 3 O2           MC          2,792        2,857        0,490   %mol(dry)
 4 N2           NO         80,002       79,998        0,053   %mol(dry)
 5 AR           NO          0,950        0,950       6,02E-4  %mol(dry)
 6 CO2          NO         16,052       16,027        0,432   %mol(dry)
 8 SO2          NO          0,160        0,160       4,34E-3  %mol(dry)
11 CO           NO         8,07E-3      8,06E-3      8,81E-4  %mol(dry)

 1 H2OV         NO          9,339        8,997        0,207   %wt
 3 O2           NO          2,624        2,695        0,473   %wt
 4 N2           NO         65,831       66,081        0,217   %wt
 5 AR           NO          1,115        1,120       3,71E-3  %wt
 6 CO2          NO         20,752       20,799        0,479   %wt
 8 SO2          NO          0,301        0,301       7,02E-3  %wt
11 CO           NO         6,64E-3      6,65E-3      7,21E-4  %wt

Stream: FGG3   (From node SSH3-FG -> To node SSH1-FG)
      M = 29.001 KG/KMOL; Master stream = FGG4

No. Name        Type      Inp.value    Rec.value    Abs.error
----------------------------------------------------------------
     Flowrate   NO        150,748      151,161        6,288   T/HR
 3 O2           MC          2,792        2,857        0,490   %mol(dry)
 4 N2           NO         80,002       79,998        0,053   %mol(dry)
 5 AR           NO          0,950        0,950       6,02E-4  %mol(dry)
 6 CO2          NO         16,052       16,027        0,432   %mol(dry)
 8 SO2          NO          0,160        0,160       4,34E-3  %mol(dry)
11 CO           NO         8,07E-3      8,06E-3      8,81E-4  %mol(dry)

 1 H2OV         NO          9,339        8,997        0,207   %wt
 3 O2           NO          2,624        2,695        0,473   %wt
 4 N2           NO         65,831       66,081        0,217   %wt
 5 AR           NO          1,115        1,120       3,71E-3  %wt
 6 CO2          NO         20,752       20,799        0,479   %wt
 8 SO2          NO          0,301        0,301       7,02E-3  %wt
11 CO           NO         6,64E-3      6,65E-3      7,21E-4  %wt

Stream: FGG4   (From node SSH1-FG -> To node ECO-FG)
      M = 29.001 KG/KMOL

No. Name        Type      Inp.value    Rec.value    Abs.error
----------------------------------------------------------------
     Flowrate   NO        126,292      125,308       14,879   T/HR
 3 O2           MC          2,792        2,857        0,490   %mol(dry)
 4 N2           NO         80,002       79,998        0,053   %mol(dry)
 5 AR           NO          0,950        0,950       6,02E-4  %mol(dry)
 6 CO2          NO         16,052       16,027        0,432   %mol(dry)
 8 SO2          NO          0,160        0,160       4,34E-3  %mol(dry)
11 CO           NO         8,07E-3      8,06E-3      8,81E-4  %mol(dry)

