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Excel Spreadsheet as a Tool for Simulating the Performance of Steam Power Plants

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Abstract

The aim of this work is to demonstrate the power of Excel software in simulating the performance of thermal systems. A steam power plant is taken as an example for the demonstration. The idea is to show how one can analyze and simulate the performance of thermal systems within the Excel environment.

The thermodynamic properties are obtained by the Excel tools developed for thermodynamics. The platform of these tools is the Microsoft Excel. The obtained properties using these tools are tested and found in good agreements with other sources.

Energy balance is performed on each heater to find the extracted mass flow rates. The obtained equations are solved simultaneously by using Excel software. The functions MMULT and MINVERSE are used to multiply the matrices and to find the inverse and hence the mass flow rates. The solver facility is used to optimize the thermal efficiency and/or the plant irreversibility.

Keywords: steam power plants, exergy, effectiveness, objective function, optimization

Nomenclature

c_p	specific heat	[kJ/kg.K]
h	enthalpy	[kJ/kg]
$\dot{I}$	irreversibility rate	[kW]
$\dot{m}$	mass flow rate rate	[kg/s]
P	pressure	[kPa]
$\dot{Q}$	heat transfer	[kW]
s	entropy	[kJ/kg.K]
T	temperature	[° C]
w	work done	kJ/kg
$\dot{W}$	power	[kW]
x	mass fraction	[-]

Greek

η	first law efficiency	[-]
ε	effectiveness	[-]
$\dot{\Psi}$	exergy rate	[kW[
ψ	specific exergy	[kJ/kg]

Subscript

d	destroyed
e	exit
F	fuel
i	inlet
k	component
o	ambient
P	product

Abbr.

BFP	boiler feed pump	
CEP	condensate pump	
Cond	condenser	
CW	cooling water	
DCA	drain cooler approach	[° C]
DEA	deaerator	
HPH	high pressure heater	
HPT	high pressure turbine	
IPT	intermediate pressure turbine	
LHV	lower heating value	[kJ/kg]
LPH	low pressure heater	
LPT	low pressure turbine	
RH	reheater	
RHS	right hand side	
SG	steam generator	
TTD	terminal temperature difference	[° C]

1. Introduction

Spreadsheets programs are used to analyze many problems in different engineering areas. They offer an attractive alternative to conventional programming that allows ready experimentation with numerical algorithms [1].

A method for obtaining a numerical approximation to solutions of systems of nonlinear differential equations of one variable using spreadsheets was presented by Kabalan, et al. [2]. The method of solution is illustrated through several examples of non-linear differential equations which demonstrate its accuracy, flexibility, and simplicity.

Demonstration techniques that enable educators to design animated graphical displays in their spreadsheet constructions in order to produce powerful demonstrations to enhance mathematical understanding were introduced by Arganbright [3].

The design and development of a Microsoft Excel-based Power System Load Flow Analysis tool and its application for system planning and operation were demonstrated by Musti and Ramkhelawan [4]. They developed a simple desktop tool which provides an interactive and simplified interface for users to store different systems with different operating conditions and then to observe the response of the system.

Musti [5] presented the design and development of a Microsoft Excel-based tool for Power System Static State Estimation. The tool can be effectively used to understand the process of state estimation and its real-time application. It contains Newton-Raphson load flow that provides system measurements, which are used as inputs to the state estimator that uses the popular weighted least square (WLS) algorithm.

El-Awad presented [6] an Add-Ins that determines the thermodynamic properties for various fluids by using Microsoft Excel. The Add-Ins provides property functions for ideal gases, saturated and superheated water, saturated and superheated refrigerants for vapor-compression (VC) systems, binary solutions of ammonia-water and water-lithium bromide for vapor-absorption (VA) refrigeration systems, reacting mixtures, and atmospheric air.

Excel-Thermax platform for performing energy and exergy analyses of the evaporative regenerative gas-turbine (ERGT) cycle was introduced by El-Awad [7].

A spreadsheet was developed to present a model that uses the effectiveness-NTU method to explicitly take into consideration the design particulars of the regenerator, such as its size and overall heat-transfer coefficient was presented by El-Awad [8].

A paper deals with the use of Microsoft Excel as an educational tool for conducting basic engineering analyses related to thermal-fluid systems was presented by El-Awad [9]. The paper focuses on using Excel and its Goal-Seek command for solving thermal-fluid problems that require iterative solutions by presenting three related examples from the subjects of heat-transfer, fluid dynamics, and thermodynamics.

In this paper, the spreadsheet is utilized to perform a thermodynamic analysis of a selected steam power plant of 350 MW rated power.

