FROSTING AND LEAKAGE TESTING OF AIR-TO-AIR ENERGY RECOVERY SYSTEMS

DR. HARRY J. SAUER, JR., P.E.
Fellow ASHRAE

DR. RONALD H. HOWELL
Member ASHRAE

JAMES R. WRAY

ABSTRACT

As part of an investigation on the operating characteristics of air-to-air heat exchangers, t limiting conditions that produce frosting were determined as well as the adequacy of provisio for the prevention of frosting and ice buildup. Also investigated for various types of energ recovery systems was the cross leakage or contamination of the fresh air by the exhaust air.

FROSTING

General

Frosting in air-to-air heat exchangers is a problem that can exist in locations of subfreezing temperatures.

In all air-to-air energy exchangers, condensation will occur when some portion of the transfer surfaces or media attains a temperature below the dew point of the warm airstream. Provisions for condensate removal, such as drain pans or recessed ductwork, should be incorporated into the system so that the condensate will be prevented from flowing into the ductwork.

In cases of outside air temperatures below 32 F (0°C), this condensate may freeze. Whil a partial freeze-up may not cause any permanent damage to the heat exchanger, it will result reduced heat recovery, reduction of exhaust airflow, and increased exhaust airstream pressure drop.

Frosting (sublimation of water vapor) and icing (freezing of subcooled condensate) in sensible exchangers can occur at subfreezing supply air temperatures when the surface temperature drops below the frost point of the exhaust air. The rate at which frost will accumulate depends on the temperature of the supply air, humidity ratio of the exhaust air, exchanger effectiveness, and duration of frosting conditions. Daily temperature fluctuations will reduce the risk of frosting. Generally, frost will first form on the discharge face of the exhaust airstream and then increase in both thickness and depth of penetration consistent wi the duration and intensity of the frosting conditions. In extreme cases, airflow can stop completely.

The designer of HVAC systems incorporating energy recovery requires means to predict if frosting will occur and if there is justification in incorporating frost prevention equipmen or control.

Work in the area of frosting was carried out under ASHRAE RP-133 by Gawley, Fisher, and others (1). Tests for frosting were made on the hygroscopic rotary heat exchangers using the naturally occurring subfreezing ambient of Manitoba, Canada for the supply inlet and the temperature and humidity of the exhaust inlet was controlled. The onset of frost was indica

---

Harry J. Sauer, Jr., Professor of Mechanical and Aerospace Engineering, University of Missou Rolla; Ronald H. Howell, Professor of Mechanical Engineering, University of Missouri-Rolla; James R. Wray, Research Assistant, Department of Mechanical Engineering, University of Misso Rolla, Rolla, MO.

THIS PREPRINT FOR DISCUSSION PURPOSES ONLY. FOR INCLUSION IN ASHRAE TRANSACTIONS 1981, V. 87, Pt. 1. Not to be reprinted in whole or in part without written permission of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 345 E. 47th St., New York, NY 10017. Opinions, findings, conclusions, or recommendations expressed in this paper are those of the author(s) and do not necessarily reflec the views of ASHRAE.

the range of outdoor inlet air temperatures produced [to -10 F (-23°C)], thus preventing frosting.

Frosting or Freezing with Plate Exchanger System

The fixed surface plate exchanger tested in this program might be classified as a counterflow, pure-plate heat exchanger, consisting of only primary heat transfer surface. The plate exchanger transfers sensible heat only, except when the temperature of one airstream is low enough to cause condensation in the opposing airstream. If the temperature of the incoming airstream is sufficiently low, freezing of the condensate, and/or frosting, will occur. Since the plate exchanger contains no specific provisions to prevent frosting, an extensive test program was conducted in order to determine the limiting conditions that will produce frosting or ice buildup in the plate unit. Although it was not possible to reduce the results to a single frosting line, a fairly narrow band has been defined: below which, frosting can be expected, and above which, frost should not be found. These results are shown in Fig. 1. The frost threshold temperature values from ASHRAE's 1979 Equipment Handbook (2) for corresponding exhaust air conditions are also plotted in Fig. 1. Fair agreement exists between the two sets of data. Both sets of results show that in the fixed plate exchanger, the greater the moisture content of the exhaust gas stream, the less likely that freezing will occur on the surface of the exchanger.

