ON THE PARAMETERS OF SINGLE-STAGE MINIATURE LIQUEFIERS OF THE HAMPSON TYPE FOR GASES OF THE A GROUP

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Single-stage Hampson liquefiers have been studied in open system. The relation between gas consumption, operation pressure, and liquefaction time has been determined, as well as the dependence of cooling power on the number of capillary layers in the miniature heat exchange system.

The dependence of the time necessary for gas liquefaction on the ratio of the mass of the heat exchange system to its effective heat exchange area has also been found.

1. Introduction

The Joule-Thomson effect permits the construction of small, simple single-stage miniature liquefiers. The diameters of these liquefiers usually vary from 6–15 mm, while the corresponding lengths amount to 60–150 mm. Such miniature liquefiers are reliable, and operated in open system, permit the liquefaction of small amounts of gases in a very short time. They are frequently used for low temperature cooling of small objects, and have found many applications, in particular in electron microscope technique, in the detection of infrared radiation and cryosurgery, *i.e.*, in those domains where it is essential to obtain a low temperature in a small volume in a very short time. The cooling powers of such liquefiers are quite small, varying from some tenths of a watt to several watts.

The use of miniature liquefiers is particularly advantageous in case of gases of the so-called group A for which the inversion temperature of the Joule-Thomson effect is higher than about 300 K. Gases belonging to this group permit temperatures of the order of 70–80 K to be obtained by simple liquefaction.

The purpose of our studies was to get experience in the technology of production of such liquefiers, in the optimization of their operation parameters, and in the determination of the influence of the number of capillary layers in the heat exchange unit on the cooling power of the liquefiers.[1]

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[1] This problem is extensively discussed in the Ph. D. thesis of one of the authors: E. Bodio, *Miniature liquefier in closed circuit*, INTiBS PAN, Wrocław.

2. Experimental

The studies started with a very simple model of miniature liquefier which consisted of a single layer of copper capillary tube coiled up helically. Next the model was extended by adding parallelly a second, third and further layers, thus forming a miniature heat exchange system of the type introduced by Hampson.

The miniature heat exchange units were made from copper capillaries $\varnothing 1.3 \times 0.4$ mm which were additionally "ribbed" with copper wire with the diameter of 0.5 mm to increase the heat exchange surface. The coil pitch of the copper wire fins was 1.5 mm.

Bearing in mind that the isoenthalpic Joule-Thomson effect is dependent on the temperature, kind, and the pressure of the gas [1, 2], we have accepted as the main parameters of the investigated liquefiers the following so-called "easily measurable parameters":

starting pressure of the gas p
initial temperature of the gas T_0
consumption of the gas m
the boiling temperature of the
liquefied gas T_w
time needed for liquefaction t

The following empirical relationship between the liquefaction time and the pressure and consumption of the gas was found from measurements made on miniature liquefiers operated in open system

$$\ln G = A \cdot p + \ln B \qquad (1)$$

where

$$G = \frac{T_0 - T_w}{t \cdot m}.$$

The quantities A nad B appearing in Eq (1) are empirical constants.

In case of liquefiers operated in an open system and supplied with gas from high pressure flasks, the time necessary for liquefaction depends on the initial gas pressure. The determination of this dependence requires time-consuming measurements. The empirical formula (1), however found in the present paper permits the prediction of the changes in the time t necessary for liquefaction with changing pressure to be made, if only one measurement of this time is made for a given starting pressure p.

The dependence (1) determined experimentally for various miniature liquefiers is shown in Fig. 1 for pressures ranging from 80 to 150 atm. On the other hand Fig. 2 gives the dependence of G on the initial value of the starting pressure of argon, nitrogen, and atmospheric air.