2. Excel in mechanical engineering-using Add-Ins

The thermodynamic properties of water are not included in Microsoft Excel. Those properties which are needed to perform the thermodynamic analysis can be inserted by using Add-Ins files. The following steps should be taken to implement the Add-Ins file of thermodynamic properties of water:

1- Download the fluid packages [10].
2- Click on the thermodynamic menu and follow the instructions.

To make sure that it works, for example, find the enthalpy for water at given pressure and temperature, just write "= h", choose h_PT_H_2O and set the pressure and temperature *in order*, and you will have the enthalpy, see Figures 1a and 1b.

All other properties can be generated for any arbitrary two independent properties.

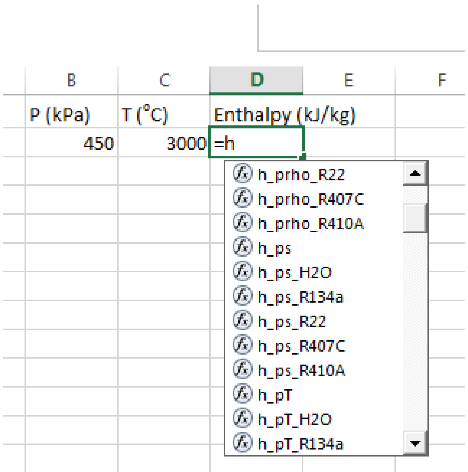

Figure 1a: Typing the property

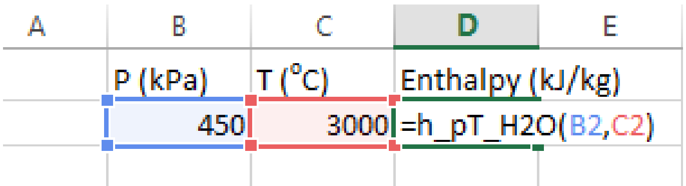

Figure 1b: Generating the property-enthalpy

3. Tools and methods

The steam power which will be simulated within the Excel software environment is shown in Figure 2. All properties will be generated by the Add-Ins fluid package [10]. The seven linear equation which is obtained by taking energy balance on the seven heaters will be solved by using Excel facilities to obtain the mass fraction which is extracted from the steam turbine.

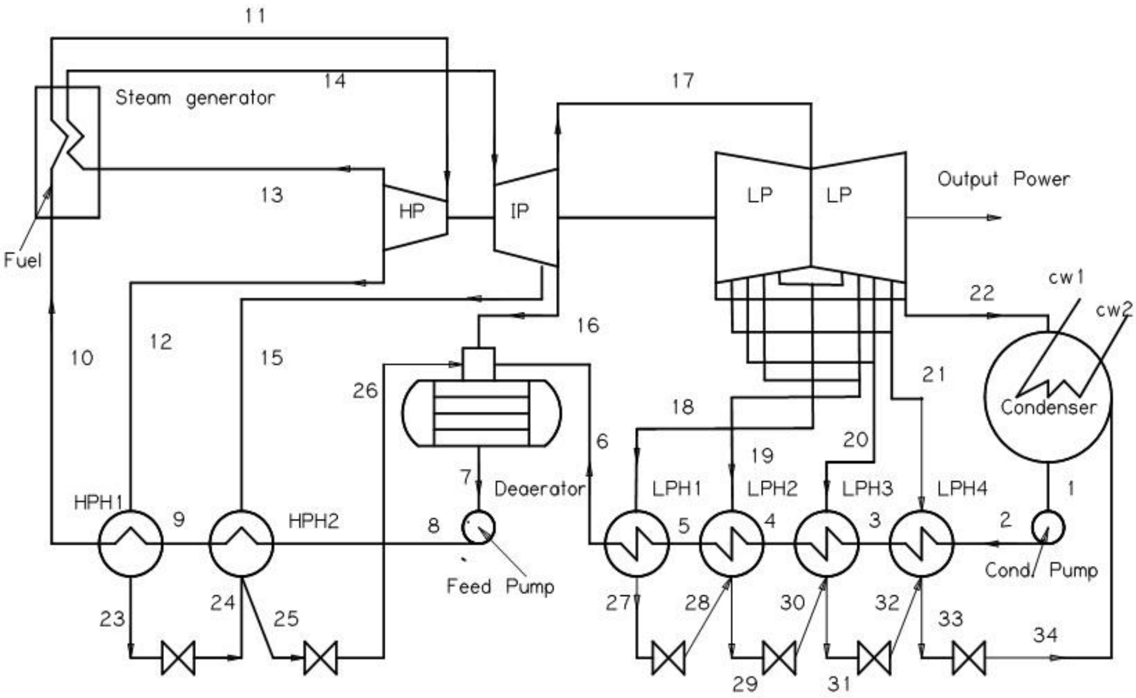

Figure 2: Schematic of the steam power plant

The plant data is tabulated in Table 1.

