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The Helium Engineering Demostration Loop (HENDEL) was constructed in March, 1982. The hot gas duct is installed in the Adapter section of HENDEL. The hot gas duct of 15 m in length connects the second-stage He gas heater H_{32} and the first-stage He gas cooler C_{31}. Thermal performance tests of hot gas duct have been carried out since March, 1982. By measuring temperatures of the pressure tube and internal insulation layer and the heat flux distributions at the surface of the duct, the experimental correlation of the effective thermal conductivity of internal insulation layer was obtained.

In this paper, thermal diffusivity of internal insulation layer is estimated by analyzing the transient temperature measurements with a heat transfer computer code, AYER. The following values were obtained:

Thermal diffusivity : 1.5×10^{-6} (m^2/s)

Specific heat : 1.16 (kJ/kg·K).

Keywords : High-temperature, Gas-Cooled Reacter, Helium Gas Loop, Hot Gas Duct, Internal Insulation, Thermal Diffusivity, Specific Heat

高温配管内部断熱層の温度伝導率

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（1985年4月8日受理）

大型構造機器実証試験ループ（ＨＥＮＤＥＬ）には，繊維系の内部断熱層を設けた高温配管が設置してある。この配管の断熱性能を把握することを目的として，昭和57年度から実施したＨＥＮＤＥＬの運転で，耐圧管表面温度・熱流束・有効熱伝導率等の計測を行ってきた。

本報では，伝熱コードＡＹＥＲを用いて過渡状態の温度を解析し，配管の内部断熱層の温度伝導率を求め以下の結果を得た。

温度伝導率　1.5×10^{-6}（m^2／s）
比熱　1.16（ＫＪ／kg．Ｋ）

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1. Introduction

The Helium Engineering Demostration Loop (HENDEL) was constructed in March, 1982. The hot gas doct is installed in the Adapter section of HENDEL. The hot gas duct of 15m in length connects the second-stage He gas heater H_{32} and the first-stage He gas cooler C_{31}. Thermal performance tests of hot gas duct have been carried out since March, 1982. By measuring temperatures of the pressure tube and internal insulation layer and the heat flux distributions at the surface of the duct, the experimental correlation of the effective thermal conductivity of internal insulation layer was obtained.

In the previous test results,[1),2)] temperature distributions on the pressure tube of the hot gas duct were almost uniform in both the circumferential and axial directions. The maximum temperature of pressure tube was about 150°C and the effective thermal conductivity of internal insulation layer was 0.52 W/m·K at 950°C of He gas temperature. These values were less than the design ones.

However, it is still necessary to investigate the time-dependent deterioration of insulating characteristics and transient temperature distribution of the pressure tube, in order to design a VHTR hot gas duct system. Particularly, it is important to know the transient temperature distribution of pressure tube in the case of rapid change of He gas temperature. For this purpose, accurate thermal diffusivity of internal insulation layer is required.

In this paper, thermal diffusivity of the internal insulation layer is estimated by analyzing the transient temperature measurements with a heat transfer computer code, AYER[3].

2. Experiment

2.1 Temperature measurement

Temperature of the pressure tube was measured with K-type thermocouples of glass-fiber sheath. Eight thermocouples were installed circumferentially at an equal interval. As for temperature measurement in the internal insulation layer, K-type thermocouples with metal sheath were used. Seven thermocouples were installed at the same cross-section. The measuring positions of temperature are shown in Fig. 1.

2.2 Data processing system

A data processing system is shown in Fig. 2. A data logger of HP-3497A and a mini-computer of HP-9845C are the main parts of the data processing system which connect an extender of HP-37023A.

2.3 Test condition

He gas pressure and flow rate are 2.0 MPa and 0.5 kg/s, respectively. In order to oscillate the He gas temperature sinusoidally, electric power input to He gas heater was varied at 140 μHz. The variation range of He gas temperature, as shown in Fig. 3,was about 540°C-640°C.

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3. Results and Discussion

3.1 Steady state

Table 1 shows temperatures at all measuring positions, when He gas pressure, flow rate and temperature were 2.0 MPa, 0.5 kg/s and 590°C, respectively. The maximum temperature difference of three thermocouples in the first circumferential layer (see Table 1) was about 4°C, and that in the second circumferential layer was about 12°C. These temperature differences might be attributed to the small difference of the axial positions of three thermocouples. On the other hand, the maximum circumferential temperature difference at the pressure tube was 10°C, which might be attributed to the variation of total heat transfer coefficient around the tube. The HENDEL building is equipped with many ventilating fans, and the working of fans clearly affects the air flow pattern aruond the hot gas duct.

Figure 4 shows the radial temperature difference calculated by a computer code, AYER, and the measured ones (Table 1). The calculated results show good agreement with the experimental ones. In the calculation, the following equation was used for the effective thermal conductivity of internal insulation layer[1].

$$\lambda_{eff}\ (W/m\cdot K) = 0.0196 + 4.70\times10^{-4}\cdot T\ (K) \quad \text{---}\ (1)$$

3.2 Thermal diffusivity of internal insulation layer

Thermal diffusivity is defined by the following equation :

$$a = \frac{\lambda_{eff}}{1000 \cdot C_p \cdot \rho} \quad \text{--- (2)}$$

λ_{eff} : Effective thermal conductivity (W/m·K)

a : Thermal diffusivity (m^2/s)

C_p : Specific heat (kJ/kg·K)

ρ : Packing density of the insulation (kg/m^3)

Here, λ_{eff} was already measured in previous tests, and the packing density of internal insulation was 250 kg/m^3. Since specific heat of internal insulation layer is unknown, thermal diffusivity can not be calculated.

For thermal diffusivity measurement, two methods have been proposed[4]. One is a step-heating method, the other is cyclic heating method. In this experiment, the later was used because He gas temperature in HENDEL could be controled easily. Thermal diffusivity of internal insulation layer was estimated by analyzing the experimental data with AYER.

Figures 5 (a)~(k) show the transient temperature changes of the liner, first circumferential layer, second circumferential layer, pressure tube, when He gas temperature was oscillated at 140 μHz. The peak temperature at the measuring positions delayed a little, compared with the first peak temperature at the liner. The delay time of the first peak temperature between the liner and the other measuring positions were measured. Table 2 shows the measured delay times.

On the other hand, the delay time was calculated by AYER, when thermal diffusivity of internal insulation layer varied. We have considered that thermal diffusivity of internal insulation layer might be higher than that of insulation material, and lower than that of He gas. Tables 3 and 4 show thermal properties of He gas and insulation (KAOWOOL). The maximum thermal diffusivity of He gas is 1.1×10^{-4} m^2/s in Table 3. The minimum thermal diffusivity of insulation is 2.3×10^{-6} m^2/s in Table 4. Therefore thermal diffusivity in the calculation was varied from 2.3×10^{-6} m^2/s to 1.1×10^{-4} m^2/s.

Thermal diffusivity of internal insulation layer was determined by comparing measured delay time in the second circumferential layer with the calculated one. The following equation shows a relation between thermal diffusivity and the calculated delay time in the second circumferential layer.

$$a = 1.0\times10^{-5}\cdot\exp(-1.3\times10^{-3}\cdot\tau) \qquad \text{--- (3)}$$

a : Thermal diffusivity (m^2/s)

τ : Delay time (sec.)

