

**Problems with Gas Turbine Heat Recovery Steam Generator Design.**

**Introduction-**

At a large Petro Chemical manufacturing complex there is a Gas Turbine Combined Heat and Power Plant.

The existing gas turbines were at the end of their economic lives and a project was underway to retrofit one of the gas turbines with a more modern, more efficient engine.

**Machinery Details-**

The combined heat and power plant (CHP) that is the subject of this case study was commissioned with gas turbine driven alternators generating power for the manufacturing site.

The gas turbine exhaust gas heat was recovered in heat recovery steam generators (HRSG's or known as Waste Heat Boilers).

In the CHP there is three gas turbine and HRSG sets.

A project was underway to replace the first unit with a more modern, more efficient gas turbine set.

The original engines had approaching 200,000 hours operation on them and had become quite an inefficient way of generating electricity.

Due to a good long term gas supply contract it was financially attractive to remove the old gas turbines and alternators and retro fit modern machines.

The net result is almost double the electrical output for the same amount of gas burned due to the big increase in thermal efficiency of the modern gas turbines.

The HRSG's were to be reused but the exhaust gas exit temperature of the new gas turbines is much higher than on the older machines.

In order to reuse the HRSG's therefore, an extra bank of steam generating tubes was installed just upstream of the existing HRSG's existing tube banks.

To get maximum efficiency from the up rated plant an economiser was also fitted at the downstream end of the HRSG before the exhaust finally exits to the existing stack.

**Initial investigations -**

The HRSG and Gas Turbine configuration of the plant was fairly unusual in that two of the gas turbines HRSG's shared a boiler drum between two sets of steam raising tube banks. The third gas turbine had its own HRSG.

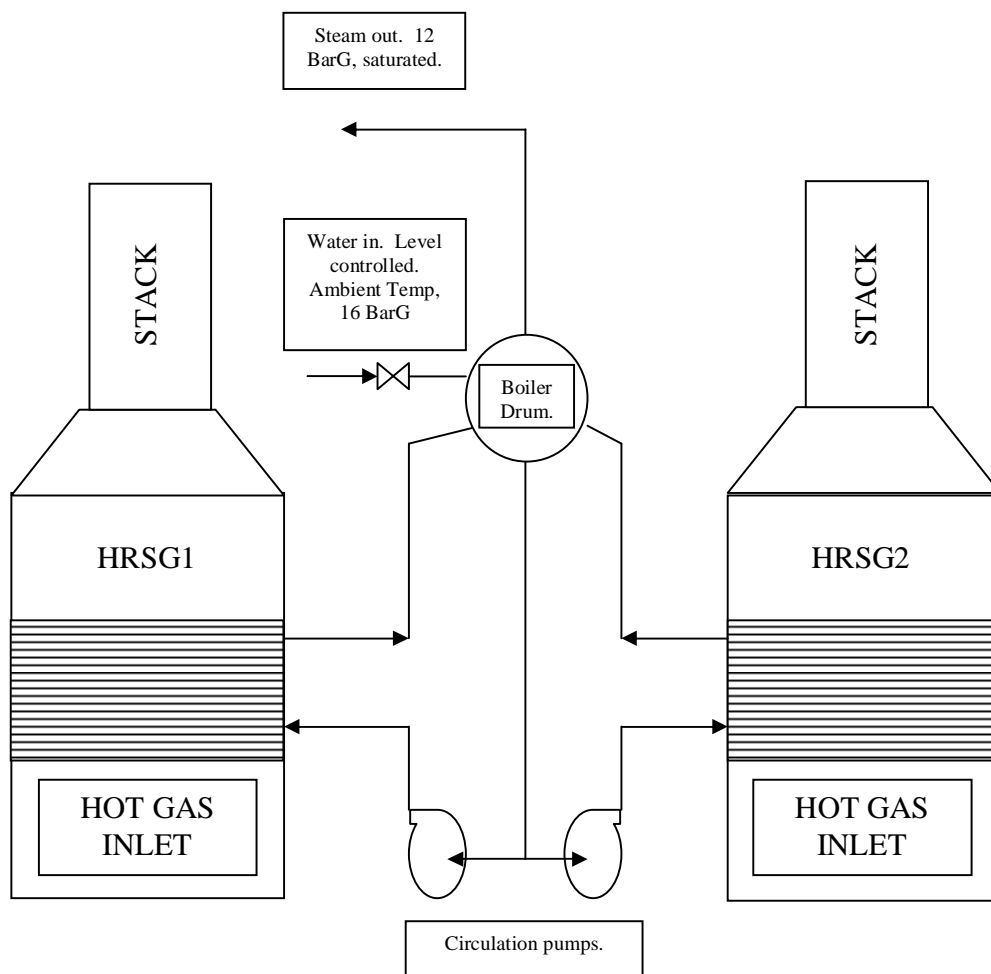
A sketch of the before and after configurations is shown below.

