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DISPERSION OF GAS BUBBLES IN A TWO-DIMENSIONAL MHD TURBULENCE

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The dispersion of small gas bubbles in a vertically upwards liquid metal two-phase flow is investigated theoretically as well as experimentally. Local void fraction measurements are presented for a vertical sodium-argon flow with and without an external transverse magnetic field. Due to the material parameters of liquid sodium, high non-dimensional parameters are reached with a conventional electromagnet of $B \leq 0.45$ T: Hartmann number $Ha \leq 3000$, interaction parameter $N = 100$-800 for a Reynolds number Re in the region of 10^4-$7 \cdot 10^4$ ($Ha/Re \cdot 10^3 = 40$-300). These parameters indicate that a well-developed two-dimensional MHD turbulence should exist in the channel flow. The dispersion of an initially narrow void distribution shows this behavior clearly. The measurements will be compared with that of Lykoudis [1] and Michiyoshi [2]. However, in these papers two-dimensional turbulence was not reached (or not possible, resp.), so that the obtained experimental results can be considered as the first measurements showing the influence of two-dimensional turbulence on the transport of small gas bubbles.

Introduction

An external magnetic field has a suppressing effect on turbulent fluctuations in a flow of a conducting fluid. When the ratio Ha/Re exceeds a critical value, the overall pressure drop corresponds to the theoretical values delivered by the laminar flow theory. However, direct measurements of velocity pulsations confirmed that residual disturbances remain in the flow [3, 4]. The persistence of two-dimensional vortices with axes parallel to the field lines in a strong magnetic field can be explained by the model of two-dimensional MHD turbulence. However, some questions remain unresolved with respect to the detailed flow structure and, in particular, concerning the heat and mass transfer in their special type of flow.

Here we present experimental results on a sodium/argon bubbly flow exposed to a transverse magnetic field. We selected this configuration since:

- the material properties of liquid sodium allow investigations in the interesting range of high interaction parameters;
- own developed resistivity probes were available for local void fraction measurements in the channel.

Experimental Results

The local void fraction was measured in a vertical sodium-argon flow in order to study local properties of liquid-metal MHD two-phase flows.

The sketch of our test section is shown in Fig. 1. The test section consists of a vertical channel with stainless steel walls and a rectangular cross-sectional area of 45×50 mm^2. The flow passes through a region of an external homogeneous transverse magnetic field with a pole face length of 320 mm and a field strength maximum of 0.45 T.

Argon bubbles were injected into the test section through a single orifice (diameter 0.9 mm) centered in the channel cross section. The injector is located just at the beginning of the magnetic pole face region. The bubble detection is carried

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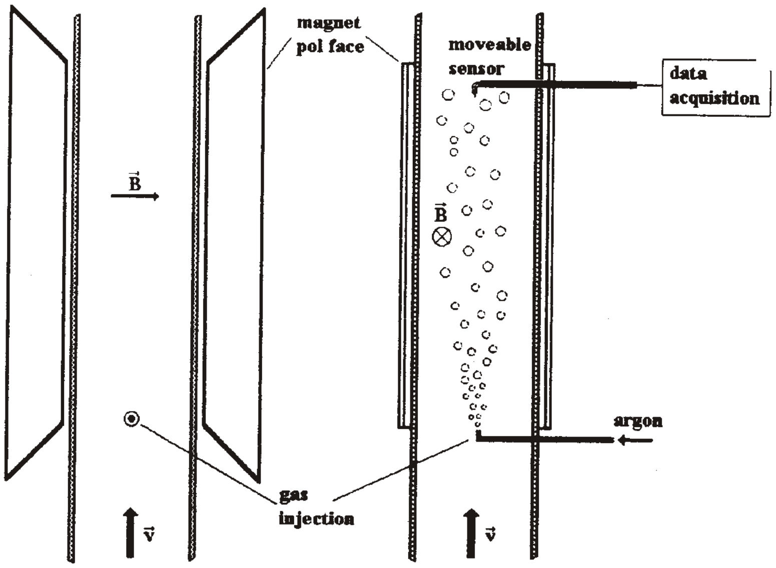


Fig. 1. Scheme of the two-phase test section.