Frosting or Freezing with Twin-Tower System

Twin-tower enthalpy recovery systems are designed primarily for operating temperatures in the comfort-conditioning range. During summer operation, the system will operate with any building supply air temperatures as high as 46°C (115 F). Winter supply air temperatures as low as -40°C (-40 F) can generally be tolerated without freeze-up or frosting problems, since the sorbent solution is an effective anti-freeze at all useful concentrations.

No frosting or freeze-up was incurred during low temperature testing in RP-173 of the twin-tower, open run-around system.

CROSS CONTAMINATION

General

Cross contamination, or mixing, of air between exhaust and supply airstreams can occur due to leakage which results from different static pressures in the two airstreams, with air being driven from a higher to a lower static pressure region. Leakage of exhaust air into the supply air in most installations is minimized or prevented by maintaining the exhaust stream at a lower static pressure than the supply stream.

Under ASHRAE RP-133 (3) determination of exhaust air leakage in rotary heat exchangers was determined by means of a tracer gas: sulphus hexafluoride (SF_6). The procedure was to inject the tracer gas, at a constant rate, into the air just prior to the first fan. A sample of exhaust air was then taken at the measuring station after the fan and samples of supply air were taken at the measuring stations before and after the exchanger. These samples of air were removed via the psychrometric measurement stations with suitable syringes. The concentration of SF_6 in the samples of air was determined by gas chromatography and used to calculate supply air contamination by exhaust air. SF_6 is inert, relatively non-toxic, colorless, odorless, tasteless, non-flammable, non-corrosive and thermally stable. It is not a normal background constituent of air. The six fluoride atoms in the molecule make the compound extremely sensitive to an electron capture detector. There are certain problems which must be considered when using SF_6 as a tracer. The detector unit may require frequent calibration to maintain the desired accuracy. The measurements are in the form of chromatographic peaks which may require special equipment for automation and data processing. Concentrations of tracer are measured with a gas chromatograph equipped with an aluminum oxide column and a "pulsed mode" electron capture detector. Oxygen, which is also an electron capturing gas, elutes first and is followed by SF_6, which is measured separately.

Cross-Contamination Methods Employed in RP-173

The electron capture detector necessary for detecting sulphur hexafluoride is an optional, and unavailable, feature of the chromatograph borrowed for use on this project. The unit employed for the early leakage testing was a dual-column gas chromatograph equipped with a dual thermal-conductivity (TC) detector and two flame-ionization detectors.

$$V_{in}C_{in} - V_{in}C = V\frac{dC}{dt},$$

$$\frac{V_{in}}{V}\,dt = \frac{dC}{C_{in}-C},$$

$$\ln\frac{C-C_{in}}{C_o-C_{in}} = -\frac{V_{in}}{V}t,$$

$$C - C_{in} = (C_o-C_{in})e^{-\frac{V_{in}}{V}t}, \text{ and}$$

$$V_{in} = -\frac{V}{t}\ln\frac{C-C_{in}}{C_o-C_{in}},$$

where

V_{in} = leakage rate

C_{in} = tracer gas concentration in

C = tracer gas concentration at time t

C_o = initial concentration

V = system volume

t = time.

The concentration of the methane followed an exponential rise. When this concentration is plotted on a semi-log plot against time, the slope of the line becomes the time constant. The actual leakage flow rate then is the volume of the space divided by this time constant.

It should be noted that the absolute value for concentration is not needed here; only relative values are needed, since the ratio of concentrations is used in the calculations. Hence the equipment does not need to be calibrated for concentration as long as the indication is linear. But the disadvantages of this method are: 1) it does not give continuous indication of infiltration rate; 2) it is not a steady-state measurement; hence there could be problems involving the tracer due to its absorption and adsorption characteristics.

