*Proceedings World Geothermal Congress 2000*
*Kyushu - Tohoku, Japan, May 28 - June 10, 2000*

# UPSTREAM REBOILER DESIGN AND TESTING FOR REMOVAL OF NONCONDENSABLE GASES FROM GEOTHERMAL STEAM AT KIZILDERE GEOTHERMAL POWER PLANT, TURKEY

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**Key Words:** geothermal power plant, noncondensable gas, upstream reboiler, Kizildere, Turkey.

**ABSTRACT**

The Kizildere geothermal power plant in Turkey is a unique geothermal power plant with an installed capacity of 20.4 $MW_e$.

The most significant characteristic of the field is the high level of noncondensable gases (NCG's), in amounts as high as 10-20% (with an average of 13% at the inlet of the turbine) by weight of steam. The NCGs are being extracted from the condenser by gas compressors that consume about 18.3% of the total power production of the plant.

An upstream reboiler process is another approach to remove the NCG's from geothermal steam before they enter the turbine. Upstream reboilers therefore provide a cleaner and less corrosive steam supply to the turbine and condenser, increasing power generation performance for very high NCG content.

In this paper, upstream reboiler systems are investigated as an alternative to conventional gas extraction systems for Kizildere geothermal power plant. Both vertical tube and direct contact type reboilers have been designed and evaluated. The direct contact type is being tested at the Kizildere field and is covered in this paper since the vertical tube type has been reported upon and tested extensively in the past.

The direct contact tests have been carried out in the field with a gas removal efficiency 76.3±22.6% at the base case.

## 1. INTRODUCTION

In a conventional geothermal power conversion process, steam expands through a turbine to subatmospheric pressure in a condenser. NCG's are removed from the condenser by jet ejectors or compressors. This process is appropriate for many geothermal resources where the NCG content is low.

On the other hand, for high NCG content, the steam required for jet ejectors or consumed electricity for compressors can be a large fraction of the total power produced. Thus, the conventional power conversion process using a condensing turbine is not the best one for resources with exceptionally high NGC.

Because of potential operational and environmental advantages, Electric Power Research Institute (EPRI), USA began studying a process to remove $H_2S$ from geothermal steam upstream of the turbine. In 1978 EPRI awarded a contract to Coury and Associates to study the feasibility of this concept by testing a tubular type reboiling process at The Geysers, USA (steam-dominated system) during 1979 and 1980. During more than 1000 hours of accumulated test time, the average $H_2S$ removal efficiency obtained was 94% and the heat transfer coefficient was high enough to make the cost of the heat exchanger competitive with alternative $H_2S$ abatement system costs (Coury and Associates, 1981).

In 1982, Glenn E. Coury (Coury and Associates) obtained a patent entitled "Method of separating a noncondensable gas from a condensed vapour" for his invention (Coury, 1982).

To evaluate the process for liquid-dominated geothermal resources, EPRI arranged additional tests at Cerro Prieto, Mexico in 1984-1985. Under a related EPRI project (RP 1197-5), Bechtel Group Inc. built a test unit using the same reboiler vessel previously operated at The Geysers. Among the main results, it was reported that the process is capable of removing 94% by weight of noncondensable gases from geothermal steam, with 1.3% gas content for 110 test runs at various operation conditions (Awerbuch *et al.*, 1984; Angulo *et al.*, 1986; IIE, 1987; Lam *et al.*, 1992).

The advantages of direct contact reboilers versus tubular type reboilers for the fields which contain very high NCG were reported in a few articles (Hankin *et al.*, 1984; Awerbuch *et al.*, 1984; Duthie and Nawaz, 1989). Bechtel Group obtained two patents on tray type direct contact reboilers both entitled "Geothermal Reboiler Apparatus and Method" (Awerbuch and Van Der Mast, 1985; Soo-Hoo and Benz, 1990).

ENEL, Italy and Bechtel Group applied a tray-type direct contact reboiler system to the 30 $MW_e$ Latera geothermal power plant, where the NCG content is 3.5% at the wellhead. Test production and reboiler tests have been conducted since May 1999. This is the first application in the geothermal industry in the world of the reboiler concept on a commercial scale (Allegrini *et al.*, 1989; Sabatelli and Mannari, 1995; Baldacci, 1999).

