Course name: Thermal Design & Optimization

Project name: Compressed Air Energy Storage (CAES) Simulation & Improvement

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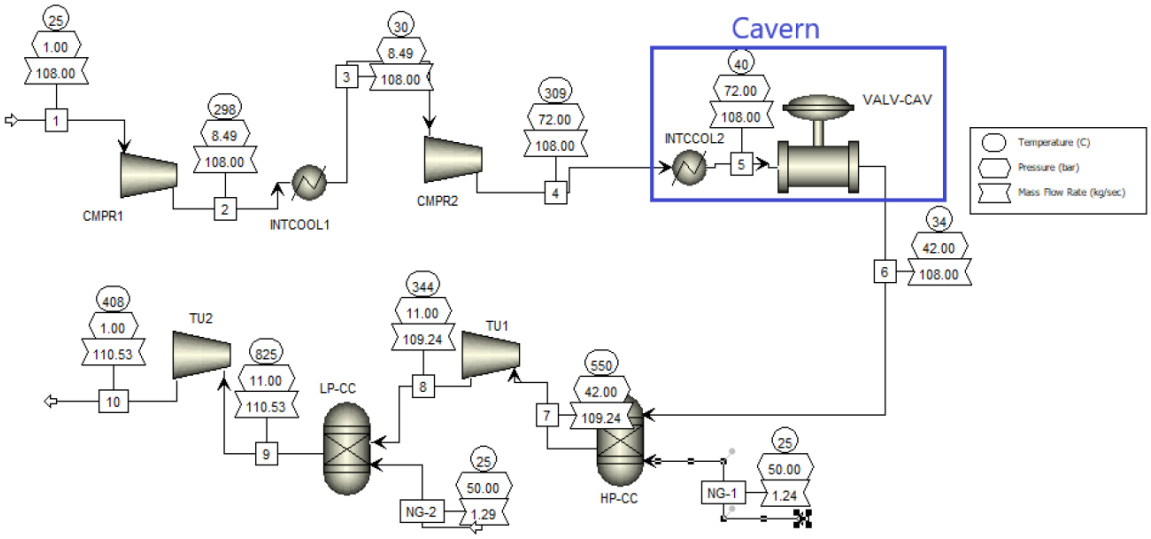
Introduction:

The overall aim of this project is to improve the design of Huntorf CAES plant in terms of fuel consumption and economic viability. For this endeavor, at the beginning the Huntorf CAES plant is simulated with the help of Aspen Plus software. Subsequently, thermodynamic, exergy, and economic analysis are performed to identify irreversibility and areas of improvement.

In the next section, possible approaches for improving the design were investigated, and the new and improved CAES plant is simulated. Similar analysis to the previous section is done to provide a suitable comparison between the old and new design, showcasing the impact of suggested improvements.

Base Plant Simulation and its data:

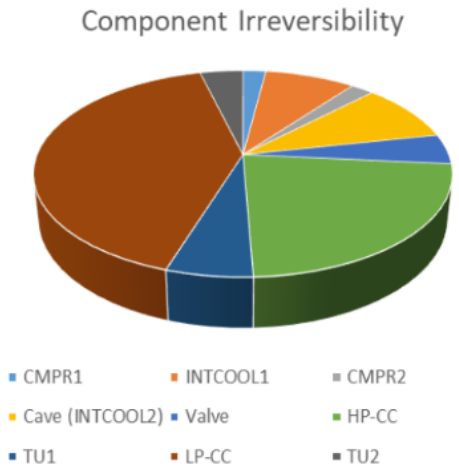


Base Plant simulated by Aspen Plus.

Streams	Amount of Exergy
1	0.3954
2	29.085
3	20.195
4	49.6354
5	39.835
6	34.7954
7	75.43
8	44.58
9	67.46
10	14.82
NG-1	65.101
NG-2	66.76
11	30.9478
12	0
13	31.7141
14	0
15	24.8185
16	53.8626

Exergy vector for every stream.

Components	Irreversibility (MW)
CMPR1	2.2582
INTCOOL1	8.89
CMPR2	2.2737
Cave (INTCOOL2)	9.8004
Valve	5.0396
HP-CC	24.4664
TU1	6.0315
LP-CC	43.88
TU2	4.2226
system	106.8624



Equipment Irreversibility.

Streams	Exergy Cost (MW)	Unit Exergy Cost Vector (k)
1	0.3954	1
2	31.3432	1.077641396
3	31.3432	1.55202773
4	63.0573	1.270409828
5	63.0573	1.582962219
6	63.0573	1.812230927
7	128.1583	1.699036192
8	75.613397	1.696128241
9	142.373397	2.11048617
10	0	0
NG-1	65.101	1
NG-2	66.76	1
11	30.9478	1
12	0	0
13	31.7141	1
14	0	0
15	52.544903	2.117166751
16	142.373397	2.643270043

Exergy Cost.