It was found that the constant A in Eq. (1) does not depend on the type of the liquefier but depends only on the sort of the particular gas, whereas the constant B depends on the particular liquefier and its individual properties only.
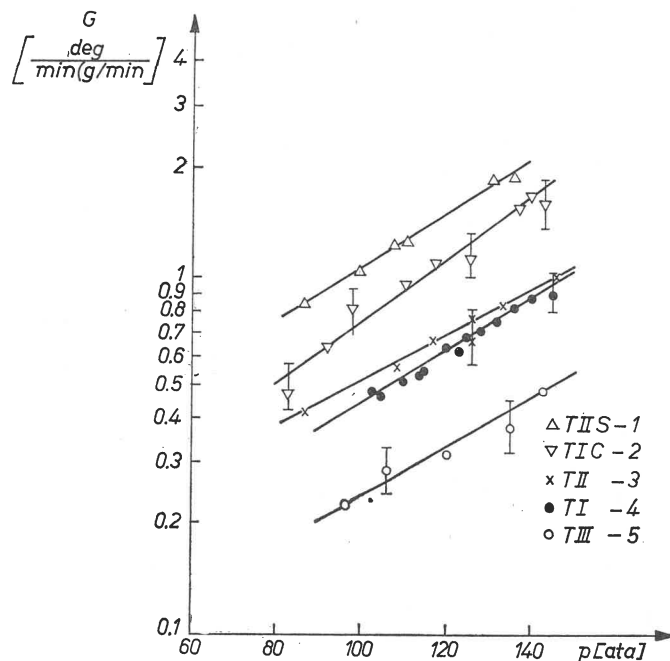
Fig. 1. Plot of the dependence $\ln G = Ap + \ln B$ for various liquefiers working gas — nitrogen. 1 – Double layer heat exchange unit, metal casing. Thermal insulation — foam plastic; 2 – Single layer heat exchange unit, metal casing. Thermal insulation — foam plastic; 3 – Double layer heat exchange unit. Thermal insulation — glass Dewar vessel; 4 – Single-layer heat exchange unit. Thermal insulation — glass Dewar vessel; 5 – Three-layer heat exchange unit. Thermal insulation — glass Dewar vessel
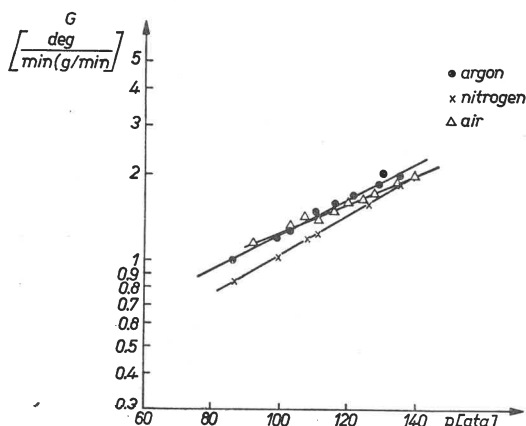

Fig. 2. Dependence $\ln G \doteq Ap + \ln B$ for nitrogen, argon, and atmospheric air. Liquefier with a double-layer heat exchange system and foam plastic insulation

TABLE I

Number of capillary layers in heat exchange system	Nitrogen		Argon	
	$A\ 10^{-2}$	B	$A\ 10^{-2}$	B
one (glass Dewar vessel)	1.65	0.08	1.28	0.18
two (as above)	1.51	0.11	1.28	0.18
three (as above)	1.59	0.05	1.21	0.13
four (as above)	—	—	1.32	0.12
two (foam plastic)	1.64	0.20	1.38	0.30
one (foam plastic)	1.53	0.25	1.46	0.32
	$A = 1.6 \pm 0.14$		$A = 1.32 \pm 0.14$	

$$A = \left[\frac{1}{\text{atm}}\right]; \qquad B = \left[\frac{\text{deg}}{\text{min} \cdot \text{g/min}}\right].$$

The values of the constants A and B are given in Table I.

The dependence of the cooling power of miniature liquefiers on the number of capillary layers in the miniature heat exchanger is shown in Fig. 3. It can be easily seen that the greatest increase in cooling power is obtained by adding the second and the third capillary
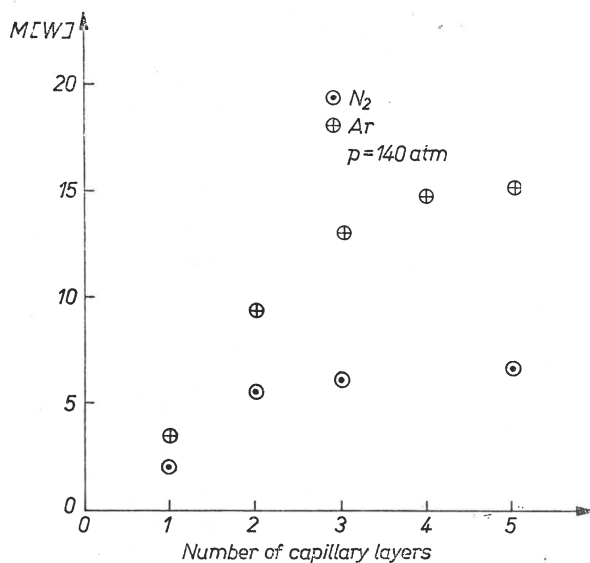

Fig. 3. Dependence of cooling power of miniature liquefiers on the number of capillary layers in heat exchange unit. Initial pressure 140 atm

layer. Further extension of the heat exchange unit by adding further capillary layers is already very little effective. If, namely, we accept the cooling power of a five-layer heat exchange unit as 100% for initial pressure of 140 atm, then the relative powers of double-

-layer liquefiers are 60% and 75% for argon and nitrogen, respectively. The cooling powers of three-layer miniature liquefiers are: for argon 85% and for nitrogen 90% of that of a five-layer liquefier.

