

# Using ethoxylated polyalkylphenol formaldehyde as additive to enhance some physical properties of Egyptian jet fuel A1

A. M. Al Sabagh<sup>1</sup>, E. Azzam<sup>1</sup>, N. M. Nasser<sup>1</sup>, F. T. Abdel Haliem<sup>2</sup> and A. M. El-Shafey<sup>3\*</sup>

<sup>1</sup>Egyptian Petroleum Research Institute, Egypt.

<sup>2</sup>Chemistry Department, Faculty of Science, Egypt.

<sup>3</sup>King Khaled University, Saudi Arabia.

Accepted 23 May, 2016

---

## ABSTRACT

No doubt, petroleum chemistry is one of the most important fields in this century due to its immense several uses and its reflection on the economy. Jet fuel A1, is one of the basic petroleum products, referred to as a kerosene cut. Polymeric surfactant, ethoxylated polyalkylphenol formaldehyde, was prepared based on local raw materials used in petroleum industry. This paper highlights a way of improving some physical properties of the Egyptian jet fuel A1 by adding these polymeric surfactants. They can be used as freezing point depression agents. On the other side these additives are essential to discharge the jet fuel A1 by increasing the electrical conductivity with surface tension reduction to prevent collision of charges, repulsion during refueling and transportation. They also play an axial role to modify the fuel particle size and enhance atomization leads to complete fuel ignition result in indirect rationalization of the fuel consumption.

**Keywords:** Ethoxylated polyalkylphenol formaldehyde, jet fuel A1, freezing point, electrical conductivity, density, calorific values, emulsion stability.

---

\*Corresponding author. E-mail: sommy\_28@yahoo.com.

---

## INTRODUCTION

### Freezing point

Turbine fuels must have low freezing points: -40°C for Jet A and -50°C for Jet A-I and Jet B.

### Electrical conductivity

Higher electrical conductivity is always desired to have high capacitance and high power density in supercapacitors. The electrical conductivity was significantly enhanced with adding polymeric surfactants to fuel (Yang et al., 1991).

### Static electricity generation

The generation of electrostatic charge is intrinsic to many industrial operations. The rate of charge generation is notoriously difficult to predict, however, operations

involving rapid and energetic movement and the contact and separation of surfaces will produce increased charging. Milling of powder, for example, will generate more charge than pouring. In industry charge generation mechanisms are as follows:

- i) The contact and separation of solid surfaces such as moving webs over rollers.
- ii) The movement of personnel.
- iii) The flow/movement of liquids.
- iv) The production of mist or aerosols.
- v) The flow or movement of powders.
- vi) Charging by induction in an electric field.

### Investigation of electrostatic discharge in aircraft fuel tanks during refueling

The development of high levels of electrostatic charge on

JP-4 fuel (Avedisian and Callahan, 2000) or any jet fuel during aircraft refueling is a common occurrence. Whenever a hydrocarbon liquid flows with respect to another surface, a charge is generated in the liquid. Aircraft refueling allows the jet fuel to contact large surface areas due to its passage through pipes, hoses, and filter/separators before entering the aircraft tanks, causing the fuel to become highly charged. JP-4 (as well as other jet fuels) usually possesses a high capacity for accepting a charge (high charge tendency) in conjunction with a low capacity to bleed off the charge (low conductivity). The low conductivity prevents the charge from readily bleeding off to ground, so that fuel enters the tank highly charged. This highly charged fuel may then discharge to ground in the form of sparks, most of which are too low an energy level to ignite the fuel, but some of which may contain sufficient energy to ignite the fuel/air mixture and cause an internal explosion. In addition to a spark of sufficient energy, the fuel/air mixture must be within a flammable range to produce ignitable vapors. For JP-4 fuel, this flammable range, expressed in terms of temperature, extends from  $-35^{\circ}\text{F}$  to approximately  $+60^{\circ}\text{F}$ .