Streams	C ($/s)	c ($/MWh)
1	0	0
2	1.61436841	185.422238
3	1.599787584	183.747521
4	3.254920452	185.826441
5	3.223034995	184.00607
6	3.223006195	184.004426
7	4.505344697	126.556305
8	2.662710681	126.773281
9	3.976758453	100.554814
10	0	0
NG-1	1.283936389	71
NG-2	1.316655556	71
11	1.693532389	197
12	0	0
13	1.735466028	197
14	0	0
15	1.74737022	119.717279
16	3.824423122	96.7029201

Exergo-Economic cost of each stream.

Components	CD+Z ($/s)
LP-CC	0.868018895
Cave (INTCOOL2)	0.537766971
HP-CC	0.484129665
INTCOOL1	0.47247074
TU1	0.307298339
TU2	0.270280541
Valve	0.257616883
CMPR2	0.204755077
CMPR1	0.202737701

Components	f	r
CMPR1	0.3904749	-0.046744886
INTCOOL1	0.0308608	-0.009031907
CMPR2	0.3923378	-0.0462891
Cave (INTCOO	0.0592923	-0.009796079
Valve	0.0001119	-8.93568E-06
HP-CC	0.0033005	-0.001244522
TU1	0.3100043	-0.054039397
LP-CC	0.0030043	-0.001980612
TU2	0.5636193	-0.038306408

Left: Destroyed Exergy by components. Right: Exergo-economic factor (f), and relative cost difference (r).

The results showed that combustion chambers, cavern system and intercoolers have the highest exergy destruction. Also, the f value of combustion chambers is lowest, meaning they are more suited for improvement from thermodynamic point of view.

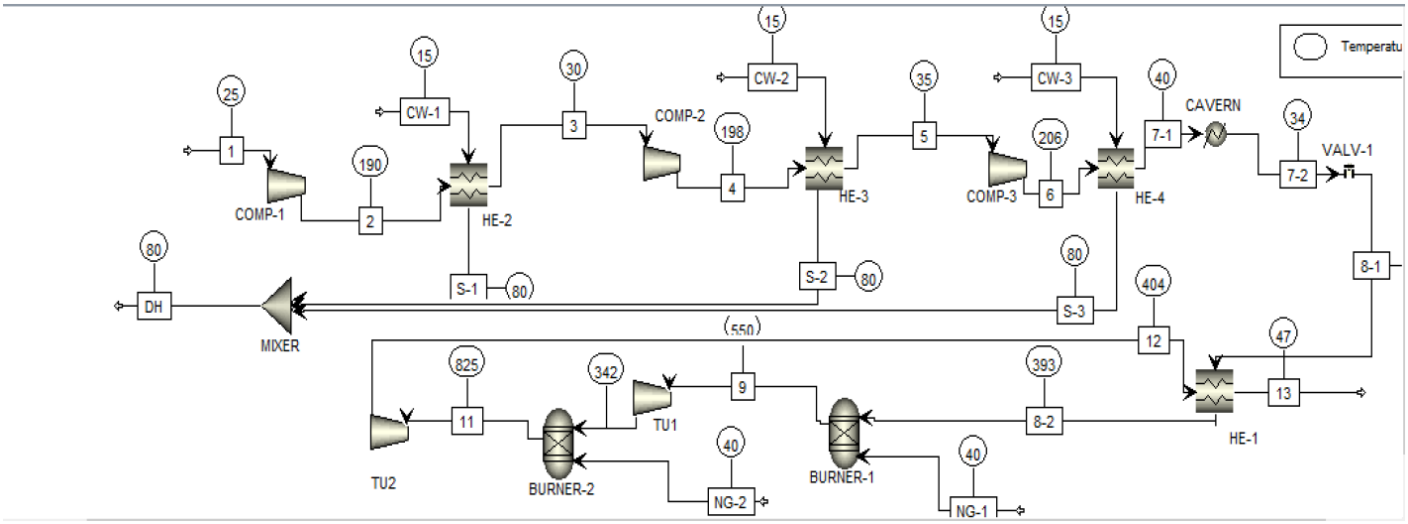
OPEX		Income	
Annual Gas consumed ($)	64869814.8	Annual Electricity produced ($)	81457435.44
Annual Electricity consumed ($)	44409857.65	Annual District heating ($)	
Sum	109279672.4	Sum	81457435.44

Base plant economic performance summary.

The results for basic plant are completely unsatisfying. As it is evident the plant's expenses have exceeded its income, meaning it is losing capital each year.

