DEVELOPMENT OF A STANDARD TEST FACILITY FOR EVALUATION OF ALL TYPES OF AIR-TO-AIR ENERGY RECOVERY SYSTEMS

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ABSTRACT

This paper describes the development and qualification of a test facility for providing a uniform method for testing all types of HVAC air-to-air energy recovery systems. Conformance of the method to applicable ASHRAE Standards is described.

INTRODUCTION

The increased demand for heat recovery equipment is resulting in the establishment of many new manufacturers and the use of heat exchangers before their operating characteristics are fully known and understood.

In September 1972, an agreement between ASHRAE Research Canada and the University of Manitoba to develop "Standard Procedures for Rating Air-to-Air Heat Exchangers" was ratified. The acceptance of standard procedures for testing will, in addition to providing comparable performance data in this field, eliminate inconsistencies in terminology and interpretation and use of the measured data.

Under the guidance of the ASHRAE Air-to-Air Energy recovery Committee TC 5.5, this ASHRAE Standard 84-78 - "Method of Testing for Rating Air-to-Air Heat Exchangers" - has been developed. The standard prescribes methods for rating the heat transfer capacities, the thermal effectiveness, and supply air contamination of air-to-air heat exchangers.

The purposes of Standard 84-78 are to:

a. Establish a uniform method of testing for obtaining rating data;

b. Specify types of test equipment for performing such tests;

c. Specify data required and calculations to be used.

A schematic diagram of the air-to-air heat exchanger test apparatus recommended by ASHRAE standard 84-78 (1) is given as Fig. 1. The test apparatus primarily consists of two air ducts. The supply air duct runs from the entrance of the test apparatus (outside) through an air treatment station, measuring station one, the supply side of the heat exchanger, measuring station two, a second air treatment station, and the first fan. The exhaust side of the test apparatus runs from the exit of the first fan to the exit of the second fan. It also contains two measuring stations similar to those on the supply side.

The fans serve the purpose of supplying sufficient pressure increase in order to create air flow through the supply and exhaust sides of the test apparatus. The fans may be either constant or variable speed fans; however variable speed fans allow finer adjustment of air flow rates. Bypass systems are located near each fan for additional control of air flow rates.

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2) Determine the thermal performance of these units over a realistic range of operating conditions encountered in comfort air conditioning;

3) Determine the cross leakage or contamination of the fresh air by the exhaust air;

4) Determine the limiting conditions that will produce frosting or ice build-up and the practicability of the manufacturers' recommendations regarding its prevention;

5) Detecting the occurrence of corrosion to the materials usually employed in the manufacture of heat exchangers and its effect on the operating characteristics of these types of heat exchangers.

The thermal measured thermal performance includes as a minimum: (a) the capacity of the heat exchanger (sensible, latent, and total heat transfer rates); (b) the exchanger's effectiveness (sensible, latent, and total); and (c) pressure drop characteristics of the exchanger.

TEST FACILITY

General

The test loop includes all necessary provisions for:

(a) heating, cooling, humidifying, and/or dehumidifying the air to simulate the following field conditions:

WINTER

Fresh Air: -10* to +60 F (-23° to +16°C) @RH = ambient
*Lower to -25 F (-32°C) if necessary to create frosting

Exhaust Air: 70 to 80 F (21° to 27°C) @RH = 20 - 70%

SUMMER

Fresh Air: 85 to 105 F (29° to 41°C) @RH = ambient*
*Approx. 72 F (22°C) dew point

Exhaust Air: 75 F (24°C) @RH = 50%

(b) varying the pressure differential between the supply duct and the exhaust duct;

(c) establishing larger flow rates of supply air than exhaust air;

(d) measurements at four stations, dry-bulb temperatures, wet-bulb temperatures, and static pressures;

(e) injection and measurement of concentration of tracer gas.

Based on the selection of test exchangers made in accord with the ASHRAE monitoring subcommittee, design flow rate for the test facility is 2000 scfm (944 ℓ/s).