By substituting the measured delay time (τ = 1470 sec.) into eq. (3),we get

$$a = 1.5\times10^{-6}\ (m^2/s).$$

And, by substituting this value into eq. (2) , we get specific heat of internal insulation layer:

$$c_p = 1.16\ (kJ/kg\cdot K).$$

Figures 6 (a),(b),(c) show the variation of calculated

temperature using the estimated thermal diffusivity of internal insulation layer. The calculated temperature showed good agreement with the measured ones, except for Fig. 6 (c). In Fig. 6 (c), the disagreement between the calculated and the measured was attributed to the fact that air flow around the pressure tube was not well simulated in the calculation.

4. Conclusion

Thermal diffusivity of the internal insulation layer was obtained by comparing the delay time of the peak temperature measured in the temperature oscillating test with that calculated by AYER. The following value of thermal diffusivity was derived.

$$a = 1.5\times10^{-6}\ (m^2/s).$$

The result obtained by this experiment will surely be helpful for the design work of HTGR as well as for the fabrication of similar facilities.

References

1) M. Hishida et al. ; Nuclear Engineering and Design, 83 (1) (1984) 91.

2) K.Kumitomi et al. ; JAERI-M 83-082 (1983).

3) R.G.Lauton ; LA-5613-MS (1974).

4) 日本熱物性研究会編; 熱物性資料集 ー断熱材編ー, (1983) 15.

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Table 1 Temperatures of the hot gas duct in steady state

Measuring position		Temperature (°C)
Liner Tube	1	583.0
First circumferential layer	2	435.1
	3	432.1
	4	431.4
Second circumferential layer	5	248.9
	6	257.5
	7	261.3
Pressure tube	8	100.4
	9	105.3
	10	97.5
	11	103.2
	12	100.5
	13	99.4
	14	95.7
	15	100.3

Table 2 Delay time of the first peak temperature between the liner and the other measuring positions

Measuring position		Delay time (sec)
First circumferential layer	2	658.8
	3	781.2
	4	781.2
Second circumferential layer	5	1440.0
	6	1321.2
	7	1470.0
Pressure tube	8	2571.0
	9	2540.4
	10	3179.4
	11	2509.8
	12	2571.0
	13	2509.8
	14	2996.4
	15	2236.2

Table 3 Thermal properties of He gas (2.0 MPa)

Temperature (°C)	Density (kg/m^3)	Specific Heat (kJ/kg·K)	Thermal Conductivity (W/m·K)	Thermal Diffusivity (m^2/s)
0	3.53	5.18	0.14	7.66×10^{-6}
200	2.05	5.18	0.21	1.98×10^{-5}
400	1.44	5.18	0.28	3.75×10^{-5}
600	1.11	5.18	0.33	5.74×10^{-5}
800	0.91	5.18	0.38	8.06×10^{-5}
1000	0.76	5.18	0.43	1.09×10^{-4}

Table 4 Thermal properties of KAOWOOL (Isolite Babcock Refractories)

Temperature (°C)	Density (kg/m^3)	Specific Heat (kJ/kg·K)	Thermal conductivity (W/m.K)	Thermal diffusivity (m^2/s)
0	192	0.75	0.33	2.29×10^{-6}
100	192	0.80	0.37	2.41×10^{-6}
200	192	0.84	0.39	2.42×10^{-6}
300	192	0.87	0.45	2.69×10^{-6}
400	192	0.90	0.50	2.89×10^{-6}
500	192	0.92	0.55	3.11×10^{-6}
600	192	0.95	0.60	3.29×10^{-6}
700	192	0.97	0.66	3.54×10^{-6}
800	192	1.00	0.71	3.70×10^{-6}
900	192	1.02	0.76	3.88×10^{-6}
1000	192	1.03	0.81	4.10×10^{-6}

