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OPERATING DATA ON A NOVEL ABSORPTION REFRIGERATION CYCLE

New York State Energy Research and Development Authority

Agreement No. 1418-EEED-IE-90)

PROGRESS REPORT

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I. Executive Summary

This report describes the modifications and repairs made to the 200 ton absorption refrigeration pilot plant since April 1992, when Clarkson University assumed responsibility for it. Current operating problems and the performance of the plant, achieved to date, are detailed.

Performance has been limited by small air leaks into the absorption section of the plant and by plugging in a heat exchanger which has limited the flow of purified glycol to the absorber. Nonetheless, the plant has been operated for periods of over eight hours with sustained cooling loads of 40 tons. Chilled water has been produced at a temperature as low as 38 degrees Fahrenheit.

The principal leak sources have been pinpointed. Plans are described for achieving plant operation at designed levels.

II. Description

A 200 ton refrigeration pilot plant has been constructed at Clarkson University to demonstrate the capabilities of a novel absorption refrigeration process which uses water as refrigerant and ethylene glycol as absorbent. The goal is to obtain sufficient operating data to permit the design and construction of efficient commercial installations of 1,000 to 6,000 ton capacity. A specific objective is to show the process's ability to produce a cold stream containing an ice slurry. Funds for construction of the pilot plant came from NYSERDA, under Agreement No. 1240-EEED-AEP-89, as well as from the U.S. Department of Energy, the Eastman Kodak Company, and the Puraq Company, a small business which owns the patent for the refrigeration process.

Existing commercial absorption refrigeration systems use either relatively hazardous working fluids (water-ammonia) or potentially corrosive fluids (LiBr-water). The ethylene glycol-water system with relatively non-hazardous and non-corrosive fluids holds the promise of high energy efficiency and the ability to produce a pumpable ice slurry. Because of this system's relatively large absorber volume, potential applications focus on high capacity installations. The 200 ton refrigeration pilot plant was designed for scaling the absorber to larger capacity by extending its length while keeping liquid and vapor velocities constant.

Figure 1 is a process flowsheet which identifies important components of the plant by code. Pumps are coded P-1 through P-9, heat exchangers are H-1 through H-7, etc. Table 1 lists activities at the pilot plant on a monthly basis.

Clarkson University assumed responsibility for the pilot plant in April 1992, following substantial construction delays which are described in the Puraq Company's Final Report to NYSERDA under agreement 1240-EEED-AEP-89. Efforts since then have largely focused on bringing the plant into operation. Numerous difficulties have been encountered and slowly overcome. Briefly, the spring and summer of 1992 were spent getting the plant ready to run. That fall we began to discover and correct operating problems. In 1993, equipment modifications made in the spring and early summer enabled us to finally run the plant for periods of several hours. In August, the distillation column was successfully operated. By September, we were finally able to sustain a significant cooling load in the absorber. At this point our vacuum requirements were more stringent, needing close to 5 torr absolute pressure in the absorber. Unfortunately, small air leaks and vacuum pump problems stymied our further progress. In late October, Carrier Corporation absorption refrigeration technicians with leak detection equipment were able to pinpoint the leak sources.

A detailed description of our most successful run is presented in the next section. The temperature of the chilled stream was brought to 38 degrees Fahrenheit; this is a lower cold temperature than the LiBr-water absorption system can achieve. We were able to bring the absorber pressure briefly to 4.6 torr, indicating the ability to approach a 32 degree cold stream.

Interest in the project continues to come from a variety of organizations. Tennessee Eastman, Niagara-Mohawk, the New York State Power Authority, the Trane Company, and the Carrier Corporation have all inquired about the project. Engineers from the Canadian National Research Council made a site visit.

