

**CONTROLLING STEAM PRODUCTION IN HEAT RECOVERY STEAM
GENERATORS FOR COMBINED CYCLE AND ENHANCED OIL RECOVERY
OPERATIONS**

By

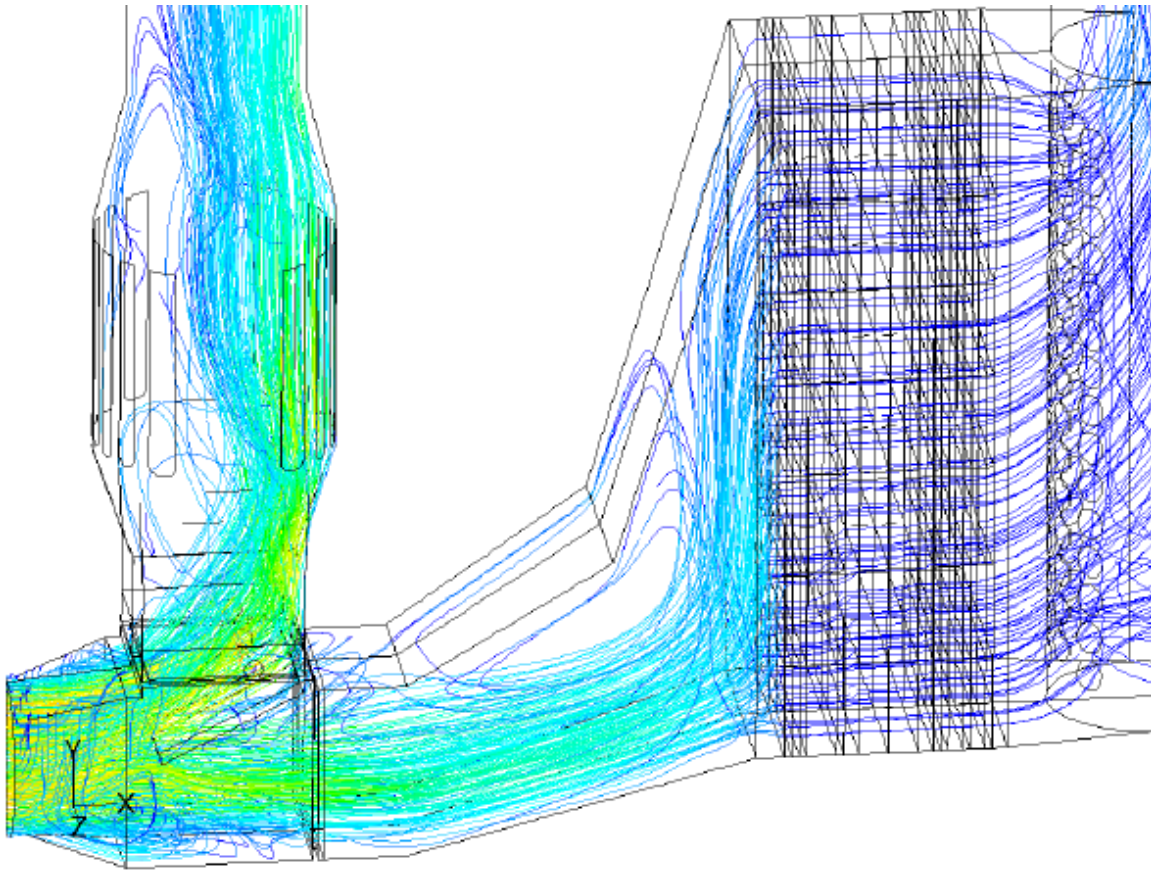
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ABSTRACT

Many producers of heavy oil are seeking new flexibility with steam injection for enhanced oil recovery (EOR) in marginally performing oil fields. At the same time these producers can earn extra revenue by selling power generated as a byproduct of the EOR system. Combustion Turbines (CT) coupled with heat recovery steam generators (HRSG) offer the best opportunity for increased efficiency and flexibility to meet the fluctuating markets for oil production and electricity. To meet the requirement for lower initial capital costs, producers may consider initially building a straight EOR system with CT, HRSG and EOR pipeline to the oil fields. Later, as the oil field depletes, a steam cycle can be added to replace the revenue lost as EOR steam demand drops. By essentially selling to two different markets, EOR and the power grid, it becomes advantageous to add flexibility to the EOR steam production, while at the same time not limiting the operation of the combustion turbine.