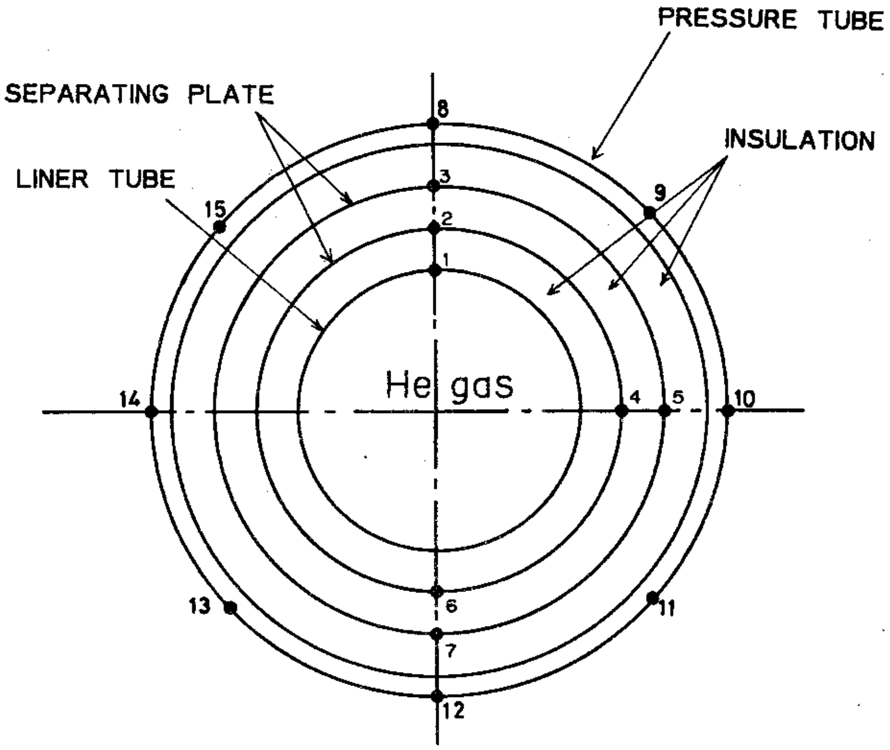

Fig. 1 Measuring positions of temperatures

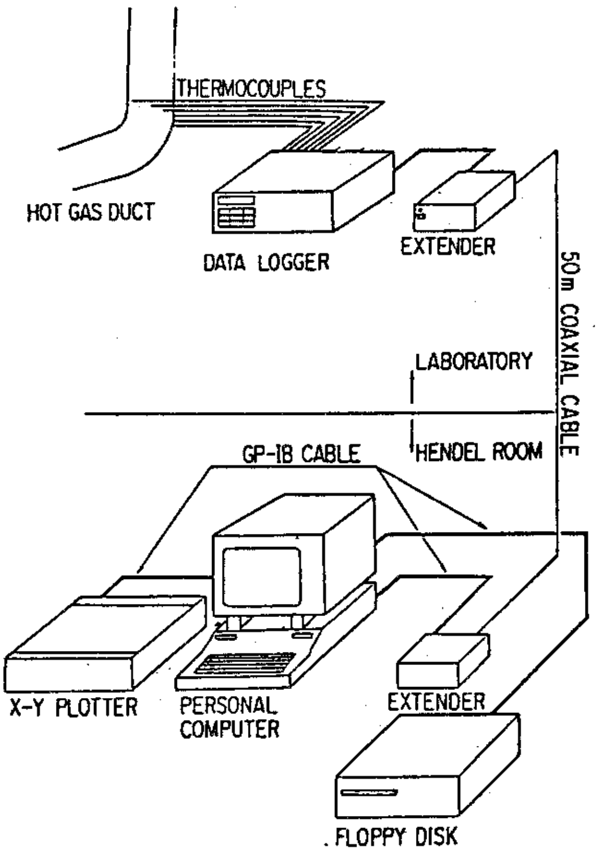

Fig. 2 Data processing system

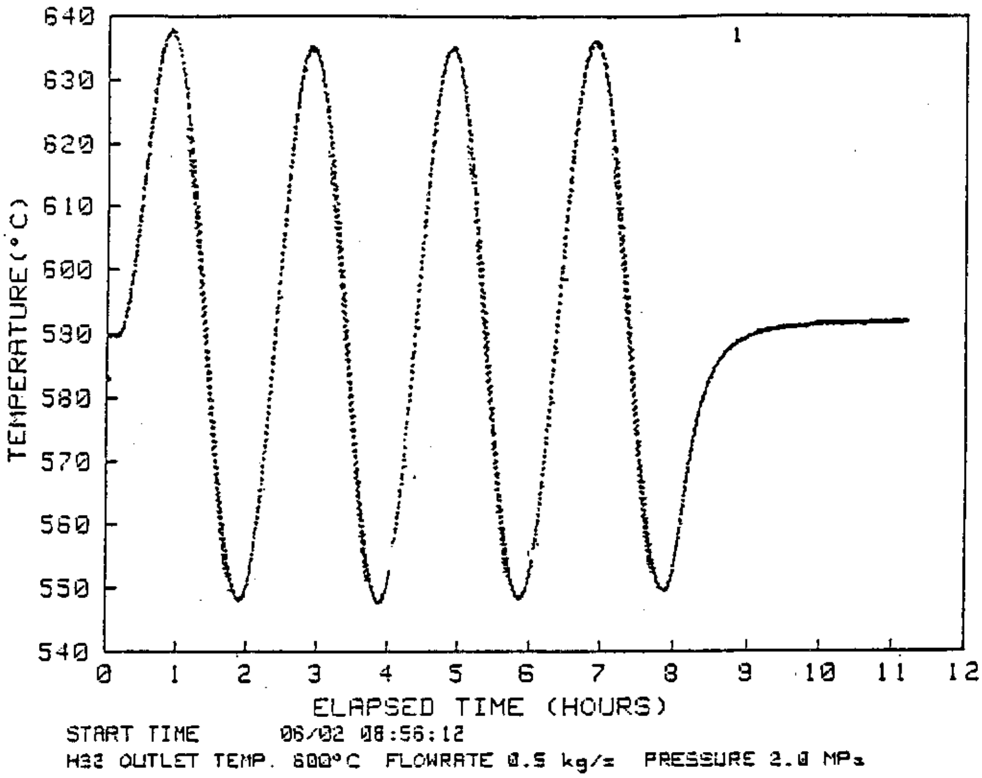

Fig. 3 Variation of He gas temperature

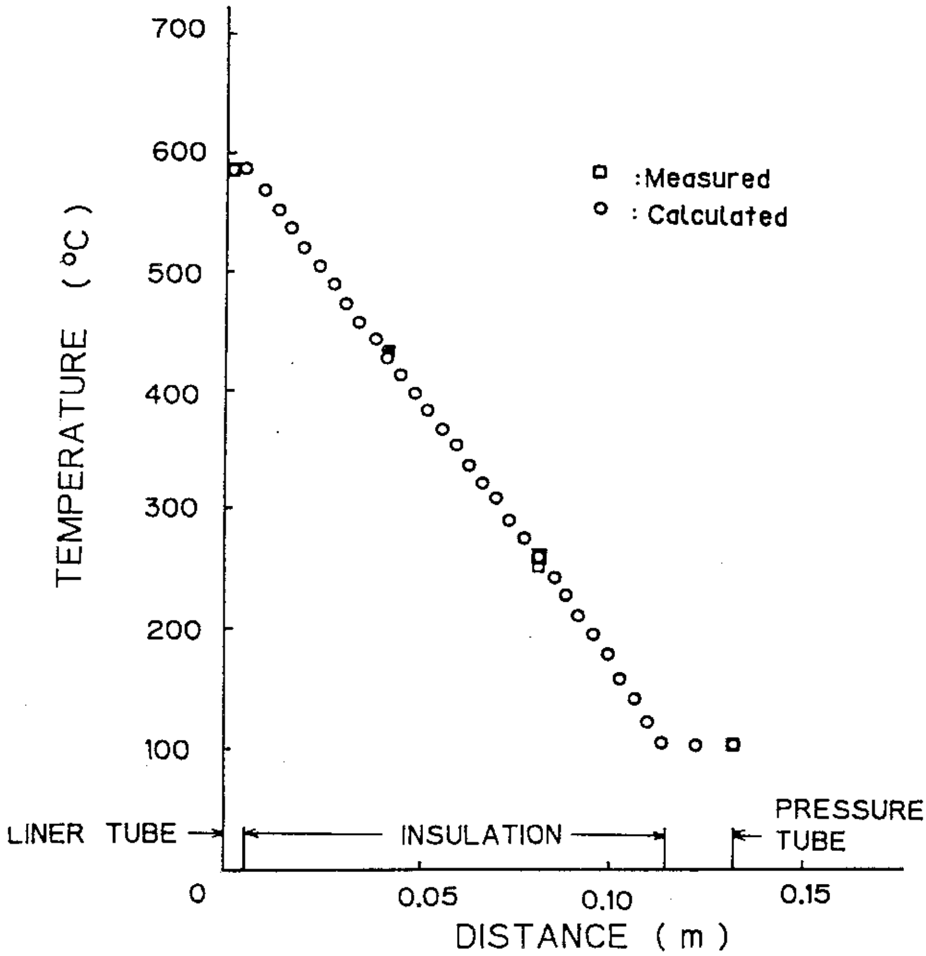

Fig. 4 Calculated and measured temperatures at steady state