Table 1

Refrigeration Pilot Plant Start-Up Activities

Date	Accomplishment
April '92	Assume responsibility for the refrigeration pilot plant.
May - June	New heater resets were purchased and installed (the electrical contractor had installed resets of too low an amperage), a level controller for the cooling tower was installed, wiring to the vacuum pressure indicating controllers was corrected and the instruments were tuned, wiring for a set point signal was run to the condensate level controller, and piping connections were corrected on the liquid level indicators. Thermocouples, differential pressure cells and vacuum pressure indicators were calibrated. Damaged control valves were returned to Bray Valves for repair.
July	The instrument technician resolved a ground loop problem within the Bray valves by disconnecting their internal ground wiring.
July-August	System was flushed with water, chemically cleaned with citric acid and ammonia, and flushed again with water. The initial 14 drums of ethylene glycol were charged. A U-bend was installed between the glycol holding tank's overflow and the distillation column. An inverted U-bend was installed in the distillation column's level indicator's upper leg. Mike Godlewski defended his M.S. thesis which included details of the corrections made through June 1992, a start-up manual, and a Fortran simulation program.
Sept-October	A new graduate student was taken on. Vacuum leaks were sealed. The vacuum pump's shaft was realigned. Pump P-9 was freed from seizure due to scale build-up on its impellor. Initial start-up attempts were made. Five more drums of ethylene glycol were obtained and charged to the system. Cavitation problems were recognized with pumps P-4 and P-5, while flow through pump P-2 was seen to be less than the design flowrate. On the last night in October, all water lines were frozen.
Nov-April	Orders were placed for a new impellor and casing on pump P-2, new pipe supports on and sealing the top of the cooling tower, a new reflux pump (P-6), and a control valve and flow indicator for the reflux line. New ball valves and gaskets were obtained to replace those damaged on the frozen water lines.

May-June
'93 Installation of the above equipment was carried out. Additional repairs were made on pump P-9's check valve and cover plate, and on the main steam valve. The liquid strainer's on all pumps were cleaned (P-1, P-2, P-3) or removed (P-4 and P-7). A recirculation loop was placed around P-5, and a flow meter bypass and check valve were installed on its discharge line.

July Start-up showed low flow through pump P-6. Pump P-7 had a short circuit, and two control valves malfunctioned. All these electrical problems were corrected, chiefly by our instrument technician. A faulty dp cell was replaced with a spare mechanical differential pressure indicator.

August Pump P-6's 4 3/4" impellor was replaced with a new 6 1/8" impellor. System started-up and ran for four hours. Considerable water was distilled from the ethylene glycol. As the distillation bottom's temperature rose to where the bottom's product would be relatively pure glycol, the liquid levels dropped to a point too low for control of transfer flow rates.

September Eight more 55 gallon drums of ethylene glycol were obtained from Texaco Chemical Co. and charged to the system. Low flow of purified glycol through P-2 was found to be due to plugging in H-6 by rust particles. Air leakage kept the absorber pressure above 25 torr. Tightening all bolts atop the absorber and holding tank, brought the absorber's vacuum pressure to below 6 torr. The plant was operated throughout the day on Sept. 23. Cooling was evident from the condensate formed on the exterior of the absorber.

October In subsequent runs, air leakage into the system did not allow the absorber pressure to be brought below 8 torr. During one run the reflux to the column stopped and many gallons of glycol were passed to the chilled water holding tank. Subsequent distillation under high reflux flow conditions recovered this glycol. Technicians from Carrier Corporation leaked tested the system. Leaks were found around the manhole for the glycol holding tank (G-2), at the uppermost elbow on the vacuum line exit the absorber, and within the vacuum pump itself. Other small leaks were corrected in a vacuum controller and on the face plate of the vacuum pump's intake manifold.

November The system was prepared for winter. Water and steam lines were drained, flanges were loosened on the water line below the cooling tower to permit drainage of any precipitation, cover plates around check valves were loosened, and differential pressure cells were drained.

III. Operating Results

In mid-September Mr. Chereddy, our graduate student, climbed to the top of the absorber (G1/H1) and the glycol holding tank (G-2) and tightened all bolts. The manhole covers above both vessels had several loose bolts, probably from the effect of thermal expansion and contraction of the large manhole covers. Tightening these bolts led to significant improvement in our vacuum pressure.