In the following sections of this paper are the cross-contamination results from RP-173 on the following types of HVAC air-to-air energy recovery systems:

- Closed Run-Around (Coil Loop)
- Open Run-Around (Twin-Tower Enthalpy)
- Plate
- Heat Pipe

Cross-Contamination with Closed Run-Around System

Complete separation of the airstreams eliminates the possibility of cross-contamination between the supply and exhaust airstreams. No tracer gas tests were performed.

Cross-Contamination with Open Run-Around System

In twin-tower air-to-air energy recovery systems, the only way that contaminants of the exhaust airstream can infiltrate into the supply airstream is by absorption of the contaminant into the sorbent medium in the exhaust tower and desorption of this contaminant in the supply tower. The ability or affinity of a contaminant to do this is now known and is felt to be insignificant with normal constituents of building exhaust air.

Cross-Contamination with Heat Pipe System

In the heat pipe exchanger, a vertical partition is installed during assembly to provide a barrier to cross-contamination between the exhaust and supply airstreams. Sealing of the partition is usually accomplished by the application of silicone rubber around the perimeter of the unit. This sealed partition should effectively separate the two airstreams, preventing leakage from one to the other. For additional insurance against cross-contamination, it is possible to construct the unit with two separating partitions with a small space between them. By attaching the supply and exhaust ducts to these partitions, any leakage would seep into the space between the two ducts, rather than from one duct to the other.

The heat pipe unit tested in RP-173 had only a single separating partition of 14-gauge aluminum. With the distinct possibility of imperfect sealing, cross-contamination testing was conducted.

The same procedure as described for the plate exchanger was followed for the heat pipe exchanger. It, too, could not be pressurized and all ΔP's were maintained with constant air/gas flow. Fig. 5 shows the test arrangement.

Four runs were made at 0, 1, 2.5, and 5 in. H_2O (0, 0.25, 0.63, and 1.25 kPa).

Data from these tests are shown in Fig. 6(a), 6(b), 6(c), and 6(d). The results are summarized in Table 2.

TABLE 2

Heat Pipe Exchanger Cross-Contamination Rates

ΔP KPA	CROSS LEAKAGE RATE SCFM (actual)	% of Rated Flow
0	0.74 (0.35 ℓ/s)	0.04
0.25	1.05 (0.50 ℓ/s)	0.05
0.63	1.05 (0.50 ℓ/s)	0.05
1.25	0.94 (0.44 ℓ/s)	0.05

CONCLUDING REMARKS

Provisions provided or inherent with the various air-to-air energy recovery systems for preventing frosting worked as stated. For the one unit, the plate exchanger without specific frost prevention, the threshold of frost was located within a fairly narrow range of air conditions.

For the run-around systems, air leakage between exhaust and supply streams is not possible due to complete separation of the two airstreams. Some leakage was measured between streams for the plate and heat pipe exchangers.

REFERENCES

1. Ruth, D. W., et al., "Investigation of Frosting in Rotary Air-to-Air Heat Exchangers," ASHRAE Transactions, Vol. 81, Pt. 2, 1975.

2. ASHRAE HANDBOOK, 1979 Equipment Volume, Chap. 34, ASHRAE, N.Y., NY, 1979.

3. Fisher, et al., "Leakage and Carry-over in Rotary Air-to-Air Heat Exchangers as Determined by Microbiological and Tracer Gas Test Procedures," ASHRAE Transactions, Vol. 82, Pt. 2, 1975.

4. Bell, R. G., "Separation of Gases Likely to be Evolved from Flooded Soils by Gas Chromatography," Soil Sci., 105, No. 2, 1968.