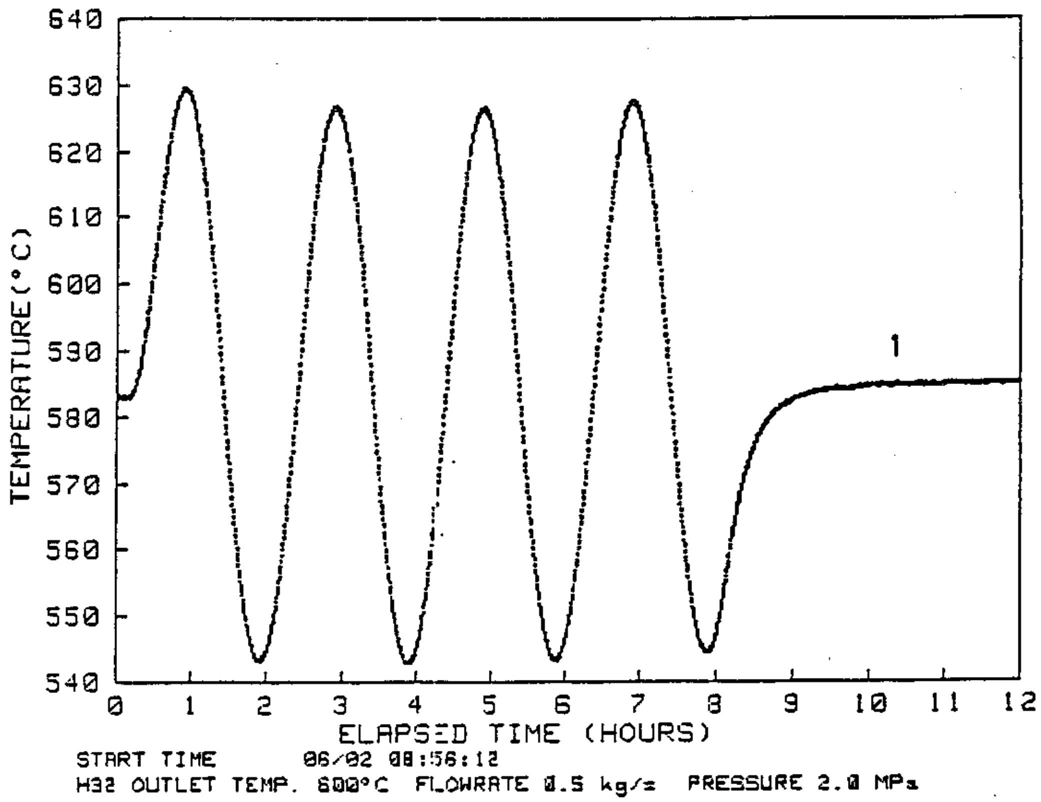

Fig. 5 (a) Variation of temperature at the liner tube

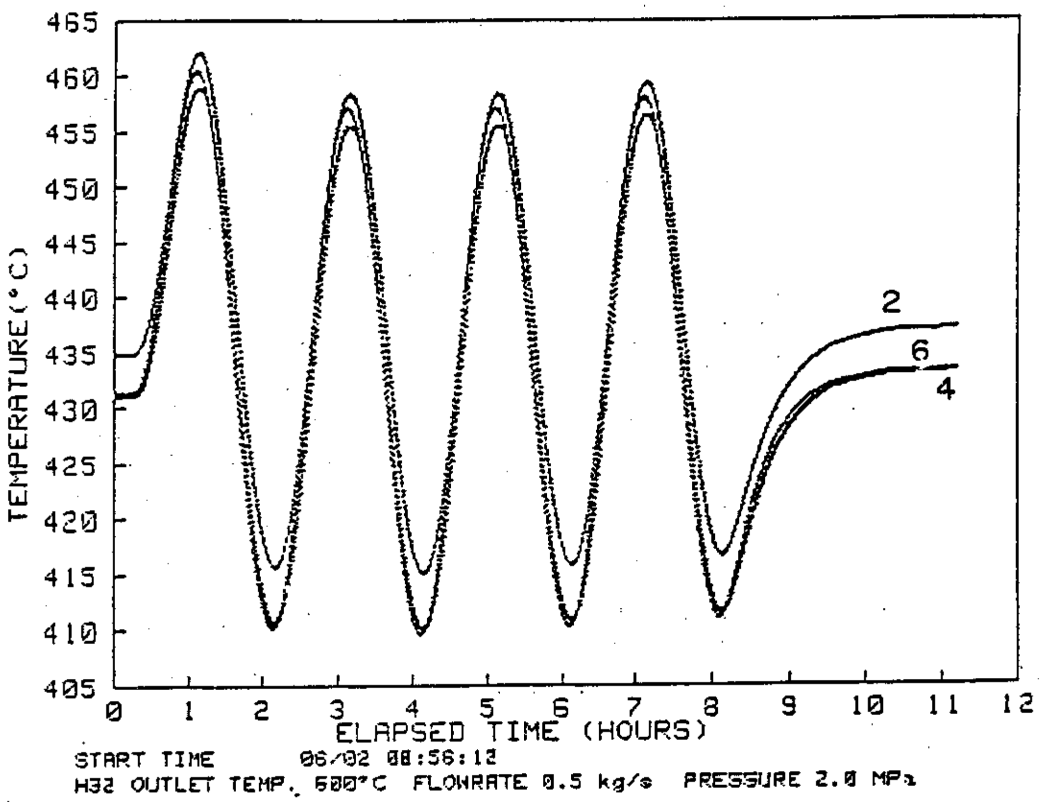

Fig. 5 (b) Variation of temperature at the first circumferential layer

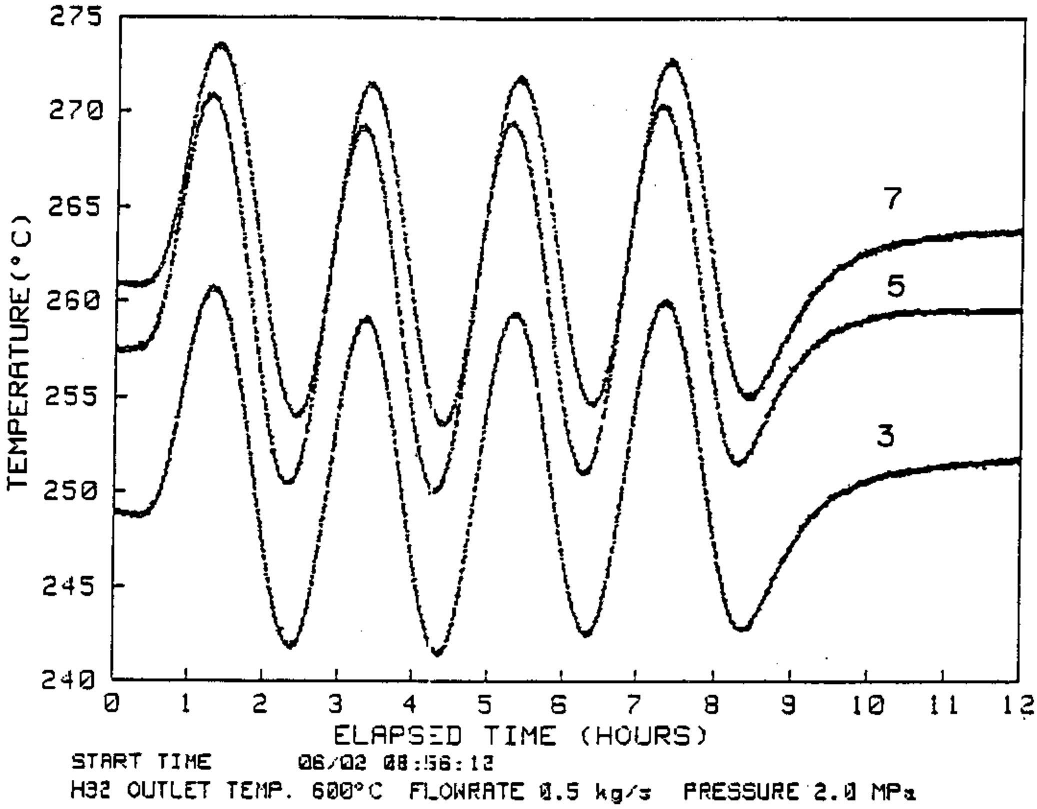

Fig. 5 (c) Variation of temperature at the second circumferential layer

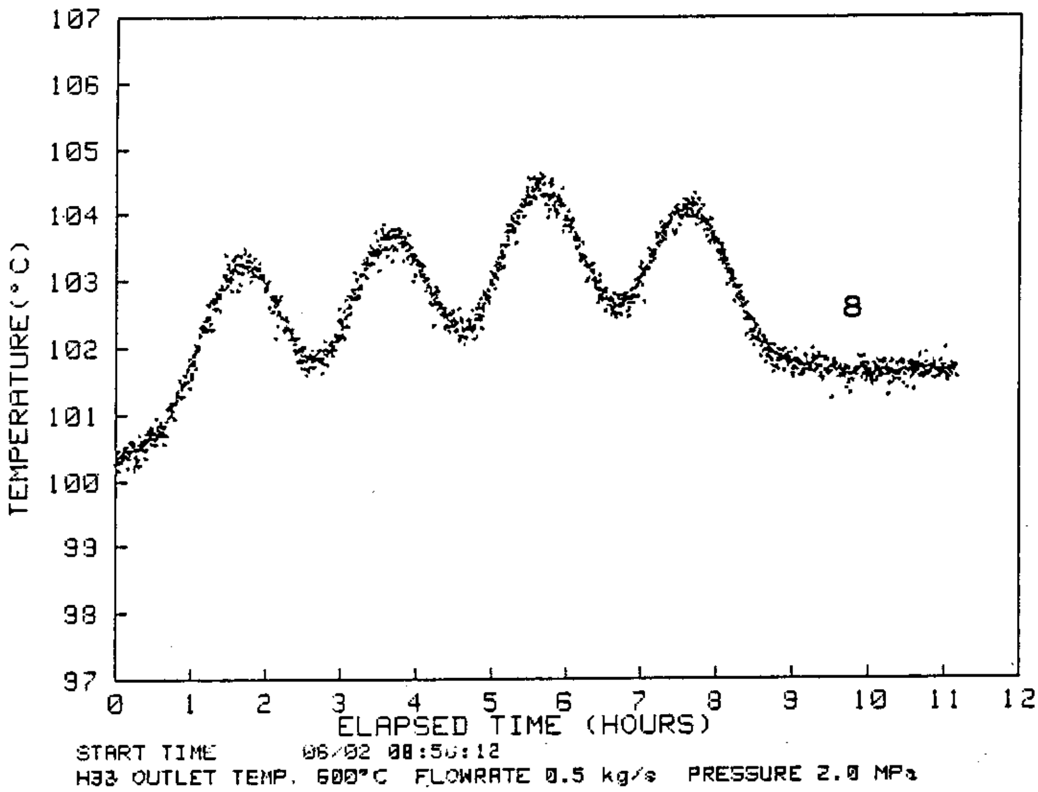