A schematic of the flow loop is given as Fig. 2. The flow loop has been planned and constructed for ease of interchangeability of the air-to-air test heat exchangers. This facilitates testing of the various types of heat exchangers with a minimum of down time.

As indicated in Fig. 2, outside air is brought into the supply side of the loop and is drawn through a series of refrigeration and steam coils where the air is cooled and dehumidified and then reheated. Humidification is possible after this point to set the specific humidity required. The air leaving this treatment station is maintained at various specified temperatures and humidities simulating normal year-round outside ambient conditions.

The air at this point enters one of the four combination air flow psychrometric stations, where air flow is determined by a set of flow nozzles and the air conditions are measured by dry- and wet-bulb thermocouples. The air then enters the outdoor air heat-recovery exchanger. After leaving the supply or outside air exchange the air then passes through the second air flow/psychrometric station where change in air conditions and possible losses or gains in air flow are measured. Air flow continues through the second treatment station where air conditions are adjusted to simulate normal return or exhaust air. Air then passes through the first of two fans. From this point the air enters the third air flow station. This station

2. the distance from the center of any nozzle to the nearest station wall shall not be less than one and one half times its throat diameter.

Taking these requirements into account the cross sectional dimension to which the air flow station was constructed was 36-1/4 in. (0.92 m) square. The further construction of the air flow measuring station continued to follow AMCA standard 210-74 (4). Flow settling screens were installed up and downstream of the nozzles.

Static pressure drop across the nozzle partition was measured with an inclined manometer using colored water. One side of the manometer was connected to static pressure taps located flush with the inner wall of the receiving settling plenum, and the other end of the manometer was connected to static pressure taps located flush with the inner wall of the discharge settling plenum. The static pressure taps were located approx. 1-1/2 throat diameters up and downstream of the nozzle partition in accordance with AMCA 210-74. The taps were centered vertically on the side walls and horizontally on the top and bottom walls. The set of four upstream pressure taps were manifolded together through a piezometer ring with a common take-off to the high side of inclined manometer. Similarly were the four downstream pressure taps manifolded together with a common takeoff to the low pressure side of the manometer. The use of a 1-in. (25.4 mm) diameter wafer of brass with the pressure tap drilled and mounted into the center helped to alleviate the surface irregularities present in the inner wood surface.

The air flow straightening and settling sections up and downstream of the nozzle partition were constructed per AMCA 210-74. The sections consisted of three sets of screens with each consecutive screen in the direction of air flow having smaller free areas. The first screen has 60% free open area, while the second screen has 50% free open area. The final screen has 45% free open area.

PSYCHROMETRIC AND TRACER GAS SAMPLING

The condition of the air was measured before and after each of the supply and exhaust heat exchangers. To measure as accurate an average air condition as possible, a sampling tube grid was placed within the air flow measuring station just downstream of the nozzle discharge settling screens. The sampling grid in accordance with ASHRAE Standard 84-78 is depicted in Fig. 5 and provides for 16 air samples from an equal area matrix across the cross section of the air flow station.

The sampling grid was designed so that from any one sampling point the distance traveled to the outlet of the grid would be identical. This was done so that if there was any temperature stratification across the cross section there would be no distortion of the average temperature due to unequal flow rates.

The air is drawn by an auxiliary fan from the sampling grid through a psychrometric measurement station. Here the humidity conditions are measured through the use of dry- and wet-bulb thermocouples. Along with these temperature measurements, a psychrometric station pressure measurement at the point of humidity measurement is also made. These three data points establish the humidity ratio of the air at that point in the loop. The actual average air dry-bulb temperature is measured with a thermocouple of the point where the sampling grid air sample is withdrawn from the air flow measuring station. All thermocouples are copper-constantan.

Inherent with either the construction or operation of particular heat recovery devices, cross flow between the exhaust and the intake air streams is possible. The method to determine the amount of such carry-over involved the use of a tracer gas. The gas is injected just upstream of the first fan, so that adequate mixing is accomplished.