This paper identifies the experimental facility used for the tests, the performance parameters used to describe the test data and presents the data obtained from a packed bed direct contact reboiler process applied in Kizildere geothermal field, Turkey which contains high levels of NCGs.

## 2. KIZILDERE GEOTHERMAL FIELD AND POWER PLANT

Kizildere geothermal field is located near the city of Denizli in Western Anatolia, Turkey (Fig. 1). The first studies began in 1968, and Kizildere geothermal power plant was installed in 1984 with an installed capacity of 20.4 $MW_e$. Besides electricity production, the resources of the field are also used for dry ice production (40,000 t/year), greenhouse heating (10,700 m²) and space heating of offices and residences (Simsek, 1985).

Kizildere geothermal field and power plant characteristics are given in Table 1. It can be seen that the amount of NCG is very high (average 13% by weight of steam) and consists mainly of $CO_2$.

In the Kizildere power plant, NCG's are extracted from the condenser by compressors and passed to the dry ice production process. The gas extraction system consumes about 2.38 $MW_e$ (18.3% of the gross capacity) due to the high NCG content (MTA, 1996).

## 3. DIRECT CONTACT REBOILER OPERATION

A packed bed direct contact reboiler process which consists of a direct contact condenser (DCC) and flash tank (FT) vessel, is shown in Fig. 2. Steam is fed under the packed bed of the DCC and flows upward where most of it condenses through the packing. The NCG's with a small amount of steam is vented through a vent stream from the top of the condenser. The condensate flows to the flash tank through a pressure reducing valve. In the flash tank some part of the condensate is flashed to a lower pressure, and the remaining condensate is sent to the top of the condenser as cooling water by a circulation pump.

## 4. TESTS

The test program was developed to demonstrate the process' general performance characteristics such as NCG removal efficiency and vent rate, and show the applicability to the existing geothermal conditions.

A 3-month test program with an accumulative test run time of approximately 260 hours was completed in January 1999 demonstrating the performance of a bench-scale packed bed direct contact reboiler. The test unit was located at the KD 14 wellhead where the NCG content is at the design level (10%).

The test unit is designed to condense a nominal 38 kg/h of incoming steam at 150.3°C with an assumed heat transfer coefficient 110,000 $W/m^2K$ (Fair, 1972). This value of the heat transfer coefficient was considered to be conservative based on the experimental studies from the literature for a packed bed with a Raschig ring. The packed height is calculated as 2 m for the given design data. In the Kizildere power plant, approximately 10 t/h of steam is required to generate 1 $MW_e$ therefore, the test unit is equivalent to about a 0.38 $kW_e$ extraction pump. The sizing criteria and design data are given in Table 2.

Because of the limited budget of the project, all components are manufactured out of carbon steel, except the galvanised piping, and all controls are manual.

### 4.1. General Description of Test Unit Installation

Fig. 3 shows the test unit installation. Supply steam for the unit is provided by a side stream from the KD 14 well steam supply to the plant. The vent gas and clean steam streams from the test unit are discharged to the atmosphere to allow the gas measurements.

The basic components of the unit are the direct contact condenser (DCC) (0.036 $m^2$), the flash tank (FT) (0.03 $m^2$), the recirculation pump (CP), the storage tank, the interconnecting piping, flowmeters (F), pressure reducing valves (PRV), manual control valves (V), pressure gauges (P), Pt-100 thermocouples (T) and instrumentation. These components are indicated in Fig. 4.

The measured physical parameters are temperature (T1, ....., T7), pressure (P1, ...., P9) and flowrate (F1, F2). The gas measurements were made at the main steam line of well KD 14 (G1), DCC vent (G2) and flash tank clean steam line (G3) by a mini separator (Fig. 4).

### 4.2. Performance Parameters

The fundamental factors which indicate the reboiler performance are $CO_2$ removal efficiency and vent rate.

Since NCGs consist of mainly $CO_2$ in Kizildere, it can be assumed that $CO_2$ represents all NCG's (see Table 1).