Fig. 5 (d) Variation of temperature at the pressure tube (measuring position 8)

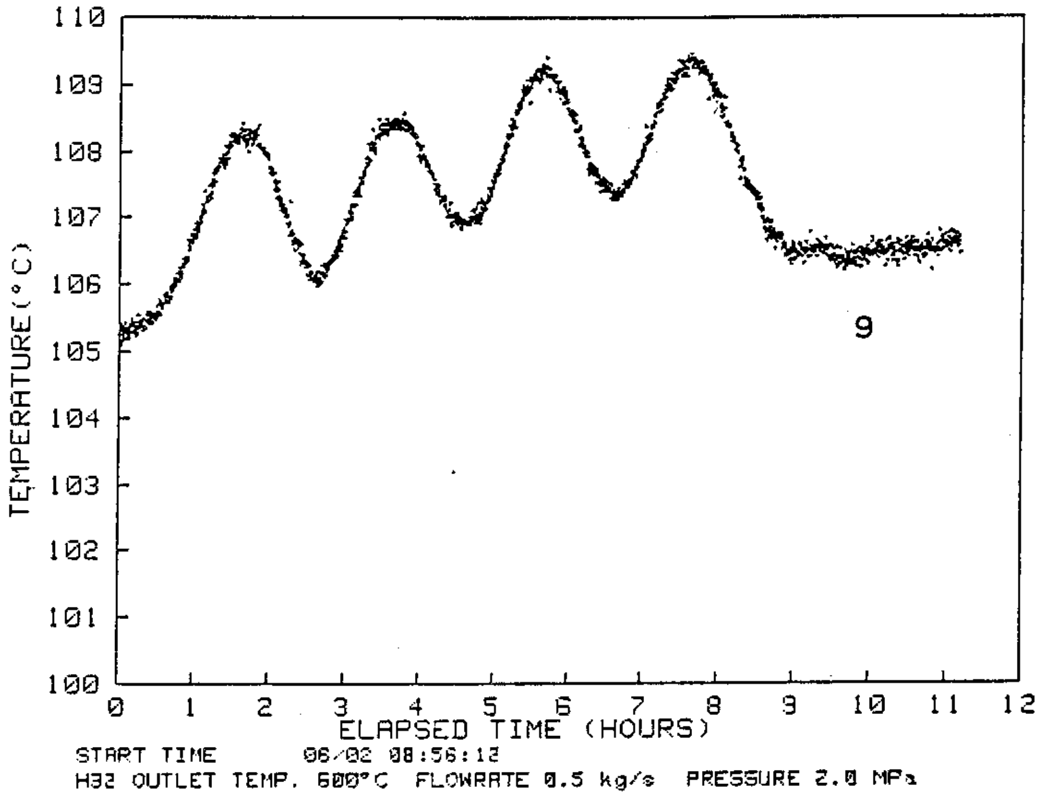

Fig. 5 (e) Variation of temperature at the pressure tube

(measuring position 9)

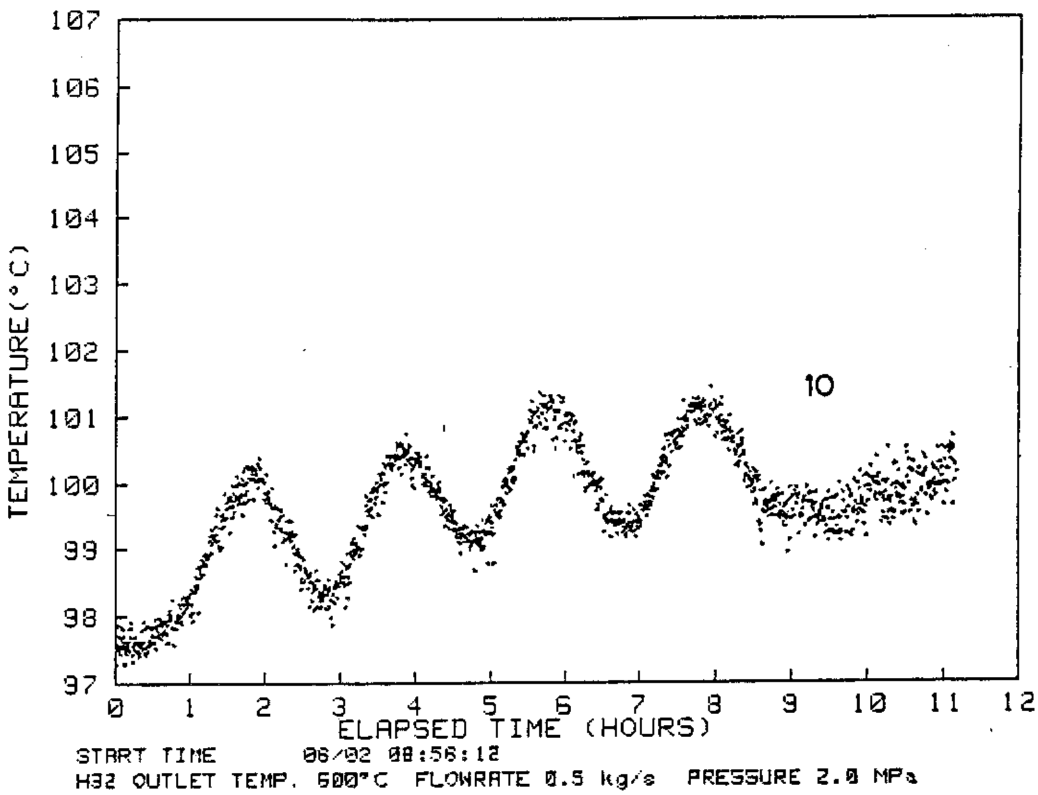

Fig. 5 (f) Variation of temperature at the pressure tube

(measuring position 10)