 1 H2OV         NO          9,339        8,997        0,207   %wt
 3 O2           NO          2,624        2,695        0,473   %wt
 4 N2           NO         65,831       66,081        0,217   %wt
```

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```
    5 AR        NO          1,115        1,120       3,71E-3   %wt
    6 CO2       NO         20,752       20,799        0,479    %wt
    8 SO2       NO          0,301        0,301       7,02E-3   %wt
   11 CO        NO         6,64E-3      6,65E-3      7,21E-4   %wt

    Stream: FGG5  (From node ECO-FG -> To node APFG)
       M = 29.001 KG/KMOL; Master stream = FGG4

    No. Name      Type     Inp.value    Rec.value    Abs.error
    ----------------------------------------------------------------
        Flowrate  NO        126,292      125,308      14,879   T/HR
    3 O2        MC          2,792        2,857        0,490    %mol(dry)
    4 N2        NO         80,002       79,998        0,053    %mol(dry)
    5 AR        NO          0,950        0,950       6,02E-4   %mol(dry)
    6 CO2       NO         16,052       16,027        0,432    %mol(dry)
    8 SO2       NO          0,160        0,160       4,34E-3   %mol(dry)
   11 CO        NO         8,07E-3      8,06E-3      8,81E-4   %mol(dry)

    1 H2OV      NO          9,339        8,997        0,207    %wt
    3 O2        NO          2,624        2,695        0,473    %wt
    4 N2        NO         65,831       66,081        0,217    %wt
    5 AR        NO          1,115        1,120       3,71E-3   %wt
    6 CO2       NO         20,752       20,799        0,479    %wt
    8 SO2       NO          0,301        0,301       7,02E-3   %wt
   11 CO        NO         6,64E-3      6,65E-3      7,21E-4   %wt

    Stream: FGG6  (From node APFG -> To node ES)
       M = 28.999 KG/KMOL

    No. Name      Type     Inp.value    Rec.value    Abs.error
    ----------------------------------------------------------------
        Flowrate  NO        161,741      160,935      10,359   T/HR
    1 H2OV      NO          8,397        8,451        0,452    %wt
    3 O2        NO          4,063        3,941        1,031    %wt
    4 N2        NO         66,708       66,651        0,472    %wt
    5 AR        NO          1,130        1,129       8,07E-3   %wt
    6 CO2       NO         19,415       19,539        1,044    %wt
    8 SO2       NO          0,281        0,283        0,015    %wt
   11 CO        NO         6,21E-3      6,25E-3      6,89E-4   %wt

    Stream: FGG7  (From node ES -> To node FGCOOL)
       M = 28.994 KG/KMOL

    No. Name      Type     Inp.value    Rec.value    Abs.error
    ----------------------------------------------------------------
        Flowrate  NO        189,479      189,575       9,126   T/HR
    3 O2        MC          7,036        7,017        0,491    %mol(dry)
    4 N2        NO         79,547       79,549        0,054    %mol(dry)
    5 AR        NO          0,945        0,945       6,09E-4   %mol(dry)
    6 CO2       NO         12,347       12,360        0,433    %mol(dry)
    8 SO2       NO          0,123        0,123       4,32E-3   %mol(dry)
   11 CO        MC         6,20E-3      6,21E-3      6,20E-4   %mol(dry)

    1 H2OV      NO          9,460        7,174        0,223    %wt
    3 O2        NO          6,700        6,850        0,508    %wt
    4 N2        NO         66,311       67,984        0,232    %wt
    5 AR        NO          1,124        1,152       3,97E-3   %wt
    6 CO2       NO         16,170       16,594        0,514    %wt
    8 SO2       NO          0,234        0,240       7,47E-3   %wt
   11 CO        NO         5,17E-3      5,31E-3      5,31E-4   %wt

    Stream: FGG8  (From node FGCOOL -> To node ENVIRON)
       M = 28.994 KG/KMOL; Master stream = FGG7

    No. Name      Type     Inp.value    Rec.value    Abs.error
    ----------------------------------------------------------------
        Flowrate  NO        189,479      189,575       9,126   T/HR
    3 O2        MC          7,036        7,017        0,491    %mol(dry)
    4 N2        NO         79,547       79,549        0,054    %mol(dry)
    5 AR        NO          0,945        0,945       6,09E-4   %mol(dry)
    6 CO2       NO         12,347       12,360        0,433    %mol(dry)
    8 SO2       NO          0,123        0,123       4,32E-3   %mol(dry)
   11 CO        MC         6,20E-3      6,21E-3      6,20E-4   %mol(dry)

    1 H2OV      NO          9,460        7,174        0,223    %wt
    3 O2        NO          6,700        6,850        0,508    %wt
    4 N2        NO         66,311       67,984        0,232    %wt
    5 AR        NO          1,124        1,152       3,97E-3   %wt
```

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```
    6 CO2        NO          16,170        16,594         0,514    %wt
    8 SO2        NO           0,234         0,240       7,47E-3    %wt
   11 CO         NO         5,17E-3       5,31E-3       5,31E-4    %wt

Stream: FLAME  (From node FIREBOX -> To node FLAME)
    M = 29.001 KG/KMOL; Master stream = FGG4