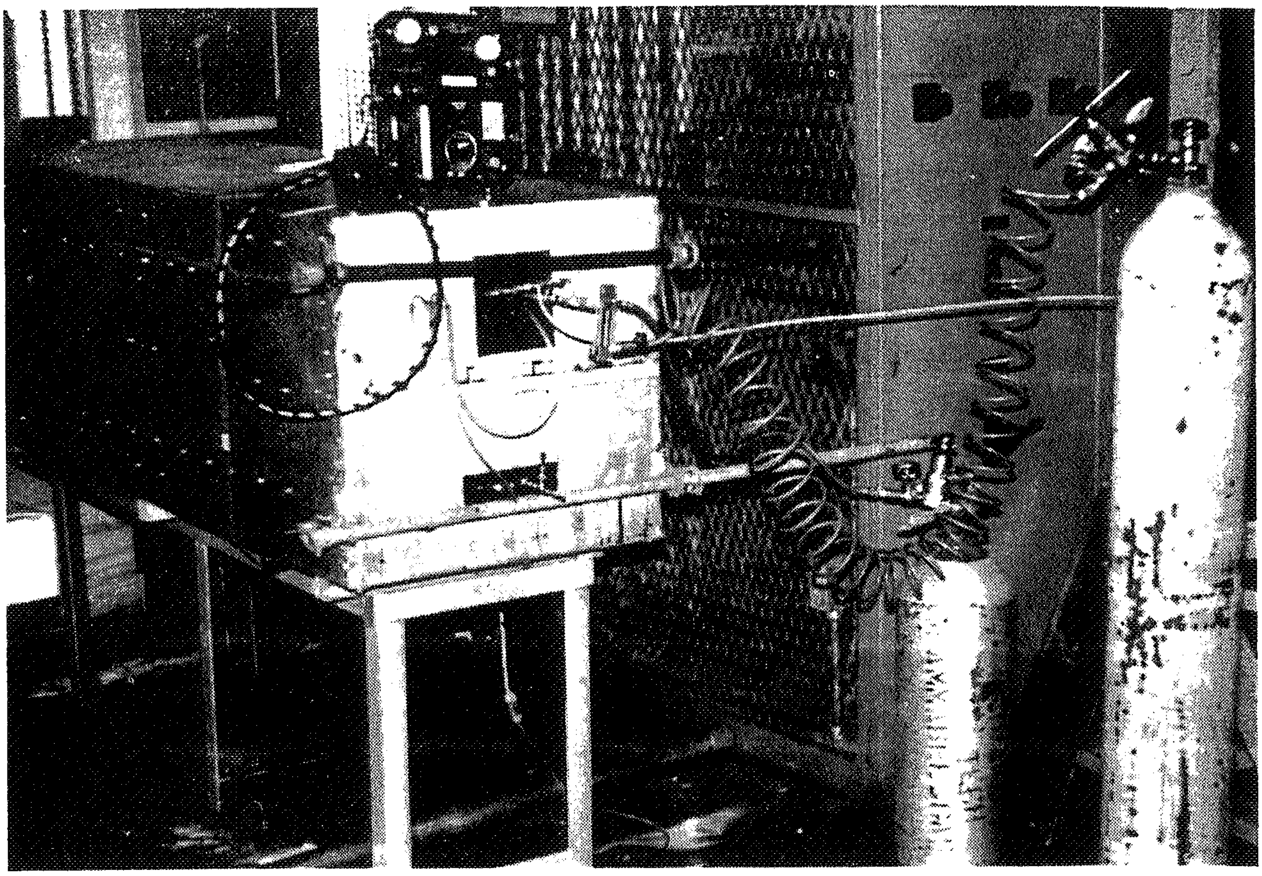

Fig. 3 Cross-contamination testing of plate exchanger

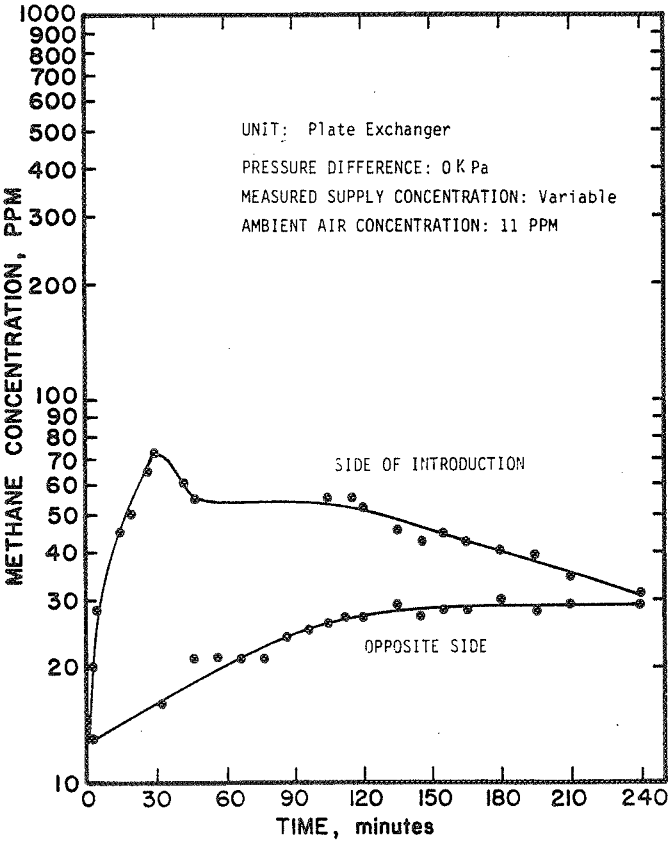

Fig. 4a Plate exchanger cross leakage at 0 KPa