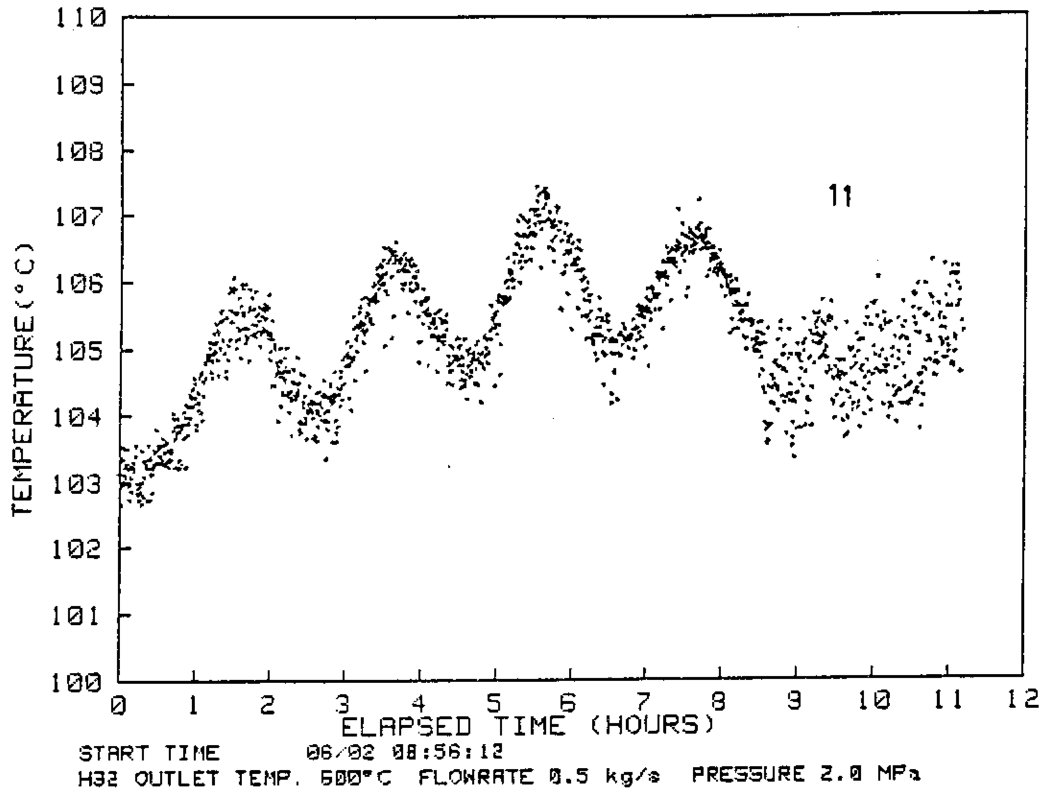

Fig. 5 (g) Variation of temperature at the pressure tube (measuring position 11)

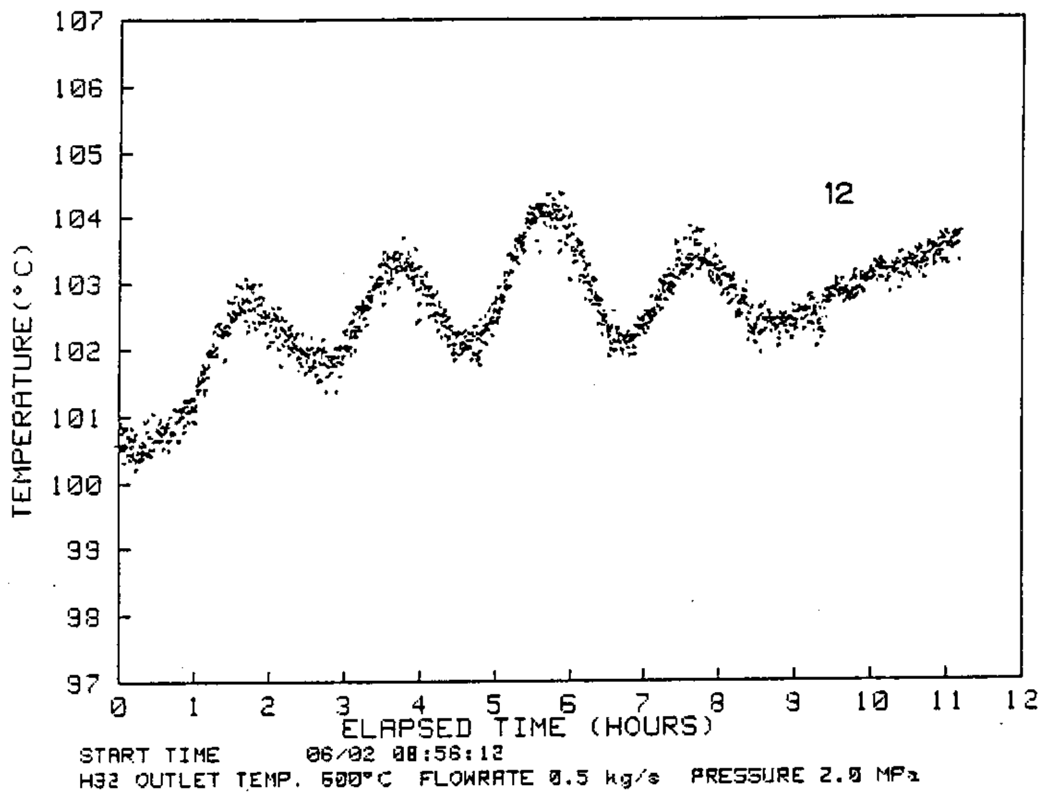

Fig. 5 (h) Variation of temperature at the pressure tube (measuring position 12)