The economy of double-layer heat exchange systems can be still better illustrated by plotting the ratio Q/m, i.e., the cooling power Q to the gas consumption m, against the number of capillary lyaers — Fig. 4.
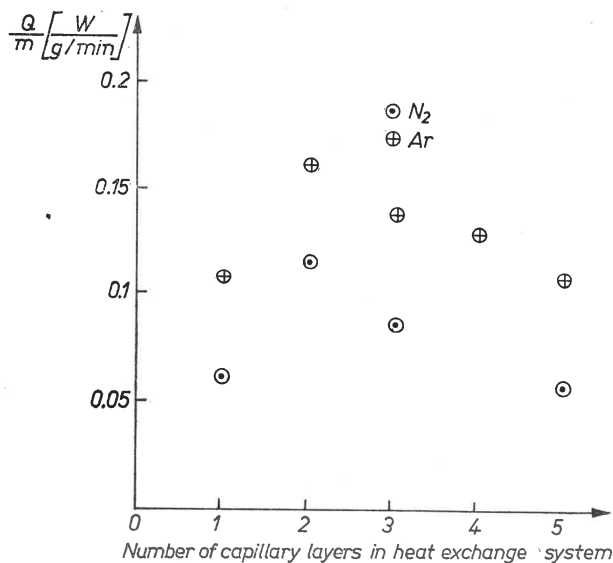

Fig 4. Dependence of Q/m on the number of capillary layers in heat exchange unit. Initial pressure 140 atm
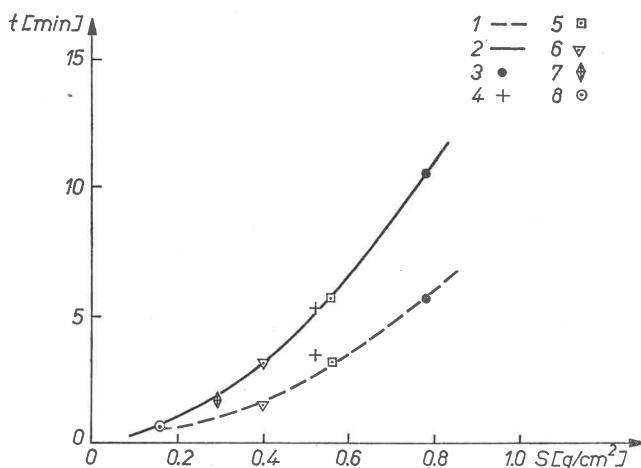

Fig. 5. Dependence of liquefaction time on the ratio of the mass of the heat exchange unit to the area of heat exchange surface. Initial pressure 140 atm *1* – argon, *2* – nitrogen, *3* – liquefier with single-layer heat exchange, *4* – liquefier with double-layer heat exchange, *5* – liquefier with three capillary layers, *6* – liquefier with single-layer heat exchange, *7* – liquefier with single-layer heat exchange, *8* – liquefier with single-layer heat exchange

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It follows from this plot that the construction of miniature liquefiers with a greater number of capillary layers is inexpedient. Already three capillary layers ensure a comparatively high cooling power.

A similar conclusion was drawn in paper [3] whose authors have shown that the heat exchange coefficient in the intertubular space of Hampson heat exchange systems decreases if the number of layers is greater than three.

In many applications of miniature liquefiers the factor of essential importance is the time needed to start the liquefaction process of the gas. It has been shown by various authors [4, 5] that this liquefaction time is significantly dependent on the initial pressure and the kind of the liquefied gas.

It follows from our studies that in addition significant influence on the liquefaction time is exerted by the ratio S of the mass of the heat exchange unit to the area of the effective heat exchange surface.

The dependence of the liquefaction time on S is given in Fig. 5. Such a dependence can be easily understood since the smaller the value of S the closer the heat exchange unit to its ideal version which, by definition, has a possible greatest heat exchange surface and a vanishingly small mass.

3. Conclusions

It follows from the studies on single-stage liquefiers of gases of the group A that

a) one can determine *a priori* the time needed for liquefaction of a given gas for arbitrary initial starting pressure and consumption of the gas using the empirical formula found in the present work:

$$\ln G = Ap + \ln B$$

b) the most practical construction of a miniature liquefier is that using two or three capillary layers in the heat exchange unit,

c) the liquefaction time is not only dependent on the initial pressure and the kind of the gas but also on the ratio of the mass of the heat exchange system to the area of the heat exchange surface.

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