The Effect of Temperature on the Breakdown Stress in Saturated Hydrocarbon Liquids

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Abstract:

This work deals with the effect of temperature on the breakdown stress in saturated hydrocarbon liquids which include n-hexane, n-heptane and n-octane under the influence of non-uniform field created by using point-plate electrode geometry. It was found that in a range of room temperature there is no large effect of temperature on the value of breakdown field in comparison with a higher range. Also it was found that the number of carbon atoms in dielectric liquid has an effect on breakdown stress. Finally, it was found that the increase in the number of carbon atoms leads to an increase in breakdown stress as a definite result of increase in the viscosity of the dielectric liquid.

تأثير درجة الحرارة على جهد الانهيار في السوائل الهايدروكاربونية المشبعة

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ملخص البحث :

في هذا البحث تمت دراسة تأثير درجة الحرارة على جهد الانهيار الكهربائي في مجموعة من السوائل الهايدروكاربونية المشبعة والتي تتضمن n-hexane, n-heptane, n-octane تحت تأثير المجال الكهربائي الغير المنتظم والناتج من استخدام منظومة الأقطاب الكهربائية إبرة– صفيحة. حيث وجد انه في مدى درجة حرارة الغرفة لا يوجد تأثير كبير لتغير درجة الحرارة على قيمة المجال اللازم للانهيار الكهربائي مقارنة بدرجات أعلى من هذا المدى، كذلك فقد كان لعدد ذرات الكربون في السائل العازل تأثيرا على جهد الانهيار حيث وجد إن زيادة عدد ذرات الكربون يؤدي إلى زيادة هذا الجهد كنتيجة حتمية لزيادة لزوجة المادة العازلة.

Introduction:

The breakdown mechanism in condensed phases is not really much different than that in the gas phases, only the mechanism of energy loss was changed. The density of liquid hydrocarbons is known to vary over a considerable range depending upon molecular size and shape, thus it is possible to vary the density of a liquid dielectric, not only by pressure change but also by carrying out experiments on a variety of liquid hydrocarbons.

Electrical breakdown of liquid dielectrics is preceded by the growth of streamer in the liquid. Consequently, a great deal of research has been devoted to obtain accurate descriptions of the conditions such as streamer initiation and propagations and streamer velocity which leading defently to electrical breakdown.

Some of these conditions which were observed included electron avalanche [Kattan et.al.,1989], cavitations [Kovobrjnikov and Yanshin 1987], electrostatic parameters acting on the dielectric [Alexeff et. al.,1990] and the effect of temperature which is discussed in this investigation. The most important parameter act on the electrical breakdown of hydrocarbon liquids is the speed of propagation of negative streamers. The studies on such parameters have shown that the form and the speed of negative streamer propagation change dramatically as the streamer propagates across the electrode gap [Stricklett et. al.,1991].

During its initial stages of growth the negative streamer form a complex structure some times referred to as a negative bush type. Both the extent and the dynamics of the bush have been shown to be highly dependent on the ambient pressure [Yamashita et. al.,1990]. The creation of ions in the bulk of the liquid or at the metal electrodes play an important rule in the mechanisms of electrical breakdown processes in dielectric liquids.

Theoretical models have been experimentally verified in polar liquids and in non –polar ones by describing ion injection by a two- step processes, a step of creation of ions at the electrode (the charge transfer step) followed by a step of escape of ions out of the image- force region [Nemamcha et. al.,1987]. The presence of space charge can distort severely the local electric field and can influence strongly the generation and loss of charged particles by ionization and chemical reactions [Yan et. al.,2001].