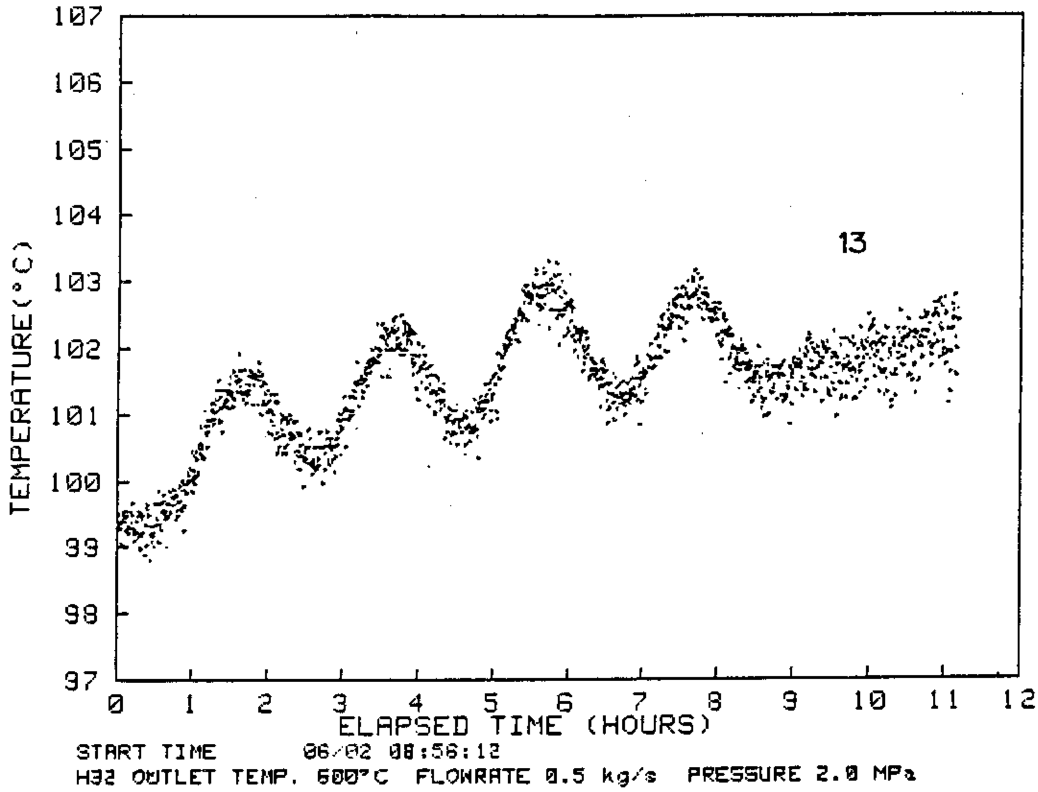

Fig. 5 (i) Variation of temperature at the pressure tube (measuring position 13)

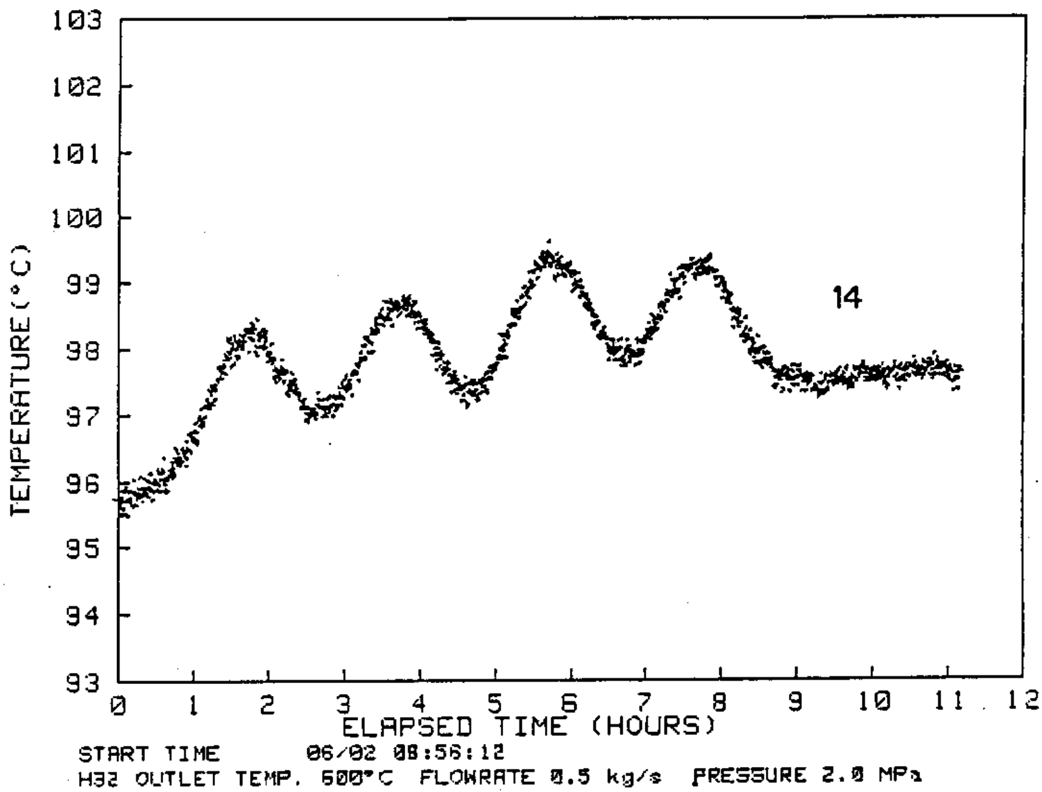

Fig.5 (j) Variation of temperature at the pressure tube (measuring position 14)

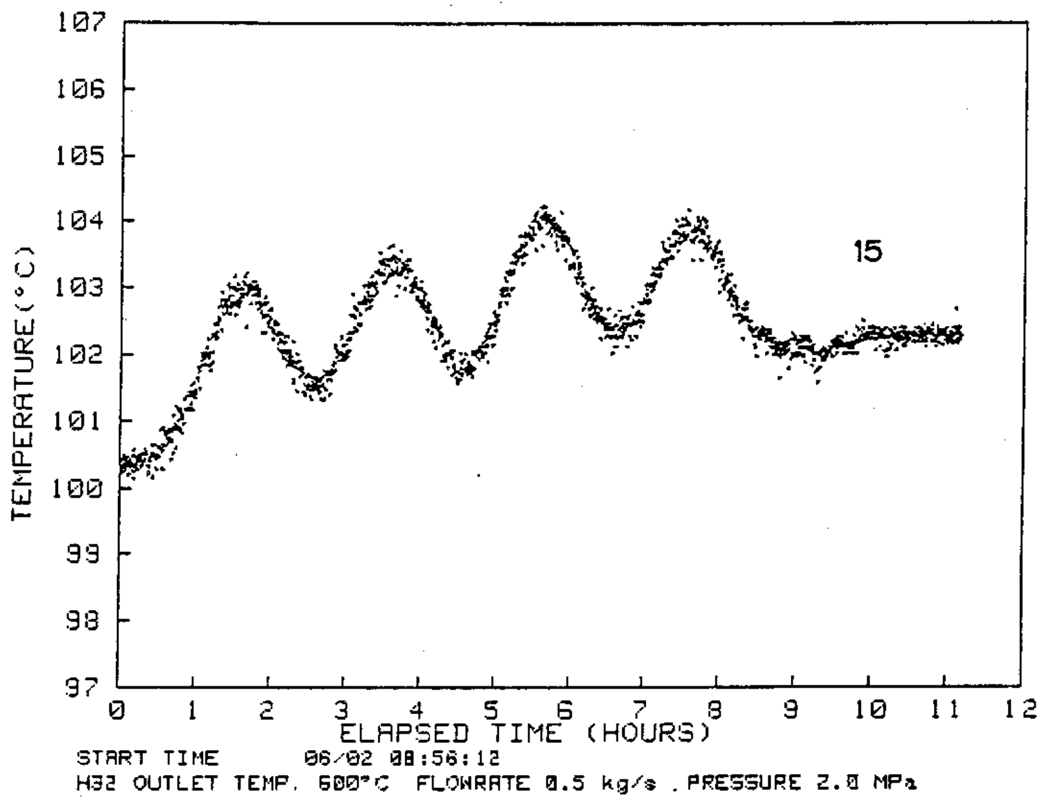

Fig. 5 (k) Variation of temperature at the pressure tube

(measuring poaition 15)