Table 1: Design parameters of the 350 MW steam power unit

HPT inlet temperature, T_{11} [ºC]	538	DCA [ºC]	5.6
HPT inlet pressure, P_{11} [kPa]	17490	**Bleeding pressures [kPa]**	
Reheat temperature, T_{14} [ºC]	538	Bleeding (1) , P_{12}	4350
Reheat pressure, P_{14} [kPa]	4350	Bleeding (2), P_{15}	2030
Pumps efficiency [%]	75	Bleeding (3), P_{16}	977
Turbines efficiency [%]	85	Bleeding (4), P_{18}	549
Generator efficiency [%]	93.5	Bleeding (5), P_{19}	298
TTD (HP) [ºC]	2.8	Bleeding (6), P_{20}	161
TTD (LP) [ºC]	0.0	Bleeding (7), P_{21}	69

3.1. Thermodynamic modeling

For the analysis, steady-state, steady flow processes are assumed. Pressure drop due to friction, heat exchange with surroundings, the change in kinetic and potential energies are neglected.

The mass balance can be written as:

$$\sum(\dot{m}_i)_k = \sum(\dot{m}_e)_k \quad (1)$$

The first law of thermodynamics can be written as:

$$\sum_k \dot{Q}_k + \sum(\dot{m}_i h_i)_k = \sum(\dot{m}_e h_e)_k + \dot{W}_k \quad (2a)$$

The cycle mass flow rate is calculated by:

$$\dot{m}_{cycle} = \frac{\dot{W}(MW)}{w\left(\frac{kJ}{kg}\right)} \quad (2b)$$

And the first law efficiency can be written as:

$$\eta = \frac{Energy\ (sought)}{Energy\ (cost)} \quad (3)$$

Exergy is defined as the maximum useful reversible work that can be obtained from a given mass in a given state when the mass brought reversibly into thermodynamic equilibrium with the environment.

The exergy flow rate can be written as:

$$\dot{\Psi} = \dot{m}[(h - h_0) - T_0(s - s_0)] \quad (4)$$

And the exergy balance for a given component can be written as;

$$\sum_{i}^{N}\left(1-\frac{T_0}{T}\right)\dot{Q}_k+\sum_{i}^{N}\dot{\Psi}_{i,k} = \sum_{e}^{N}\dot{\Psi}_{e,k}+\dot{W}_k+\dot{I}_k \quad (5)$$

By using the definitions of Fuel-Product-Loss (F-P-L). Fuel and Product are expressed by exergy flow. Exergy balance for a single component (k) is given as:

$$\dot{\Psi}_F = \dot{\Psi}_P + \dot{\Psi}_D \quad (6)$$

Where $\dot{\Psi}_F$, $\dot{\Psi}_P$ and $\dot{\Psi}_D$ are the input exergy (fuel), exergy rate of the desired product, and the exergy destroyed (irreversibility) during the process, respectively.

The effectiveness of every single component (k) is given by:

$$\varepsilon_k=\frac{\dot{\Psi}_P}{\dot{\Psi}_F} = 1-\frac{\dot{\Psi}_D}{\dot{\Psi}_F} \quad (7)$$

The definitions of F-P (Fuel-Product) for the current power unit are given in Table 2. The effectiveness of the power cycle is given as:

$$\varepsilon = \frac{\dot{W}_{net}}{\dot{m}_{fuel}\times\psi_{fuel}} \quad (8)$$

The fuel exergy is approximated as:

$$\frac{LHV}{\psi_{fuel}} \approx 1.00565 \quad (9)$$

Table 2: F-P exergy definitions

Comp.	Fuel	Product	Comp.	Fuel	Product
SG	$\dot{\Psi}_{Fuel_{SG}}$	$\dot{\Psi}_{11}-\dot{\Psi}_{10}$	HPH2	$\dot{\Psi}_{15}+\dot{\Psi}_{24}-\dot{\Psi}_{25}$	$\dot{\Psi}_{9}-\dot{\Psi}_{8}$
RH	$\dot{\Psi}_{Fuel_{RH}}$	$\dot{\Psi}_{14}-\dot{\Psi}_{13}$	DEA	$\dot{\Psi}_{6}+\dot{\Psi}_{16}+\dot{\Psi}_{26}$	$\dot{\Psi}_{7}$