No. Name        Type      Inp.value     Rec.value     Abs.error
----------------------------------------------------------------
      Flowrate  NO         150,748       151,161         6,288    T/HR
    3 O2        MC           2,792         2,857         0,490    %mol(dry)
    4 N2        NO          80,002        79,998         0,053    %mol(dry)
    5 AR        NO           0,950         0,950       6,02E-4    %mol(dry)
    6 CO2       NO          16,052        16,027         0,432    %mol(dry)
    8 SO2       NO           0,160         0,160       4,34E-3    %mol(dry)
   11 CO        NO         8,07E-3       8,06E-3       8,81E-4    %mol(dry)

    1 H2OV      NO           9,339         8,997         0,207    %wt
    3 O2        NO           2,624         2,695         0,473    %wt
    4 N2        NO          65,831        66,081         0,217    %wt
    5 AR        NO           1,115         1,120       3,71E-3    %wt
    6 CO2       NO          20,752        20,799         0,479    %wt
    8 SO2       NO           0,301         0,301       7,02E-3    %wt
   11 CO        NO         6,64E-3       6,65E-3       7,21E-4    %wt

Stream: FLAMEASH   (From node FIREBOX -> To node FLAME)
    M = 100 KG/KMOL; Master stream = FGA4

No. Name        Type      Inp.value     Rec.value     Abs.error
----------------------------------------------------------------
      Flowrate  NO           7,245         7,256         0,278    T/HR
    7 AH        F          100,000       100,000                 %wt

Stream: FUELGAS  (From node ENVIRON -> To node FIREBOX)
    M = 21.542 KG/KMOL

No. Name        Type      Inp.value     Rec.value     Abs.error
----------------------------------------------------------------
      Flowrate  F            0,768         0,768                 T/HR
    6 CO2       F           20,000        20,000                 %wt
   10 CH4       F           50,000        50,000                 %wt
   11 CO        F           30,000        30,000                 %wt

Stream: FW1  (From node SPLFW1 -> To node ECO-FW)
    M = 18.015 KG/KMOL; Master stream = FWIN

No. Name        Type      Inp.value     Rec.value     Abs.error
----------------------------------------------------------------
      Flowrate  NO         108,937       108,956         3,887    T/HR
    2 H2OL      F          100,000       100,000                 %wt

Stream: FW2  (From node ECO-FW -> To node BOILER)
    M = 18.015 KG/KMOL; Master stream = FWIN

No. Name        Type      Inp.value     Rec.value     Abs.error
----------------------------------------------------------------
      Flowrate  NO         108,937       108,956         3,887    T/HR
    2 H2OL      F          100,000       100,000                 %wt

Stream: FWIN  (From node ENVIRON -> To node SPLFW1)
    M = 18.015 KG/KMOL

No. Name        Type      Inp.value     Rec.value     Abs.error
----------------------------------------------------------------
      Flowrate  MC         113,249       116,406         3,830    T/HR
    2 H2OL      F          100,000       100,000                 %wt

Stream: HOTAIRBURN  (From node SPL-AIR2 -> To node FIREBOX)
    M = 28.966 KG/KMOL; Master stream = AIR-IN

No. Name        Type      Inp.value     Rec.value     Abs.error
----------------------------------------------------------------
      Flowrate  MC          32,515        31,945         6,052    T/HR
    3 O2        F           23,200        23,200                 %wt
    4 N2        F           75,470        75,470                 %wt
    5 AR        F            1,280         1,280                 %wt
    6 CO2       F            0,050         0,050                 %wt
```

```
Stream: HOTAIRMILL  (From node SPL-AIR2 -> To node FIREBOX)
    M = 28.966 KG/KMOL; Master stream = AIR-IN

No. Name       Type      Inp.value     Rec.value     Abs.error
---------------------------------------------------------------------
    Flowrate   MC         31,285        30,758        5,857   T/HR
 3 O2          F          23,200        23,200                %wt
 4 N2          F          75,470        75,470                %wt
 5 AR          F           1,280         1,280                %wt
 6 CO2         F           0,050         0,050                %wt

Stream: HOTAIRTERT  (From node SPL-AIR2 -> To node FIREBOX)
    M = 28.966 KG/KMOL; Master stream = AIR-IN

