Two Phase Flows with Magnetic Nanofluids in a Presence of a Magnetic Field

Gerardo Carbajal
Universidad del Turabo, Caguas, PR, USA, gcarbajal1@suagm.edu

Edwar Romero
Universidad del Turabo, Caguas, PR, USA, eromero@suagm.edu

ABSTRACT

The effect of air bubbles in 70 % isopropyl alcohol with magnetic nanoparticles (Fe_3O_4) in both the absence and presence of a magnetic field was studied. In this study, the magnetic nanofluids in isopropyl alcohol was found to counteract the buoyancy force of bubbles in the absence of the magnetic field. The air bubbles were generated by an air pump, that allow to study the behavior of the bubble rise with magnetic nanofluids in presence of a magnetic field. The air bubbles stay suspended much longer in presence of a magnetic field than in absence of a magnetic field. In presence of a magnetic field, the average size of the departing bubbles decreased and the bubble frequency increased by 19 percent compared with the bubble flow with nanofluids in the absence of a magnetic field. Additionally, it was observed that the magnetic field affected the air bubble velocity in the bulk fluid.

Keywords: Air bubble, magnetic field, magnetic nanofluids

1. INTRODUCTION

Two-phase flows occur in a variety of industrial process, such as in boilers, condensers, and nuclear cooling systems, Bergman et al. (2011) . The mixtures of two-phase substances may be composed of gas and liquid, air and water, steam/water, or gas and solid, etc. A detailed information of two-phase flow in pool or flow boiling can be found in the literature (Carey 1992, Collier 1996). The two phase flow is affected by gravity (Merte, 1992). In order to counteract gravity effects, magnetic field has been applied to alter the bubble grow or collapse. Shalobasov et al (1971) showed, in a cavitation tunnel filled with tap water, that a magnetic field of less than one tesla can significantly change the degree of cavitation erosion. Later, Shal'nev et al. (1975) concluded that the growth rate of a spark-generated cavitation bubbles in stationary tap water is significantly increased by an applied magnetic field. A more recent investigation by Kang et al. (2002) revealed that a uniform magnetic field can reduce the bubble grow and collapse in a viscous fluid. Hammitt et al. (1975) also investigated the effect of a magnetic field on cavitation inception by using a vibratory apparatus in tap water; However, they did not find any difference in threshold pressure-amplitude for cavitation inception. Another piece of evidence on the effect of a magnetic field on bubble dynamics was given by the experiment conducted by Wong et al (1976). This work studied the effect of a magnetic field on the growth of gas bubbles supplied through an aperture. They showed that if a magnetic field is applied perpendicular to the direction of gravity, the bubble departure frequency from a plate in a liquid metal can be significantly reduced. Related work in this are were reported by Chi (1993), Ishimoto (1995) and Liu (2004),

In the present study a magnetic nanofluid was mixed with water and isopropyl alcohol to investigate the air bubble velocity and collapse under the effect of a uniform magnetic field.

2. THE EXPERIMENTAL SETUP

Figure 1 depicts the experimental setup; it consisted of :(1) glass, (2) magnets, (3) mark levels, (4) bubble ring, (5) hose, and (6) air pump. Bubbles were generated by injecting air from the bottom side of a glass container. The container was filled with 940 ml of 70% isopropyl alcohol (rubbing alcohol), that allow the visualization of the bubbles rise and departure. An air pump (AC2000 aquarium pump) was used to inject a constant volume flow rate of air into the container. Magnetic nanofluids (10nm particles in size) with density a of 1,300 kg/m^3, and specific magnetism of 363 gauss (G) were used in the experiment. The magnetic field was applied by two ceramics permanent magnet placed at the top and bottom of the cube, where the magnetic north pole was on the top side while the south pole was on the bottom side as shown in Fig. (1). The surface magnetic field strength of the magnet was 3,850 G and its dimensions were of 4x4x1 inches. The air bubble velocity was measured by using three different mark levels 1, 2 and 3 with a separation of one inch. This mark level made possible to measure the distance traveled by the air bubbles in a certain period of time. The experiment with the magnetic fluid was done with different quantities in volume: 5 ml, 10 ml, 15 ml and 20 ml respectively with and without in the presence of the magnetic field. The bubble behavior and displacement were recorded with a digital video camera intalled in front of the container.

