Rethink planning for heat-recovery systems

Better early design of steam generators can save lots of money in operating cogeneration plants

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Heat-recovery steam generators (HRSGs) in cogeneration plants differ from those in combined cycle plants in several ways. Steam pressure levels, steam temperatures and reheat parameters for many large steam turbines are standardized. Thus, large combined cycle plants apply steam parameters. **Result:** HRSG designs are optimized to generate these steam parameters.

However, in the case of cogeneration plants, steam pressure, flow and temperature can vary tremendously and there can be a wide range of operating pressure levels. Cogeneration plants have the flexibility to import or export steam to or from the HRSG to be superheated in or outside the HRSG. High-pressure (HP) and low-pressure (LP) steam parameters will vary depending on plant needs. Firing temperatures will differ depending on the turbine selected and on facility steam demand. Fresh air can be used to augment steam production should the gas turbine trips or part of the exhaust gases can be bypassed for other processing needs.

Site-specific evaluations. Cogeneration plants, refineries and petrochemical/chemical plants acknowledge that HRSG configurations are very site specific. Plant engineers should evaluate the HRSG and site steam parameters. The engineering team should determine the type of HRSG required and its configuration before developing purchase specifications of the unit. Early engineering work on the HRSG will save substantial monies over the long-term operation of the unit.

Design and discovery exercises. Simulation is a valuable tool; it helps engineers evaluate the gas/steam temperature profiles in a multiple-pressure unfired or fired HRSG units. Engineers can evaluate the design and off-design performance for complex HRSGs using simulation tools without specifically designing the HRSG.[1] The plant engineer can rough out an HRSG configuration and optimize this configuration (whether single or multiple pressure) before sending bids to the HRSG suppliers. This exercise is typically not done by HRSG suppliers—they are busy with equipment bids and inquiries. Too often, HRSGs are built based only on specifications; the designers do not have the time to optimize system parameters or determine the unit's configuration.

The following example illustrates the design/optimization benefits for a cogeneration unit by performing simulation studies on the HRSG configuration during the conceptual design phase. The designers do not need to know the HRSG's physical dimensions, tube sizes, fin configuration, etc. The pinch and approach points for the evaporator alone can be applied to determine the gas/steam temperature profiles and duty for each heating surface.

Case history. A cogeneration plant requires 200,000 lb/h of steam at 600 psig and 700°F and LP steam of 25,000 lb/h at 150 psig saturated. The feedwater is at 230°F. A gas turbine with an exhaust gas flow of 1 million lb/h (MMlb/h) at 1,000°F is available. The question is whether the HRSG should be a simple, sin-

FIG. 1 Design of a single-pressure HRSG.

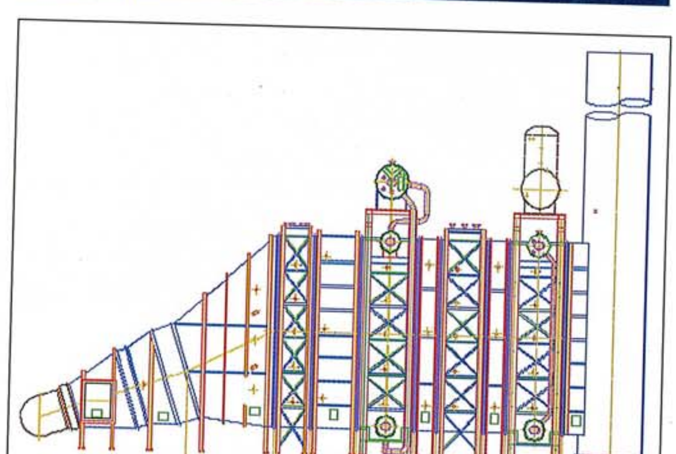

FIG. 2 Design of a multiple-pressure HRSG.

HRSG performance: Off-design case

Project-study units-British case-case4d remarks- amb temp.-°F=70
heat loss- %=1 gas temp. to HRSG °F 1,000 gas flow-lb/h=1,000,000
% vol. CO_2=3, H_2O=7, N_2=75, O_2=15, ASME eff-%=777.27 tot duty-
MM Btu/h=246.4.