As can be seen, the two HRSG's share a common boiler drum.

The steam generating tube banks are dedicated to each gas turbine set though.

At start up there is full flexibility whether start up is one or both turbines and whether or not one turbine is already running or not.

Originally there was no economiser fitted to the HRSG's.

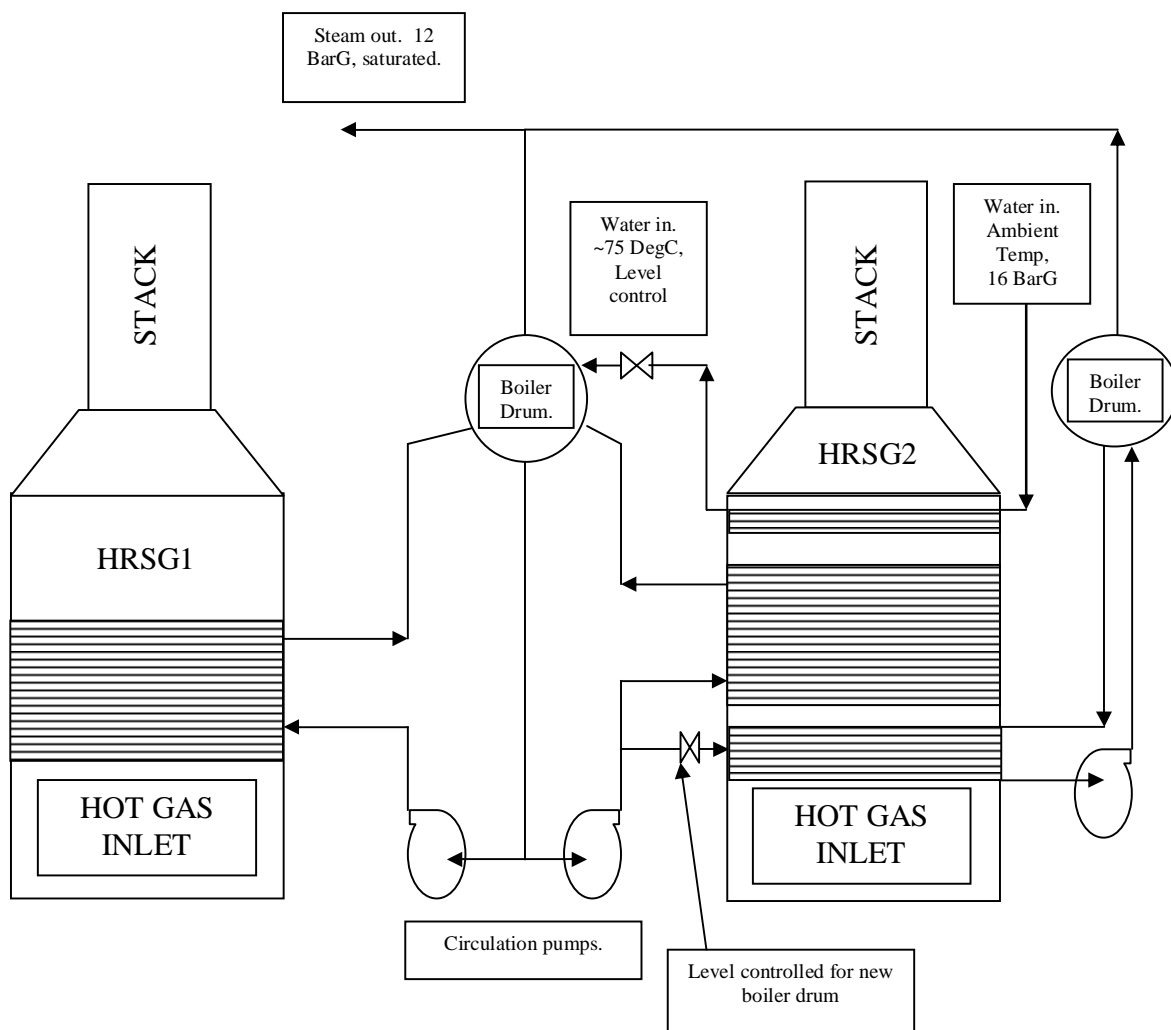


**HRSG's as originally installed.**

The sketch below shows how the HRSG's were to be modified and up rated by the addition of an economiser and extra steam generating tubes with their own boiler drum.

Only one of the gas turbines/HRSG's was being replaced in the first phase of the project.

The sketch below shows how the first up rated HRSG was designed and installed with the up rated, new gas turbine.



**Up rated HRSG's as designed and installed for one new gas turbine.**

As can be seen in the above sketch, a new auxiliary boiler drum was installed with a new steam generating tube bank and circulating pump. An economiser was added but this fed the original steam drum not the new one.

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Altogether, this was quite an elegant scheme and certainly made the best use of the existing HRSG system.

The idea is that HRSG1 is running with its gas turbine and water is bled across to HRSG2 when ready to start the gas turbine on HRSG2.

Control studies showed that the controls would work fine with the whole system acting as one complete HRSG.

So there was a high degree of confidence that the system was workable.

With both gas turbines and both HRSG's operating, if either was to trip the other would remain running.