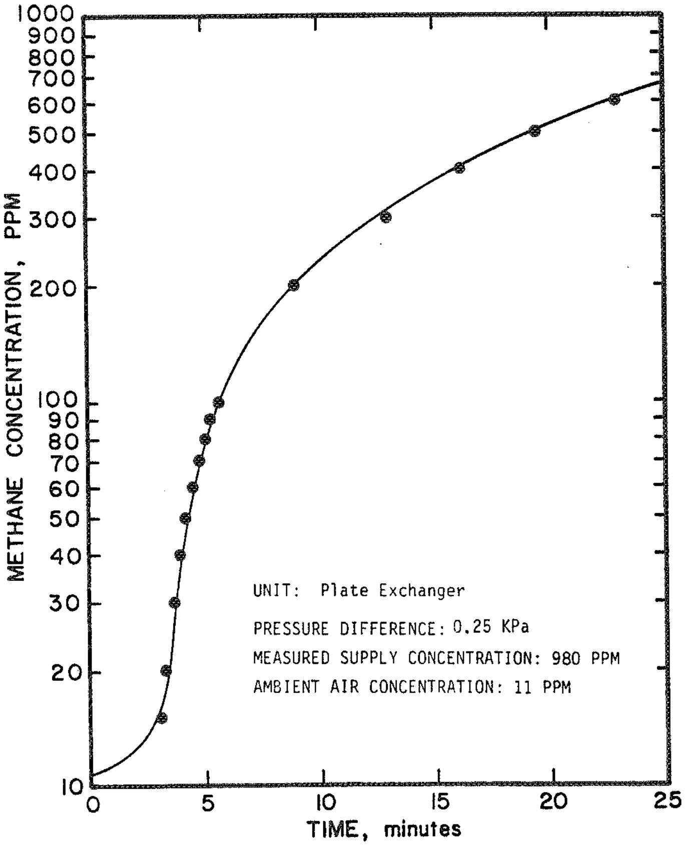

Fig. 4b Plate exchanger cross leakage at 0.25 KPa

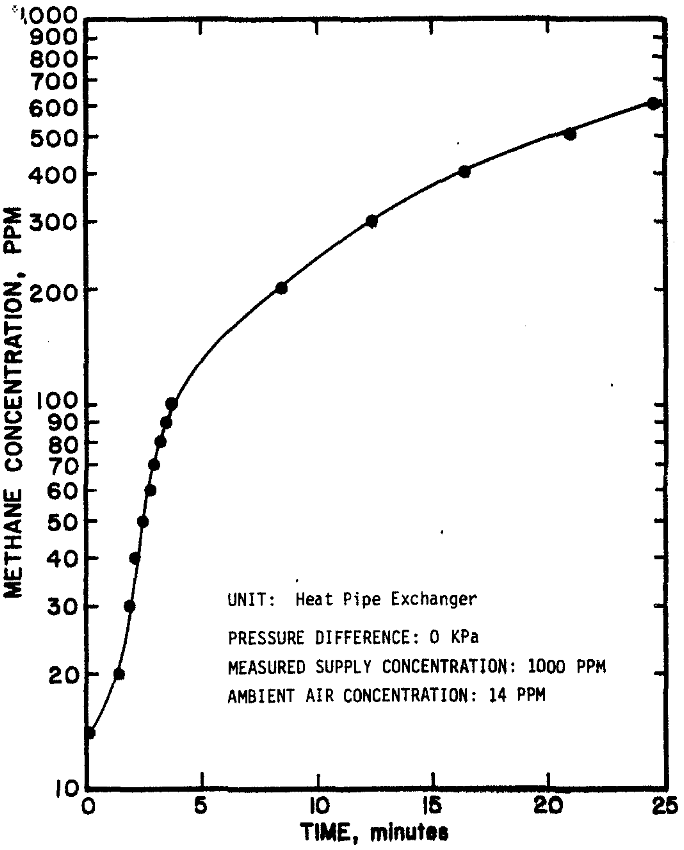