HPT	$\dot{\Psi}_{11} - \dot{\Psi}_{12} - \dot{\Psi}_{13}$	$\dot{W}_{HPT}$	LPH1	$\dot{\Psi}_{18} - \dot{\Psi}_{27}$	$\dot{\Psi}_{6} - \dot{\Psi}_{5}$
IPT	$\dot{\Psi}_{14} - \dot{\Psi}_{15} - \dot{\Psi}_{16} - \dot{\Psi}_{17}$	$\dot{W}_{IPT}$	LPH2	$\dot{\Psi}_{19} + \dot{\Psi}_{28} - \dot{\Psi}_{29}$	$\dot{\Psi}_{5} - \dot{\Psi}_{4}$
LPT	$\dot{\Psi}_{17} - \dot{\Psi}_{18} - \dot{\Psi}_{19} - \dot{\Psi}_{20} - \dot{\Psi}_{21} - \dot{\Psi}_{22}$	$\dot{W}_{LPT}$	LPH3	$\dot{\Psi}_{20} + \dot{\Psi}_{30} - \dot{\Psi}_{31}$	$\dot{\Psi}_{4} - \dot{\Psi}_{3}$
Cond	$\dot{\Psi}_{22} - \dot{\Psi}_{34} - \dot{\Psi}_{1}$	$\dot{\Psi}_{cw2} - \dot{\Psi}_{cw1}$	LPH4	$\dot{\Psi}_{21} + \dot{\Psi}_{32} - \dot{\Psi}_{33}$	$\dot{\Psi}_{3} - \dot{\Psi}_{2}$
HPH1	$\dot{\Psi}_{12} - \dot{\Psi}_{23}$	$\dot{\Psi}_{10} - \dot{\Psi}_{9}$	CEP	$\dot{W}_{CEP}$	$\dot{\Psi}_{2} - \dot{\Psi}_{1}$

3.2. Steps of the analysis

The main steps of the analysis by using the Excel spreadsheet is summarized in the following steps:

(i) Step 1: Assign the properties values for the given states.

(ii) Step 2: Use your knowledge in thermodynamic to generate the properties, such as the enthalpy, entropy, and specific volume when necessary as shown in Table 3.

Table 3: Generating the properties

STATE	P(kPa)	T(°C)	Tsat(°C)	h(kJ/kg)	s(kJ/kg.K)	hs(kJ/kg)	v (m3/kg)
1	7	39.0009		163.366	0.55908		0.00100749
2	977	39.1216		164.669	0.56032	164.327	
3	977	89.5533		375.793	1.18683		A
4	977	113.487		476.725	1.4563		
5	977	133.297		560.933	1.66869		
6	977	155.392		655.83	1.89604		
7	977	178.877		758.23	2.12865		0.00112587
8	17490	182.602		783.019	2.14262	758.232	
9	17490	210.339		905.063	2.40239		
10	17490	252.581		1098.46	2.78571		
11	17490	538		3389.6	6.38515		

(iii) Step 3: To find the mass fraction for each heater, solve the set of the linear equations which are developed by taking energy balance on the feed water heaters (Eq. (2a)). Use MINVERSE to create the inverse matrix, and MMULT to multiply the two matrices. Here, the generated inverse matrix is multiplied by the original one to obtain the unknowns (the mass fractions).

(iv) Step 4: Calculate the exergy at the all state points by using Eq. (4).

(v) Step 5: Calculate the irreversibility (Eq. (6)), the first law efficiency (Eq. (3)) and the effectiveness (Eq. (8)).

The results could be optimized by selecting the objective function, which might be the efficiency (maximizing) or the plant irreversibility (minimizing). Also, the constraints must be selected, which might be the bleeding pressures by letting them vary in a certain range, for example, +/- 10 %.

To make the optimization in Excel, follow the following steps:

(i) Step 1: Select *data* from the menu.