Valves are omitted from the sketches above for clarity, but if one gas turbine was to trip then the tripped HRSG would be valved off to prevent heat loss from the other still on line HRSG on the common boiler drum.

Starting up from cold the design intent was that gas turbine and HRSG1 would be started up and then gas turbine and HRSG2.

The author joined the project team as the commissioning engineer and it was whilst familiarising myself with the design that I first realised that there was fatal flaw in the design.

At the time, the project was about 80% constructed so the design had been Hazard and Operability studied in detail.

However, the author realised that if the plant was cold there were problems in trying to start up gas turbine and HRSG2 when gas turbine HRSG1 wasn't available.

The thinking by myself was that once HRSG2 had its new gas turbine and was fully commissioned if there were problems on gas turbine HRSG1 then how would we start up gas turbine HRSG2 from cold?

The problem in fact was very likely to occur.

The plant had interruptible gas tariffs and it was obvious that if there was restricted gas available then given the choice between which gas turbine and HRSG to run, it would be the most efficient one.

The problem with starting up gas turbine HRSG2 from cold is quite obvious when you look at it.

First of all the feed water for the auxiliary steam drum is taken off the circulating pumps of the old boiler drum.

In steady state running this is not a problem.

However, if gas turbine HRSG2 is started from cold then the heat input to the steam generating tubes at the front end of the boiler connected to the auxiliary drum will heat up and the pressure will rise in them much faster than the temperature and pressure in the old generating tubes and boiler drum.

