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E8-88-360

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CHARACTERISTICS OF HORIZONTAL TWO-PHASE HELIUM FLOW AT LOW MASS VELOCITIES

Presented at the 12th International Cryogenic Engineering Conference, July 12-15, 1988, Southampton, UK

1988

INTRODUCTION

The flow sections of superconducting magnets for modern accelerators (HERA, UNK, KEK) are typified by annular and circular horizontally oriented channels. Low mass velocities ($m < 50$ kg/s/m^2) and near-adiabatic conditions characterize such systems. Under designing and optimizing of a.m. constructions the key input data are the pressure drop ΔP, void fraction ϕ, and flow pattern map $M(v', v'')$. The present report performs results of ΔP, ϕ, $M(v', v'')$ investigation.

EXPERIMENTAL ARRANGEMENT

The cryogenic equipment was placed in four horizontal flow cryostats. The experimental channel parameters are listed in the Table. A helium refrigerator (300 W at 4.5 K level) supplied helium circulation through experimental channels. The test bench circuit as well as the measurement procedures were described in detail in /1/. Tests covered the following parameters variations: mass velocity m = 20-300 kg/s/m^2; quality x = 0-1; pressure P = 0.12-0.20 MPa.

Table

Experimental channels

channel number	cross section	sizes, mm			measurements	visualisation
1	circle	d=7.92		ℓ =430	ΔP, ϕ	present*
2	circle	d=4.60		ℓ =2000	ΔP	absent
3	annulus	d_1=13	d_2=11.1	ℓ =600	ΔP, ϕ	absent
4	rectangle	h=30	Δ=1.0	ℓ =400	ΔP	present*

* *the intermediate glasses of visual sections were kept under nitrogen temperature to shield thermal irradiation.*

The electronic system made to CAMAC standard enabled digital measurements. A microcomputer system was added to facilitate data processing, graphing, and recording.

RESULTS AND DISCUSSION

(a) Flow Regimes

The investigation of flow regimes was carried out using high-speed photography. The photographs obtained bear evidence of two-phase helium flow regimes being stratified (smooth or wavy) at low mass velocities (see Fig.1). Bubble regime occurrence is possible only when the quality is small ($x \leq 0.05$). That's true for both circular channel and slot ones. Fig.2 shows the boundaries of bubble and stratified regimes

a)

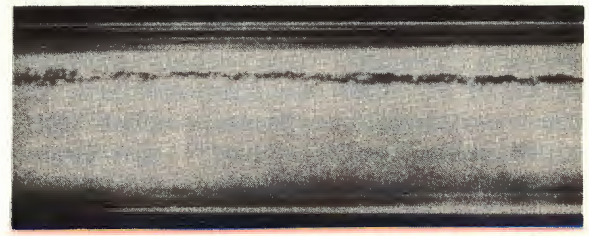
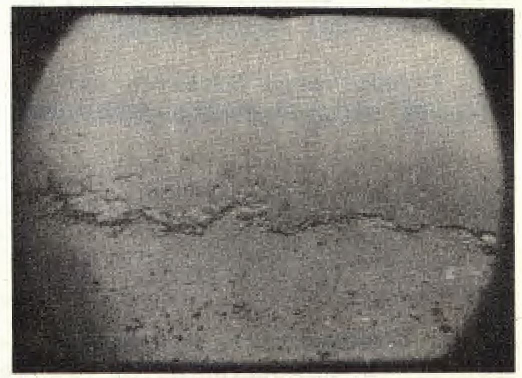


Fig.1. Stratified helium flows for P=0.125 MPa.
a) channel 1; m=20 kg/m²s; x= 0.11; b) channel 4; m= =36 kg/m²s; x=0.37.

b)



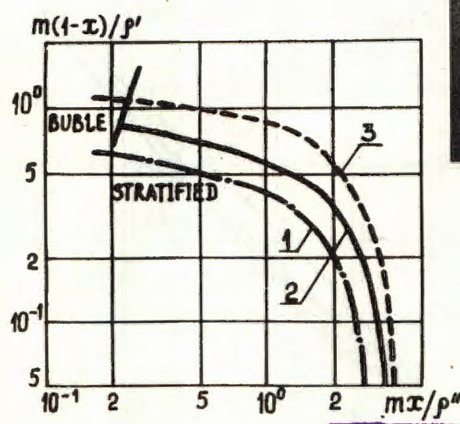


Fig.2. Flow pattern map of helium. 1 - channel 4; P = =0.125 MPa; 2 - pipe 5.8 mm id; P=0.13 MPa /1/; 3 - channel 1; P=0.16 MPa.

at P = 0.12–0.16 MPa for such channels as nos 1 and 4 (see the Table). The results for comparatively thin annular channels obtained earlier are rather similar to these data. A significant discrepancy should be noted to exist between data presented and those from Baker [2] and Mandhane et al. [3]. This failure of popular maps is corroborated by work [4].

(b) Pressure Drop

The experimental results on pressure drop for stratified flows ΔP^* vs x are plotted in Fig.3, where x is the quality and ΔP^* is the dimensionless pressure drop

$$\Delta P^* \equiv (\Delta P - \Delta P')/(\Delta P'' - \Delta P'),$$

where ΔP is the pressure drop of two-phase flow, $\Delta P'$ the pressure drop of single phase liquid flow and $\Delta P''$ of single phase vapour flow at $m = idem$. The experimental values of $\Delta P'$ and $\Delta P''$ are well correlated by the calculations with the help of Colebrook's formula for rough tubes in agreement with the results of [5]. The obtained ΔP^* data are perceptibly lower than the results of homogeneous model (HM). At the same time some experimental points from [5] are approximated well by the HM correlation.

