Field Testing of Membrane Separation System for Continual Removal of Non-Condensable Gases from Binary Power Plants

C. Mohr, G. Mines and K. Bloomfield

Idaho National Engineering and Environmental Laboratory

Keywords

Binary plant, condenser efficiency, non-condensable gas removal

ABSTRACT

A membrane-separation system for continual removal of non-condensable gases from binary plant condenser vapor has been built and is undergoing testing. Previous reports have described its principles of operation, design, and results of testing in an isopentane-working-fluid unit. These results indicated that the unit is capable of maintaining a low noncondensable gas inventory in the plant condenser. In addition, loss of working fluid resulting from condenser-purging operations was reduced to a fraction of its previous value through use of the continuous removal system. Tests being performed in an isobutane-working-fluid plant have indicated that system modification is needed for unattended long-term operation. These modifications were made in April/May 2004, and testing has resumed. The host plant currently operates with a severe, atypical air intake rate, testing the removal system's performance at a purge rate several times its design operation. This paper reports the results of the ongoing tests.

Background

The background of this membrane-based process has been described at previous GRC technical presentations. The presence of non-condensable gases (NCGs) in a vapor condensing on a cold surface is known to degrade heat transfer coefficients and raise condenser pressure. The NCG accumulates at the vapor/liquid interface, restricting movement of the vapor toward the interface and lowering the partial pressure of the vapor at the interface. When the condenser serves to provide a low-pressure sink for turbine exhaust, the end result is a higher turbine back-pressure and reduced turbine output. Binary plants have NCGs in their working fluid vapors that can be introduced into the system several ways. In cold weather, sub-atmospheric condenser pressures can lead to in-leakage of air, while during normal operation NCGs may be introduced if the working fluid leaking past the turbine seal is recovered from the turbine gearbox lubricant. Residual air from maintenance operations is another source of NCGs. Binary plants are normally equipped with systems that are used intermittently to purge NCGs from their condensers. These usually employ refrigerated condensers to allow recovery of most of the working fluid from the purged mixture. The frequency and duration of purges vary among different plants, depending on both the rate of NCG accumulation and the plant's operating procedures. The result of the accumulate/purge cycle of NCGs is that the plant operates at some average NCG fraction that is above the minimum that can be achieved with the purge system. This results in an average turbine output that is reduced from what would be obtainable with a minimum NCG content in the condenser.

The performance improvements expected with the proposed membrane system have been described previously. Significant reductions in organic losses and improved generating performance were predicted. The first tests at an isopentane plant verified the low condenser air levels and reduced working fluid losses that result from use of the membrane system. Operating data suggested improved power generation, but this conclusion is only qualitative because of the varying operating conditions and the lack of a suitable unit for comparison.

NCG Removal System Description

The concept is based on membranes that separate condensable hydrocarbons from non-condensable gases. Two such membranes have been tested and found suitable for the specific fluids used in binary geothermal plants: polydimethylsiloxane (PDMS) and "Hyflon." PDMS preferentially absorbs and permeates the condensable hydrocarbon, while "Hyflon," a material proprietary to Membrane Technology and Research, Inc., Menlo Park, CA, employs a molecular sieving mechanism to preferentially permeate the smaller NCG species. Both membrane materials were tested by MTR and found well suited

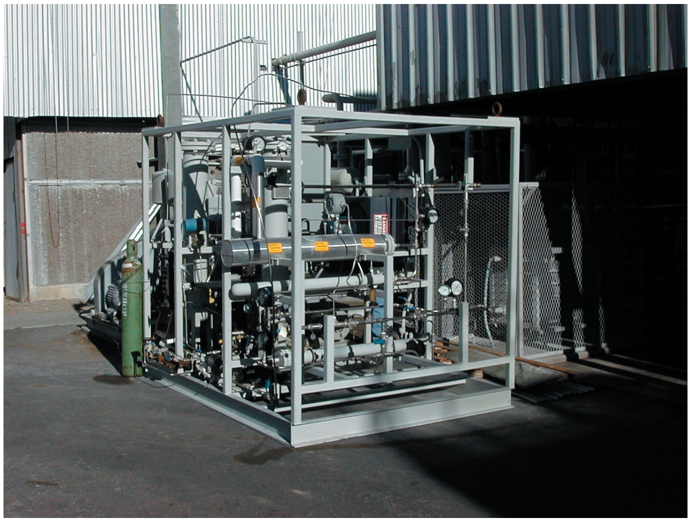

Figure 1. Skid-mounted prototype system installed in host site plant.