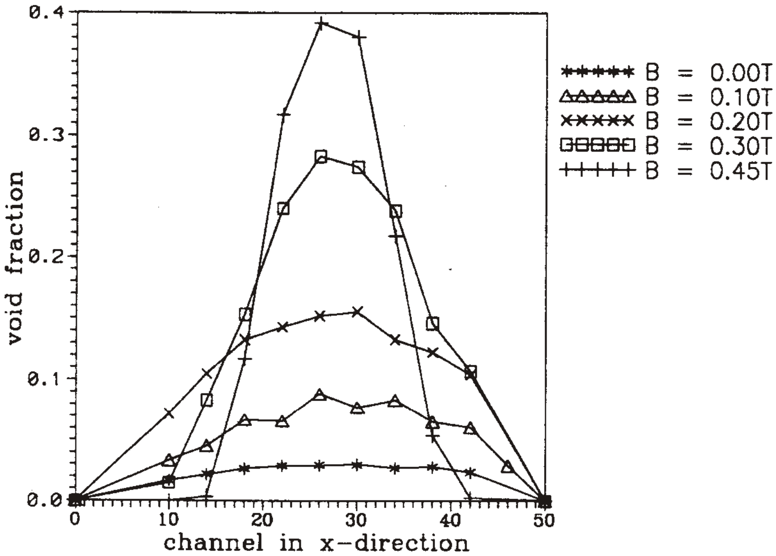


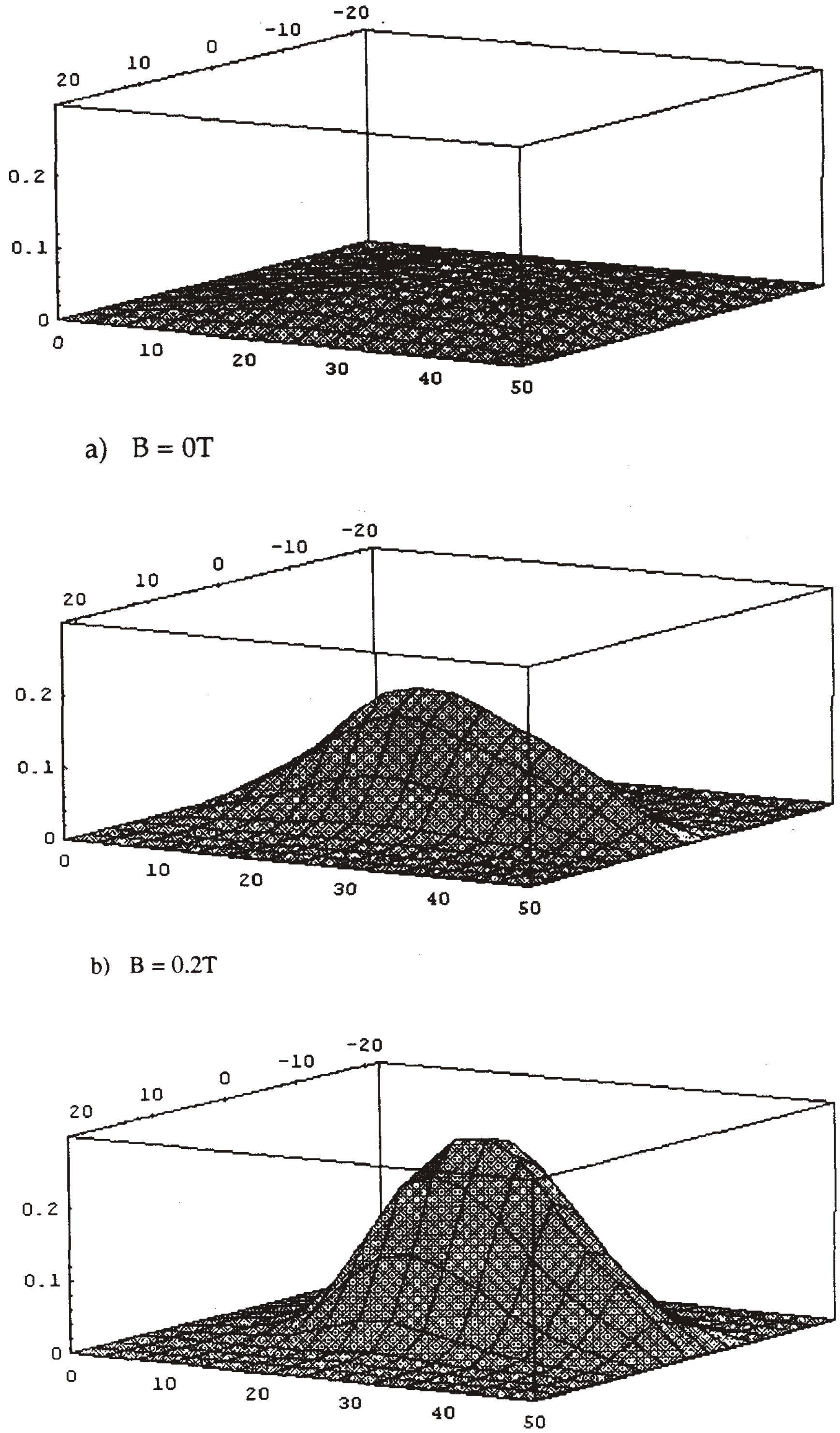
Fig. 2. Local void fraction perpendicular to the direction of the field lines for various intensities of the magnetic field.

out by means of single-wire resistivity probes after a distance (in the flow direction) of 290 mm. The probes delivered reproducible results over a period of several hours. It is possible to move the probe nearly completely over the whole channel cross section by means of a traversing mechanism.

