ENGINEERING RESEARCH JOURNAL (ERJ)

Vol. 1, No. 39 Jan. 2019, pp.18-22.

Journal Homepage: www.feng.bu.edu.eg

Effect Of Electromagnetic Field On Combustion Of Candle Flame

Hamdy Hassan Marouf [1,2] ,Ismail M. Elsemary[1] ,Ahmed A.Abdel Rahim[1,3] , M. F. Abd Rabo [1]

[1] Combustion and Energy Technology Lab, Mechanical Engineering Department, Shoubra Faculty of Engineering, Benha University, Cairo, Egypt., [2] The petroleum projects & technical consultations co. (Petrojet company),Cairo, Egypt. , [3] the British university in Egypt.

Abstract. The effect of magnetic field on the candle is the basis of explanation the effect of magnetic field on flames. The magnetic field enhances combustion process between fuels, which are diamagnetic material and oxygen which is paramagnetic material. It is found that a free convection heat transfer from candle flame may be significantly affected by the presence of a magnetic field; this effect appeared in the increasing of flame height and luminosity and brightness of candle flame. When pyrex tube fixed around the candle with lack of oxygen, candle flame quenched after10 seconds. In the presence of magnetic field, candle flame life increased to 22 seconds. When these experiments repeated to allow oxygen to entry from bottom of the candle, the flame quenched after 25 seconds without magnetic field and reached to 40 seconds with it. This means that the magnetic field increases oxygen concentration. Because of the oxygen is paramagnetic material, the magnetic field increases the oxygen concentration around the candle flame and the magnetic field enhances the buoyancy force of the candle flame. This means that there is a complete combustion in the presence of the magnetic field.

Keywords : Electromagnetic field, Candle, Combustion.

1. INTRODUCTION

Much research on the relation between combustion and magnetic fields has taken place all over the world. The nature of the studies has varied over a wide range, such as the influence of the magnetic fields on the flame, quenching the flame by magnetic field, the relation between the magnetic field and microgravity conditions. Also, there are many studies explained the effect of the electric field on the candle and the flame.

The fact that magnetic fields can influence combustion was first realized over one hundred and seventy years ago. As early as 1846, Faraday applied a magnetic field to a flame on a candle and he found that permanent magnets could cause candle flames to deform into equatorial disks [1, 2] and found that the flames were more luminous when placed in an external magnetic field. Faraday attributed the change in the flame shape to the presence of charged particles in the flames interacting with the magnetic fields. This experiment formed the basis for magnetic field effects on flames.

Later, researchers found that the interaction between flame ions and the magnetic fields were much too small to cause the flame deflection. Von Engel and Cozens [3] showed that the change in the flame shape could be attributed to the diamagnetic flame gases in the paramagnetic atmosphere. The changes in the flame behavior were attributed to a pressure gradient caused by the difference in magnetic permeability's. Para magnetism occurs in materials composed of atoms with permanent magnetic dipole moments. In the presence of magnetic field gradients, the atoms align with the magnetic field and are drawn into the direction of increasing magnetic field. Diamagnetism occurs when atoms have no net magnetic dipole moment. In the presence of magnetic gradient fields, diamagnetic substances are repelled towards areas of decreasing magnetism. Oxygen is an example of a paramagnetic substance. Nitrogen, carbon monoxide and dioxide, and most hydrocarbon fuels are examples of diamagnetic substances.

S.Ueno [4] examined the ability of the magnetic field to quench flames by placed a candle flame between two columnar electromagnets, hollowed out, to enclose the flame and exposed it to a field of 1.5 T and a gradient of 50-300T/m in the direction perpendicular to the pole axis when the distance of the air gap was in a range of 5-10 mm. The flame was quenched soon after the application of the magnetic field. It was even noticed that the flame life time increased with decreasing magnetic fields and fields below a critical value of 0.9 T would no longer quench the flame.

In zero gravity, convection does not carry the hot combustion products away from the fuel source, resulting in a spherical flame front. In 2000, experiments by NASA[5] confirmed that gravity plays an indirect role in flame formation and composition. The common distribution of a flame under normal gravity conditions depends on convection, as soot tends to rise to the top of a flame (such as in a candle in normal gravity conditions), making it yellow. In microgravity or zero gravity environment, such as in orbit, natural convection no longer occurs and the flame becomes spherical, with a tendency to become bluer and more efficient.