for use with isobutane and isopentane working fluids, and the NCG (air). Current tests are being performed with two PDMS modules. As indicated previously, plant operating data was analyzed to estimate the rate of NCG buildup in the condenser, leading to performance specifications for the removal system. A prototype system was then designed and fabricated by MTR. Figure 1 shows the skid-mounted unit as installed at the current host test site (Mammoth Pacific isobutane plant).

Review of the First Test Installation and Startup

The unit was first installed on a modified Ormat unit at Steamboat for testing with isopentane working fluid. Operational issues uncovered during original startup and early operation were discussed previously[1,2]. The most persistent problem involved reliable pumping of liquid condensate back into the plant condenser. The pump used to return liquid to the condenser was sometimes ineffective due to vapor-locking, leading to the unit tripping on high level in the first knockout drum. Occasional trips resulting from liquid accumulation in the second knockout drum were also noted. A modification to the control system, wherein the compressor is unloaded during liquid pump operation, raises the pressure in the first knock-out (KO) drum and liquid return pump and has successfully solved the vapor-lock problem. Changes to the timers for emptying the KO drums were able to avoid liquid-accumulation trips, and long-term operation requiring occasional manual restart was achieved.

Details of unit performance during the first test have been reported previously[2]. In summary:

- Continuous operation was achieved, although liquid-level trips occurred about once per day.
- During optimal steady-state operation, vent gas with 0.5% isopentane was measured, while the plant condenser composition was less than 1% air. During this period, the vent rate was 150 to 300 ml/min (intermittent). Sample chromatograms taken before and after four days of removing air from the condenser indicated that a condenser content less than 1% air was achieved.
- During operation when the plant condenser contained high concentrations of air (>5%,), the vent rate increased to over 2 l/min with an organic content of about 4%.

Second Test Installation and Startup

The unit was installed on a Holt-design, isobutane plant near Mammoth Lakes CA in March 2003. The inability to pump liquid back into the plant condenser was more severe in this application, probably resulting from the increased volatility of isobutane compared to isopentane and the higher air introduction rate, which reduced the interval between pumping cycles. Several hardware and logic changes made alleviated some of the problem, but were not successful in that the unit would not run for any extend period. As a result, a system to return liquid to the plant condenser using high-pressure compressor exhaust was designed and installed. This system featured installation of a third vessel, the "Liquid Accumulation Vessel" shown in the schematic, Figure 2. Introducing the third vessel allows the system to continue to remove NCGs from plant condenser vapor while the vessel is purged to return liquid to the plant.

Performance During the Second Test

The modifications described above have been completed, and testing of the modified plant has begun. Performance data will be available and presented at the '04 GRC technical meeting. The plant to which the unit is attached has an extremely high air leakage rate, on the order of 400 gm air per