Surf	gas temp. in/out °F		wat/stm in/out °F		duty MMb/h	pres psia	flow lb/h	pstm %	pinch °F	apprch °F	US Btu/h°F	module no.
burn	1,000	1,232	0	0	69.69	0	3,247	0				
sh	1,232	1,106	491	700	35.4	615	199,986	100			61509	1
desh	1,182	1,182	637	589	0	621.7	5,576	0				
evap	1,106	511	453	491	161.38	628.4	209,409	100	20	37	928109	1
eco	511	319	230	453	49.62	638.4	211,503				682311	1

stack gas flow=1,003,247 % CO_2=3.55 H_2O=8.09 N_2=13.77.
Fuel gas: vol%
methane=97 ethane=3
LHV-Btu/cuft=934 LHV-Btu=21,460 aug air-lb/h=0

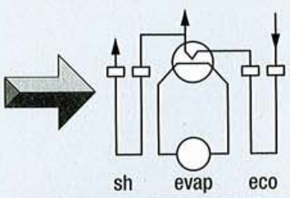

FIG. 8 Single-pressure HRSG-fired case—15,000 lb/h process.

choice. The plant engineer must understand the needs of the facility to make the best decisions regarding the HRSG configuration.

Evaluating HRSGs. Using an HRSG simulation program, the single-pressure HRSG was designed with a pinch and an approach point of 15°F and 10°F and the 25,000 lb/h steam was taken off from the drum. In the off-design fired case, the program computes the fuel input and firing temperature once the steam demand is set at 200,000 lb/h. The simulation results are shown in Figs. 3 and 4 for both unfired and fired cases. Figs. 5 and 6 show the design and performance with a multiple-pressure HRSG.

HRSG performance-design case

Project-study1 units-British case3d remarks- amb temp.-°F=70
heat loss- %=1 gas temp. to HRSG °F 1,000 gas flow-lb/h=1,000,000
% vol. CO_2=3, H_2O=7, N_2=75, O_2=15, ASME eff-%=71.22 tot duty-
MM Btu/h=176.3.

Surf	gas temp. in/out °F		wat/stm in/out °F		duty MMb/h	pres psia	flow lb/h	pstm %	pinch °F	apprch °F	US Btu/h°F	module no.
sh	1,000	925	490	700	20.37	615	138,366	100			56,054	1
evap	925	540	475	490	102.95	622	138,366	100	50	15	578,395	1
eco	540	468	350	475	19.07	632	139,749				215,049	1
evap	468	411	350	366	14.67	165	16,786	100	45	16	211,245	2
eco	411	335	230	350	19.26	700	156,703				236,999	3

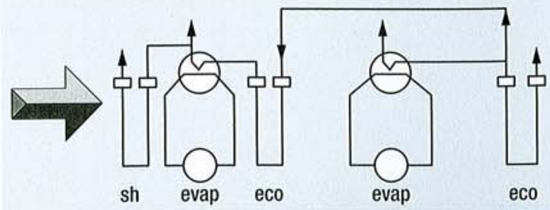

FIG. 9 Multiple-pressure HRSG unfired case—15,000 lb/h process.

HRSG performance: Off-design case

Project-study1 units-British case-case3P remarks- amb temp.-°F=70
heat loss- %=1 gas temp. to HRSG °F 1,000 gas flow-lb/h=1,000,000
% vol. CO_2=3, H_2O=7, N_2=75, O_2=15, ASME eff-%=80.54 tot duty-
MM Btu/h=246.5.