$CO_2$ removal efficiency and vent rate are based on the following equations:

$$CO_2\ \text{Removal}\ (\%) = \left[1 - \frac{(CO_2\ \text{content})_{\text{clean steam}}}{(CO_2\ \text{content})_{\text{inlet steam}}}\right] * 100 \quad (1)$$

$$\text{Vent Rate}\ (\%) = \frac{(\text{steam content})_{\text{vent stream}}}{(\text{steam content})_{\text{inlet stream}}} \quad (2)$$

For various inlet steam, vent, flash tank and flash tank clean steam pressures, $CO_2$ removal efficiencies and vent rates are calculated.

## 5. RESULTS

For 0.2 MPa DCC inlet stream ($P_3$ in Fig. 4), 0.1 MPa flash tank ($P_8$) and 0.155-0.225 MPa DCC vent pressures ($P_4$), $CO_2$ removal efficiency and vent rate at the vent stream is calculated and plotted in Fig. 5. As the vent rate increases, $CO_2$ removal efficiency decreases because of increasing steam flowrate at the vent stream. $CO_2$ removal efficiency versus DCC vent pressure is plotted in Fig. 6. For a narrow range of vent pressure ($P_4$) of 0.18-0.215 MPa, $CO_2$ removal efficiency changes between 15-98%. This indicates that vent pressure does not have a significant effect on $CO_2$ removal efficiency. During the tests $CO_2$ removal efficiency was obtained as 76.3±22.6% for a wide range of reboiler parameters.

$CO_2$ removal efficiency also increases as the flash tank clean steam line pressure increases as shown in Fig. 7. But this is limited because the produced clean steam flowrate is decreased. As the flash tank clean steam line pressure decreases, the clean steam flowrate increases but the enthalpy decreases. Therefore there is a trade off between flash tank pressure and the clean steam flowrate.

The amount and condition of the steam going to the turbine depends on the vent rate and temperature difference between the DCC and the flash tank ($\Delta T$). As the vent rate increases, the amount of steam available to the turbine decreases. As the $\Delta T$

increases, the temperature and pressure of the clean steam decreases so that less power can be derived per unit of steam. During the tests, ΔT usually kept at about 5°C and it ranged between 0.2-9°C. It can be concluded that the vent rate and ΔT are the main factors controlling the $CO_2$ removal efficiency and process economics.

The net energy produced by a power plant with the upstream reboiler process compared with output without the process is affected by the following: the difference between power produced by a turbine using pure steam and one using steam containing NCG's; the parasitic power used to drive the gas compressors to remove NCG's from the condenser; the decrease in pressure and temperature of the steam entering the turbine caused by the ΔT between DCC and flash tank; the heat loss in the reboiler that is reflected in the blowdown rate that is the fraction of inlet steam ejected as water and therefore not available to be reboiled to make clean steam for the turbine; the decrease in steam flow to the turbine caused by venting some steam along with NCG's in the vent gas stream; the parasitic power required to run the condensate recirculation pump.

Table 3 gives a comparison of the thermodynamic analysis of two cases for Kizildere geothermal power plant using each of the factors listed above for 0.22 MPa DCC inlet steam pressure and a ΔT of 5°C. The vent rate is chosen as 7% and the corresponding gas removal efficiency as 93.4% since the measured vent rate ranged between 0-7% in Fig. 5. Calculations give a 35.3% reduction in parasitic load of the plant increasing the net capacity by 10.6% from 10 $MW_e$ to 11.06 $MW_e$.

## 7. CONCLUSIONS

The problems encountered during the tests were mostly control problems because the unit was controlled manually. It was observed that the lack of a mist eliminator in the condenser caused the drift of cooling water through the vent stream. This is one of the important reasons for low $CO_2$ removal efficiency.

The next step is to improve the test unit with automatic control and to check the physical measurements by conducting chemical analysis for each stream.

## ACKNOWLEDGEMENTS

The authors would like to thank Ege University Science-Technology Research and Application Center (EBILTEM) for funding the project under contract Bil/1997/08 and the Turkish Electric Authority (TEAS) for giving permission to conduct the tests in Kizildere geothermal field. Special thanks are given to the Turkish Science and Technology Council (TUBITAK-BAYG) for giving a scholarship to the first author which allowed research on direct contact reboilers in the USA.