The psychrometric sampling grid of the third air flow measuring station withdraws a sample of air. The concentration of the inert gas in the exhaust air is determined with the use of a gas chromatograph analyzer. Similar samples from air flow measuring stations one and two are also taken and analyzed. The sample from station one verified the purity of the incoming air while the samples from station two determine the amount of carry-over. Tests are to be taken without heat or moisture added between stations two and three and with equal air flow rates.

CALIBRATION AND PRELIMINARY MEASUREMENTS

Prior to running tests the nozzles diameters were checked. Each nozzle throat was measured in four places approx. 45° apart in each of two places, one at the nozzle discharge and the other inspected to assure that it was at a temperature of 32 F (0°C), and each psychrometric station was checked to assure sufficient water was available for the wet-bulb thermocouples. Fans 1 and 2 were then started and the desired supply and exhaust air flow rates were obtained by varying the amount of air bypassed to the laboratory using the bypass after each fan. Additional flow control was also available by varying the speed of the second fan. Once the air flow rates through the supply and exhaust sides of the test apparatus were stable the desired temperature and humidity conditions of the air at measuring stations 1 and 3 could be created using the air treatment stations located upstream from station 1 and 3. The temperature at measuring stations 1 and 3 was controlled by the heating and cooling coils while the humidity was controlled by use of the humidifiers. After the temperature and humidity of the measuring stations are at the desired points some minor flow adjustments were required, since the change in temperature of the air will affect the air flow through the test apparatus due to its change in density. Once the air flow rates and station temperatures were stable the air flow rates through the psychrometric stations were checked and flow rates set at 1000 ft per min (5.08 m/s). At this point the system was allowed approx. 2 hr to stabilize. Once the system was considered stabilized the desired data was recorded.

For each test the following were recorded:

- Temperature of air flowing through each measuring station;
- Static pressure drop across the nozzle plate;
- Static pressure of air entering the supply and exhaust side of the heat exchanger;
- Static pressure drop across the supply and exhaust side of the heat exchanger;
- Wet- and dry-bulb temperatures of air aspirated through each of the psychrometric stations;
- Static pressure of air in each psychrometric station;
- Barometric pressure;
- Temperature of air entering sampling probe; and
- Room temperature.

From this data, the temperatures, humidity ratio, enthalpy, density and mass flow rate of supply and exhaust air were calculated for each of the four measuring stations. From these calculated values the sensible, latent, and total effectiveness values could be determined.

Fig. 13 is a sample DATA SHEET indicating the data needed for the results calculations. Not shown on this sheet are the many additional temperatures and pressures monitored, which, although needed to assume uniformity and stability in flow conditions, are not required in the results analysis.

CONCLUDING COMMENTS

A test facility, very similar to that developed and used for testing rotary air-to-air exchangers under ASHRAE RP-133 has been developed and used for testing the following:

- Coil-loop (closed run-around) type heat exchanger;
- Twin-tower (open run-around) enthalpy type exchanger;
- Heat pipe type exchanger; and
- Plate type exchanger.

The facility can simulate a wide range of outdoor ambients with air flow rates up to approx. 4000 scfm (1900 ℓ/s).

REFERENCES

1. ---, ASHRAE Standard 84-78: Method of Testing Air-to-Air Heat Exchangers, 1978.

$$\varepsilon = (M_{SUP}, M_{MIN}, X_1, X_2, X_3)$$

where

ε = sensible, latent, or total heat effectiveness

X = dry-bulb temperature, humidity ratio, or enthalpy respectively

M_{SUP} = mass flow rate of supply air

M_{EXH} = mass flow rate of exhaust air

M_{MIN} = minimum value of M_{SUP} or M_{EXH}

The uncertainty of the sensible effectiveness can now be written as

$$W_{\varepsilon_{SEN}} = [(\frac{\partial \varepsilon_{SEN}}{\partial M_{SUP}} W_{M_{SUP}})^2 + (\frac{\partial \varepsilon_{SEN}}{\partial M_{MIN}} W_{W_{MIN}})^2 + (\frac{\partial \varepsilon_{SEN}}{\partial T_1} W_{T_1})^2 + (\frac{\partial \varepsilon_{SEN}}{\partial T_2} W_{T_2})^2 + (\frac{\partial \varepsilon_{SEN}}{\partial T_3} W_{T_3})^2]^{1/2} \quad \text{(A-4)}$$