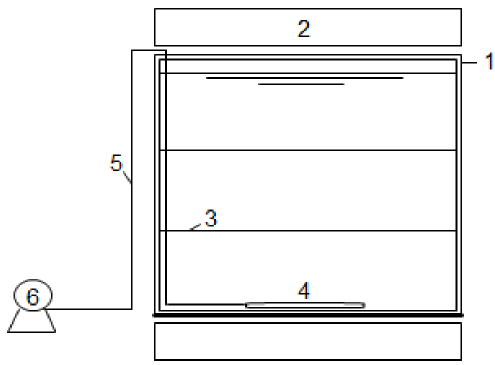

Figure 1: Schematic of the experiment. 1 glass, 2 magnets, 3 mark levels, 4 bubble ring, 5 hose, 6 air pump.

3. RESULTS AND DISCUSSIONS

Figures 2 illustrates the air bubble displacement in a glass containing isopropyl alcohol. It is observed that bubble are well dispersed on the top side of the container. The low density and viscosity of isoprppyl alcohol allow a better dispersion of the bubbles in the container. Figure 3 depicts a similar experiment but with nanofluid and without the presence of the magnetic field. In this case the effect of the nanofluids in the bulk viscosity affcted the bubble dispersion.

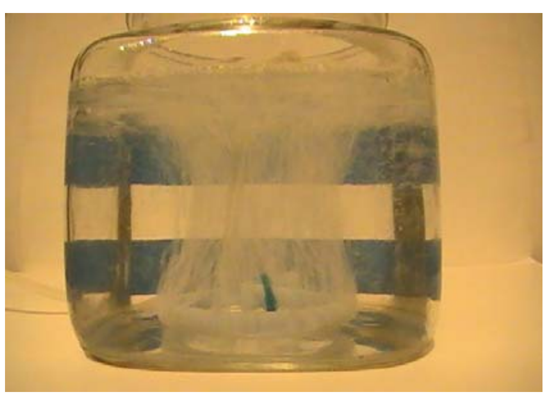

Figure 2: Air bubble rise in glass containing isopropyl alcohol

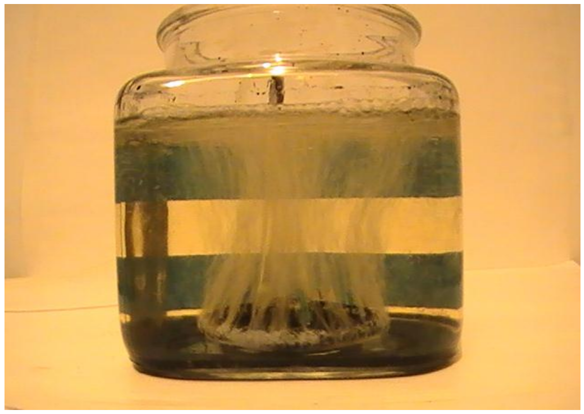

Figure 3: Air bubble rise in glass containing isopropyl alcohol with nanofluids and without the presence of the magnetic field.

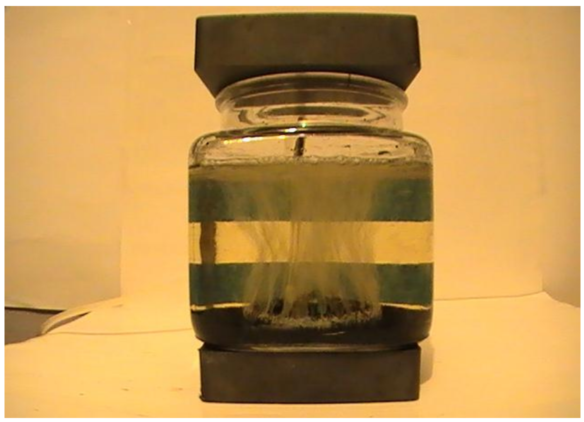

Figure 4: Air bubble rise in glass containing isopropyl alcohol with nanofluids and with the presence of the magnetic field.

Figure 4 shows the bubble interaction in the presence of the magnetic field. In order to see the effect of both the nanofluids and the magnetic field, two different experiments were conducted. The first experiment consisted in the analysis of the air bubble velocity with nanofluids, but without the magnetic field. Four concentrations of nanofluids were evaluated: 5ml, 10 ml, 15 ml and 20 ml respectively. The second experiment was similar to the first but with the presence of the magnetic field. The results were initially compared with the air bubble without nanofluids and magnetic field (base case).