Fig. 6a Heat pipe exchanger cross leakage at 0 KPa

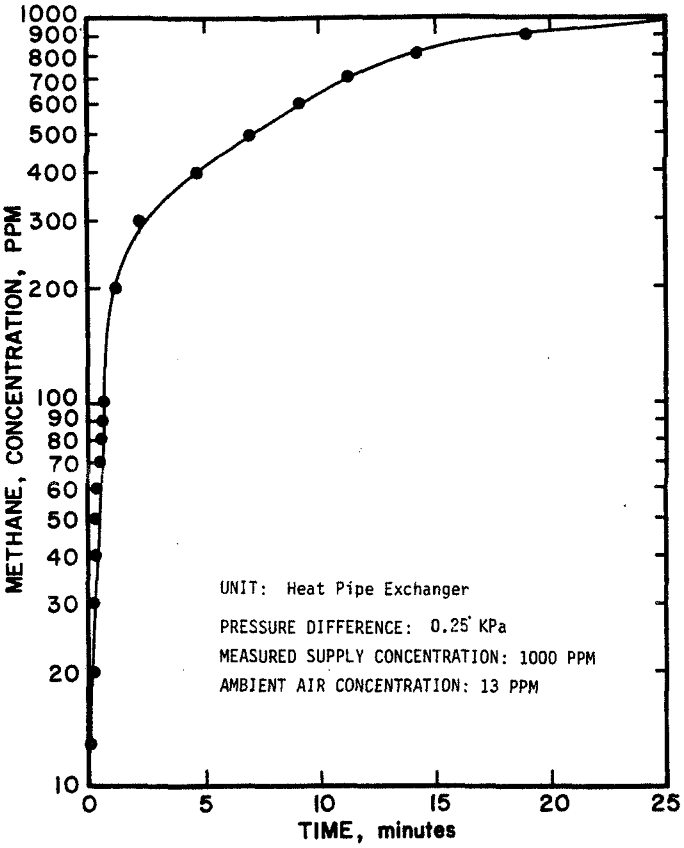

Fig. 6b Heat pipe exchanger cross leakage at 0.25 KPa

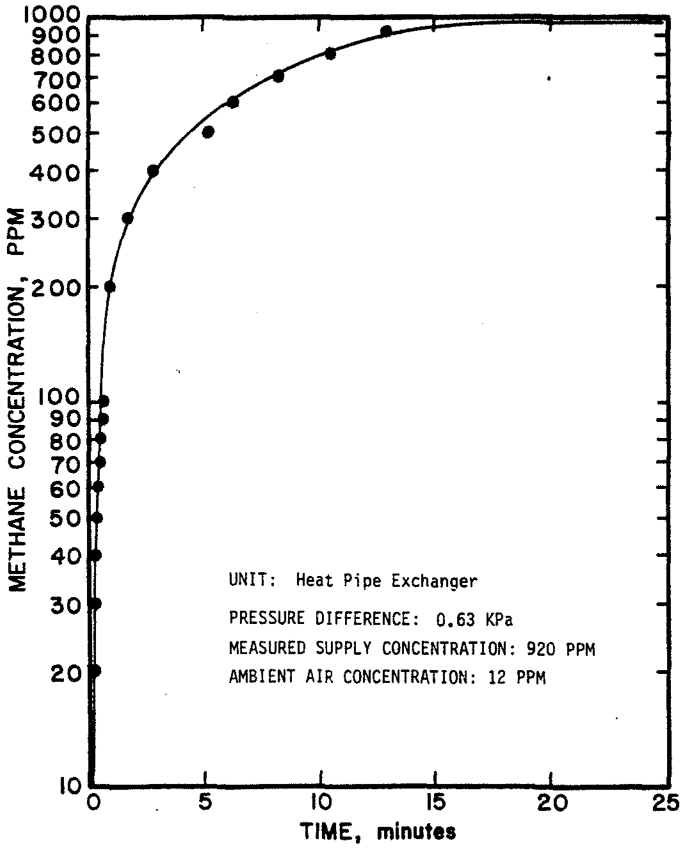