The uncertainties in temperature and pressure measurements used in this calculation were assumed to be at the maximum allowable uncertainties specified by ASHRAE Standard 84-78 (1). These maximum uncertainties were 0.1 F on all temperature measurements and 1.0% of all respective pressure measurements.

In Table A-I the results of applying the uncertainty analysis to the specific tests for the heat pipe air-to-air heat exchanger are shown. The two largest uncertainties can be seen to be 0.075 (7.05%) and 0.0672 (6.72%). All other test conditions (95% of the total) yield uncertainties of less than 4% in the effectiveness when the primary measurements are made in accordance with ASHRAE Standard 84-78.

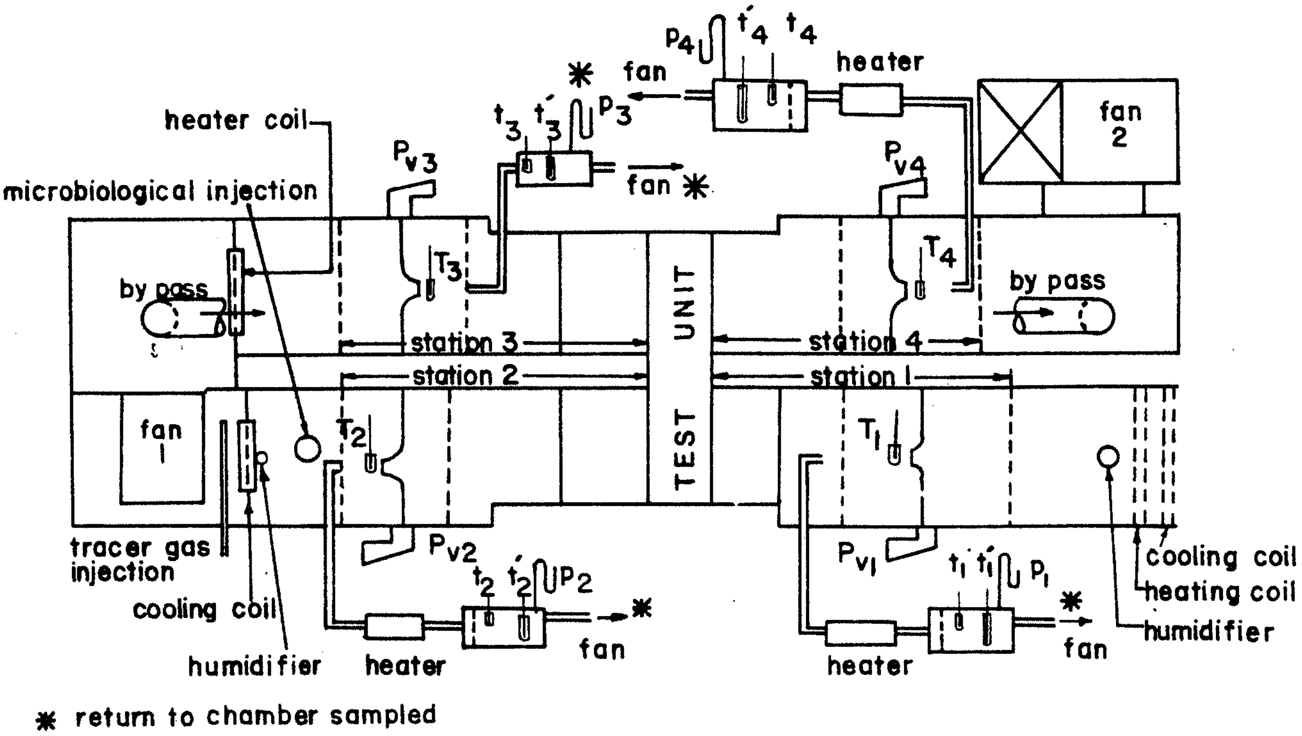

Fig. 1 Schematic diagram of typical air-to-air heat exchanger test equipment (ASHRAE Standard 84-78)