Surf	gas temp. in/out °F		wat/stm in/out °F		duty MMb/h	pres psia	flow lb/h	pstm %	pinch °F	apprch °F	US Btu/h°F	module no.
burn	1,000	1,238		0	69.99	0	3,261	0				
sh	1,238	1,110	491	700	36.06	615	200,183	100			62,218	1
desh	1,187	1,187	641	587	0	621.5	6,278	0				
evap	1,110	559	451	491	149.93	627.9	193,905	100	67	39	600,711	1
eco	559	459	327	451	26.07	637.9	195,844				217,989	1
evap	459	407	327	366	13.52	165	15,061	100	41	38	211,364	2
eco	407	326	230	327	20.96	700	211,055				238,405	3

stack gas flow=1,003,261 % CO_2=3.55 H_2O=8.09 N_2=74.57 O_2=13.77.
Fuel gas: vol%
methane=97 ethane=3
LHV-Btu/cuft=934 LHV-Btu=21,460 aug air-lb/h=0

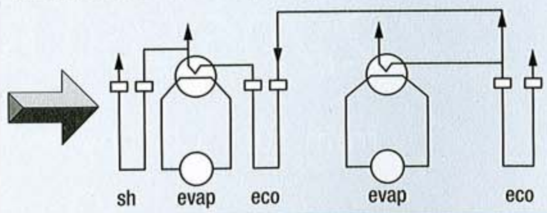

FIG. 10 Multiple-pressure HRSG fired case—15,000 lb/h process.

To study the need for complex HRSG configurations, the process steam demand was reduced to 15,000 lb/h from 25,000 lb/h. The HRSG design and performance for a single-pressure unit is shown in Figs. 7 and 8. Figs. 9 and 10 show the simulation results for a multiple-pressure HRSG.

Analysis. Table 1 summarizes the design and performance for all three operating cases.

From the simulation results, when the LP steam demand is 25,000 lb/h, the multiple-pressure option provides a fuel savings of over 9.2 MM Btu/h on a lower heating value basis. Based on fuel cost of $10/MM Btu, the annual savings for this design is:

HRSG performance-design case

Project-study units-British case-case1d remarks- amb temp.-°F=70
heat loss- %=1 gas temp. to HRSG °F 1,000 gas flow-lb/h=1,000,000
% vol. CO_2=3, H_2O=7, N_2=75, O_2=15, ASME eff-%=70.14 tot duty-
MM Btu/h=175.

Surf	gas temp. in/out °F	wat/stm in/out °F	duty MMb/h	pres psia	flow lb/h	pstm %	pinch °F	apprch °F	US Btu/h°F	module no.
sh	1,000 930	490 700	19.12	615	129,907	100			52,299	1
evap	930 505	480 490	114.36	622	154,907	100	15	10	908,790	1
eco	505 345	230 480	41.48	632	156,456				701,552	1

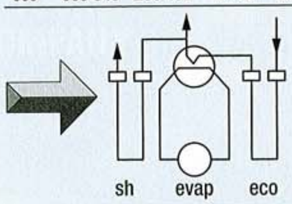

FIG. 3 Unfired single pressure case—25,000 lb/h LP steam.

HRSG performance: Off-design case

Project-study units-British case-case1d remarks- amb temp.-°F=70
heat loss- %=1 gas temp. to HRSG °F 1,000 gas flow-lb/h=1,000,000
% vol. CO_2=3, H_2O=7, N_2=75, O_2=15, ASME eff-%=78.22 tot duty-
MM Btu/h=257.

Surf	gas temp. in/out °F	wat/stm in/out °F	duty MMb/h	pres psia	flow lb/h	pstm %	pinch °F	apprch °F	US Btu/h°F	module no.
burn	1,000 1,263	0 0	79.12	0	3,687	0				
sh	1,263 1,138	491 700	35.55	615	200,456	100			58,637	1
desh	1,214 1,214	638 589	0	622.5	5,728	0				
evap	1,138 512	449 491	170.29	629.9	219,727	100	20	41	939,130	1
eco	512 314	230 449	51.14	639.9	221,924				700,462	1

stack gas flow=1,003,687 % CO_2=3.63 H_2O=8.23 N_2=74.51 O_2=13.61.
Fuel gas: vol%
methane=97 ethane=3
LHV-Btu/cuft=934 LHV-Btu=21460 aug air-lb/h=0

FIG. 4 Single pressure HRSG fired case—200,000 lb/h HP steam and 25,000 lb/h process steam.