Until recently, the primary charging medium was considered to be the filter/separator used to filter out impurities and to separate water from the fuel during refueling. To a lesser extent the associated piping, valves, and other hardware in the refueling system (Jackson et al., 1991) also contributed to the charge build up. The aircraft plumbing system (primarily the tank inlet, if improperly designed) also has been considered an important mode of generating a static discharge. Based upon these factors, the primary thrust of most static electricity programs has been either to determine the most effective way of reducing the charging capabilities of the filter/separator devices or to determine how the charge imparted by the system can be effectively relaxed to a relatively harmless level. Most Air Force combat aircraft now contain foam inside the fuel tanks to suppress explosions resulting from gunfire, but the question has been raised as to whether the foam causes a significant charge to be generated within these tanks. If so, such a charge could be more serious than that introduced by the refueling system, because the charge relaxation time within the tank becomes virtually nonexistent. In addition, it was felt that if a significant charge should be generated within the tank (Dalton et al., 2003), the addition of antistatic additives that decrease relaxation time might not only be ineffective, but might increase the level of charge and the likelihood of spark discharge if insufficient additive is used.

### Combustion of liquid fuels

Unfortunately, perfect combustion under stoichiometric conditions is seldom achieved in industrial or marine applications. This is particularly true when burning heavy

cracked residual fuels having high aromatic/asphaltene contents and high carbon/hydrogen ratios. Especially, since early 1985s, when the use of residual fuel in boiler plant, large diesel engines and to a limited degree, industrial – type gas turbines, increased rapidly, a large amount of research and development work has been carried out by boiler manufacturers, machinery builders, oil companies, research organizations and others into the mechanism of combustion, fuel injector and burner design, droplet formation during fuel injection, admixture of fuel and combustion air and carbon and ash formation. In large diesel engines, intensive work has been carried out on fuel pump and injector nozzles. Similarly, improved pressure-jet, air and steam-atomizing oil burners have been developed for large oil-fired boilers and furnaces.

### Gross and net calorific value

#### Gross calorific value

The quantity of heat liberated by the complete combustion of a unit of fuel when the water produced is assumed to recondensated as a liquid

#### Net calorific value

The quantity of heat liberated by the complete combustion of a unit of fuel when the water produced is assumed to remain as a vapor and the heat is not recovered:

- a) For coal and oil, the difference between net calorific values (NCVs) and gross calorific values (GCVs) is approximately 5%.
- b) For most natural gas and manufactured gases, the difference is approximately 9 to 10%.

### Combustion dynamics of jet fuel droplets with additives

- i) Prior research to Jp8 has centered on its role as a coolant to improve thermal stability.
- ii) This effort led to development of an additive consisting of blend of detergent/dispersant (Betz 8Q405, 27.3% (volume percent)), butylated – hydroxyl – toluene (BHT, 9.8%), metal deactivator (MDA, 1.2%), and Solvent oil (61.7%) at 256 ppm in Jp8.
- iii) This additive is termed “+100”.
- iv) At the same time, surprisingly little is known about how +100, or other additives for that matter, influences droplet combustion of Jp8 as the present study examine the aspect of improving the combustion of Jet Fuel A<sub>1</sub> by adding non-ionic surfactants.

v) They discussed the combustion dynamics of Jp8 droplets blended with +100 and hexanol ( $C_6H_{14}O$ ).

vi) Specific aspects investigated include the evolution of the droplet, flame, and soot dynamics and how hexanol and +100 influenced these quantities, the sooting propensities of Jp8 +100 and hexanol; and the development of a scaling relationship to consolidate the measurements. Hexanol was chosen as an additive because it has a boiling point close to the range of boiling points of Jp8 constituents at which micro explosions (Hughes, 1980) are not expected to occur; it has a low propensity for water absorption and a higher liquid thermal diffusivity than Jp8 which will reduce the droplet heating period; and the reduced sooting tendency of hexanol compared to Jp8.

vii) In addition to Jp8 and hexanol, pure nonane droplets were used to calibrate the fiber-supporting design with a free droplet method.

viii) Jp8 soots extensively; its multicomponent nature increases the potential for mi-coexplosions which can challenge the interpretation of the data by the difficulty of knowing precisely which species have a dominant role in this process.

ix) As a fuel, Jp8 is at the other end of the spectrum of a miscible binary fuel blended such as the nonane/hexanol mixture (Lovstrand, 1981), which was shown to burn without any of these complex processes.

x) The study demonstrates the extent which spherical symmetry can provide benchmark data for fuel characterization and analysis of a complex fuel system like Jp8, as it has been well known to do for ideal fuel system.

xi) For the experiments the ambient gas was a blend of oxygen with an inert, nitrogen or helium: 21% oxygen (mole percent) in 70% helium.

xii) The higher oxygen concentration in helium was required because of difficulty in spark-igniting the test droplets at lower oxygen concentrations.

xiii) Droplet burning in the 70% He/30%  $O_2$  mixture was included for two reasons.

xiv) It would identify the role of soot formation on the various combustion parameters since in helium sooting tendencies would be greatly reduced, and the higher helium gas thermal conductivity relative to nitrogen would alter heat transfer to the droplets and thereby the droplet burning dynamics, principally the evolution of droplet diameter and the initial droplet heating period.

