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THEORETICAL AND EXPERIMENTAL INVESTIGATION IN RELATIONSHIP OF THE DEVELOPMENT OF THE GAS-TO-GAS HEAT PIPE EXCHANGER FAMILY

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Abstract

The Chemical and Food Engineering Department of the Technical University of Budapest has developed a gas-to-gas heat exchanger family with closed two-phase-thermosyphons (CTT) or heat pipes.

This paper reports the theoretical fundamentals and the experimental investigations of the CTT heat exchanger family.

Keywords: closed two-phase thermosyphon, CTT, heat pipe, gas-to-gas heat exchanger, pilot plant examination.

1. Introduction

Utilization of the heat exchange between the gas-phase mediums is of great importance in several industrial areas.

The low value of heat transfer coefficients of the gas phase requires the extension of heat transferring surface by finning. This can be realised by construction of heat exchanger having an intermediate, i.e. the vapour of a liquid between the two surfaces and covers, respectively. The recognition of the above mentioned facts led to the application of the closed two-phase thermosyphons (CTT) and of heat pipes in the gas-to-gas heat exchangers.

The Chemical and Food Eng. Dep. of the Technical University Budapest has developed a gas-to-gas heat-exchanger family for the Ganz Factory.

This paper reports on the experimental work of the development on the main results and informs of the development of this type family.

2. Theoretical Fundamentals

We have tested at the start of our investigations how the heat transfer coefficients of the CTT and heat pipes can be defined. *Fig. 1* shows the

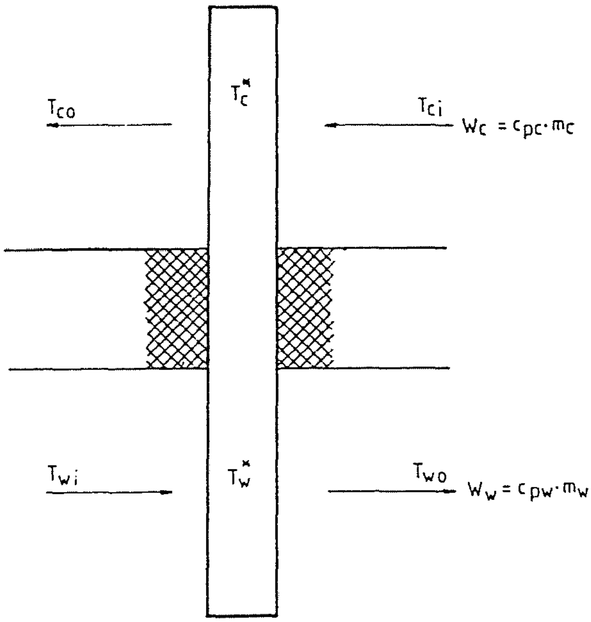

Fig. 1.

structure of the CTT, *Fig. 2* illustrates the temperature distribution inside and outside.

In the case when the geometry of the evaporator and of the condensation part are equal and the axial heat flux in the wall is ignored, the overall heat transfer coefficient can be written:

$$\frac{1}{k_1} = \frac{1}{k_{1c}} + \frac{1}{k_{1w}} + R'_{ax}, \tag{1}$$

where R'_{ax} means the axial heat resistance. We can note the overall heat transfer coefficients of the warm and cold sides:

$$\frac{1}{k_{1c}} = \frac{1}{h_c} + R'_c + \frac{1}{h_k} \tag{2}$$

and

$$\frac{1}{k_{1w}} = \frac{1}{h_w} + R'_w + \frac{1}{h_E}. \tag{3}$$

By the optimal state of the heat pipe and of CTT, respectively, $\Delta T^x \to 0$ and $T_c^x = T_w^x = T^x$.

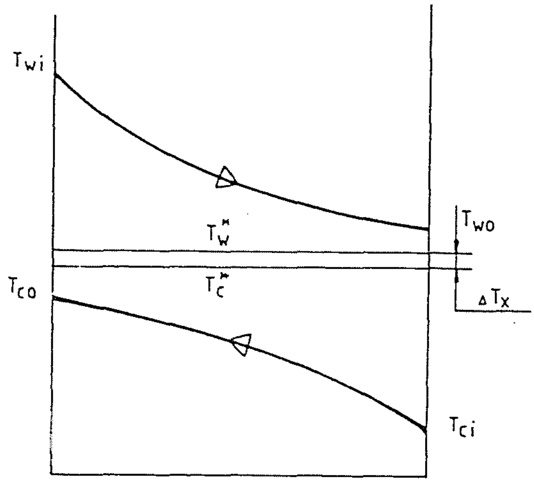

Fig. 2.