(ii) Step 2: select *solver*, see Fig. 3. Solver Add-Ins must be activated through:

$$Options \rightarrow add\ ins \rightarrow go\ (excel\ add\ ins) \rightarrow check\ the\ solver\ add\ ins\ box$$

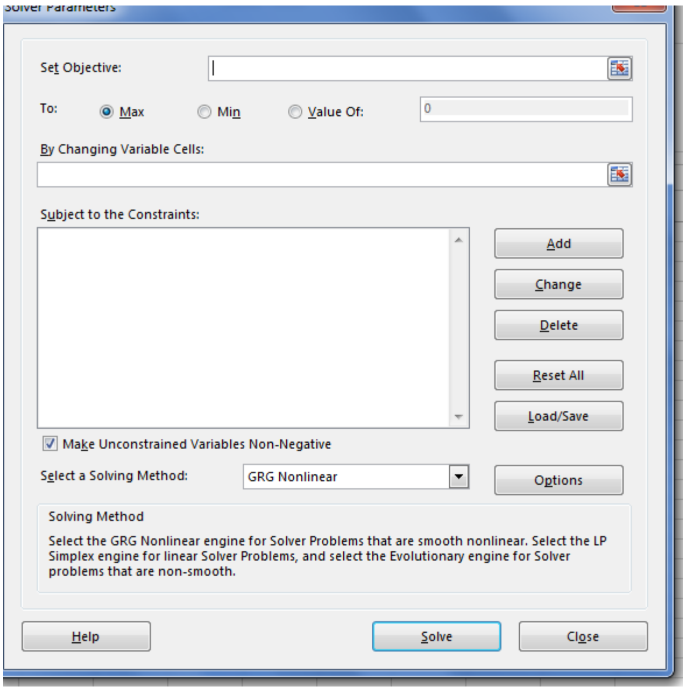

Figure 3: The Add-Ins solver

(iii) Select *maximize* (for thermal efficiency), or *minimize* for the irreversibility.

(iv) Select the objective function *cell* (efficiency or irreversibility).

(v) Select the constraints *cells* and set the limits.

(vi) Select the optimization *method*.

(vii) Push on the *solve* button to implement the optimization.

4. Results and discussions

The properties at each state are generated and tabulated in Table 4.

Table 4: The properties at each state

STATE	P(kPa)	T(°C)	h(kJ/kg)	s(kJ/kg.K)	STATE	P(kPa)	T(°C)	h(kJ/kg)	s(kJ/kg.K)
1	7	39	163.3655	0.5591	19	298	209	2883.997	7.3540
2	977	39	164.6685	0.5603	20	161	153	2777.243	7.3987
3	977	90	375.7926	1.1868	21	69	90	2650.336	7.4605
4	977	113	476.7254	1.4563	22	7	39	2367.544	7.6204
5	977	133	560.9334	1.6687	23	4350	216	925.5933	2.4761
6	977	155	655.8304	1.8960	24	2030	213	925.5933	2.4819
7	977	179	758.2299	2.1286	25	2030	188	799.9385	2.2175
8	17490	183	783.0186	2.1426	26	977	179	799.9385	2.2209
9	17490	210	905.063	2.4024	27	549	139	584.5979	1.7278
10	17490	253	1098.458	2.7857	28	298	133	584.5979	1.7287
11	17490	538	3389.603	6.3851	29	298	119	499.9804	1.5180
12	4350	338	3053.422	6.4841	30	161	113	499.9804	1.5187
13	4350	338	3053.422	6.4841	31	161	95	398.7221	1.2519
14	4350	538	3529.322	7.1597	32	69	90	398.7221	1.2526
15	2030	429	3312.014	7.2150	33	69	45	187.3257	0.6351
16	977	337	3130.352	7.2682	34	7	39	187.3257	0.6358
17	977	337	3130.352	7.2682	cw-in	101.325	15	63.07903	0.2245
18	549	271	3003.61	7.3097	cw_out	101.325	32	134.1932	0.4642

Solving the seven linear equations which are developed by taking mass and energy balance on the feed water heaters (use Eqs. (1 &2a)) will result in the mass fractions (x_{12}, x_{15}, x_{16}, x_{18}, x_{19}, x_{20} and x_{21}) which are extracted for each heater. The linear equations are set in a matrix form. The functions MMULT and MINVERSE are used to multiply the matrices and to find the inverse, see Tables. 5a and 5b.

Table 5a::Matrix for the seven equations

EQ	x12	x15	x16	x18	x19	x20	x21	RHS
1	2127.83	0.00	0.00	0.00	0.00	0.00	0.00	193.39
2	125.65	2512.08	0.00	0.00	0.00	0.00	0.00	122.04
3	144.11	144.11	2474.52	0.00	0.00	0.00	0.00	102.40
4	94.90	94.90	94.90	2419.01	0.00	0.00	0.00	94.90
5	84.21	84.21	84.21	84.62	2384.02	0.00	0.00	84.21
6	100.93	100.93	100.93	101.26	101.26	2378.52	0.00	100.93
7	211.12	211.12	211.12	211.40	211.40	211.40	2463.01	211.12

Table 5b: The inverse matrix

4.70E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
-2.35E-05	3.98E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
-2.60E-05	-2.32E-05	4.04E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00
-1.65E-05	-1.47E-05	-1.59E-05	4.13E-04	0.00E+00	0.00E+00	0.00E+00
-1.43E-05	-1.27E-05	-1.37E-05	-1.47E-05	4.19E-04	0.00E+00	0.00E+00
-1.65E-05	-1.47E-05	-1.59E-05	-1.70E-05	-1.79E-05	4.20E-04	0.00E+00
-3.20E-05	-2.85E-05	-3.07E-05	-3.28E-05	-3.45E-05	-3.61E-05	4.06E-04

The obtained mass fractions are tabulated in Table 6.