The presence of the nanofluids affected the overall properties of the bulk fluid. Figure 5 represents the air bubble velocity of the base case compared with the presence of the nanofluids. The results indicates that the air bubble velocity decreases with the presence of the nanofluid; it is because the average bulk viscosity of the fluid increases; as consequence the bouyancy force was counteracted by the increase of the viscosity (drag force). When the concentration of the nanoparticles increases the bulk viscocity increases too resulting in a reduction of the air bubble velocity. A similar performance in the air bubble velocity was observed with the presence of the magnetic field, Fig. 6. However, the results indicates an increase of the air bubble velocity due to the presence of the magnetic field; this caused an additional force that increased the net bouyancy force on the bubble (see Fig. 6).

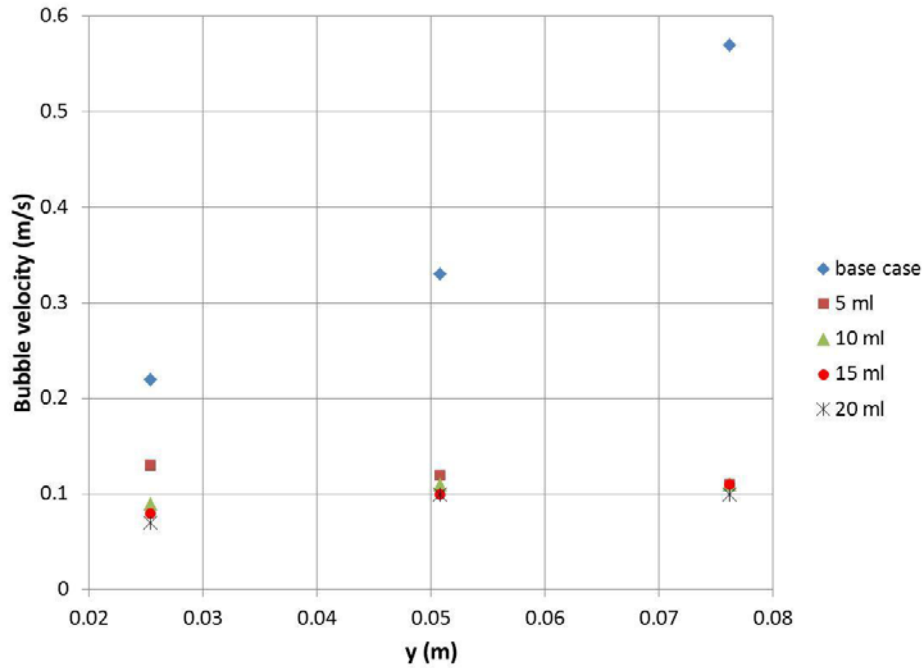

Figure 5: Air bubble velocity with nanofluids and without the presence of the magnetic field.