The efficiency given for the cold and warm side are

$$P_{1c} = 1 - \exp\left(-\frac{k_{1c}A_c}{W_c}\right), \tag{4}$$

$$P_{1w} = 1 - \exp\left(-\frac{k_{1w}A_w}{W_w}\right). \tag{5}$$

Introducing $R = \frac{W_c}{W_w}$, the reciprocal value of a CTT efficiency can be written

$$\frac{1}{P_1} = \frac{1}{P_{1c}} + R\frac{1}{P_{1w}}. \tag{6}$$

We study the heat exchanger consisting of 'n' pipe rows with the method of KAYS and LONDON [1]. In that case the structure and surface of the CTT and air velocity in all rows are similar, k_w and k_c are almost equal. This results that efficiency will be almost equal, too. The efficiency of the whole heat exchanger can be written

$$\frac{1-RP}{1-P} = \left(\frac{1-RP_1}{1-P_1}\right)^n. \tag{7}$$

This is true only in the case, if every row consists of the same pipes number.

If the pipes have triangle arrangament, the following rows consist of pipes of 'j' and '$j-1$' number, respectively.

When P_j and P_{j-1} sign the two row efficiencies and as

$$\frac{A_i}{A_{j-1}} = \frac{i}{j-1}, \tag{8}$$

we can note

$$P_{cj} = 1 - \exp\left(-\frac{k_c A_j}{W_c}\right), \tag{9}$$

$$P_{cj-1} = 1 - \exp\left(-\frac{k_c A_j}{W_c}\frac{j-1}{j}\right). \tag{10}$$

The efficiency of the warm side can be written similarly. The connection between efficiencies:

$$(1 - P_{cj})^{j-1} = (1 - P_{cj-1})^{j}, \tag{11}$$

$$(1 - P_{wj})^{j-1} = (1 - P_{wj-1})^{j}. \tag{12}$$

We can note for the efficiency of the heat exchanger, that:

$$\frac{1-RP}{1-P} = \left(\frac{1-RP_j}{1-P_j}\right)^{n/2} \cdot \left(\frac{1-RP_{j-1}}{1-P_{j-1}}\right)^{n/2}, \tag{13}$$

where

$$\frac{1}{P_j} = \frac{1}{P_{cj}} + R\frac{1}{P_{wj}}, \tag{14}$$

$$\frac{1}{P_{j-1}} = \frac{1}{P_{cj-1}} + R\frac{1}{P_{wj-1}}. \tag{15}$$

If the efficiency of an experimental equipment was determined, from this the row efficiencies P_j, P_{j-1} cannot be determined by analytical means, only by numerical ones. On the basis of *Eqs.* (9) to (15), using the results of measurements the row efficiencies were determined by parameter identification.

3. Experimental Investigations

We used during our measurements CTT-s, having steel tubes with at fins. The tubes had diametres of 57 and 49 mm (with fins), respectively. The CTT-s were filled with ammonia working fluid.

We built into the pilot-plant heat exchanger 4 rows, containing 3 and 2 CTT-s per row.

The experimental equipment can be seen on *Fig. 3*.

We carried out measurements for the determination of efficiency. We changed meanwhile the flow of gas mass flow rate and the inlet temperatures of warm and cold sides and the angle, too.

As far as the efficiency we determined if on the basis of the above mentioned row efficiency, which is demonstrated in *fig. 4* in the function of linear gas velocity. On the basis of the above measurements it became possible to develop a CTT type family of finned tubes, having ammonia filling. The series of size can be seen on *Table 1*.