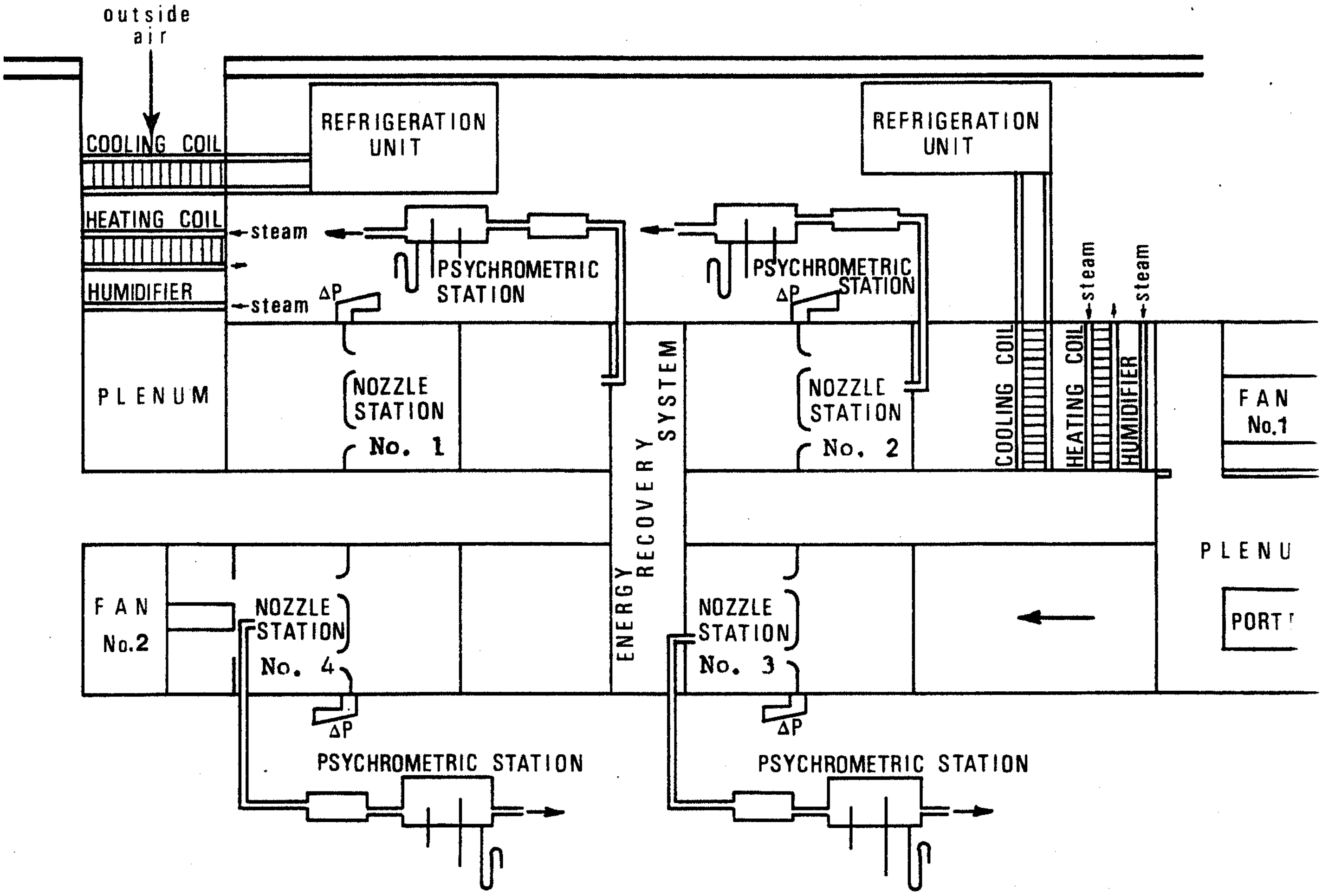

Fig. 2 Schematic of test loop for air-to-air energy recovery systems

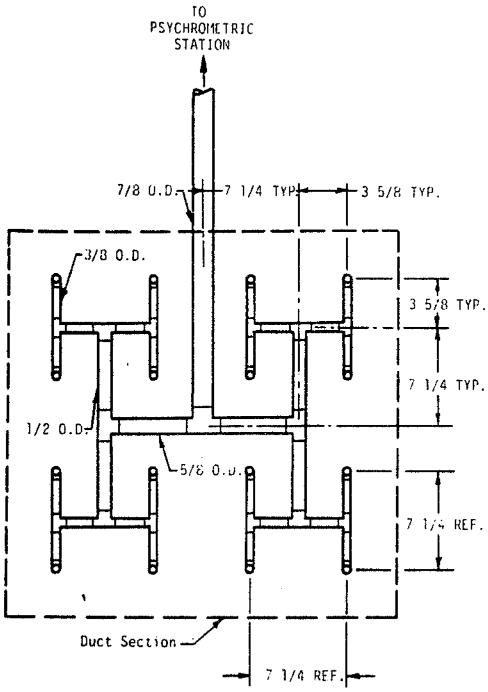

Fig. 5 Dimensions of psychrometric and tracer gas sampling probe