On September 23, start-up of the plant began shortly before 8:30 a.m. The initial system pressure was at 23" Hg (175 torr) due to air leakage overnight. Shortly after 9 a.m., pressure had fallen to 110 torr and steam was applied to the distillation column. Blockage in the aluminum heat exchanger (H-6), limited the flow of purified glycol to the absorber to about 60 gpm. The design flowrate for this stream is 120 gpm. The cooling tower fan was operated on low power, and the steam flowrate was slowly increased until at 10 a.m. the steam control valve was fully open. By 11 a.m. the system pressure had dropped to 32 torr, and the distillation column was sealed off from the vacuum pump. Every few hours, the absorber was sealed off from the vacuum line and the distillation column's pressure was reduced to 30 to 40 torr. Just before noon, the absorber pressure reached 13 torr and pump P-7 was turned on to circulate the chilled absorber water through heat exchanger H-7. By monitoring the flowrate and temperature change of the process cooling water, the refrigeration load could be found; also, from the chilled absorber water flowrate and temperature exit H-7, the temperature in the bottom of the absorber could be determined. There is no thermocouple giving a direct temperature measurement of the chilled water.

At 1:30 p.m. the absorber pressure had fallen to 10 torr. However, it took until 4:30 p.m. to achieve 9 torr. Between 5:15 and 5:40 the following process changes were made: the recirculating flow of glycol through P-4 was increased slightly, oil was added to the vacuum pump, and the flow of reflux to the distillation column was reduced. The absorber pressure dropped from 8.8 torr at 5:40 to 7.8 torr at 6:30, down to 7.2 torr at 7 p.m., and 6.4 torr at 8:05.

At this point we tried an experiment. Pump P-7 was turned off. Without a cooling load on the absorber, its pressure went down to 5.3 torr in a few minutes and to 4.7 torr ten minutes later. When P-7 was restarted the absorber pressure quickly rose to 5.96 torr and held at that level. At 9 p.m., pump P-7 was turned off for 5 minutes. During this time the absorber pressure fell to 4.6 torr. When P-7 came on again, the absorber pressure rose to 5.75 torr and held there. At 9:30 p.m., we began to shut down the system.

In subsequent runs, air leaks worsened and we were unable to bring the absorber pressure below 8 torr. With hindsight, we should have continued our Sept. 23rd run into the early hours of the morning. However, at the time, we felt that this was merely the first of many demonstration runs.

Discussion

The pilot plant run of September 23 demonstrated the ability of the ethylene glycol-water absorption system to produce a cooling effect. While the observed cooling load was 500,000 Btu/hr, which is considerably below the design cooling load of 2.4 million Btu/hr (200 tons), this was expected because of low glycol flowrates through both P-2 and P-4. Also, the air leaks would cause the absorber to be less efficient per unit of glycol because non-condensibles create a mass transfer resistance.

Another measure of the system's performance is how closely the chilled water temperature approaches 32 degrees Fahrenheit. The equilibrium vapor pressure of water at this temperature is 4.4 torr. An energy balance around heat exchanger H-7 shows that the chilled water temperature dropped to 38.2 degrees F. This was achieved at an absorber pressure of 5.75 torr. So a leak rate one-third lower should have produced the target pressure of 4.4 torr and a cold stream at 32 F. Despite all of the system's limitations, i.e. air leaks and limited glycol flowrates, it was able to achieve a lower cold temperature than the LiBr-water system can produce.