Table 1

V m^3/h	Q kW	P	$a \times b^*$ mm	c mm	n	z
2500	14.0	0.33	400×500	270	5	28
	16.0	0.38		320	6	33
	17.5	0.41		370	7	39
	18.9	0.45		425	8	44
5000	23.5	0.28	500×630	270	5	38
	28.0	0.33		320	6	45
	32.0	0.38		370	7	53
	35.0	0.42		425	8	60
	28.0	0.33	630×800	270	5	48
	32.0	0.38		320	6	57
	35.0	0.42		370	7	67
	37.4	0.45		425	8	76
10000	55.5	0.33	800×1000	270	5	58
	61.0	0.36		320	6	69
	63.8	0.42		370	7	81
	69.0	0.45		425	8	92
	63.8	0.38	1000×1000	270	5	73
	69.0	0.42		320	6	87
	75.0	0.45		370	7	102
	83.0	0.50		425	8	116

* Cross-section of evaporator or condensator part

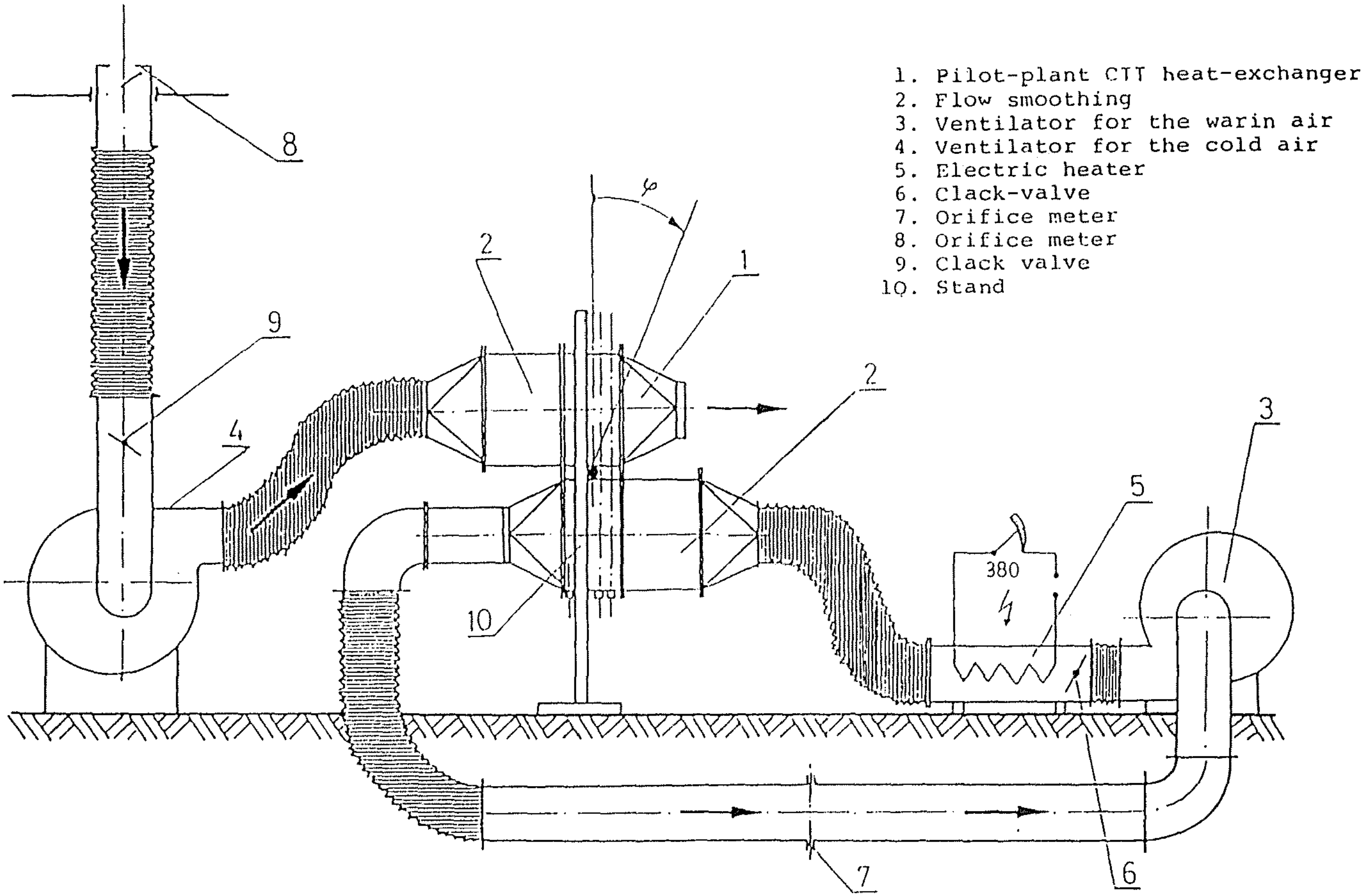
1. Pilot-plant CTT heat-exchanger
2. Flow smoothing
3. Ventilator for the warin air
4. Ventilator for the cold air
5. Electric heater
6. Clack-valve
7. Orifice meter
8. Orifice meter
9. Clack valve
10. Stand
8
φ
2
1
9
2
3
4
5
380
10
7
6

Fig. 3.