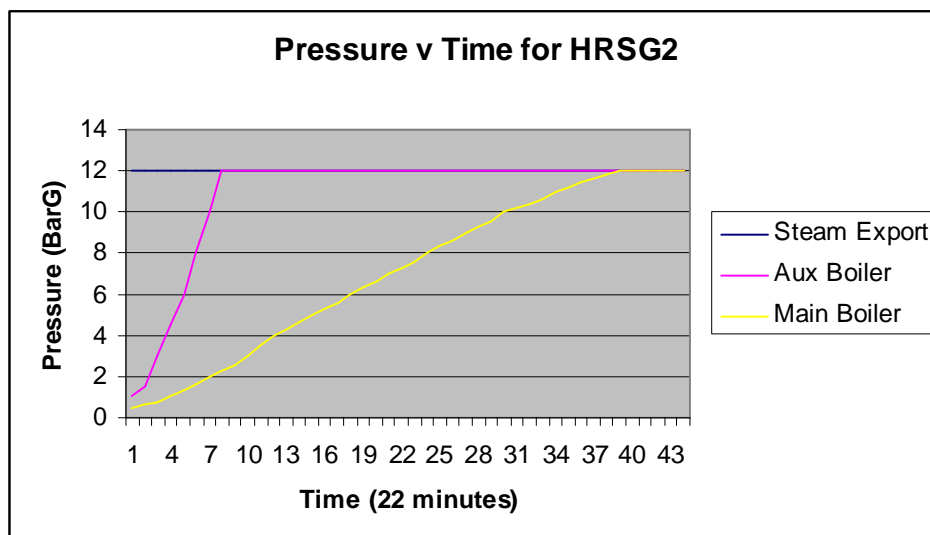
The problem with this scenario is that if the auxiliary boiler drum then starts exporting steam at 12 BarG but the pressure in the old boiler is much less than 12 BarG, then no feed water can flow into the auxiliary boiler from the main boiler.

Hence the auxiliary boiler would be in danger of boiling dry before the main boiler caught up in pressure started exporting steam.

Modelling of this scenario proved that there was indeed a big problem, the HRSG could not as designed be started from cold.

Modelling actually predicted that the auxiliary boiler would up to pressure and exporting steam within 4 minutes of starting the gas turbine up while the old main boiler would take almost 20 minutes to start exporting steam.

This is represented in the Excel Chart below-



**Pressure v Time for main and auxiliary boilers**

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**Further investigations -**

Given the late stage in the project that this came to light it was very important that a solution be found quickly and installed as soon as possible.

At this point fate dealt a further blow to the project making a solution all the more urgent.

Gas turbine HRSG1, the turbine of which was approaching 200,000 hours operation suffered a major mechanical failure.

In fact the failure was very serious and meant that gas turbine HRSG1 was at the end of its life until a new gas turbine could be fitted and the HRSG system up rated to suit.

This meant that until a solution to the cold starting problem of gas turbine HRSG2 was found and implemented it could not be commissioned.

Luckily there was actually a simple solution available.

A feed water connection could be made into the existing water pipe to the old boiler drum.

