Abstract

A liquid flow driven by surface tension and their tendency to decay into drops has been of great scientific interest. However little is known about this phenomenon in presence of another external driving force e.g. magnetic field in magnetic fluids (MF). Our work is devoted to the experimental study of the breakup length, the wavelength of jet perturbation and distribution of drop sizes in dependence on flow velocity for MF in magnetic field parallel and perpendicular to the jet.

Keywords: jet instability; breakup length; magnetic fluid

1. Introduction

Flowing of the liquid with free surface and rapid breakup of jet into drops is interesting area of scientific study due to many interesting physical problems which are not fully understood yet and also because of great variety of applications [1-5]. In spite of many investigations on nonmagnetic fluids, there are less studies devoted to breakup of magnetic fluid jet [6-8].

The accepted mechanism of jet breakup involves flow from regions of the liquid column with smaller radii, where Laplace pressure is larger, to crest regions where the pressure is lower, until pinch-off occurs.

For the flow of MF in the presence of magnetic field, the new parameters emerge, so-called magnetic pressure and magnetic-fluid pressure [6-8].

In this paper we present results of experimental study of the breakup of magnetic fluid jet in magnetic field parallel and perpendicular to the jet in dependence on flow velocity.

* Corresponding author. Tel.: 00421-907-955-006. E-mail address: svikova@gmail.com.
2. Experimental

In our experiments, jets were produced when a fluid leaves a nozzle with 1.25 mm in diameter in the bottom of cylindrical container with 48.6 mm in diameter (see Fig. 1).

For the measurements, we used two types of magnetic fluids. First was oil based magnetic fluid with magnetization of saturation \(580 \text{ G}\), and density \(\rho = 1.647 \text{ g cm}^{-3}\). By the drop method, we found out the value of surface tension \(\sigma_1 \approx 0.57\sigma_0\), where \(\sigma_0\) is the surface tension of water. Second was water based magnetic fluid with \(\rho = 1.14 \text{ g cm}^{-3}\) and with magnetization of saturation \(115 \text{ G}\). The value of surface tension was determined as \(\sigma \approx 0.5 \sigma_0\).

The Helmholtz’s coils were used to create the magnetic field, with strength 4.6 mT.

Fig. 1 Schematic diagram of the experimental apparatus.

In all experiments, the experimental container was filled up to the height 5.5 cm, above the nozzle. Fluid was forced through the nozzle due to hydrostatic pleasure. During flowing out of the liquid, the jet was recorded by camcorder. From video the breakup length, perturbation wavelength and size distribution of arising drops was measured.

3. Results and discussion

Fig. 2 shows sequence of 25 jet photos taken during one second with time step 0.04s for oil based and for water based MF without magnetic field and in magnetic field parallel and perpendicular to the jet. We can notice that length of the jet before breaking into drops oscillates around mean breakup length due to separation of drops. Also we can notice periodical perturbation on the stream. They are initiated at the nozzle and disintegration of cylindrical jet arises from their growth [1]. Ending stage of the jet and size distribution of drops depend on type of MF and on direction of applied magnetic field.

In Fig. 3 we show mean breakup length \(l\) of the jet (together with mean deviation during one second) in dependence on time and Fig. 4 presents dependence of \(l\) on velocity of flow \(v\). According our results overall dependence can be divided into two regions: \(1^\text{st}\) region - for larger value of \(v\), \(l\) decreases with decreasing \(v\) linearly. \(2^\text{nd}\) region - suddenly the slope is changed and \(l\) is less dependent on \(v\) until it falls down to zero.
At first region the jet breaking is governed by capillary instability and is known as Rayleigh regime [4]. In the frame of Rayleigh the linear theory dependence of breakup length vs. velocity is predicted and slope $k$ is connected with the time of perturbation development [6]. Extension of Rayleigh’s theory for non-viscid magnetic fluid without gravity in magnetic field parallel to the jet have shown that magnetic field reduce breakup rate and increase the wavelength of the fastest growing perturbation. According this theory intact length and size of arising drops should increase [7,8]. Theoretical predictions of influence of homogenous magnetic field perpendicular to the jet on breakup are according our knowledge missing.

In 1st region we observe that the slope $k$ increases in perpendicular magnetic field in comparison with the case of zero magnetic field for both magnetic fluids. Also perpendicular magnetic field cause the jet is less stable (larger oscillations of $l$ around mean value are observed). In parallel magnetic field the 1st region can be observed due to experimental arrangement only for water based magnetic fluid and there is small increase of $k$. At 2nd region (smaller velocity) influence of gravity cannot be neglected and is no theoretical prediction of influence of magnetic field on jet breakup. According our observation in this region $l$ is almost independent on $v$ and jet is more stable. Considerable influence of parallel magnetic field we observe in the 2nd region of jetting for oil based magnetic fluid. We found pronounced increase of $l$ and transition to dripping regime (intact length $l = 0$ and only separated drops are observed) for smaller value of $v$ in presence of parallel magnetic field. It means that applying of parallel magnetic field can control dripping to jetting transition what could have practical using for example in ink jet printing controlled by magnetic field.
The most noticeable influence of magnetic field was observed by comparison of flowing of oil based magnetic fluid without magnetic field and in the magnetic field parallel to the jet. The intact length of jet increases (see Fig. 3, 4). The wavelength of the disturbance developing on the stream in 2nd region without magnetic field is $\lambda \approx 10.7\text{mm}$ and in parallel magnetic field is $\lambda \approx 15.7\text{mm}$. Size distribution of drops changes noticeable, in favor of smaller drops at parallel field.

If the oil based MF flows in parallel magnetic field and the field is suddenly turned down, we observe sudden disintegration of the jet into series drops regardless of height of the liquid level above the nozzle. After 1/25 to 2/25 s., the jet appears again and the intact length of the jet stabilizes with smaller value (see Fig.5).

Fig. 4. Mean breakup length of the jet in dependence on velocity. Magnetic field: A,D – zero; B,E – perpendicular; C,F – parallel.

Fig. 5. Sequence of jet photos during one second in parallel magnetic field. At marked time the field was suddenly switched off.
4. Conclusion

We have measured breakup length $l$ of jet of magnetic fluid flowing from the nozzle in the bottom of cylindrical container without magnetic field and in presence of magnetic field parallel and perpendicular to the jet. Dependence $l$ on jet velocity $v$ can be divided into two regions: for larger values of $v$, $l$ decreases linearly with decreasing velocity but suddenly the slope is changed and breakup length is less dependent on $v$ until it falls down to zero. At first region the jet breaking is governed by capillary instability. The linear dependence of breakup length vs. velocity is predicted at this region and slope $k$ is connected with the time of perturbation development. We observe that the slope $k$ increases in perpendicular magnetic field for both magnetic fluids and jet is less stable – larger oscillations of $l$ around mean value are observed.

Considerable influence of parallel magnetic field we observe in the 2nd region of jetting for oil based magnetic fluid. We found pronounced increase of $l$ and transition to dripping regime for smaller value of $v$ and applying of parallel magnetic field can control dripping to jetting transition.

Acknowledgement

Work was done with support of project SUSY (project APVV-LPP-0270-09).

References

[1] J. Eggers, *Rev. Mod. Phys.*, 69 (1997) 865.
[2] J. Eggers, *Phys. Fluids*, 7 (1997) 941.
[3] M. Moseler and U. Landman: *Science*, 289 (2000) 1165.
[4] V. M. Korovin, *J. Appl. Maths Mechs*, 65 (2001) 243.
[5] S. Sudo et al., *J. Mag. Mag. Mat*, 201 (1999) 306