HRSG performance-design case

Project-study units-British case2d remarks- amb temp.-°F=70
heat loss- %=1 gas temp. to HRSG °F 1,000 gas flow-lb/h=1,000,000
% vol. CO_2=3, H_2O=7, N_2=75, O_2=15, ASME eff-%=75.34 tot duty-
MM Btu/h=186.5.

Surf	gas temp. in/out °F	wat/stm in/out °F	duty MMb/h	pres psia	flow lb/h	pstm %	pinch °F	apprch °F	US Btu/h°F	module no.
sh	1,000 925	490 700	20.37	615	138,366	100			56,054	1
evap	925 540	475 490	102.95	622	138,366	100	50	15	578,395	1
eco	540 468	350 475	19.07	632	139,749				215,049	1
evap	468 376	350 366	23.67	165	27,022	100	10	16	598,320	2
eco	376 295	230 350	20.53	700	16,742				481,035	3

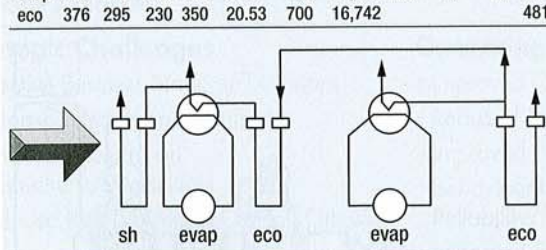

FIG. 5 Multiple pressure HRSG unfired case—25,000 lb/h process steam.

gle-pressure HRSG unit or a complex, multiple-pressure HRSG, which is more expensive.

At first sight, a multiple-pressure HRSG unit would be suggested by any consultant. However, the purpose here is to show that it sometimes may not be economical to use a multiple-pressure HRSG when a single-pressure HRSG can perform well in this situation.

HRSG performance: Off-design case

Project-study1 units-British case-case2d remarks- amb temp.-°F=70
heat loss- %=1 gas temp. to HRSG °F 1,000 gas flow-lb/h=1,000,000
4 vol. CO_2=3, H_2O=7, N_2=75, O_2=15, ASME eff-%=80.54 tot duty-
MM Btu/h=257.

Surf	gas temp. in/out °F	wat/stm in/out °F	duty MMb/h	pres psia	flow lb/h	pstm %	pinch °F	apprch °F	US Btu/h°F	module no.
burn	1,000 1,237	0 0	69.82	0	3,253	0				
sh	1,237 1,110	491 700	35.98	615	200,210	100			62118	1
desh	1,187 1,187	640 587	0	621.6	6,190	0				
evap	1,110 559	453 491	149.7	628.1	194,020	100	68	37	598,632	1
eco	559 462	333 453	25.42	638.1	195,960				216,574	1
evap	462 375	333 366	22.54	165	25,278	100	9	33	600,344	2
eco	375 284	230 333	23.31	700	221,491				481,933	3

stack gas flow=1,003,253 % CO_2=3.55 H_2O=8.09 N_2=74.57 O_2=13.77.
Fuel gas: vol%
methane=97 ethane=3
LHV-Btu/cuft=934 LHV-Btu=21460 aug air-lb/h=0

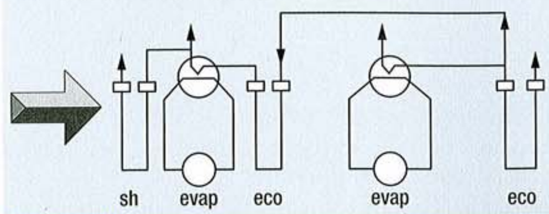

FIG. 6 Multiple pressure-fired HRSG case-25,000 lb/h process.

HRSG performance: Off-design case

Project-study units-British case-case4d remarks- amb temp.-°F=70
heat loss- %=1 gas temp. to HRSG °F 1,000 gas flow-lb/h=1,000,000
% vol. CO_2=3, H_2O=7, N_2=75, O_2=15, ASME eff-%=69.93 tot duty-
MM Btu/h=173.1.