No. Name       Type      Inp.value     Rec.value     Abs.error
---------------------------------------------------------------------
    Flowrate   MC         70,230        67,571        8,608   T/HR
 3 O2          F          23,200        23,200                %wt
 4 N2          F          75,470        75,470                %wt
 5 AR          F           1,280         1,280                %wt
 6 CO2         F           0,050         0,050                %wt

Stream: LEAK  (From node ENVIRON -> To node ES)
    M = 28.966 KG/KMOL; Master stream = AIR-IN

No. Name       Type      Inp.value     Rec.value     Abs.error
---------------------------------------------------------------------
    Flowrate   NO         27,739        28,640        7,471   T/HR
 3 O2          F          23,200        23,200                %wt
 4 N2          F          75,470        75,470                %wt
 5 AR          F           1,280         1,280                %wt
 6 CO2         F           0,050         0,050                %wt

Stream: PA  (From node SSH3-ST -> To node ENVIRON)
    M = 18.015 KG/KMOL; Master stream = FWIN

No. Name       Type      Inp.value     Rec.value     Abs.error
---------------------------------------------------------------------
    Flowrate   MC        118,550       115,694        3,830   T/HR
 2 H2OL        F         100,000       100,000                %wt

Stream: SLAG1  (From node FIREBOX -> To node SLAGC)
    M = 100 KG/KMOL

No. Name       Type      Inp.value     Rec.value     Abs.error
---------------------------------------------------------------------
    Flowrate   NO          0,805         0,806        0,031   T/HR
 7 AH          F         100,000       100,000                %wt

Stream: SLAG2  (From node SLAGC -> To node ENVIRON)
    M = 100 KG/KMOL; Master stream = SLAG1

No. Name       Type      Inp.value     Rec.value     Abs.error
---------------------------------------------------------------------
    Flowrate   NO          0,805         0,806        0,031   T/HR
 7 AH          F         100,000       100,000                %wt

Stream: SPRAY  (From node SPLFW1 -> To node SPLFW2)
    M = 18.015 KG/KMOL; Master stream = FWIN

No. Name       Type      Inp.value     Rec.value     Abs.error
---------------------------------------------------------------------
    Flowrate   MC          7,398         7,450        0,730   T/HR
 2 H2OL        F         100,000       100,000                %wt

Stream: SPRAY1  (From node SPLFW2 -> To node STC1)
    M = 18.015 KG/KMOL; Master stream = FWIN

No. Name       Type      Inp.value     Rec.value     Abs.error
---------------------------------------------------------------------
    Flowrate   NO          3,693         3,687        2,054   T/HR
 2 H2OL        F         100,000       100,000                %wt

Stream: SPRAY2  (From node SPLFW2 -> To node STC2)
    M = 18.015 KG/KMOL; Master stream = FWIN

No. Name       Type      Inp.value     Rec.value     Abs.error
---------------------------------------------------------------------
```

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```
     Flowrate   NO          3,711        3,763        2,023  T/HR
   2 H2OL       F         100,000      100,000              %wt
```

Stream: ST1 (From node SSH1-ST -> To node STC1)
    M = 18.015 KG/KMOL; Master stream = FWIN

```
No. Name        Type     Inp.value    Rec.value    Abs.error
-----------------------------------------------------------------
     Flowrate   NO        108,226      108,244        3,887  T/HR
   2 H2OL       F         100,000      100,000              %wt
```

Stream: ST1C (From node STC1 -> To node SSH2-ST)
    M = 18.015 KG/KMOL; Master stream = FWIN

```
No. Name        Type     Inp.value    Rec.value    Abs.error
-----------------------------------------------------------------
     Flowrate   NO        111,919      111,932        4,090  T/HR
   2 H2OL       F         100,000      100,000              %wt
```

Stream: ST2 (From node SSH2-ST -> To node STC2)
    M = 18.015 KG/KMOL; Master stream = FWIN

```
No. Name        Type     Inp.value    Rec.value    Abs.error
-----------------------------------------------------------------
     Flowrate   NO        111,919      111,932        4,090  T/HR
   2 H2OL       F         100,000      100,000              %wt
```