For example, diesel fuels blended with methanol show measurable reductions in soot formation only above 80% methanol; toluene droplets blended with methanol show nonluminous flames above 75% methanol loading (Von Pidoll et al., 1997); and for 25% hexanol in 75% nonane, soot shells were not formed in nonane/hexanol droplet flames (Lovstrand, 1981). It would be remarkable if +100 mixed at 0.0256% had any impact on sooting tendencies. The hexanol concentrations were selected to give oxygenate loading in Jp8 that would be considered reasonable from an industrial end point. Additives at less

than about 0.10 mass fraction of oxygenate are available for industrial use. Using this as a baseline, a 50% volume fraction concentration of hexanol in Jp8 was selected which corresponds to an oxygenate mass fraction of 0.078 for Jp8 +50 % hexanol.

### Emulsion stability

An emulsion is defined as two immiscible liquids wherein droplets of one phase (the dispersed or internal phase) are encapsulated within sheets of another phase (the continuous or external phase) (James and Charles, 1985). There are two basic forms of emulsion. The first is the oil-in-water (O/W) emulsion in which oil droplets are dispersed and encapsulated within the water column. The second is the water-in-oil (W/O) emulsion in which droplets of water are dispersed and encapsulated within the oil. For either type of stable emulsion to form, three basic conditions must be met:

1. The two liquids must be immiscible or mutually insoluble in each other;
2. Sufficient agitation must be applied to disperse one liquid into the other; and
3. An emulsifying agent or a combination of emulsifiers must be present.

Emulsions have found numerous applications in foods, cosmetics, medicine, paints, hydraulic fluids, asphalt, polymerization, printing, fiber production, metal processing, wood processing, etc (Stiegler, 2000). The effects of surfactants of different chain lengths have been investigated by Ghaicha et al. (1995). The consensus among most investigators is that prolonging the agitation beyond an optimum time does little to improve the quality of the emulsions, and the optimal time varies with different emulsion (Campanelli and Cooper, 1989). Given the ingredients of an emulsion and the emulsifying machine, the most significant parameter that can be varied to produce different emulsions is the stirring intensity. More efficient agitation gives better emulsion. Emulsion formation in simple mixers has been the subject of many detailed studies (Washington, 1996). It has been found that the interfacial area increases with increasing rotational speed and diameter of the stirrer and with decreasing diameter of the container tank. Temperature often has indirect effects on emulsification as a result of altering the interfacial tension, adsorption of emulsifier and viscosity. Because both viscosity and interfacial tension decrease with the increase in temperature, higher temperature is favorable for emulsification. There is also some evidence that a sharp increase or decrease of temperature tends to coagulate the particles, thereby causing the deterioration of emulsions. In recent years, considerable attention has been given by chemical engineers to the determination of the optimum emulsifying temperature for different emulsifiers. The

emulsifying agent may be any surface-active substance which can form a thin interfacial film between the two liquids and maintain the emulsion by minimizing the contact, coalescence and aggregation of the internal dispersed phase. The surfactant should surround the dispersed droplet as a non-adhering film. In water-in-oil emulsions, asphaltene, resins and paraffin waxes act as natural emulsifying agents stabilizing W/O mixture (Zaki et al., 2000). Presumably, these agents provide the required film around the water droplets which resists rupture, thus preventing water-water coalescence (Canvari, 1982). Jerzy and Bengt (1990) pointed out that emulsion stability is dependent on the structure of the surfactant. An effective testing procedure of water-in-oil emulsion stability was investigated by Fingas et al. Their work shows that viscosity provides a more reliable measure of emulsion stability but that water content measurement is more convenient. Fingas et al. also researched the effect of shaking time and water-to-oil ratio on emulsification. They concluded that shaking times longer than 2 h adversely affect the emulsion stability. Emulsifier loses effectiveness with the increased dilution of higher water-to-oil ratio values. Surfactant dosage and the ratio of oil-to-water are important factors influencing the stability of emulsions. However, the effects of these factors strongly depend on the ingredients of the specific emulsion. The preparation of stable water-in-oil emulsion is essential for the production of stable coal oil-water slurry. The effects of several process variables on the stability of oil-in-water emulsion were studied in the present work. The variables included emulsifier dosage, ratio of oil to water, stirring intensity, emulsifying temperature and mixing time, etc.