The theoretical analysis was carried out based upon the application of momentum conservation law to each flow phase. The analytical solution $\Delta P^*(x)$ for comparatively small gap, viz

$$\Delta/h \quad \text{or} \quad (d_1 - d_2)/2d_2 \approx 0.03 - 0.09,$$

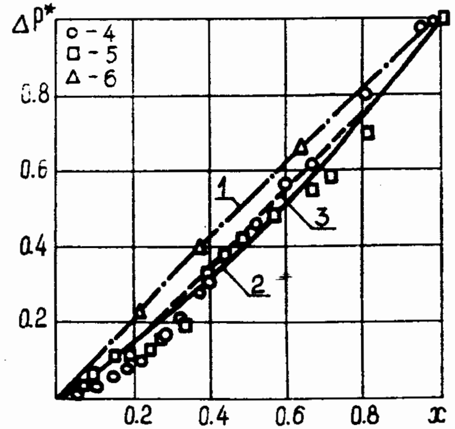


Fig.3. Dimensionless pressure drop ΔP^* versus quality for P = 0.125 MPa. 1 – homogeneous model; 2 – equation (1); 3 – solution for pipe; 4 – channel 1; m = 31 kg/m²s; 5 – channel 4; m = 49 kg/m²s; 6 – data [5]; m = 25–50 kg/m²s.

was obtained

$$\Delta P^* = \left(\left[1 - x + x\left(\frac{\rho'}{\rho''}\right)^{4/7}\left(\frac{\eta''}{\eta'}\right)^{1/7}\right]^{7/4} - 1\right)\cdot\left(\left(\frac{\eta''}{\eta'}\right)^{1/4}\left(\frac{\rho'}{\rho''}\right) - 1\right)^{-1}, \quad (1)$$

where ρ is the density; η, the dynamical viscosity, and superscripts $'$ and $''$ correspond to equilibrium liquid and vapour. The relationship (1) exhibits a satisfactory agreement with the experimental data (see Fig.3). The solution $\Delta P^*(x)$ for the circular cross section case was obtained numerically. The results of calculation are slightly higher than those of eq.(1) and lower than HM ones (see Fig.3).

(c) Void Fraction

To measure the void fraction the ϕ-sensor with annular cross section was used [6]. The capacitance C served as sensitive element. It was connected in an oscillating contour and the $C(\phi)$ function was determined through resonance frequency shift, which was measured according to radio-frequency procedures. Some results of $\phi(x)$ measurements are shown in Fig.4. It can be seen that under stratification HM calculations overestimate the ϕ values considerably. The analytical solution $\phi(x)$ for annular (slot) channels was obtained on the same as for eq.(1) basis

$$\phi = \left(1 + \frac{1 - x}{x}\left(\frac{\rho''}{\rho'}\right)^{4/7}\left(\frac{\eta'}{\eta''}\right)^{1/7}\right)^{-1}. \quad (2)$$

Eq.(2) describes satisfactorily the obtained experimental data (Fig.4). The $\phi(x)$ numerically obtained solution for circular

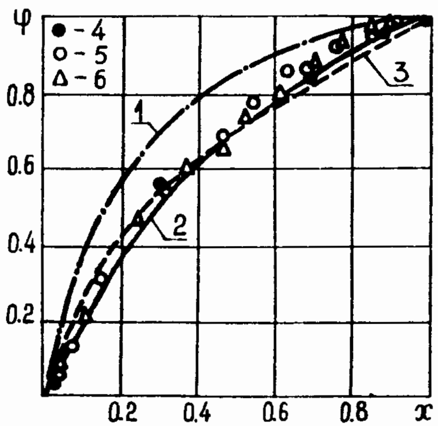


Fig.4. Void fraction versus quality. 1 – homogeneous model; P=0.125 MPa; 2 – equation (2); P=0.125 MPa; 3 – solution for pipe; P=0.125 MPPa; 4 – m=25 kg/m²s; P=0.123 MPa; 5 – m=29 kg/m²s; P=0.123 MPa; 6 – m=33 kg/m²s; P=0.129 MPa.

channel is also plotted in Fig.4. As the figure shows, the annular channel curve and the circular one are intersecting, and the corresponding values of slip factor differ by about 30-50%. The $\phi(x)$ was measured for the circular cross section channel as well. However, the results are just preliminary.

CONCLUSIONS

There is a significant difference between two-phase helium flow bubble and stratified regime boundaries and those from the well-known pattern maps. Under the considered conditions and channel geometries the pressure drops as well as the void fractions perceptibly diverge from homogeneous model results and can be calculated through eqs. (1) and (2).

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Received by Publishing Department
on May 24, 1988.

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E8-88-360

Характеристики горизонтальных двухфазных потоков гелия при низких массовых скоростях

Представлены результаты экспериментального и теоретического исследования режимов течения, гидравлического сопротивления и истинного объемного паросодержания двухфазных потоков гелия, движущихся в горизонтальных каналах кольцевого, щелевого и круглого сечений при относительно низких массовых скоростях и условиях, близких к адиабатным.

Работа выполнена в Общеинститутском научно-методическом отделении ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1988

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E8-88-360

Characteristics of Horizontal Two-Phase Helium Flow at Low Mass Velocities

Two-phase helium flows experimental and theoretical exploration results, including data on flow regimes, pressure drop, and void fraction, are presented. The circular, annular, and slot channels are examined. All the considered data are for low mass velocities and near-adiabatic conditions.

The investigation has been performed at the Scientific-Methodical Division of High Energy Physics, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1988