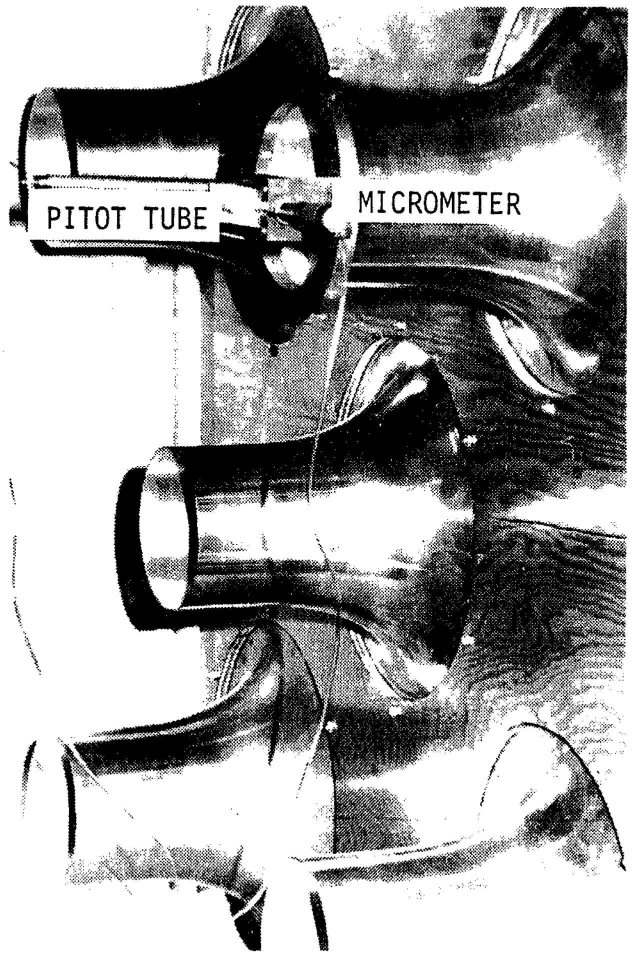

Fig. 6 Nozzle calibration device

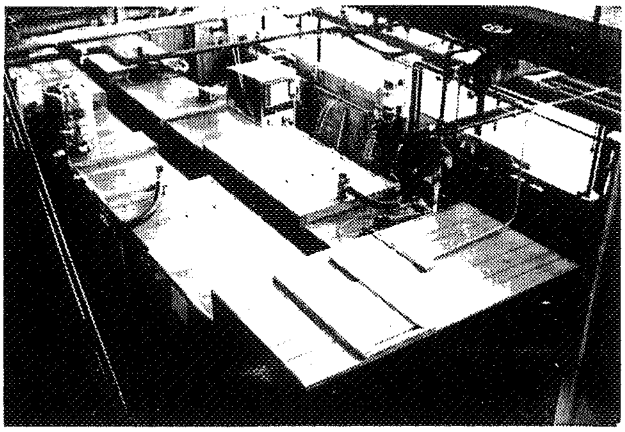

Fig. 9 Installation of coil loop exchanger

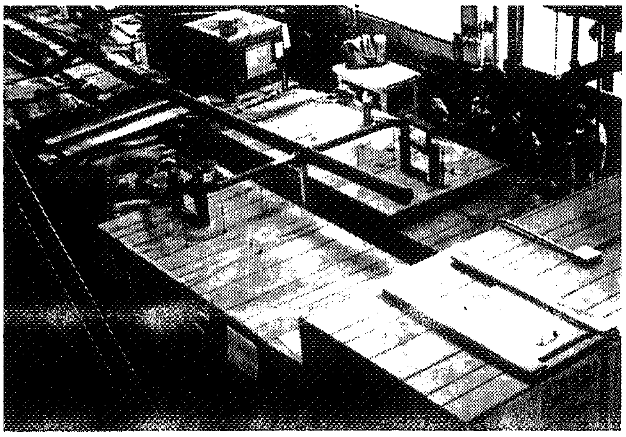