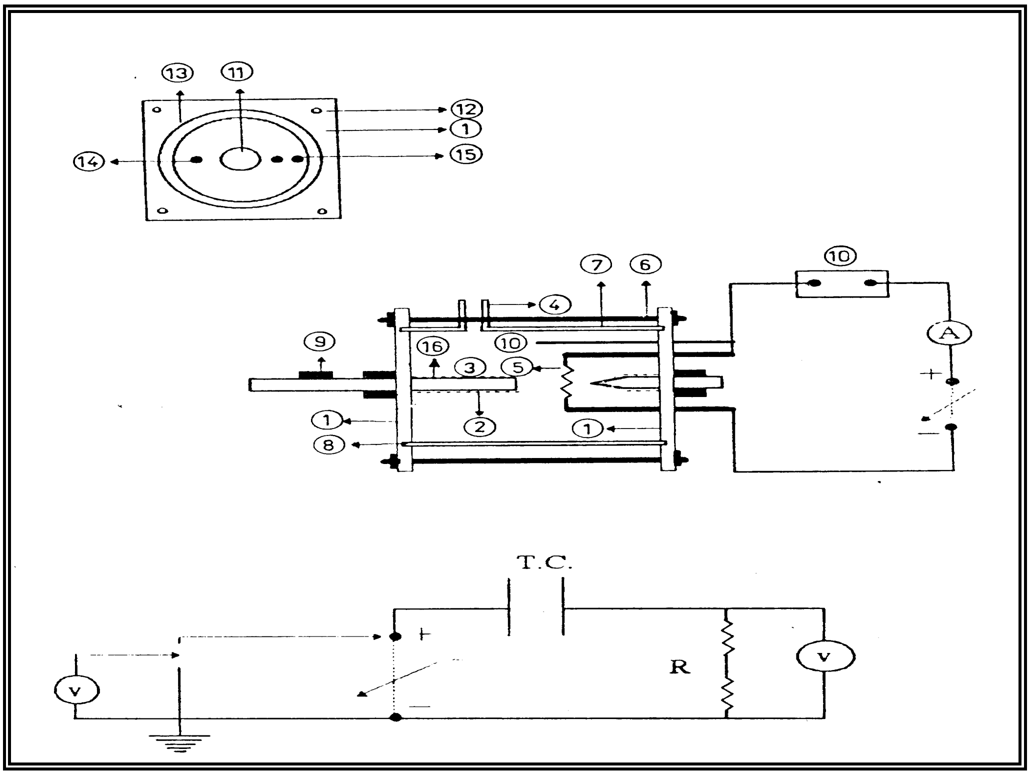
Felici [1979] investigated the behavior of free gas bubbles in an electrically stressed liquid and his basic assumptions of the treatment of bubbles theory are (1) an insulating bubble is subjected only to polarization forces, (2) an ignition bubble behaves like a conducting drop. Ignition conditions are given by Paschens law.

Tsun et. al., [2003] investigated the effect of temperature on the conduction current using two kinds of electrodes (Al and Cu) in an intrinsic aromatic hydrocarbon polymer. They found that both leakage current densities of AL and Cu electrodes are increased with increasing temperatures. Also they found that both leakage current densities using the same system of electrodes, are linearly related to square root of the applied electric field, the linear variations of current densities correspond either to Schottky emission or to Poole-Frenkel type conduction mechanism.

Experimental:

The fluids used in this investigation include n- hexane, n- heptane and n- octane having boiling point 342^{o}k, 370^{o}k and 396^{o}k and carbon atoms number c=6, c=7 and c=8 respectively, addition to have (99.9 mol. % purity).

The test cell was constructed from cylindrical glass envelop(6.0 cm in length and diameter of 4.0 cm) with Teflon basis. The brass electrodes of a radius of curvature of 0.25 mm and a diameter of 8.0 mm for plate one were used, to produce a non- uniform field emission (negative point electrode). Their surfaces were polished to a mirror finish. The electrodes were held in place and electrically isolated with Teflon, having a gap distance of 0.5 mm which was measured and fixed by means of travailing microscope. A general view of the cell assembly is shown in figure (1).



Figure(1): Experimental apparatus (Schematic diagram of the test cell and electrical circuit. A-Ammeter R-Standard Resistor V-Voltmeter 1-Teflon base 2- Brass needle electrode 3-Brass plane electrode 4-Filling port 5-Heater 6-Steel fitting rod 7-Glass envelop 8-Gasget 9-Brush 10-Temperature control 11-Electrode fitting hole 12-Rod fitting hole 13-Test dell setting grove 14-Heater voltage connection 15-Temperature control hole 16-Insulation cover.