N.I. Wakayama [6-7] studied the effect of magnetic support for combustion in diffusion flames under microgravity. Flames in an O_2-containing atmosphere rely on natural or forced convection to replenish reactants and remove hot products. Because natural convection is absent under microgravity, diffusion flames become spherical, have low power, and eventually are extinguished. Kioshita [8] study the numerical simulation of diffusion flames with and without magnetic field. Numerical computations are made of axisymmetric laminar hydrogen flames, focusing on the unsteady behavior under microgravity and the effects of the magnetic field. In the microgravity without magnetic field, it is revealed that the combustion products remain around the diffusion flame because of the lack of convection, the amount of O_2 diffusion to the flame region becomes retarded. When a gradient magnetic field is added, convection is induced around the diffusion flame by the magnetic field which induces magnetic buoyancy force due to the in homogeneity of magnetic susceptibility. The flow configuration formed by the magnetic force under microgravity is similar to that under the normal gravity without the magnetic field. Ross [9-10] showed that in the microgravity and in the absence of the buoyancy the candle flame could survive for at least 5 seconds, but did not reach a steady state in the available test time.

2.Experimental set up

The present study focused on the effect of magnetic field on the candle by using two types of magnetic devices. The first type is an electromagnetic yoke coil and the second type is a permanent magnet. The electromagnetic yoke coil has a direct effect on the candle flame. It has constant magnetic field intensity of 0.72 Tesla and AC Current of 220 Volt as shown in figure (1). The distance or the gap between the two poles can be controlled as shown in figure (2). Accordingly the strength of the electromagnetic field could be controlled. The permanent magnet has O-ring shape, as shown in figure (4). Pocket Gas Emission Analyzer model AUTOL GIC was used in the present experiment to measure the oxygen concentration in the surrounding air.

Fig (1) : The electromagnetic yoke coil placed around the candle flame.

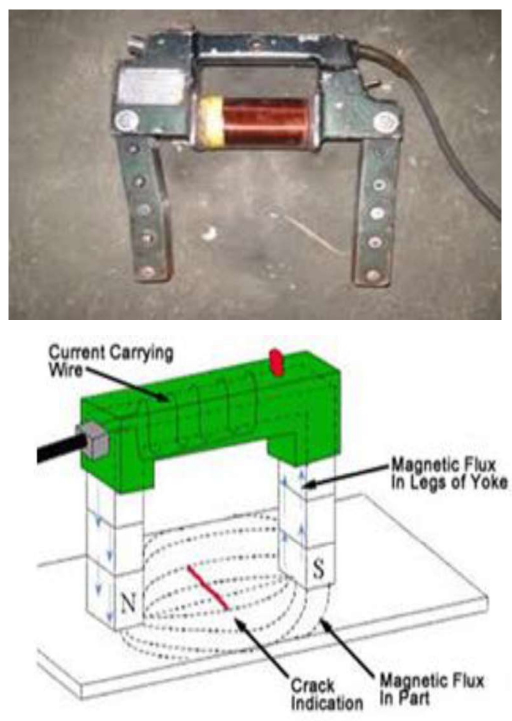

Fig (2) : The electromagnetic yoke coil and its electromagnetic theory.

3.Analysis of Results

This section introduces a discussion on how magnetic field can affect the diffusion flame characteristics of a candle such as flame height , flame deflection , flame quenching and luminosity .

3.1 The effect of the magnetic field on the candle flame height

The simplest example of diffusion flames is a candle flame. Paraffin's vaporized at the wick and diffuses into the surrounding air. Simultaneously, the air flow towards the flame due to free convection forms a mixture with the vaporized paraffin. A free convection flow field is a self-sustained flow driven by the presence of a temperature gradient. As a result of the temperature difference, the density field is not uniform. Buoyancy will induce a flow current due to the gravitational field and the variation in the density field. In general, a free convection heat transfer is usually much smaller compared to a forced convection heat transfer. It is therefore important only when there is no external flow exists.

There are two opposite forces affecting the candle flame which are; gravity force and buoyancy force, as shown in figure (3-a) . By considering the magnetic force, which is acting in the same direction as the buoyancy force, it can be concluded that the buoyancy force is enhanced and becomes dominant . Accordingly the height of the flame is increased due to the existence of the magnetic field as shown in figure (3-b). The average increase in the flame height is about 60 % based on the magnetic field intensity which is of 0.72 Tesla as mentioned earlier.

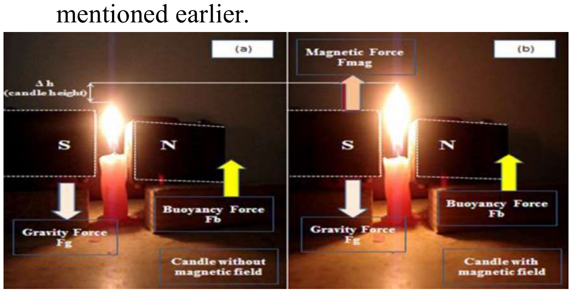

Fig (3) : Effect of electromagnetic yoke on candle flame (a) without magnetic field (b) with magnetic field.