Fig. 10 Installation of heat pipe exchanger

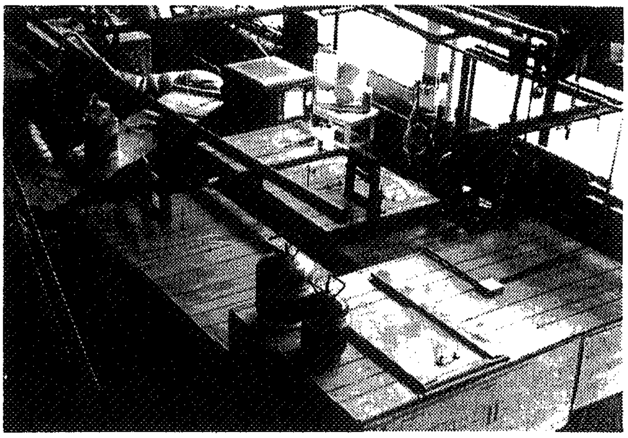

Fig. 11 Installation of plate exchanger

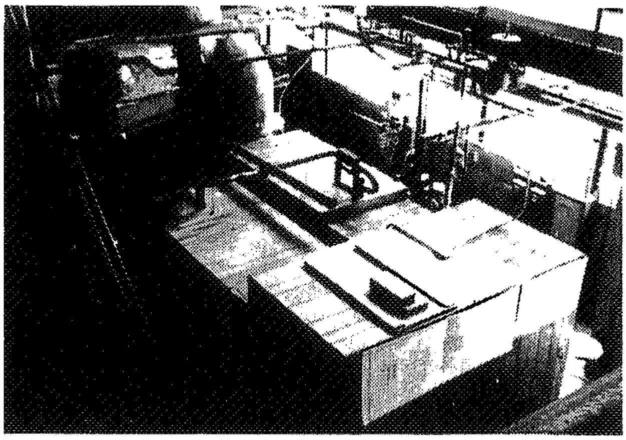

Fig. 12 Installation of twin-tower enthalpy exchanger