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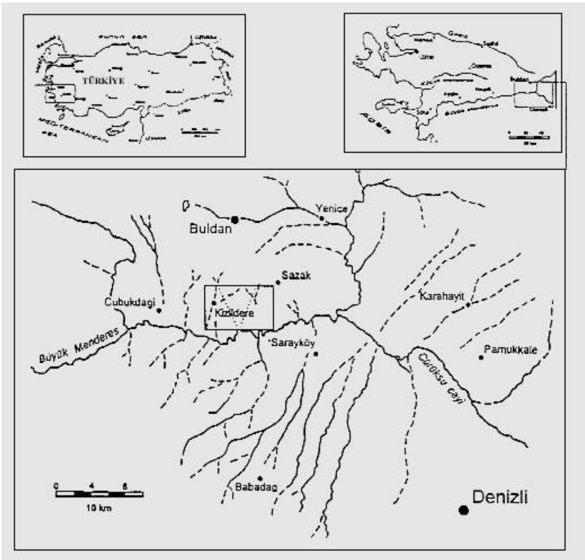


**Fig. 1.** Location of the Kizildere geothermal field, Turkey (Vogel, 1997).

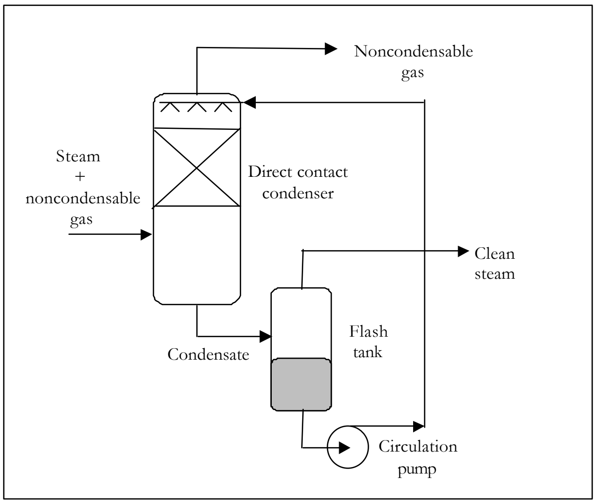


**Fig. 2.** Direct contact reboiler process, schematic.

**Table 1.** Characteristics of the Kizildere geothermal field and power plant (MTA, 1996).

| | | |
|---|---|---|
| Reservoir temperature | (°C) | 200-212 |
| Operation pressure of wellhead | (MPa) | 1.28-1.58 |
| Wellhead temperature | (°C) | 180-190 |
| Total flowrate | (t/h) | 1155 |
| Wellhead steam fraction | (%) | 10-12 |
| Steam flowrate | (t/h) | 90-140 |
| Total dissolved solid (TDS) | (ppm) | 2500-3200 |
| NCG's at the wellhead | (%) | 2.5 |
| NCG's % by weight of steam | (%) | 10-20 (average 13) |
| $CO_2$ content in NCG's | (%) | 96-99 |
| $H_2S$ content in NCG's | (ppm) | 100-200 |
| Separator pressure | (MPa) | 0.48-0.55 |
| Turbine inlet pressure | (MPa) | 0.47 |
| Power plant capacity | ($MW_e$) | 20.4 (installed), 13 (gross), 10 (net) |
| Consumption of gas compressors | ($MW_e$) | 2.38 (18.3% of gross capacity) |
| Total parasitic load | ($MW_e$) | 3 (23% of gross capacity) |

**Table 2.** Sizing criteria.

| | | |
|---|---|---|
| Bed type | | Packed bed, random |
| Packing type | | Raschig ring |
| Packing material | | Metal |
| Bed diameter | (inch) | 6 |
| Bed diameter/material size | (-) | 12 |
| Volumetric heat transfer coefficient | ($W/m^3K$) | 110,000 |
| Vent rate | (%) | 0-20 |
| Main steam line temperature | (°C) | 150.3 |
| Main steam line pressure | (MPa) | 0.48 |
| DCC inlet pressure | (MPa) | 0.2 |
| DCC inlet steam flowrate | (kg/h) | 38 |
| Temperature difference between DCC and flash tank | (°C) | 0.2-9 |
| Flash tank inlet pressure | (MPa) | 0.1-0.18 |
| Drain flowrate | (kg/h) | DCC inlet steam flowrate * %1 |
| Condensation rate | (%) | 90 |
| NCG content | (%) | 10 |
| | | |