From the previous figure, it is found that the candle flame height could be increased by the presence of the magnetic field. This result is agreed well with Faraday experiment [1] and other published experimental data [3]. Faraday used a permanent magnet only. In the present experiment, the permanent magnet and the electromagnetic yoke are used.

3.2 The effect of the magnetic field on the candle flame deflection

In the present experiment, when the magnet affected the candle, the flame deflected and went away the magnet as shown in figure (4). This phenomenon is known as the flame does not like the magnet.

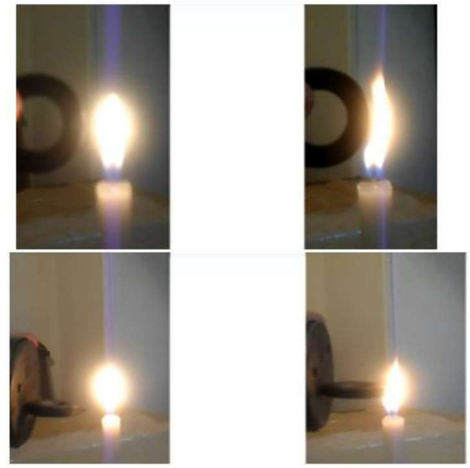

Fig.(4): showing that the candle flame bent to escape from the magnet.

3.3 The effect of the magnetic field on the candle flame quenching

To study the life time of flame before quenching under the present setup, The oxygen level has to be controlled become the limited magnetic strength. So, a Pyrex tube was used to limit the amount of air around the flame as shown in figure (5). In the first trail, the tube is positioned in a way to prevent the air to flow from the bottom side as shown in figure (5). In the second trail, the air is allowed to move from the bottom and from the top of the tube as shown in the figure (6).

Table (1) shows that, the life time before quenching is enhanced when the flame exposed to the magnetic field in both cases.

Table (1) : the life time of the candle flame before quenching with and without magnetic field.

Trail type	The life time before quenching (seconds)	
	Without magnetic field	With magnetic field
First trail	10	22
Second trail	25	45

The longer time of the flame in case of magnetic field could be explained by the increased concentration and better utilization of the oxygen around the candle in this case. To confirm this fact, the oxygen concentration is measured around the flame. Two samples were analyzed by the exhaust analyzer. The concentration of air showed heigh value (25 %) in case of using the electromagnetic yoke coil around the flame compared to normal concentration of 21 %.

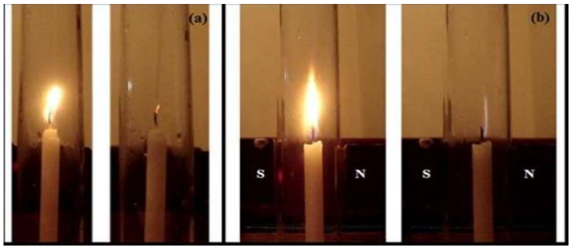

Fig.(5): Candle flame quenching when Pyrex tube was fixed above the candle (no space for air entry from the bottom) (a) without magnetic field (b) with magnetic field.

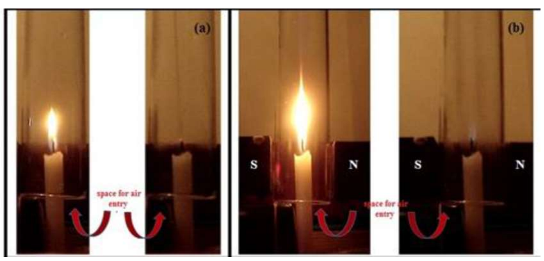

Fig.(6): Candle flame quenching when Pyrex tube was fixed above the candle (with space for air entry from the bottom) (a) without magnetic field (b) with magnetic field.

3.4 Candle flame luminosity & brilliance.

Figure (7) shows the variation of candle flame luminosity and brilliant when using magnetic field. It is shown that flame became more luminous and more brilliant, gradually compared to without a magnetic field, this fact is agreed with the Faraday experiment [1], Gillion and Gilard [13]

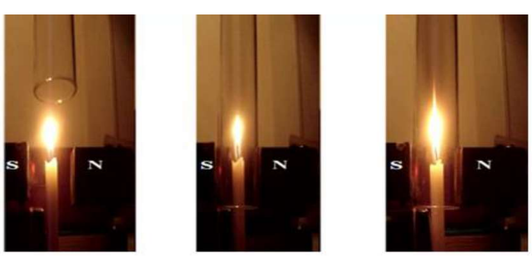

Fig.(7): Comparison between the candle flame without magnetic field (before and after using pyrex tube) and using the magnetic field with pyrex tube.