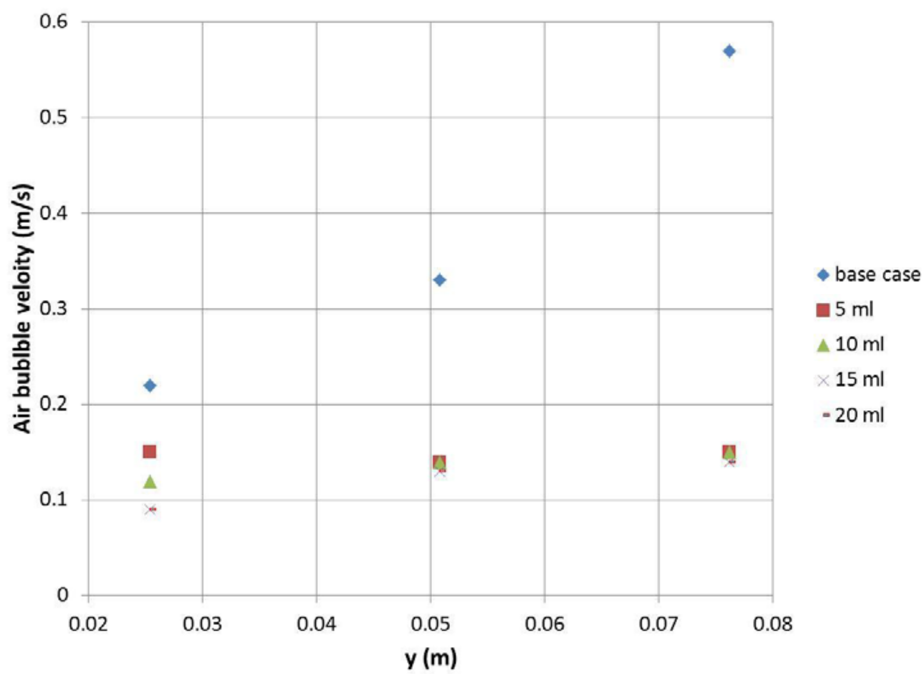

Figure 6: Air bubble velocity with nanofluids and with the presence of the magnetic field.

The increase of the air bubble velocity is primarily caused by the strong influence of the magnetic field acting along the container. Under the presence of a uniform magnetic field, the magnetic nanofluid experience a magnetization, as a result an additional body force or magnetic force appear, which affect the average bulk velocity of the air bubbles. The magnitude of this body force is directly related with the magnitude of the magnetic field. It was noticed that the air bubbles under the influence of the uniform magnetic field experienced a smaller volume growth compared with case without magnetic field; we suspect that the the magnetic field exerted a damping effect on the air volume size. Also, it was noted that the air bubble was significantly deformed during the injection process. Later, the bubble grows a little bit and then depart from the bottom side of the tank. This suggests that presence of the magnetic field cause an unkown phenomena that affected the bubble growth and departure. Shalobasov and Shal'nev (1971) stated that the Coulomb force exerted on each ion on the bubble surface may change the behavior of a bubble to a certain degree. Kang et al. (2002) suggested that it is necessary a further investigation, considering the influence of charges existing on the bubble surface, to obtain a reliable explanation for such anomalous behavior of a bubble in nonconducting liquids. Wong et al.(1976) suggested that under the applied magnetic field, generation of bubbles will make the parallel magnetic lines of force bead. Magnetic lines of force have a feature similar to elastic behavior: the deformed lines tend to go back to parallel and straight lines so that a force making the curved lines straight will be generated. Hence, in the horizontal direction a force would act on the bubble. It points at the center of the bubble and makes the bubble elongated in the direction of magnetic field. This shape of the elongated bubble in the presence of magnetic field was discussed by Fox et al. (2006).

The experimental results indicates that the magnetic field increases the net air bubble velocity as seen in Figs (7)-(9). Figure 7 demonstrates that the magnetic field increases the net velocity of the air buble for a nanofluid concentration of 5ml. A similar behaviour was found for the concentrations of 10ml (Fig. 8) and 15ml (Fig. 9) respectively. At one inch deep (0.025 m), it was found an increase of 15 percent of the air bubble velocity for a concentration of 5 ml under the presence of the magnetic field. The results suggest that the magnetic field plays an important role on the air bubble volume growth and velocity.