Table 6: Mass fractions

x12 (kg/kg)	0.090888
x15	0.044037
x16	0.033524
x18	0.032621
x19	0.028214
x20	0.032697
x21	0.063251

The heat transfer and work done per kilogram of the steam are calculated by using the first law of thermodynamics (Eq. (2a)). Those are, heat transfer to the steam generator (qh), heat transfer in the condenser (qc), work done by the high pressure turbine (whp), the work done by the intermediate pressure turbine (wip), work done by the low pressure turbine (wlp), work done by the condensate pump (wcp) and the work done by the feed pump (wfp). The net work done (wnet) is then calculated and tabulated in Table 7.

Table 7: Specific heat transfer and work

qh	2723.791	kJ/kg
qc	-1557.86	kJ/kg
whp	336.181	kJ/kg
wip	354.7077	kJ/kg
wlp	567.7104	kJ/kg
wCP	-1.08353	kJ/kg
wfp	-24.7887	kJ/kg
wnet	1232.727	kJ/kg

By knowing the net power output (350 MW), Eq (2b) is applied to calculate the cycle mass flow rate (283.9234 kg/s).

All other mass flow rates are calculated by multiplying the mass fractions by the cycle mass flow rate, the results are tabulated in Table 8.

Table 8: Mass flow rates

m12 (kg/s)	25.8053
m15	12.5031
m16	9.5182
m18	9.2620
m19	8.0106
m20	9.2835
m21	17.9584
SUM	92.3412

The rate of heat transfer and power can be calculated and tabulated by multiplying the specific quantities from Table 7 by the cycle mass flow rate, the results in MW are shown in Table 9.

Table 8: Rate of heat transfer and power

Qh	773.3480	[MW]
Qc	-442.3136	[MW]
Whp	95.4496	[MW]
WIP	100.7098	[MW]
WLp	161.1863	[MW]
WCP	-0.3076	[MW]
WFP	-7.0380	[MW]
Wnet	350	[MW]

The thermal efficiency (Eq. (3)), fuel exergy (Eq. (9)), effectiveness (Eq. (8)) and all other heat transfer (Eq. (2a)) is now calculated and tabulated in Table 10.

Table 10: Selected results

Eta_thermal		0.452578	m_F*LHV	909.8212	MW
W_net	350	MW	Fuel Exergy	904.7096	MW
mass_cy	283.9234	kg/s	Q_SG	650509.8	kW
T_{CW_i}	25	C	Q_RH	122838.2	kW
T_{cW_e}	32	C	Q_total	773348	kW
cp	4.18	kJ/kg.K	Effectiveness	0.386864	
m_{cw}	15114.64	kg/s			

Exergy at each state is calculated (Eq. (4)) and tabulated in Table 11.

Table 11: Exergy at each state

STATE	Exergy [kJ/kg]	Exergy [MW]	STATE	Exergy [kJ/kg]	Exergy [MW]
1	1.0293	0.2922	19	19.6358	5.5751
2	1.8039	0.5122	20	18.8293	5.3461
3	22.0360	6.2565	21	27.2331	7.7321
4	39.1574	11.1177	22	67.5421	19.1768
5	56.5229	16.0482	23	17.4411	4.9519
6	79.0704	22.4499	24	17.2859	4.9079
7	128.1340	36.3802	25	19.3411	5.4914
8	148.7568	42.2355	26	19.2042	5.4525
9	193.3523	54.8972	27	2.4141	0.6854
10	272.4597	77.3577	28	2.4056	0.6830
11	1490.4327	423.1687	29	3.1610	0.8975
12	102.2267	29.0245	30	3.1481	0.8938
13	1022.5234	290.3183	31	2.8091	0.7976
14	1272.0383	361.1614	32	2.7880	0.7916
15	51.3214	14.5713	33	0.3963	0.1125
16	32.4474	9.2126	34	0.3625	0.1029
17	804.8485	228.5153	cw-in	0.0000	0.0000
18	27.0358	7.6761	cw_out	0.3382	5.1120

The total irreversibility of the steam cycle is found (Eq. (6)) equals to 554.709 MW as seen in Table 12.