This paper discusses the design and control systems necessary to control steam production in the HRSG while minimizing the restrictions on the operation of the CT. Altering the steam production in a HRSG can be accomplished by pegging from higher pressure to lower pressure, bypassing the Water Preheater (WPHTR), venting main steam, using the diverter damper, and changing the CT load. One such system is the Cogeneration Thermoelectric Power Plant Termoçu that is currently under construction in the Brazilian state of Rio Grande do Norte. The design includes two (2) GE 7FA combustion turbines running in cogeneration mode with two Vogt Power International (VPI) HRSGs.

In addition, special HRSG design considerations are discussed for altering the steam production by operating the diverter in a fixed intermediate position, where only part of the CT exhaust gas is admitted into the HRSG.

INTRODUCTION

Thermal Enhanced Oil Recovery (TEOR) technologies have been used for more than 40 years to increase the efficiency of recovery of heavy crude oil and to increase oil recovery from marginal oil fields. In the future worldwide oil markets will rely more and more on oil obtained by TEOR as the supply of oil that can be obtained by primary (pressure depletion) and secondary (waterflooding) extraction methods decreases. Heavy oil reserves will also become more attractive over time as the easy to extract light crude oil reservoirs are depleted.

The Primary TEOR technology in use today is steam flooding. This accounts for two-thirds of the TEOR production in the United States. Currently worldwide production of heavy crude by TEOR is estimated at 1.3 million barrels per day, primarily in California, Sumatra, and Venezuela. In steam flooding, steam is injected into a well or series of wells where it decreases the viscosity of the oil and drives oil out through separate production wells.

Combustion Turbine (CT) cogeneration is a preferred source for TEOR steam flooding because of low capital costs, short construction times, and relative ease of operation. CT Cogeneration has been an especially effective method of TEOR, since electric power produced in the cycle can be used for fluid lift and plant power. This may permit the facility to operate independent from the electricity grid, and can be crucial for fields located in remote areas. For less remote areas, excess electric power generated in the cycle can be sold to the grid. Conversely, the facility can draw on the grid during outages to limit interruptions in oil production.

In the past it has been difficult for plant operators to maximize the revenue gained from two different markets (electricity revenue and oil production revenue). Since most Cogeneration systems were passive, in that the heat generated in the CT was used to produce steam for the process, there was little flexibility in steam production. The operator could either follow the steam demand (and thereby limit power generation) or follow the grid demand and vent any excess steam produced in the system. The purpose of this paper is to lay out the methods employed to limit steam production in the Central Térmica De Cogeração Termoaçu Cogeneration plant, currently under construction in the Brazilian state of Rio Grande do Norte, so as not to limit the operation of the CT.

PLANT DESCRIPTION

The Termoaçu project consists of two (2) GE 7FA natural gas fired CTs, feeding two (2) unfired Vogt Power International, two pressure level, no reheat HRSGs. The units are erected by Camargo Correa to supply TEOR steam to two heavy oil fields in the Brazilian state of Rio Grande do Norte. The two HRSGs are designed to provide a combined 622 T/hr of HP steam to the oil fields, and extra power generated will be sold to the regional grid. The HRSGs do not have any CO or SCR systems to reduce emissions.

The project is being built in three phases. Phase I (years 1-8) is completely cogeneration, where the two CT / HRSG trains will supply all the steam generated to the oil fields. The LP section will supply steam for the deaerator (DA) only and the LP drum will be the feedwater source. The system will operate with 100% make-up water, and back pressure to the HRSGs will be provided by fixing the steam flow rate to individual steam flood well heads and controlling the steam production in the HRSGs. To save initial capital cost the Steam Turbine (ST), Condenser, and the LP main steam lines are not part of Phase I. However the HRSG is designed to accommodate Phase II addition of the combined cycle steam piping without modification.

Phase II (years 9-12) will be both cogeneration and combined cycle operation, when TEOR steam demand is expected to drop as the oil fields gradually deplete. The ST, condenser, and LP main steam lines are expected to be installed at this time. The plant will operate in both cogeneration and combined cycle operation in this phase.

Phase III (years 13+) will occur once the oil field is depleted. At this time the plant will operate in combined cycle only. Figure 1 gives a simplified diagram of the HRSG.