Conclusions

It is found that the candle flame could be significantly affected by the presence of the magnetic field; this effect appeared in the increasing of the flame height, the luminosity, brightness and the candle flame life time. Because of the oxygen is paramagnetic material, the magnetic field increases the oxygen concentration around the candle flame . This means that there is a complete combustion in the presence of the magnetic field.

References

[1]. M. Faraday, " On the Diamagnetic Conditions of Flame and Gases", The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science, Series 3, Vol. 31, No. 210, December 1847, pp.401-421.

[2]. F. Zantedeschi, " On the Motions Presented by Flame when under the Electro- Magnetic Influence", The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science, Series 3, Vol. 31, No. 210, December 1847, pp.401-424.

[3]. A. V. Engle and J. R. Cozens, "Flame Plasmas," Advances in Electronics and Electron Physics, Vol. 20, 1964, pp. 99-146.

[4]. S. Ueno, "Quenching of Flames by Magnetic Fields", Journal of Applied Physics, Vol. 65, No. 3, February 1989, pp. 1243-1245.

[5]. NASA, Microgravity- A Teacher Guide with Activities in Science, Mathematics, and Technology.EG-1997-08-110-HQ Education Standards Grades 5-8, 9-12.

[6]. N. I. Wakayama "Magnetic Acceleration and Deceleration of O2 Gas Streams 97 Injected into Air", IEEE Transactions on Magnetics, Vol. 31, No.1, January 1995, pp.897-901.

[7]. N. I. Wakayama "Magnetic Promotion of Combustion in Diffusion Flames", Combustion and Flame, Vol. 93, 1993, pp. 207-214.

[8]. S.Kinoshita, T.Takagi, H.Kotera and N. I. Wakayama " Numerical simulation of diffusion flames with and without magnetic field",

[9]. H.D.Ross and R.D.Sotos, " Observation of Candle flames under various atmosphere in microgravity",Combust.Sci. and Tech., vol.75, pp155-160,1991.

[10]. H.D.Ross, R.D.Sotos and J.S. T'ien "Candle flames in microgravity", Combust. Sci. Tech N96-15556, 75:155-160, 1991

[11]. A. Alsairafi, J.S. T'ien ,S.T.Lee, D.L.Dietrich and H.D.Ross," Modeling candle flame behaviour in variable gravity", NASA/CP-2003-212376/REV1

[12]. O.Fujita, K.Ito, T.Chida, S.Nagai and Y.Takeshita," Determination of magnetic field effects on a jet diffusion flame in a microgravity environment", Twenty-Seventh Symposium on Combustion / The Combustion Institute, 1998/pp.2573-2578.

[13]. P. Gillon, W.Badat, V.Gilard and B. Sarh," Magnetic Effect On Flickering Laminar Methane/Air Diffusion Flames ",25 th ICDERS, August 2-7, 2015 ,Leeds, UK

[14]. G.Legros, T.Gomez,M.Fessard,T.Gouche, T.Ader, P.Guibert, P.Sagaut,J.L.Torero," Magnetically induced flame flickering ",Science Direct, Proceeding of the Combustion Institute 33(2011), , pp:1095-1103,

[15]. R. Musalem, P. Reszka, C. Fernández, R. Demarco, J.-L. Consalvi and A. Fuentes," Charaterization of a buoyant candle flame ", MCS7, Chia Laguna, Cagliari, Sardinia, Italy, September 11-15, 2011

[16]. Yunhua Gan, Mei Wang, Yanlai Luo, Xiaowen Chen and Jinliang Xu," Effects of direct-current electric fields on flame shape and combustion characteristics of ethanol in small scale ", Advanced Mechanical Engineering , 2016,Vol.8(I)1-14.

[17]. R.Gunko, " Buoyancy flame ", 24th International Young Physicists' Tournament, third problem of IYPT, 2011.

[18]. R.Anbarafshan, H.Azizinaghsh,R.M.Namin, " Flame in Horizontal electrical field,Deviation and Oscillation ", IYPT, 2011.

[19]. P.B.Sunderland, J.G.Quintiere, G.A.Tabaka,D.Lian and C.W.Chiu," Analysis and measurement of candle flame shapes", ScienceDirect, Proceeding of the Combustion Institute 33 (2011) 2489-2496.

[20]. L.T.Gritter, J.S.Cromption, S.Y.Yushanov and K.C.Koppenheofer , " Analusis of Burning Candle ", Excerpt from the Proceeding of the COMSOL Conference 2010,Boston.

[21]. F. Vera, R.Rivera and C.Nunez , " Burning a candle in a simple Experiment with a long history",Spring Science business media B.V.2011.

[22]. A.Hamins, M.Bundy and S.E.Dillon, " Characterizition of candle flame",Journal of Fire Protection Engineering, Vol.15-November 2005.