Fig. 6c Heat pipe exchanger cross leakage at 0.63 KPa

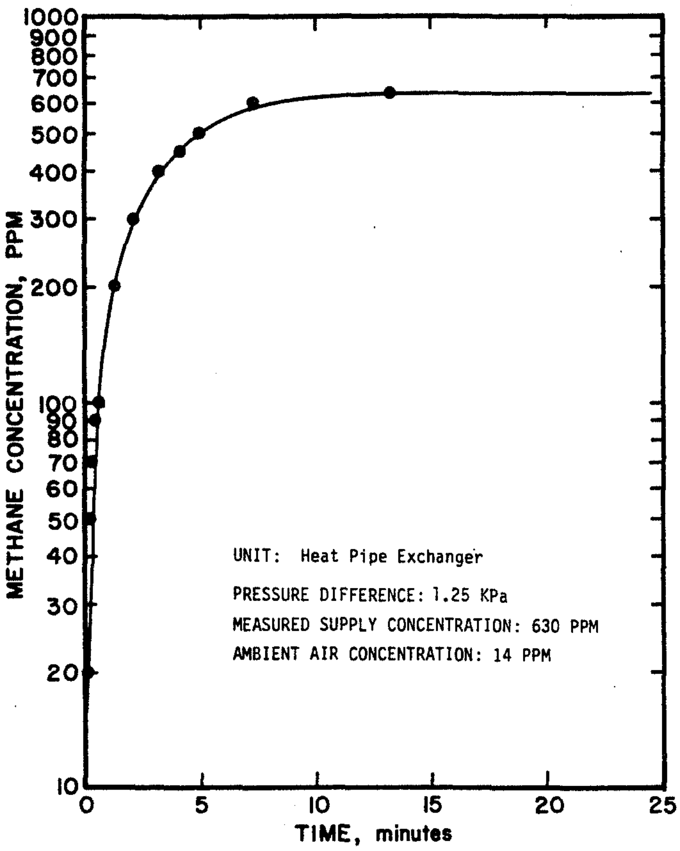

Fig. 6d Heat pipe exchanger cross leakage at 1.25 KPa