Due to the damping effect of the external magnetic field on the velocity fluctuations, an increasing concentration of the gas phase in the channel center can be expected with increasing field intensity. This focusing effect in the direction perpendicular to the field lines is shown in Fig. 2 for a mean sodium velocity of 0.1 m/sec.

Moreover, first measurements of the local gas distribution over the channel cross section revealed a distinct anisotropy of the turbulent bubble dispersion [5]. Meanwhile, we extended our measurements and were able to confirm these results by further more detailed investigations.

Typical distributions of the local void fraction for a mean sodium velocity of 0.1 m/sec are displayed in Fig. 3a, b, and c. While the gas phase for B = 0 T in Fig. 3a is nearly equally distributed, plots b and c show clearly that the suppression of bubble dispersion is more pronounced in the field direction than in the direction perpendicular to it. This different influence on the dispersion process parallel and perpendicular to the field lines decreases with further increasing magnetic field



a) B = 0T

b) B = 0.2T

c) B = 0.3T

Fig. 3. Profiles of the measured local void fraction distribution. Direction of the magnetic field: x.

as shown in Fig. 3c. Moreover, the maximum value of the void fraction is considerably increased in Fig. 3c compared to Fig. 3b due to the overall focusing effect of the magnetic field.

The strong anisotropy in the distribution of the void fraction indicates clearly the presence of two-dimensional vortices in the flow. The mass transfer of the argon bubbles is much more restricted in the direction of the magnetic field lines than perpendicular to it.

TABLE 1. Comparison of the Experiments Regarding Characteristic Parameters

	Lykoudis	Michiyoshi	FZR facility
Liquid metal	mercury	mercury	sodium
Gas	nitrogen	argon	argon
Test section	circular (Ø 38 mm)	circular (Ø 23 mm)	rectangular (45x50 mm^2)
Wand material	plexiglass	lucite	stainless steel
Re	$6.8\cdot10^4$-10^5	$7\cdot10^4$-$1.4\cdot10^5$	10^4-$7\cdot10^4$
Ha_{max}	900	220	2000
$\left(\frac{Ha}{Re}\right)_{max}\cdot10^3$	13	3	200
N_{max}	12	0.7	400
$(N\cdot Rm)_{max}$	0.2	0.01	30

At first glance these findings are in total contradiction to experimental results obtained in mercury/nitrogen (argon) two-phase flows by Lykoudis and Michiyoshi [1, 2], respectively. They obtained a nearly equal dispersion of gas bubbles in both directions parallel and transverse to the magnetic field lines, with a slightly stronger focusing effect perpendicular to the field direction. However, these experiments took place with a completely different set of dimensionless parameters (see Table 1) in a circular channel geometry. According to [6] in the case of a transverse magnetic field the critical value Ha/Re at which the pressure drop begins to correspond to laminar flow can be determined as follows:

$$\left(\frac{Ha}{Re}\right)_{cr}=\left[215-85\cdot e^{(-0.35\beta)}\right]^{-1} \quad ; \quad \beta=\frac{b}{a}$$

where a is the half-width of the cross section parallel to the magnetic field and b is the half-width of the cross section perpendicular to the magnetic field.

For $\beta = 1$ we get a critical value of about $6.5\cdot10^{-3}$. While this value was clearly exceeded in our sodium/argon flow, the critical ratio was just reached (in [1]) or not reached (in [2]) in the other experiments.

In addition, a circular cross section does not provide, if at all, a good prerequisite for the development of two-dimensional MHD turbulence. So the crucial difference between [1, 2] and our experiment is that the preconditions for a well-developed two-dimensional MHD turbulence were given in our case in contrast to [1, 2].

Conclusions

The mass transfer of small argon gas bubbles injected through a single orifice into a turbulent sodium flow exposed to a transverse magnetic field was investigated.

As the main result, a strong anisotropy was found in the local void distribution measured in the cross-sectional area. Due to the influence of the magnetic field, a general concentration process of the dispersed gas phase in the center of the channel can be observed. However, the bubble dispersion is much more restricted parallel to the magnetic field than perpendicular to it.

The anisotropic void distribution represents a typical phenomenon of two-dimensional MHD turbulence.

The next steps in our research program will be further measurements of the bubble distributions with systematic variations of the dimensionless parameters (Ha, Re, N) and a quantitative estimation of the mass transfer in terms of the corresponding dispersion coefficients.

Moreover, some open questions have to be clarified regarding the influence of the M-shaped velocity profile or the magnetic pressure on the bubble dispersion.

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