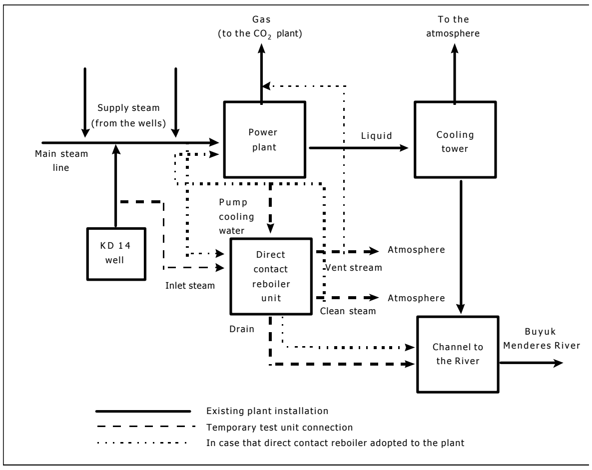


**Fig. 3.** Direct contact reboiler test unit installation at KD 14 of Kizildere power plant.

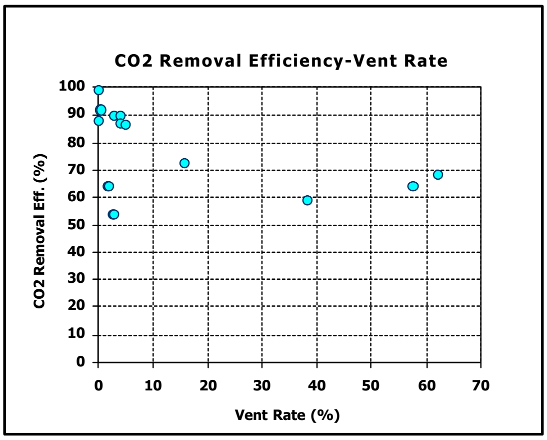


**Fig. 5.** Vent rate effect on the $CO_2$ removal efficiency

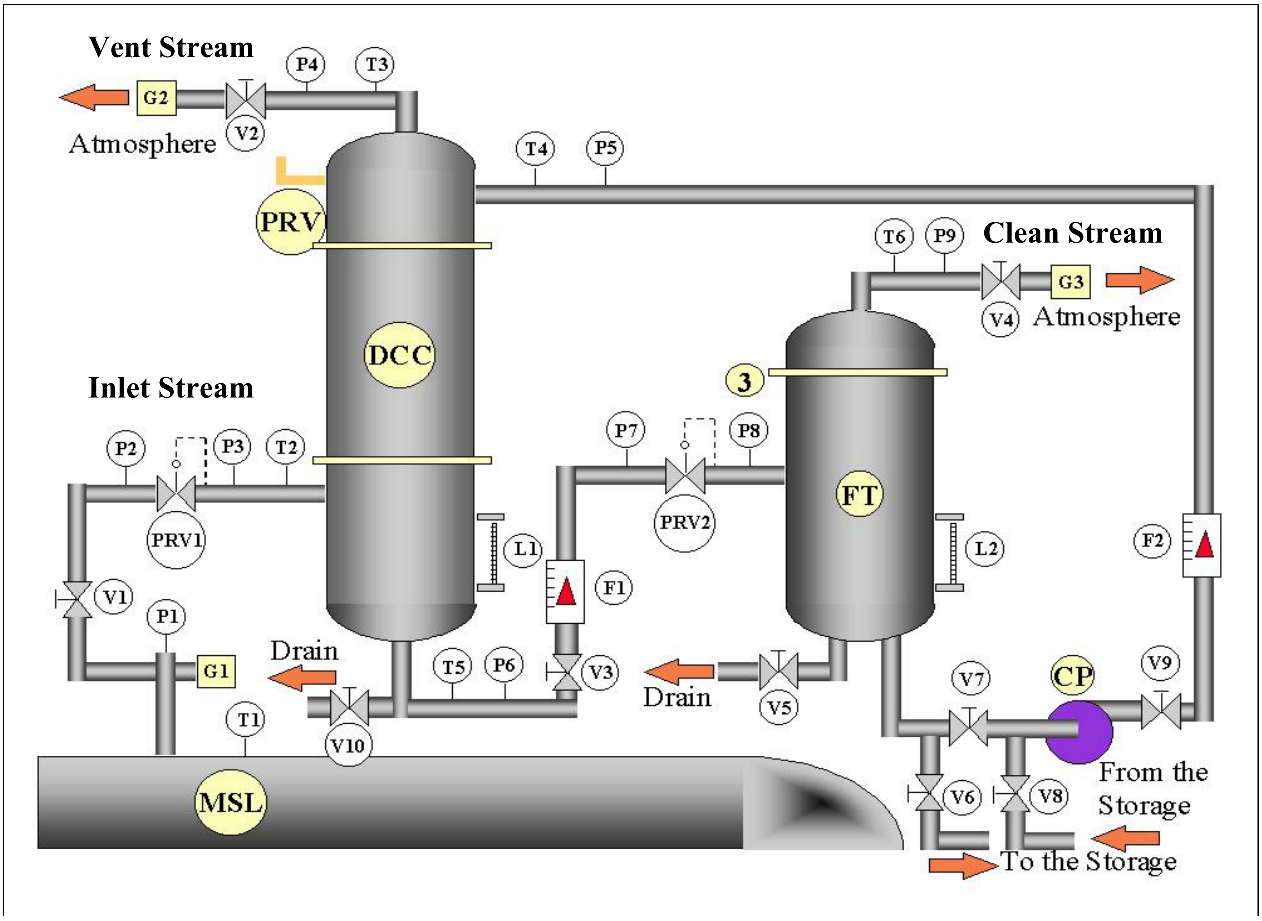


**Fig. 4.** Test unit set-up, instrumentation.

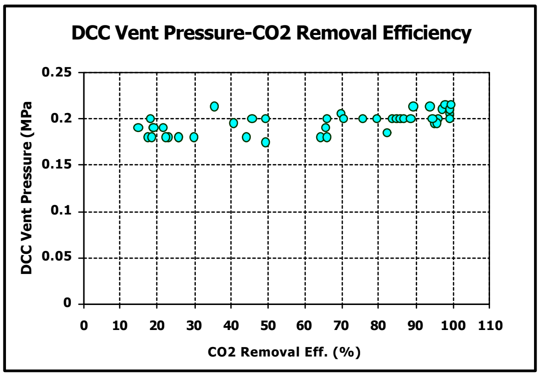


**Fig. 6.** Direct contact condenser vent pressure effect on the $CO_2$ removal efficiency.

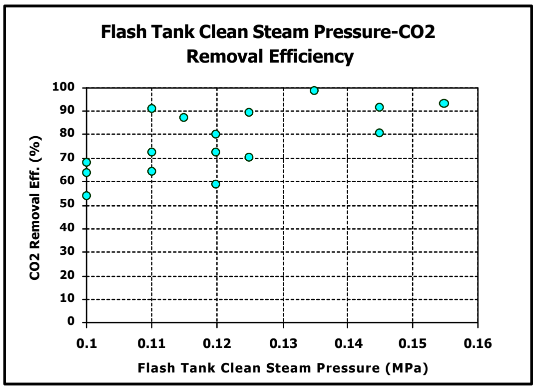


**Fig. 7.** Flash tank clean steam line pressure effect on the $CO_2$ removal efficiency

**Table 3.** Power loss of Kizildere geothermal power plant with and without reboiler process.

| **Power loss** | **With reboiler (kW)** | **With reboiler (%)** | **Without reboiler (kW)** | **Without reboiler (%)** |
|---|---|---|---|---|
| NCG (compare with pure steam) | 73.5 (NCG content 6.6%) | 3.0 | 1432.5 (NCG content 13%) | 37.6 |
| Compressors | 121.8 | 4.9 | 2380.0 | 62.4 |
| Pressure drop ($\Delta$P,$\Delta$T) | 298.5 | 12.1 | - | - |
| Drain (%1* DCC inlet steam flowrate) | 705.2 | 28.6 | - | - |
| Vent (%6.782* DCC inlet steam flowrate) | 899.8 | 36.6 | - | - |
| Pump | 366.0 | 14.8 | - | - |
| **Total** | 2464.8 | 100.0 | 3812.5 | 100.0 |