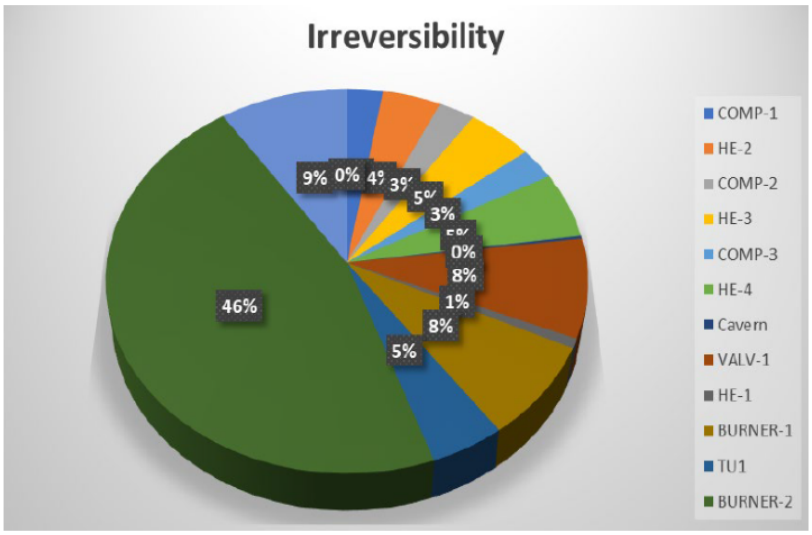
Improved Plant Simulation and Its data:

Based on the analysis, several changes were implemented on the CAES system. The two-stage compressor system were changed into 3 stage to lower the costs of equipment construction. Furthermore, using pinch analysis several heat streams were valorized, as pre-heating stream and to produce hot water.



Improved CAES Plant.

Components	Irreversibility (MW)
COMP-1	1.55800194
HE-2	2.533909167
COMP-2	1.56478653
HE-3	2.851385199
COMP-3	1.57707373
HE-4	3.280565825
Cavern	0.1467058
VALV-1	4.90445855
HE-1	0.474323599
BURNER-1	4.67377366
TU1	2.70055401
BURNER-2	27.04624289
TU2	5.53939393
MIXER	0.000060978
Total	58.85123581



Equipment irreversibility for new system.

Streams	Exergy Cost (MW)	Unit Exergy Cost Vector (k)
1	0.3954	1
2	18.8891	1.08989632
3	14.733498	1.082342838
4	33.553798	1.087005209
5	28.85626628	1.077013248
6	48.09536628	1.081891535
7-one	42.80487599	1.074221915
7-two	42.80487599	1.078191489
8-one	42.80487599	1.230160686
8-two	71.33339883	1.422451651
9	90.77780266	1.398327629
10	52.65112554	1.393079206
11	118.8688452	1.544427992
12	28.52852284	1.538849462
13	0	0
14	18.4937	1
15	18.8203	1
16	19.2391	1
17	38.12667712	1.561065249
18	90.34032234	1.708144047
19	0	0
CW-1	0.046500699	1
CW-2	0.048050722	1
CW-3	0.051150769	1
DH	14.2893262	3.681783594
NG-1	19.44440383	1
NG-2	66.21771964	1
S-1	4.202102699	3.413314571
S-2	4.745582442	3.731050159
S-3	5.34164106	3.875974475

Streams	C ($/s)	c ($/MWh)
1	0	0
2	0.953172063	181.6613511
3	0.754394209	184.3295566
4	1.724817218	185.0563082
5	1.494522808	186.4510833
6	2.487073024	186.1606133
7-one	2.224294991	187.0689211
7-two	2.192409534	184.3872722
8-one	2.192380734	184.3848501
8-two	2.936739055	148.2091246
9	3.318632685	131.6079186
10	1.979326957	135.3357022
11	3.282692166	99.41790702
12	0.82384612	103.960729
13	0	0
14	1.012016361	197
15	1.029888639	197
16	1.052806306	197.0000001
17	1.244526535	117.5107789
18	2.30817058	91.9790175
19	0	0
CW-1	0.000129169	10.00003032
CW-2	0.000133474	9.999982935
CW-3	0.000142085	9.99996696
DH	0.652854783	164.4778197
NG-1	0.383486853	70.99999994
NG-2	1.305960582	71.00000001
S-1	0.184813584	158.3323754
S-2	0.217375958	164.9014545
S-3	0.250665242	168.9358869

Left: Exergy cost for new system. Right: Exergo-economic values for new system.

OPEX		Income	
Annual Gas consumed ($)	28180601.12	Annual Electricity produced ($)	80346302.25
Annual Electricity consumed ($)	52654033.92	Annual District heating ($)	15656648.4
Sum	80834635.04	Sum	96002950.65

Improved plant economic performance summary.

Parameter	Improved CAES
i=WACC	5.03%
NPV ($)	67918739.23
IRR	8.50%
BCR	0.996066173
PBT	16

Economic analysis results for improved plant.