Table 12: Irreversibilities of the cycle components.

Component	IRR(MW)	Component	IRR(MW)	Component	IRR(MW)
SG	419.4946	HPH1	1.6122	Cond.	13.8755
RH	73.6724	HPH2	1.3261	Trap1	0.0440
HPT	8.3762	FWH	0.7348	Trap2	0.0389
IPT	8.1524	LPH1	0.5889	Trap3	0.0024
LPT	21.8229	LPH2	0.4301	Trap4	0.0037
CP	0.0877	LPH3	0.5811	Trap5	0.0059
FP	1.1828	LPH4	2.6667	Trap6	0.0096
TOTAL Irreversibility = 554.7092 MW WNET=350 MW Effectiveness = 0.3869					

Optimization:

The next step of the analysis is an attempt to reduce the cycle irreversibility. For optimization:

- Minimizing the irreversibility is chosen as the objective function.
- The HPT inlet pressure, the maximum and minimum feed water heaters pressures are chosen as the constraints variables.
- The variables let to vary in the range of -/+ 10%.

To minimize the irreversibility, follow the following steps:

(i) Select *data* from the menu and then go to the *solver*.
(ii) Select the objective function (cell contains the total irreversibility).
(iii) Select *minimize* (for the irreversibility).
(iv) Select the constraints *cells* as shown in Table 13, and set the limits as shown in Table 14.

Table 13: The constraints variables

State	P [kPa]
11	17490
12	4350
18	549
19	298
20	161
21	69

Table 14: Setting the limits

-10%	cell	Variable	10%
879.3	B3	977	1074.7
15741	B12	17490	19239
3915	B13	4350	4785
1827	B16	2030	2233
494.1	B19	549	603.9
268.2	B20	298	327.8
144.9	B21	161	177.1
62.1	B22	69	75.9

(v) Select the optimization *method* (GRG Nonlinear).
(vi) Push on the *solve* button to implement the optimization as shown in Fig. 4.

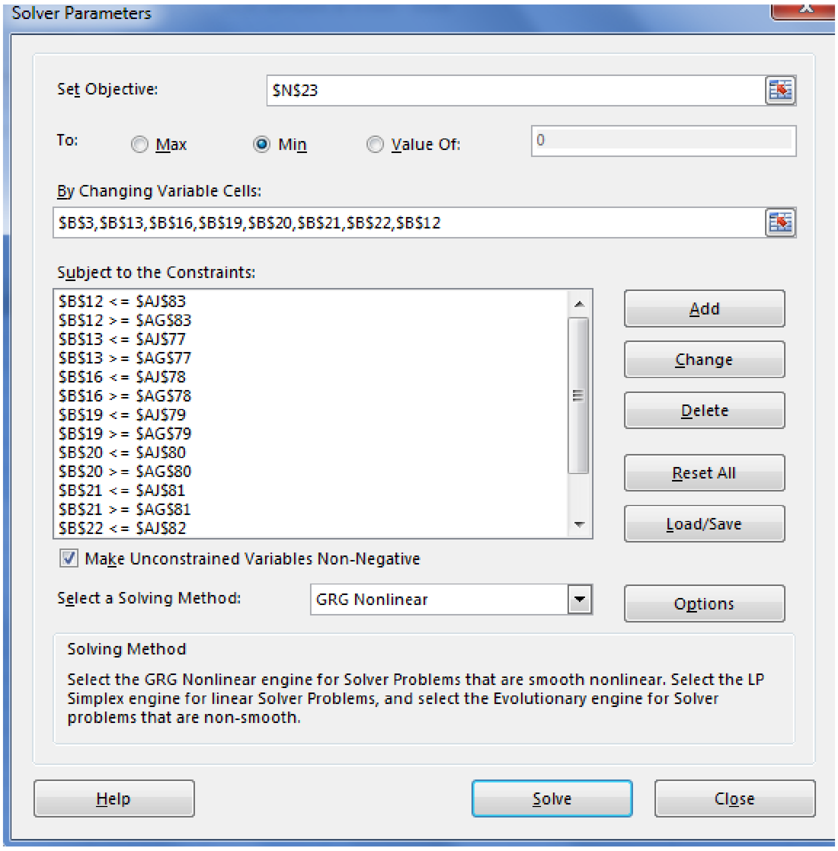

Figure 4: Add-Ins solver

<u>The new solution after optimization</u>

The new property values are now generated as shown in Table 15.