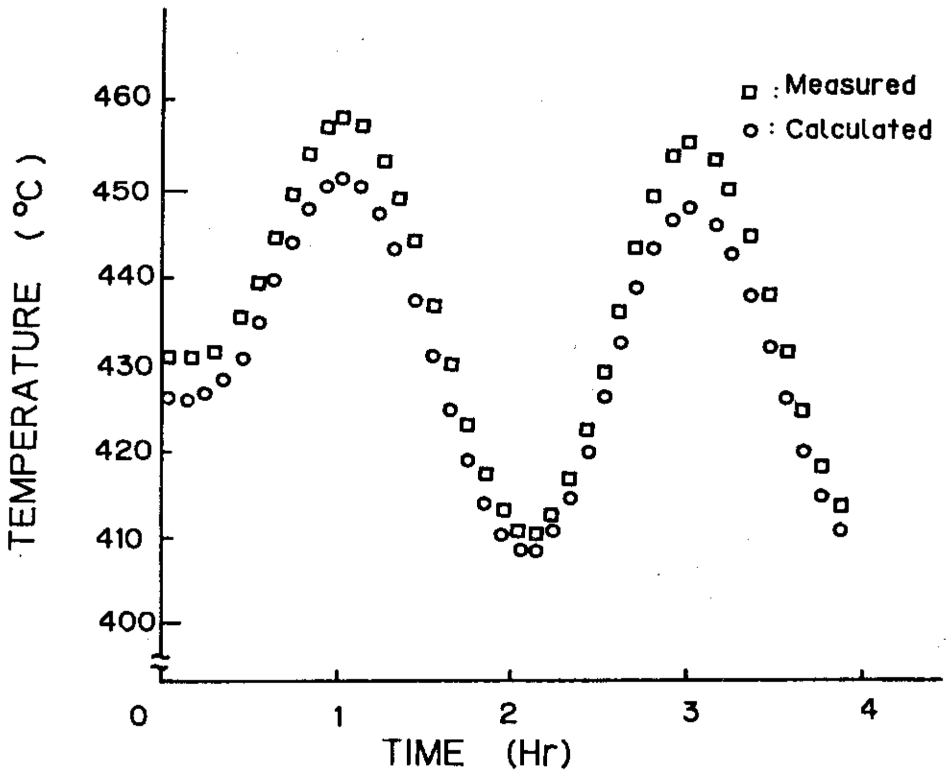

Fig. 6 (a) Calculated and measured temperatures at the first circumferential layer

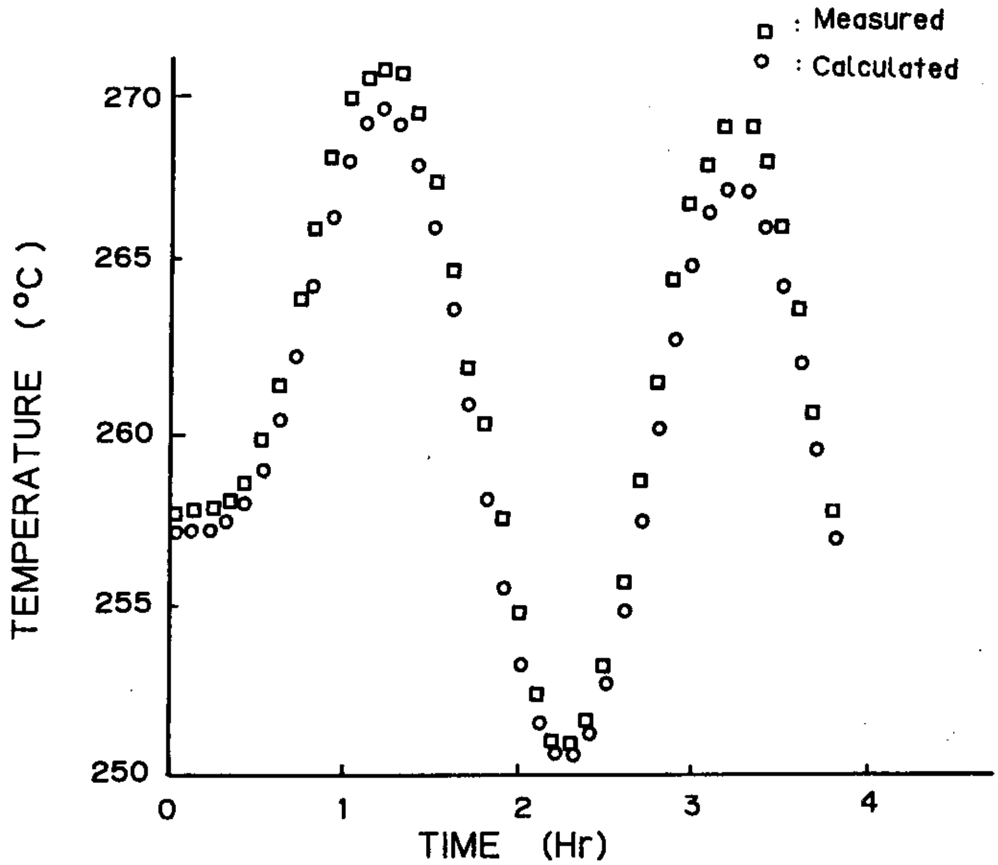

Fig. 6 (b) Calculated and measured temperatures at the second circumferential layer

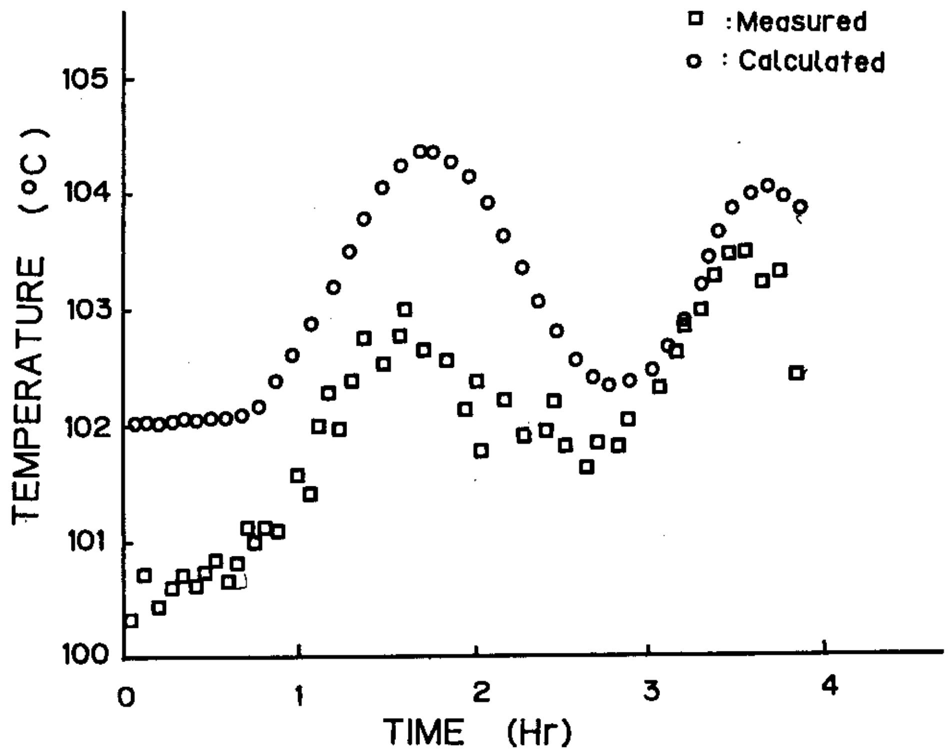

Fig. 6 (c) Calculated and measured temperatures at the pressure tube (measuring position 8)