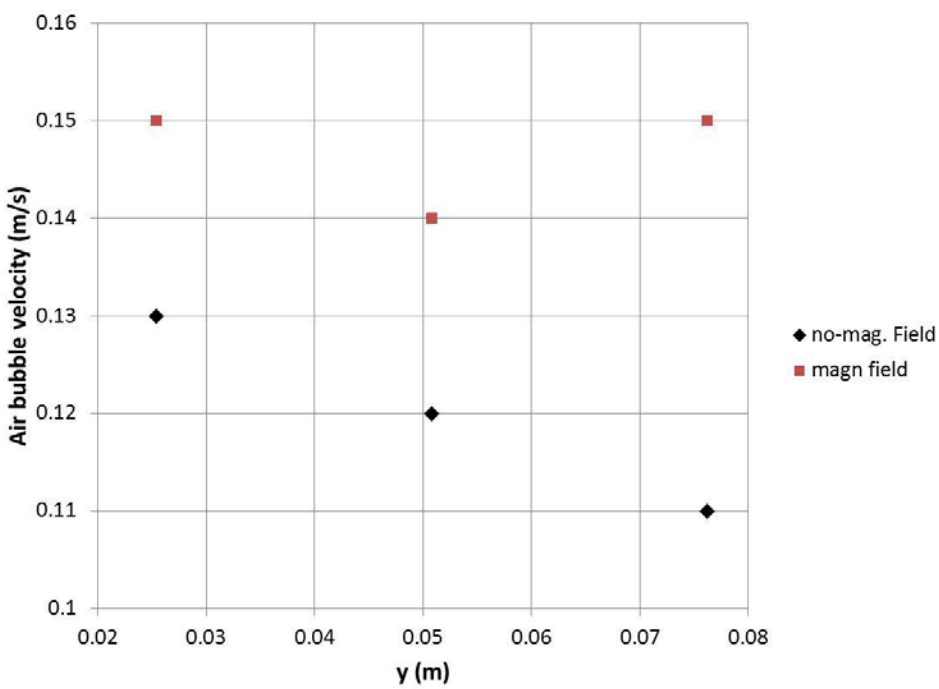

Figure 7: Air bubble velocity with nanofluids and without the presence of the magnetic field (5 ml nanofluid).

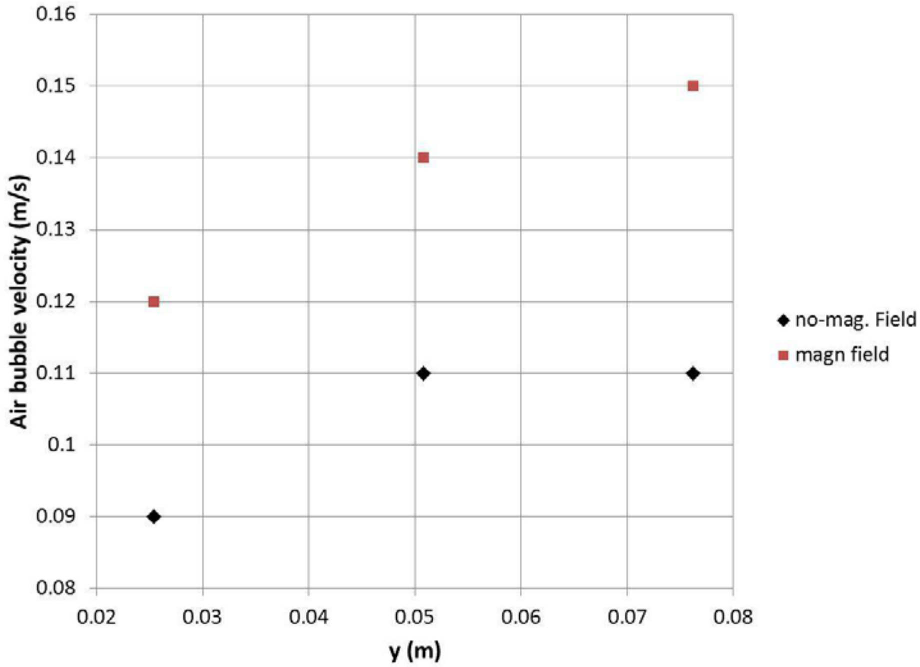

Figure 8: Air bubble velocity with nanofluids and without the presence of the magnetic field (10 ml nanofluid).