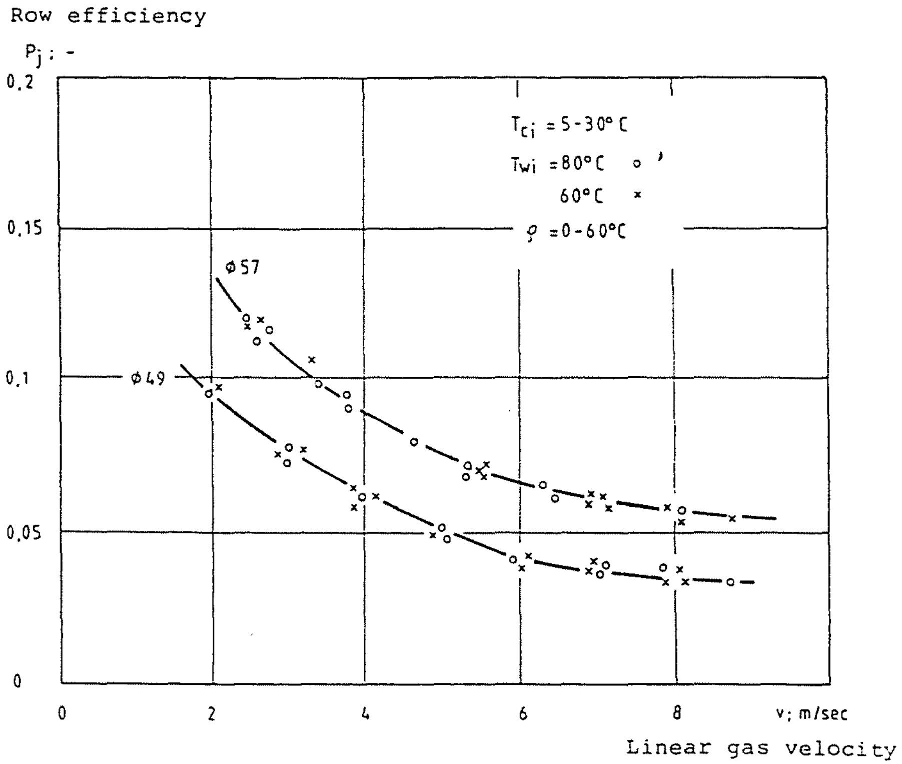

Fig. 4.

4. Summary

This publication reports on the details our of work, which we performed in the course of development of CTT-s and heat pipes. We solved the manufacturing of two-phase closed thermosyphons and filling of them with different working fluids, and testing. A pilot-plant measuring equipment was constructed for the testing of gas-to-gas heat exchangers. By this we measured the efficiency of an experimental heat exchanger for two different types of finned tubes. By the method described previously we determined the row efficiency.

This work made possible the development of a CTT gas-to-gas heat exchanger type series.

5. Nomenclature

a	size of width	Q	heat flow rate
A	heat transfer surface	R'	thermal resistance
b	size of height	R	heat capacity rate ratio
c	size of depth	T	temperature
c_p	specific heat	ΔT	difference of temperature
h	heat transfer coefficient	v	linear gas velocity
k	overall heat transfer coeff.	V	volume flow rate
m	mass flow rate	W	heat capacity rate
n	number of rows	z	number of CTT
P	efficiency	ϕ	angle

Indexes

ax	axial	K	condensator
c	cold	o	outlet
E	evaporator	w	warm
i	inlet	x	vapour
$j, j-1$	referring to the given row	1	referring to one row

References

1. KAYS, W. M. — LONDON, A. L. (1958): Compact Heat Exchangers, Mc. Graw-Hill, Palo Alto, California, 1958.