The dc voltage applied to the electrodes was obtained from a 12 Kv stabilized dc power supply. For further stabilization in the circuit and an accurate conduction current measurements, we used a standard resistor R of 100.0 μΩ with an error 0.01. A calibrated high tension probe (15 Kv) was used for potential difference measurements, which acts on the test cell and then measured by means of a VTVM. The circuit diagram for setting up the voltage is shown in figure (1).

The liquid cooling was produced by using a mixture of ice granules and Sodium Chloride to reach 278^0K, and liquid heating was achieved through a resistance wire fed by Ac current from power supply.

Temperature control was achieved by using a bimetal temperature control switch connected to the heater circuit. Temperature stability is of better than ± 0.5 degree.

Results and Discussion

From figure (2) we can see that the increase in the number of carbon atoms, increases in length of molecular chain of the tested liquid leads to decreasing in conduction current at a given field strength, which may be attributed to the increase in the density of dielectric liquid as the number of carbon atoms in it increased.

When the density of a dielectric is sufficiently increased, another barrier grows which is called vibration excitation barrier and becomes dominant compared to the excitation barrier at low density.

The probability of vibration excitation starts from zero for very low-energy electrons, increases through a maximum, and again decreases for very high-energy electrons whose interaction time is too short to induce appreciable vibration [Crowe et. al., 1954].

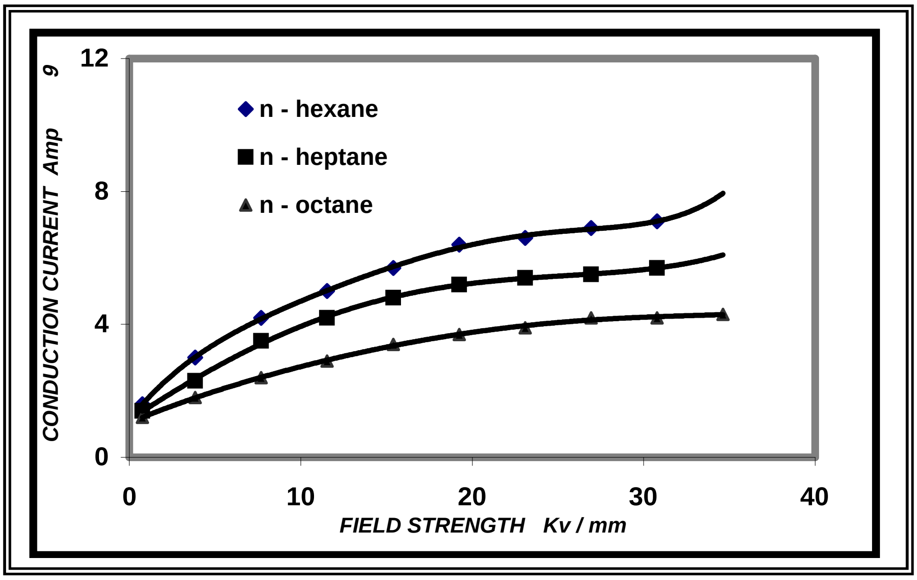


Figure (2) The conduction current as a function of applied electric field at different saturated hydrocarbon liquids (T=303 oK)

Figure (3) shows the dependence of the conduction current in n-hexane on temperature. As can be seen, the conduction current increases systematically with an increase in temperature and no differences were found as a result of changing the direction of the applied voltage. This behavior may be attributed to different mechanisms of electrical conductivity such as molecular dissociation and ionization effect which has been caused by cosmic rays.

In general this phenomenon is similar to that occurring in gases and such processes as avalanche ionization and attachment and detachment of electrons to/from atoms and neutral particles occur. So an increase in the temperature of the liquid usually causes a reduction in the electric strength of the liquid.