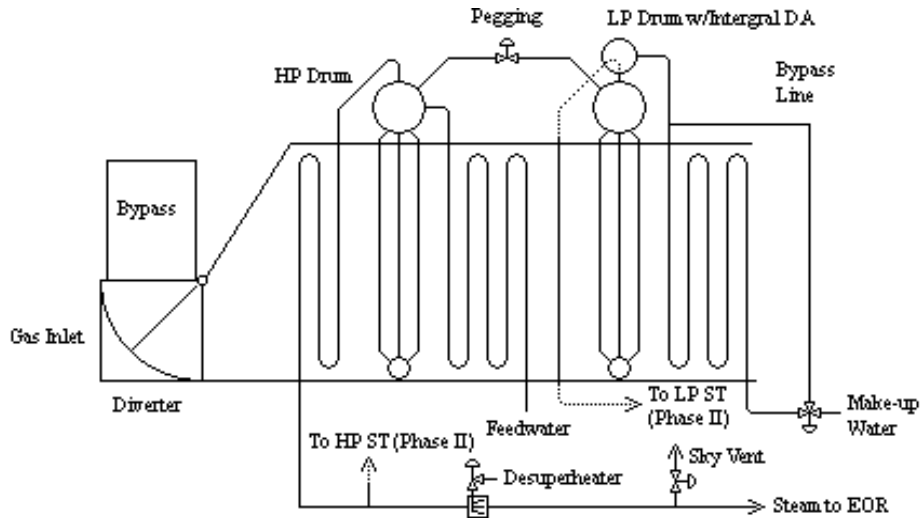


Figure 1

LIMITING STEAM PRODUCTION

In TEOR operations there can be variability in the steam demand as the price of oil fluctuates, or as the oil field depletes. Often these changes in TEOR steam demand are predictable, stable, and can be scheduled ahead of time. This results in a plant that can operate at a relatively constant load. To provide more flexibility for plant operators, this project was designed to provide steam production that can be throttled back without affecting the base load operation of the CT. The choices available to limit steam to the TEOR operation are a) partial or full bypassing of the water preheater (WPHTR) in combination with steam pegging to maintain LP drum pressure, b) venting, c) intermediate diverter blade position, and d) diverting steam to the ST or the condenser (Phase II only). Finally the two HRSGs may be operated in different steam limiting modes, so that a combination of the different modes can produce the desired single output to the well heads.

Figure 2 shows the range of steam production to the TEOR operation. The different modes of limiting steam production can be classified as modulating and non-modulating control. The modulating modes are the WPHTR bypass and venting. They are used for fine tuning the steam production, and are characterized by the ability to react to flow or pressure signals in a linear, predictable manner. The WPHTR bypass is essentially a method of rejecting heat from the system, and has been used extensively (with recirculation) in the HRSG industry for the purpose of acid dew point control. However, in this system it is used primarily to limit steam production. As noted earlier, pegging from the HP drum is used to maintain LP drum pressure.

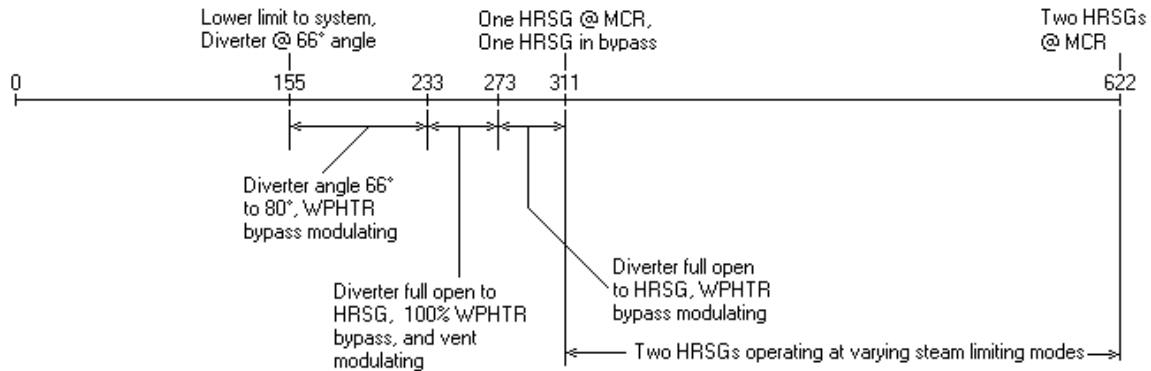


Figure 2: Steam production to TEOR process (T/hr)

Venting is used on a very narrow band of operation, from 233 to 273 T/hr. This is employed when only one HRSG is operating, and is intended to control HP drum pressure over this operating range. Venting spans the steam production range from the limits of WPHTR bypass, to the first operating point of the partial diversion of exhaust gas through the bypass stack.