Table 15: Property values after optimization

1	STATE	P(kPa)	T(°C)	h(kJ/kg)	s(kJ/kg.K)
2	1	7	39	163.366	0.5591
3	2	1074.7	39	164.8	0.5604
4	3	1074.7	87	364.348	1.1549
5	4	1074.7	112	468.678	1.4352
6	5	1074.7	135	568.593	1.6872
7	6	1074.7	158	666.766	1.9212
8	7	1074.7	183	776.636	2.1689
9	8	19239	187	804.042	2.1842
10	9	19239	215	927.559	2.4445
11	10	19239	258	1126.23	2.8341
12	11	19239	538	3369.36	6.3217
13	12	4785	336	3038.15	6.4193
14	13	4785	336	3038.15	6.4193
15	14	4785	538	3525.02	7.1117
16	15	2233	429	3308.35	7.1669
17	16	1074.7	336	3127.22	7.2200
18	17	1074.7	336	3127.22	7.2200
19	18	585.908	267	2994.65	7.2637
20	19	313.888	204	2873.7	7.3089
21	20	151.099	139	2750	7.3626
22	21	62.1	87	2620.66	7.4260
23	22	7	39	2353.94	7.5768
24	23	4785	221	948.119	2.5209
25	24	2233	218	948.119	2.5272
26	25	2233	193	820.576	2.2615

Selected results are shown in Table 16. As it can be seen both the heat flow rate (and hence the rate of the fuel consumption) and the rate of the input exergy are reduced to 902.8341 MW and 897.752 MW, respectively. A minor increase in the thermal efficiency is noticed.

Table 16: Selected results after optimization

Eta_thermal		0.45608	mf*LHV	902.834	MW
W_net	350	MW	Fuel Exergy	897.762	MW
mass_cy	285.949	kg/s	Q_SG	641422	kW
T_{cw_i}	25	°C	Q_RH	125987	kW
T_{cw_e}	32	°C	Q_total	767409	kW
cp	4.18	kJ/kg.K	Effectiveness	0.38986	
mcw	15026.2	kg/s			

Table 17, shows the exergy at each state after optimization, and Table 18, shows the irreversibility for each component and hence the total irreversibility is calculated.

Table 17: Exergy at each state after optimization

STATE	Exergy (MW)	STATE	Exergy (MW)	STATE	Exergy (MW)
1	0.2917	13	292.0990	25	6.0325
2	0.5350	14	364.6630	26	5.9877
3	5.7939	15	15.0587	27	0.7335
4	10.6871	16	10.0551	28	0.7309
5	16.5229	17	230.7789	29	0.9564
6	23.2188	18	8.0283	30	0.9519
7	38.4681	19	6.6282	31	0.7989
8	45.0002	20	5.3482	32	0.7924
9	58.1307	21	6.9793	33	0.1152
10	81.7216	22	18.9072	34	0.1056
11	425.8107	23	5.4655	CW_{-i}	0.0000
12	30.6819	24	5.4145	$CW_{\_e}$	5.0821

Table 18: Irreversibilities after optimization

Component	IRR(MW)	Component	IRR(MW)	Component	IRR(MW)
SG	410.5254	HPH1	1.6254	Cond.	13.6390
RH	75.6554	HPH2	1.3102	Trap1	0.0510
HPT	8.3217	FWH	0.7935	Trap2	0.0448
IPT	8.1494	LPH1	0.5989	Trap3	0.0026
LPT	22.0419	LPH2	0.5669	Trap4	0.0045
CP	0.0948	LPH3	0.6079	Trap5	0.0065
FP	1.3044	LPH4	2.3975	Trap6	0.0096
TOTAL Irreversibility =547.7519 MW WNET =350 MW Effectiveness =0.3899					

As it can be seen, the total irreversibility is reduced to 547.7519 with a small increase in the effectiveness

5. Conclusions

Excel spreadsheet is employed to assess the thermodynamic performance of a steam power unit. The following points are highlighted:

1. The thermodynamic properties are generated by the Excel tools developed for thermodynamics.
2. The functions MMULT and MINVERSE are used to multiply the matrices and to find the inverse and hence the mass flow rates.

3. The spreadsheet is employed to calculate exergy. Irreversibility and cycle effectiveness.
4. Solver Excel command is used to optimize the cycle performance. The objective is to maximize cycle efficiency or minimize the total irreversibility, where the selected constraints for this optimization process are the pressures
5. Excel spreadsheets are a very powerful tool for thermal systems simulation.

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