The operating data allow us to obtain other indicators of system performance. One of these is the overall heat transfer coefficient of the heat exchangers, analyzed here as the product of the overall heat transfer coefficient, U , and the total heat transfer area, A . This product is the heat transfer rate per unit of log mean temperature difference. For the aluminum heat exchanger, H-6, the observed value for UA is 130,000 Btu/hr-F, while the designed value was to be 900,000 Btu/hr-F. The plugging in this heat exchanger is obviously detrimental to its heat transfer efficiency as well as to the throughput of purified glycol. Similarly, for heat exchanger H-7, our observed value for UA is 33,000 Btu/hr-F while the design value is 75,000 Btu/hr-F. The discrepancy here is probably due to scale formation on the tube walls of the exchanger. Since this exchanger is used for measurement purposes rather than for internal heat exchange which would influence the system's thermodynamic efficiency, this scale formation is not harmful to overall performance.

IV. Equipment Problems

Through our start-up efforts we have identified many mechanical and electrical difficulties. Most of these have been overcome, some we have tried to live with, while others have recently appeared. As we achieved plant operation, more demands were placed on the system both in terms of vacuum pressure and in hours of operation. The following paragraphs describe the major hurdles remaining for achieving full system performance.

A. Air Leaks

The carrier technician pin-pointed three major sources of leaks. One was around the man-hole on the glycol storage tank, G-2. Unlike the gaskets on all other large diameter plates, this gasket is not cut so that it extends outside the cover plate. A new, oversize gasket should be cut, coated with a Loctite leak sealant, and installed beneath the man-hole cover. Some pipe or rods should be tack welded onto the existing structure to provide better support for the mechanic or operator working on this cover.

The second air leak was at a threaded pipe elbow on the vacuum line rising from the top of the absorber. This would be easy to correct except for the precarious position of the elbow, some thirty feet off the ground. Nonetheless, a mechanic should be able to break the line at the flange off the absorber, tighten the elbow and reconnect all piping.

The final leak source was the vacuum pump itself, a Rietschle Model CLF41-11 rotary vane pump. When the pump was valved off from the system, there was still a significant volume of air being discharged. The Carrier technician attached a small, portable vacuum pump to the vacuum line, and it discharged little air. The Rietschle pump will need to have its ring seals inspected, with any suspect seals replaced. Since this pump is a critical component of the project, we are seeking the services of a technician experienced with Rietschle vacuum pumps to inspect and overhaul the unit.

B. Plugging in the Aluminum Heat Exchanger (H-6)

Pump P-2 moves purified ethylene glycol from the bottom of the distillation column, through heat exchanger H-6 where energy is given up to the distillation column's feed stream, and into the top of the absorber. In fall 1992, it was noted that the flowrate through P-2 was below the designed level of 120 gpm. To correct this, a larger impellor was ordered for the pump. When the new impellor was installed, it was found that the strainer inlet to the pump was almost plugged with solids. This strainer is a cone shaped piece of stainless steel with holes about one eighth inch in diameter. It was cleaned out and the butterfly valve on the inlet side of the pump was changed to one having lug bolts. These bolts allow the strainer to be removed for cleaning without having to drain the distillation column. The new impellor and the clean strainer allowed the P-2 flow to be well over 120 gpm.

A few weeks later, it was noticed that the maximum flowrate through P-2 had fallen to only 100 gpm. The strainer was free of any plugging. Inspection of the pump, by a Gould's pump salesman, indicated no problem. The flowrate through P-2 continued to drop. It was found that

by bleeding air into the line downstream of the heat exchanger, or by having a small back flow through the heat exchanger, the flowrate through P-2 could be increased. This lead us to drain the transfer line of glycol and to attach a water hose downstream of the heat exchanger. When exchanger was back washed with water, a rust sludge was removed from the exchanger and the P-2 flowrate showed significant temporary improvement. After a single day's operation the flowrate would again drop, with the largest deterioration occuring after the system was shutdown.

We have consulted with the supplier of this heat exchanger, Energy & Environ Equipment Inc., and they believe the problem is due to the fine spacing between the aluminum rods running through the exchanger. Their recommendations are to have a high back flush flowrate to clean the entrance of the exchanger and to install a fine mesh screen inside the pump's strainer to keep the transfer line free of particulates. The screen will need to be cleaned periodically.