Non-modulating control is achieved by operating the diverter damper in a continuous intermediate position. This control is considered non-modulating because it will not respond to pressure or flow signals in the system to control steam production. Instead it will be placed into different positions based on the scheduled demand of the TEOR steam. Finer trim of the steam production will be achieved by WPHTR bypass or venting.

Based on experience from other operating units, it is understood that the exhaust gas entering the HRSG in a partial bypass does not operate in a linear fashion compared to diverter angle. In other words a slight change in diverter angle may at certain angles produce wide swings in steam production. In addition, for the control arm to operate properly, it must travel at least 5° at a time. Therefore, a theoretical move from 72° to 70° open to the HRSG, would require the diverter to move up 5° to 77° then back down 7° to 70°. These characteristics make the diverter a poor choice for direct feedback control, however coupled with the modulating controls previously mentioned, the entire system will have sufficient control to operate from 153 T/hr to 622 T/hr without limiting the CT operation.

Inlet duct flow distributions were also a concern in the partial bypass mode. A Computational Fluid Dynamic (CFD) of the HRSG/Bypass system was modeled using Fluent. The maximum open to HRSG position, to the minimum expected open to HRSG positions results are shown in figures 3 and 4. Note that on both maximum and minimum extremes the recirculation flow is minimal.

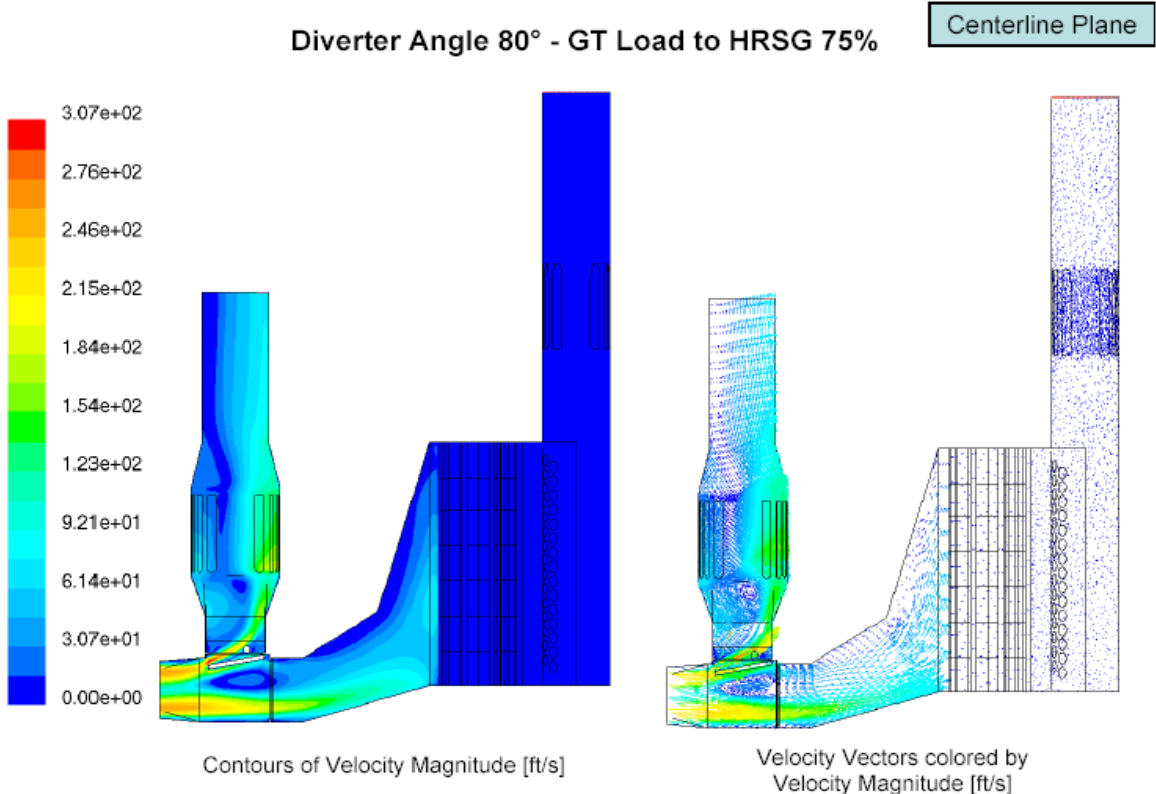


Figure 3: Maximum Expected Open to HRSG Diverter Position in Partial Bypass Mode.