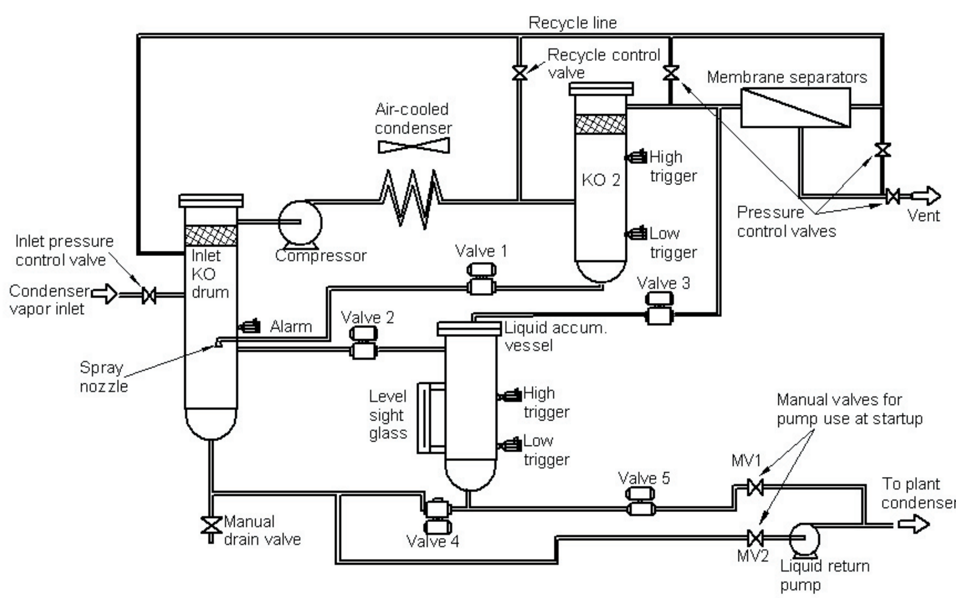

Figure 2. Modified test skid incorporating additional liquid accumulation vessel.

hour. This is about 30 times the design removal rate for the system.. Under these conditions, the unit is venting between 7 and 14 liters/minute with 4 to 6 percent isobutane in the vented mixture. The plant operator reported that at the start of an operational period the condenser contained about 12 psi partial pressure air. After two days of operation, this had decreased to about 8 psi. It is not yet known what steady state concentration of air in the condenser will be reached.

Summary and Conclusions

The unit operated at the first host-test site for about 8 months. While quantitative results for increased power generation could not be generated, the following results were noted:

- The condenser pressure was nearly equal to the adjacent Ormat unit, which was not experiencing as high of NCG introduction levels and was operating at equivalent brine conditions. Previously, the condenser operated several psi above the adjacent unit due to the higher intake of NCGs at the unit where the testing was conducted.
- The operator reported higher-than-expected power output from the test unit during periods of high ambient temperature. However, no quantitative comparison was offered.
- The working fluid loss while the unit was operating was much less than the losses associated with purging the condenser, as had been practiced previously.

The unit has been at the second host-test site for twelve months. The plant to which it is attached has a very high air introduction rate (due to turbine seal problems). The removal system vents air containing 4 to 6% working fluid at a rate of 7 to 14 liters per minute. The vent rate is about 45 times that expected for normal operation at this plant. The membranes operate effectively at this increases throughput, as evidenced by the low concentration of working fluid in the vented air. During periods of continual use (with frequent operator-assisted restarts) it reduced the plant condenser NCG content significantly (by ~1/3 in 2 days). Only the issue of frequent shutdown prevents the unit from being a significant benefit to the plant. This issue has been addressed with the modifications made to the unit, which will facilitate the return of working fluid to the plant. The testing being conducted during the summer of 2004 will confirm the adequacy of these modifications, and provide operational data over an extended period of time that will be used to validate the unit design and membrane performance.

Acknowledgements

This work was supported by the U.S. Department of Energy, Assistant Secretary for Energy Efficiency and Renewable Energy under DOE Idaho Operations Office Contract DE-AC07-99ID13727. Such support does not constitute any endorsement by the U.S. Department of Energy of the views expressed in this publication. The geothermal community has been very supportive of this investigation. The author would like to express their appreciation to the management and personnel of the Steamboat, NV and Mammoth Pacific binary power plants who have provided useful input to our investigation and to Membrane Technology and Research, Inc. for membrane testing and system design.

References

1. Mohr, C., G. Mines and K. Bloomfield, "Continual Removal of Non-Condensable Gases for Binary Power Plant Condensers", Geothermal Resources Council Transactions, Vol 25, San Diego CA, August 26-29, 2001.
2. Mohr, C., G. Mines and K. Bloomfield, "Continual Removal of Non-Condensable Gases for Binary Power Plant Condensers", Geothermal Resources Council Transactions, Vol 26, Reno, NV, September 22-25, 2002.