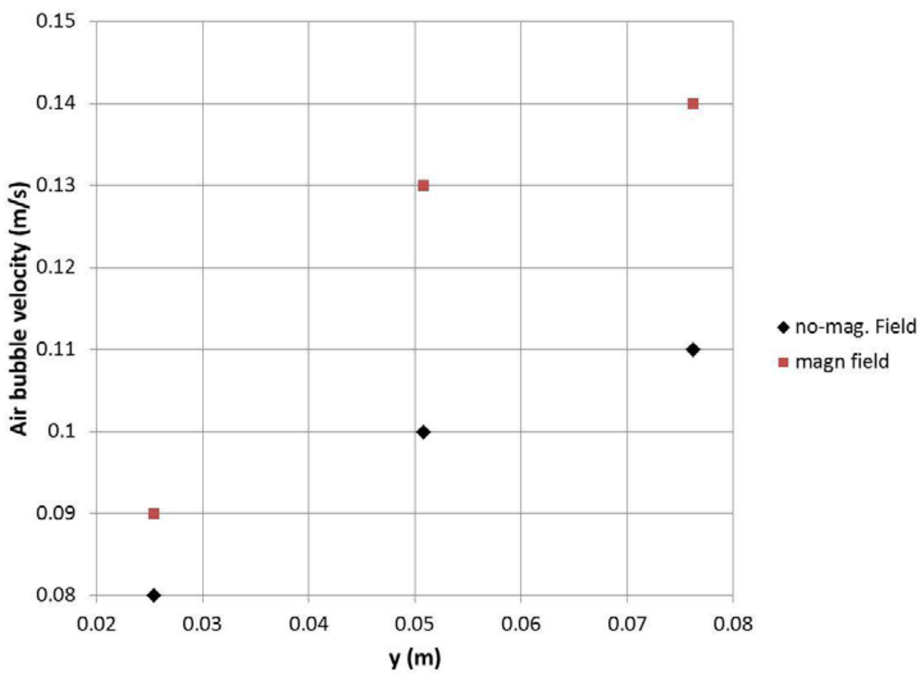

Figure 9: Air bubble velocity with nanofluids and without the presence of the magnetic field (15 ml nanofluid).

4. CONCLUSION

The experimental results indicate that the velocity of the bubbles with magnetic nanofluids increases when the magnetic field was applied. An interesting phenomena was observed, the bubble departure diameter decreases when the magnetic field was applied. Furthermore, the bubbles become slender in the middle and broader at the bottom, which makes the bubbles initially accelerate. In summary it is possible to affect the bubble growth in the presence magnetic field can.

5. ACKNOWLEDGEMENTS

The authors would like to thanks to Samuel Franceshini and Miguel Colon del Valle for their valuable contribution with the experimental data.

REFERENCES

Carey V.P (1992) "Liquid-Vapor Phase-Change Phenomena". Taylor & Francis, KY.

Chi Changqing, Wang Zhishang, Zhao Pizhi (1993) "Ferrofluid dynamics". University of Aeronautic and Astronautic Science and Technology Press, Beijing, pp 42–46.

Collier J.G., Thome J.R. (1996) "Convective Boiling and Condensation". Third Edition, Oxford University Press, USA.

Fox, R.W., McDonald, A.T., and Pritchard, P.J. (2006) "Introduction to Fluid Mechanics". Sixth Edition, John Wiley & Sons.

Hammitt F. G., Yilmaz E., Ahmed O., Bhatt N. R., and Mikielewicz J. (1975),''Effects of magnetic and electric fields upon cavitation in conducting and non-conducting liquids,'' Cavitation and Polyphase Flow Forum, ASME, 26.

Bergman T.L., Lavine A.S., Incropera F.P., Dewitt D.V. (2011) "Fundamentals of Heat and Mass Transfer". Seventh edition., Wiley and Sons.

Ishimoto J, Okubo M, Kamiyama S, Higashitani M (1995) "Bubble behavior in magnetic fluid under a nonuniform magnetic fluid". JSME Series B, Vol 38, No. 3, pp. 382–387.

Kang K. H., Kang I. S., and Lee C. M. (2002) "Effects of a uniform magnetic field on a growing or collapsing bubble in a weakly viscous conducting fluid". Phys. Fluids 14 No. 1, pp 29-31.

Liu Junhong, Gu Jianming, Lian Zhiwei, Liu Hui (2004) "Experiments and mechanism analysis of pool boiling heat transfer enhancement with water-based magnetic fluid". Vol 41, pp. 170–175.

Merte H. Jr. (1992) "Low velocity forced convection nucleate boiling at various orientations relative to earth gravity". Proceedings of ASME Engineering Foundation Conference on Pool and External Flow Boiling, Santa Barbara, California , pp. 439-445.

Shal'nev K. K., Shalobasov I. A., Kozirev S. P., and Haldeev E. V. (1975) ''Cavitation bubble in magnetic field,'' Proceedings of the Conference on Fluid Machinery, Hungary.

Shalobasov I. A. and Shal'nev K. K. (1971) ''Effect of an external magnetic field on cavitation and erosion damage''. Heat Transfer-Sov, Res. 3, 141.

Wong C. P. C., Vliet G. C., and Schmidt P. S. (1976), ''Magnetic field effects on bubble growth in boiling liquid metals,'' Proceedings of the Second Topical Conference on Technology of Nuclear Fusion 2, 407.

Authorization and Disclaimer

Authors authorize PREC to publish the paper in the conference proceedings. Neither PREC nor the editors are responsible either for the content or for the implications of what is expressed in the paper.