Stream: ST2C (From node STC2 -> To node SSH3-ST)
    M = 18.015 KG/KMOL; Master stream = FWIN

```
No. Name        Type     Inp.value    Rec.value    Abs.error
-----------------------------------------------------------------
     Flowrate   NO        115,630      115,694        3,830  T/HR
   2 H2OL       F         100,000      100,000              %wt
```

Stream: STBOIL (From node BOILER -> To node SSH1-ST)
    M = 18.015 KG/KMOL; Master stream = FWIN

```
No. Name        Type     Inp.value    Rec.value    Abs.error
-----------------------------------------------------------------
     Flowrate   NO        108,226      108,244        3,887  T/HR
   2 H2OL       F         100,000      100,000              %wt
```


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

```
Name            Type     Inp.value    Rec.value    Abs.error
-----------------------------------------------------------------
Q-ASH1          NO          0,125        0,125      5,98E-3  GJ/HR
Q-ASH2          NO          0,741        0,738        0,033  GJ/HR
Q-FGLOSS        NO         24,534       24,416        1,264  GJ/HR
Q-SLAG          NO          0,555        0,556        0,021  GJ/HR
QAP             NO         41,477       41,656        2,902  GJ/HR
QB              NO        167,994      168,465        6,421  GJ/HR
QECO            NO         23,320       22,623        3,515  GJ/HR
QLOSS           F           2,880        2,880               GJ/HR
QSSH1           NO         42,038       41,912        2,953  GJ/HR
QSSH2           NO         28,654       28,785        3,884  GJ/HR
QSSH3           NO         27,888       28,356        4,829  GJ/HR
```


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

```
Name            Type     Inp.value    Rec.value    Abs.error
-----------------------------------------------------------------
01X01T006       MC        223,831      224,290        4,404  C
01X01T007       MC        268,725      267,906        4,967  C
01X01T022       MC        405,370      404,849        7,692  C
01X01T023       MC        381,968      382,340       10,938  C
01X01T024       MC        471,252      471,201        9,024  C
01X01T025       MC        442,403      442,770       13,241  C
01X01T037       MC        535,948      537,401       10,395  C
01X01TIA113-114 MC        165,243      165,264        4,886  C
01X01TIA131     MC        146,718      146,057        2,584  C
AIREXAP         MC        340,234      340,054       10,000  C
AMBIENTAIR      MC         37,500       37,899        9,935  C
PA-BOILER       NO        309,964      309,964        0,218  C
T25             F          25,000       25,000               C
```

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```
TFLAME           NO      1816,792     1814,990       28,565  C
TFLUEGAS1        NO      1014,542     1012,500       21,683  C
TFLUEGAS2        NO       875,951      873,589       19,151  C
TFLUEGAS3        NO       738,509      734,126       22,482  C
TFLUEGAS4        NO       522,224      518,792       19,967  C
TFLUEGASEXECO    MC       373,183      373,047        9,996  C
TSLAG            F        800,000      800,000               C
TZKRAT           NO       190,069      188,976        7,048  C
```

P R E S S U R E S

```
Name             Type    Inp.value    Rec.value    Abs.error
------------------------------------------------------------
01X01P004        MC        10,176       10,176        0,031  MPAG
01X01P017        MC         9,759        9,759        0,029  MPAG
01X01P031        MC         9,400        9,400        0,028  MPAG
ATM              F       1,60E-18     1,60E-18               MPAG
```

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
------------------------------------------------------------
DTAP             NO        23,005       23,058        6,561
DTECO            NO       201,459      199,822       11,138
DTSSH1           NO       272,758      269,052       19,576
DTSSH2           NO       518,358      516,274       20,366
DTSSH3           NO       317,629      313,772       18,959
EFFICIENCY       NO        90,953       90,994        0,275
HTCAP            NO       500,813      501,835      149,177
HTCECO           NO        67,128       65,656        8,208
HTCSSH1          NO        85,622       86,543        8,328
HTCSSH2          NO        30,710       30,975        3,987
HTCSSH3          NO        48,779       50,207        9,082
Q-LOSS           NO        28,835       28,715        1,310
Q-USEFULL        NO       289,893      290,142       10,351
```

End of results

```
Calculations lasted              00:00:2.1
Report created       21.08.2013 11:35:40
```