Surf	gas temp. in/out °F	wat/stm in/out °F	duty MMb/h	pres psia	flow lb/h	pstm %	pinch °F	apprch °F	US Btu/h°F	module no.
sh	1,000 926	490 700	20.17	615	137,040	100			55468	1
evap	926 505	480 490	115.24	622	152,040	100	15	10	898,666	1
eco	505 347	230 480	40.71	632	153,560				681,768	1

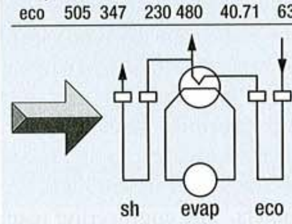

FIG. 7 Single pressure HRSG-unfired case—15,000 lb/h process.

Options. In this example, the design options include:

Single-pressure HRSG. As shown in Fig. 1, a single-pressure HRSG unit should be considered. The steam required for process or LP steam may be taken off the steam drum and the pressure reduced. This may appear inefficient; however, depending on the plant parameters and the ratio of HP to LP steam pressures and flows, this may be a good and an inexpensive option.

Multiple-pressure HRSG. Another possible solution is to use a multiple-pressure HRSG, as shown in Fig. 2, with the HP stage followed by the LP evaporator and a common economizer, which feeds the two modules. This is a more complex HRSG and it is more expensive. But this HRSG offers a higher efficiency and lower fuel consumption.

In some cases, the multiple-pressure HRSG option may be the only choice. However, it is possible that the single-pressure HRSG is equally effective as the more complex multiple-pressure HRSG and is less expensive. Steam parameters and the ratio between HP and LP steam flows and pressures determine which design is the better

TABLE 1. Summary of design and off-design performance

Case	Single-pressure		Multiple-pressure		Single-pressure		Multiple-pressure	
	Unfired	Fired	Unfired	Fired	Unfired	Fired	Unfired	Fired
HP steam, lb/h	130,000	200,000	138,000	200,000	137,000	200,000	138,000	200,000
LP steam, lb/h	25,000	25,000	27,000	25,000	15,000	15,000	16,700	15,000
Firing temp., °F	0	1,263	0	1,237	0	1,232	0	1,238
Burner duty, MM Btu/h	0	79.2	0	70	0	69.7	0	70
Exit gas, °F	345	314	295	284	347	319	335	326

Data: HP steam: 600 psig, 700°F; LP steam at 150 psig sat. Feedwater = 230°F, 1% blowdown. Exhaust gas flow = 1 MM lb/h at 1,000°F. % vol CO_2 = 3%, H_2O = 7%, N_2 = 7%, O_2 = 15%. Heat loss = 1%.

$9.2 \times 10 \times 8{,}000$ = \$736,000, assuming the unit operates in the fired mode at all times. However, if the unit operates in the fired mode only part of the time, then it is possible that the single-pressure option with its lower capital cost is more attractive.

When process steam demand drops to 15,000 lb/h, then the multiple-pressure option is not attractive. The single-pressure unit is as efficient as the multiple-pressure unit. A slight increase in LP steam is seen in the unfired mode. However, if we compare the complexity of the design and costs, the single-pressure unit can come out as the better choice.

Optimize design and performance of HRSG. Design engineers should consider applying simulation models when choosing between multiple-pressure design or single-pressure HRSG installations. Before developing specifications for the HRSG, the consultant should be aware of facility's operating possibilities and options. Specifying a multiple-pressure unit without performing such analysis can yield high capital investments as well as higher operating costs for the plant.

In situations such as when the ratio of HP to LP steam pressure increases, and if the ratio of LP to HP steam flow increases, a multiple-pressure HRSG is a better choice. However, for quantitative evaluation and analysis of results, the simulation program is extremely useful. **HP**

LITERATURE CITED

[1] Ganapathy, V., "Simplify heat recovery steam generator evaluation," March 1990, *Hydrocarbon Processing*, pp. 77–82.

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Mr. Ganapathy has published over 250 articles on steam generators and thermal design and has also authored five books on boilers, the latest entitled, *Industrial Boilers and HRSGs*, published by Taylor and Francis. He also conducts courses on boilers. Mr. Ganapathy has contributed several chapters to the *Handbook of Engineering Calculations*, published by McGraw Hill, and *Encyclopedia of Chemical Processing and Design*, published by Marcel Dekker.