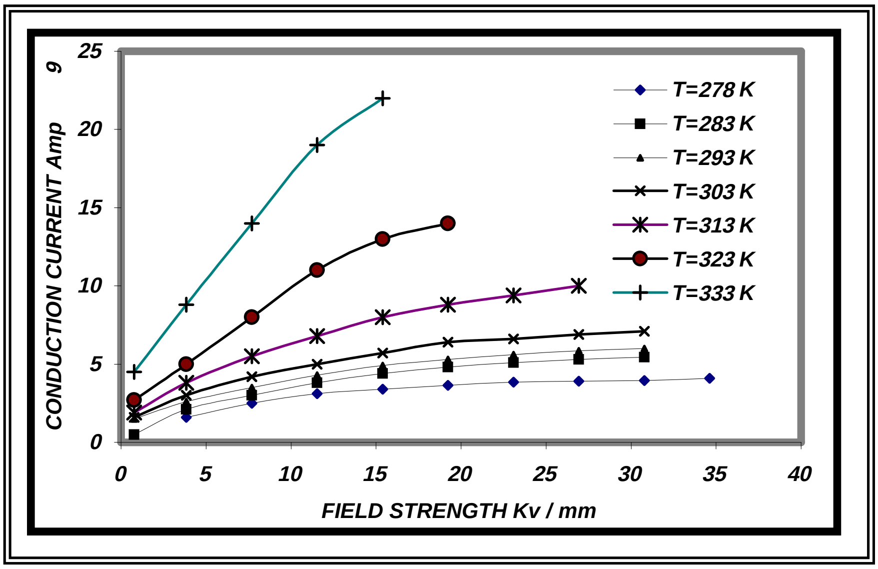


Figure (3) The conduction current as a function of applied electric field at different temperature in n-hexane

The relationship between breakdown stress and temperature is shown in figure (4).It can be seen that above room temperature in which the breakdown stress does not change sharply with temperature, the stress increases rapidly as the temperature is reduced. This behavior could be due to 1) change in the density of the liquid, and as a consequence by a change in the number of c-c bonds which lie in the path of electrons or ions moving in the liquid when subjected to electric field. 2) the formation of gas bubbles on electrodes surface and then elongated of these bubbles in liquid bulk between the two electrodes, however, these bubbles make the transition to a conducting stage much easier.

If stress is further increased, the behavior of bubbles is by no means uniform. Depending on various factors such as the pressure inside and outside the bubble and the stress which act on this bubble, a bubble may or may not experience ignition. So we shall assume ignition to occur when the voltage cross the bubble.

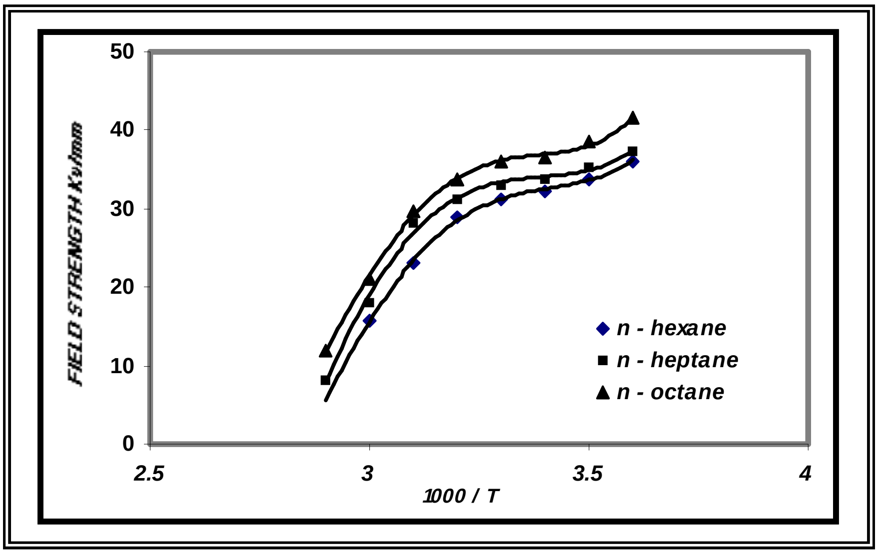


Figure (4) Temperature dependence on breakdown field strength for different saturated hydrocarbon liquids

Conclusion

From our result, we can conclude :

1. There is no effect of temperature on the breakdown stress in a range close to room temperature, but above this range there is a sharp increase in breakdown stress due to increase in the temperature of a tested liquid.
2. The conduction current decreases with an increase in a number of carbon atoms in a given liquid as a result of a change in the length of molecules chain.
3. For a given saturated hydrocarbon liquid, the conduction current increases systematically with increasing temperature.

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