To date all back washing has been done through a one inch water hose. This has limited the back wash flowrate. The flanges on the ends of the heat exchanger are for 3" pipe. We need to obtain a 3" water hose and hose couplings or 3" piping to connect our main water line with the heat exchanger.

C. Repair of Instrumentation

The flow indicating controller purchased for the reflux line (P-6 flow) was not properly wired by the electrical contractor. We operated this past fall with no control room reading of the reflux flowrate. This lead to overflow of glycol into the condenser H-2 on one occasion.

Also, in late October the control valve on the steam line malfunctioned. Previously, this controller had given trouble due to a faulty potentiometer connection. The differential pressure cell which measures the steam flowrate also needs recalibration. Clarkson's instrument technician should be able to solve these problems.

D. Replace Needle Valve

There are two main sections of the refrigeration plant: the distillation column (G-3) and its condenser (H-2), which are to be kept at close to 46 torr, and the absorber (G-1) and glycol storage tank (G-2), which are to be maintained at 4.4 torr. A single vacuum pump is to maintain the pressure in each of these sections by means of a needle valve (VA-58) which connects the 2" vacuum line coming off H-2 with the 2" vacuum line running from the absorber to the vacuum pump. The needle valve is to be closed sufficiently to maintain a 42 torr pressure drop between the condenser and the absorber. The existing needle valve cannot be so closed. This has necessitated our opening the condenser to the vacuum line on an intermittent basis. The drawbacks to this include constant attention by the operator and the danger of column upsets. Proper operation of this needle valve is necessary for automatic control of the plant.

E. Additional Ethylene Glycol Inventory

Over the last year and a half, twenty six 55 gallon drums of ethylene glycol have been added to the system. This has brought the glycol inventory in the storage vessels, G-2 and the base of G-3, to about half full when the system is shutdown. This is a minimum essential loading of

glycol. When in operation, hold-up of glycol in the distillation column and in the absorber drops the glycol levels in G-2 and G-3 to a level of only one to two percent of full. This makes it difficult to control liquid levels and to maintain an adequate flow in the glycol recycle line via pump P-4. The ethylene glycol we have used was donated by Texaco Chemical, which has recently been purchased by Huntsman Chemical. An additional three hundred gallons of glycol will provide for increased hold-up in the absorber and higher operating levels in our storage tanks. Proper control of the recycle glycol flowrate is needed to study the effect of liquid velocity on absorption.

F. Inspect Steam Heat Exchanger for Corrosion

The possible sources of the particles which cause plugging in the aluminum heat exchanger are the distillation column or the steam heat exchanger. The packing within the distillation column represents the largest iron surface in the system. Thermal expansion and slugging within the distillation column could shed particles which are then pumped into the aluminum heat exchanger. Ethylene glycol is circulated through the steam heat exchanger, H-4, by pump P-3 to provide heat for the distillation. Heat exchanger H-4 is the location in the process where the glycol is at its highest temperature; therefore, any corrosion attributable to glycol would be greatest in this exchanger. The winter-spring shutdown allows an opportunity to open and inspect this exchanger for evidence of corrosion. This point is of concern for specifying the materials of construction and inhibitor loadings in future commercial installations.

V. Plans for Winter

The data gathered during pilot plant operation in the fall will be critically analyzed. We will check for inconsistencies which would indicate an instrument in need of recalibration and compare the operating data with our computer model. We will quantitatively link the air leak rate with readily observable information such as the overnight gain in system pressure and the rate of pressure drop during initial start-up.

We will continue in our efforts to publicize the refrigeration pilot plant. Articles announcing the start-up of the plant will be sent out to various engineering publications. A presentation on the plant will be given to the Carrier Corporation process engineering group early this winter.

Solutions to the plant's equipment and instrument problems will be implemented as weather and funding allow. Proposal's seeking additional funding will be written.

The plant itself will be monitored throughout the winter.

DATE

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7/12/94

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