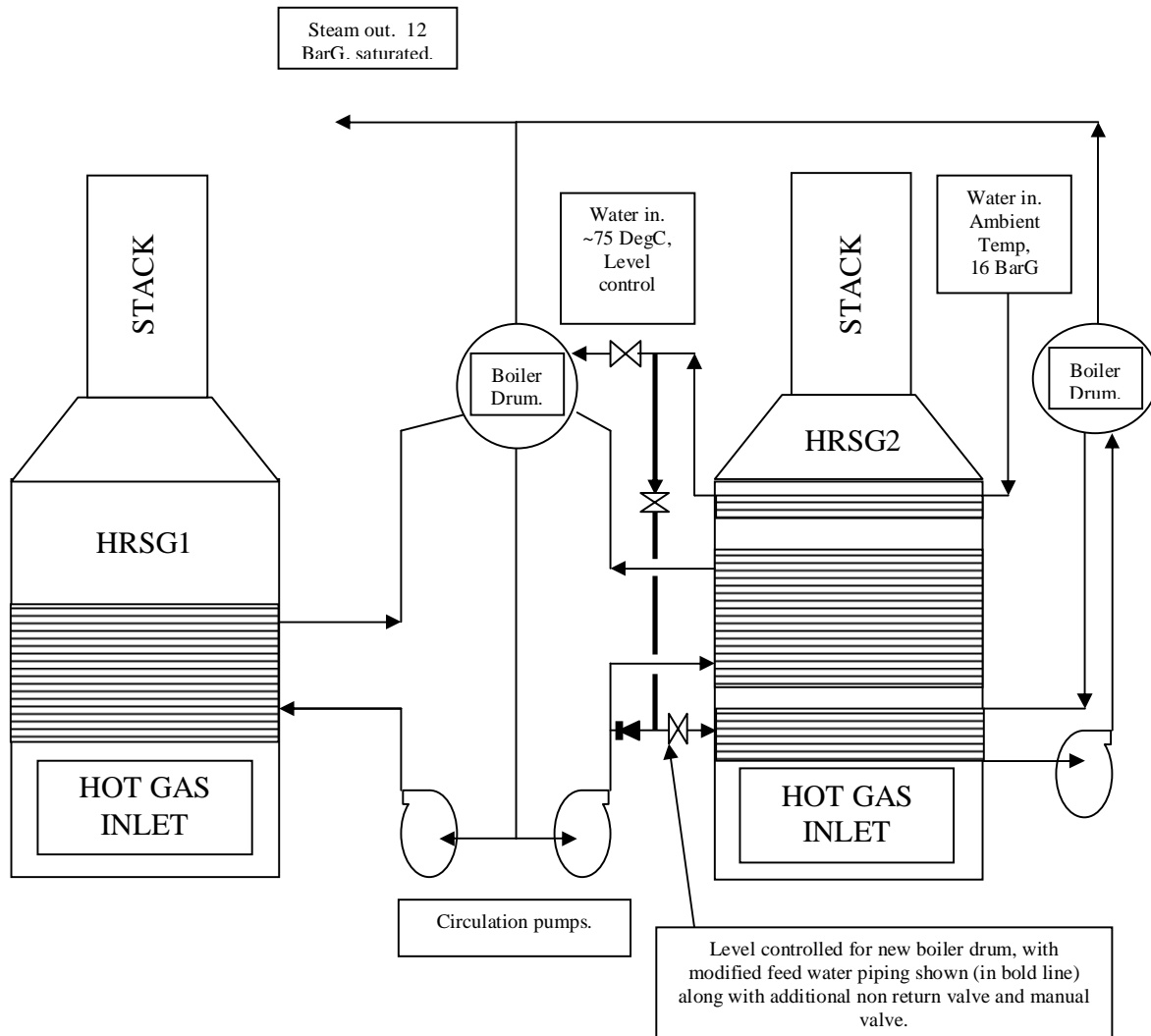
As this was always at around 16 BarG from the boiler feed pumps, there was plenty of pressure available to feed directly into the auxiliary drum for start up.

To prevent unwanted back wards flow from the auxiliary steam boiler to the old main boiler a non-return valve would be fitted.

This meant that for start up purposes a valve could be opened allowing the 16 BarG feed water to feed into the auxiliary boiler drum directly.

Then, when both boilers were exporting steam, the valve could be closed and the original design feed water would take over.

A sketch showing the modification made to the design is shown below.



**Modified feed water scheme, shown in bold. Used for cold start.**

**Conclusions-**

The above scheme shows a simple solution to the problem of not being able to cold start the system.

In fact, the logic of the way the system was designed originally was never going to be satisfactory since even if the up rated HRSG2 was started up while HRSG1 was running, it was only a matter of time before HRSG2 had to be started from cold on its own.

The project had originally overlooked this and had not catered for it in the design.

Modifications were made to the design and the unit has operated satisfactorily ever since.

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The modelling that showed the boiler sections exporting steam 4 minutes and 20 minutes after gas turbine start up were actually very closely matched in practice.

**Footnote-**

Several years on, gas turbine HRSG2 continues to operate.

Gas Turbine HRSG1 was never up rated and the gas turbine was never replaced with new.

There are no plans to ever carry out the up rate to the gas turbine or HSRG1 but the modified plant next to it continues to operate perfectly.

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**About the author-**

Stephen H Shakeshaft is a Mechanical Engineer based in the United Kingdom. He is the Principal Consultant and Director of Stephen H Shakeshaft Consulting Ltd., an engineering consultancy specialising in optimisation of existing assets and engineering design of new build projects.

Stephen has over 30 years experience of working at the “sharp end” as well as the “back room” of manufacturing industries with clients in the chemical, utility, metals, industrial gases and pharmaceutical businesses.

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The consultancy welcomes contact from all who are interested in plant and machinery maintenance, systems and development.