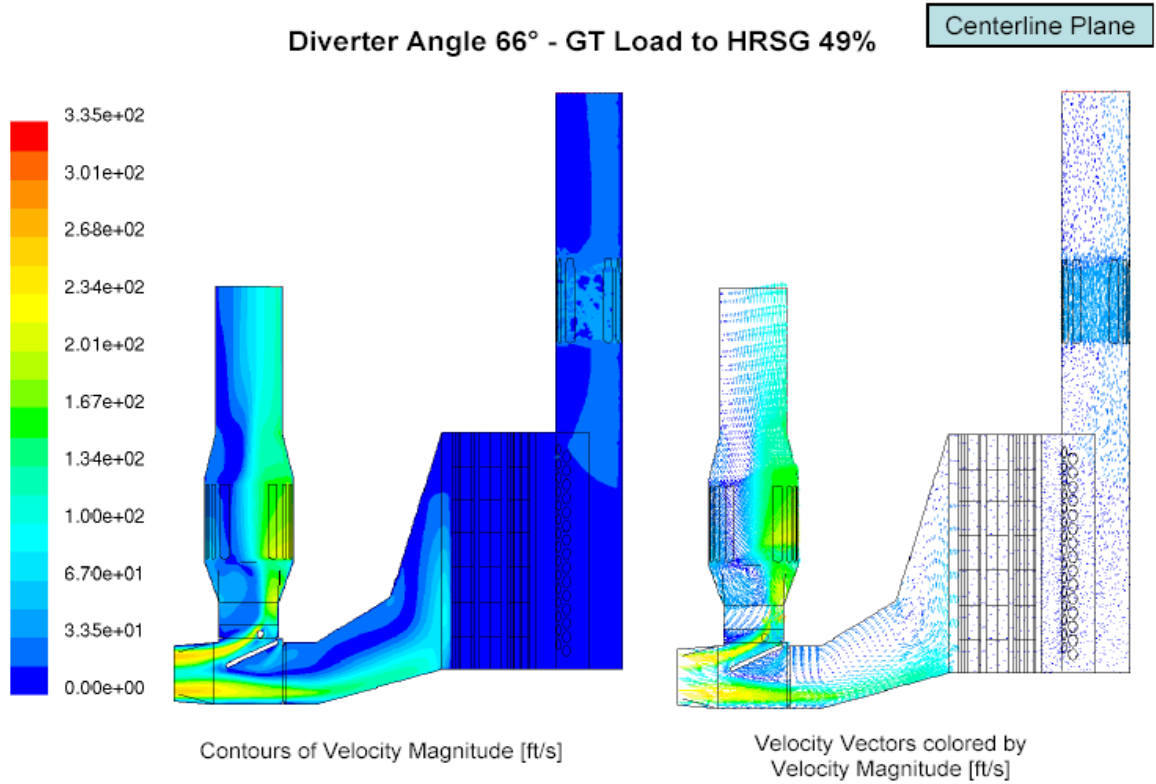


Figure 4: Minimum Expected Open to HRSG Diverter Position in Partial Bypass Mode.

Since the diverter would likely be subject to above normal vibrations while in the intermediate position, special consideration was given to critical welds in the blade and control arm. It was accepted by the end user that the diverter blade seals would be quickly eroded and in need of frequent replacement. In addition critical high temperature parts were fabricated out of creep resistant, Inconel 800 material. Finally, by limiting the open to HRSG to 80° maximum in the partial bypass, any chattering of the diverter blade to the frame is eliminated.

During Phase I the system is not designed to produce less than 155 T/hr, since circulation distribution in the HRSG may prevent all the tubes from being adequately cooled. However, in Phase II when the steam generating cycle is added the range of steam available to the TEOR process will be from essentially 0 to 622 with no venting. The only limits will be the low end capacity of the ST and the Condenser let down valve.

CONCLUSION

TEOR technologies have been used over the past half-century to increase the yields from heavy oil fields. Recently with improved model methods, and development cooperation between OEMs and end users, it is now possible to produce a TEOR system that uncouples the steam production from the CT load. By employing WPHTR bypass, pegging, venting, and partial exhaust gas bypass, it is now possible to limit steam production over a wide range of operation while not limiting the power generated in the CT cycle.

REFERENCES

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