## **MATERIALS AND METHODS**

### **Used chemicals**

The sources of chemicals used in this study are shown in Table 1.

### **Used jet fuel (jet fuel A1)**

The used jet fuel in this study was submitted by ASORC (Assiut Oil Refining Company). The general physical characterization is shown in Table 2. The GC of the used jet fuel A1 is shown in Figure 1. This batch is straight run product and additives free. Results comply with the requirements of the specification method (Def-stan 91-91 Issue 4(DerD 2494), 2002).

### **Freezing point**

The measurements were carried out in Assiut oil refining company (ASORC), using Haake N2 Supplied

Gallenkamp (Type: 001-0385) & KT Haake Bath (Type: 000-8509), (Figure 2) (Esaton, 2005).

### **Electrical conductivity**

The measurements were carried out in Egyptian Petroleum Research Institute (EPRI), using CRISON conductivity meter 522, INSTRUMENTS, S. A. Barcelona Spain (series C-522, No. 8844, 220 V, 0.1 A, and 50 Hz). All measurements were done in closed system at ambient temperature  $25 \pm 1^\circ\text{C}$ ) using deionized water (HPLC grade) (Esaton, 2005).

### **Gross and net heat of combustion**

The measurements were carried out in Naser Petroleum Company, using bomb calorimeter (Esaton, 2005).

### **Density**

The measurements were carried out in Assiut petroleum company(ASORC), using Digital Density meter DMA 55 INSTRUMENTS, AP PAAR K.G (Series 55, No.8 054, volts 115/220V AC, 1 bar (14 psi) and 40 to 60 Hz). All the measurement were carried out at  $60^\circ\text{F}$  ( $15.6^\circ\text{C}$ ), stability of thermostat  $\pm 0.01^\circ\text{C}$  (Esaton, 2005).

### **Droplet size**

The measurements were carried out in Egyptian Petroleum Research Institute (EPRI), using TOPAS, particle analysis system for liquids, serial no. FAS 360.

### **Preparation of ethoxylated polyalkylphenol formaldehyde**

The preparation of ethoxylated polyalkylphenol formaldehyde is shown in Tables 3 and 4.

### **Emulsion stability**

To determine the emulsion stability of jet fuel A1 against the polymeric surfactant solution: 10 ml of solutions were charged in graduated tube and then 5 ml of jet fuel A1 was added. The ingredients were shaken strongly for 2 min. The stability is determined (in time) after 9 ml of aqueous phase separation (Osipow, 1962).

### **Freezing point**

Freezing point in aviation fuels, the fuel temperature at

**Table 1.** Chemicals used throughout the investigation.

Materials	Source
Al Cl <sub>3</sub> anhydrous, A.R	Aldrich
Benzene, A.R	Aldrich
Coal Tare	EI-Nasr Co. for Coke and Industrial Chemicals, Egypt.
Ethylene oxide	Merk
H <sub>2</sub> SO <sub>4</sub> , A.R	Aldrich
HCl, A.R	Aldrich
n-alkane	Aldrich
n-C <sub>7</sub> to n-C <sub>16</sub>	Aldrich
Na-Metal, 99%	N.A.
Nonene	Aldrich
Dodecene	Aldrich
Formaldehyde, 37%	Heliopolis Company for Chemical Industries, Cairo, Egypt
Technical $\alpha$ -Olefin	EI-Amerya Petroleum Refining Company, Egypt
Xylene, A.R	Aldrich
ZO	A.R, Aldrich

**Table 2.** Characterization of jet fuel A1.

Property	Units	Results	Limits	Method
Appearance:		Pass	Clear, bright and Visually free from solid matter and undissolved water at ambient temperature	Visual
Composition:				
Total acidity	mg KOH/g	0.001	Max. 0.015	IP 354/ASTM D3242
Aromatics hydrocarbon				
Types aromatics	%v/v	17.12	Max. 25.0	IP 156/ASTM D1319
Total aromatics	%v/v	-	Max. 26.5	IP 436/ASTM D6379
Sulfur, total	%m/m	0.16	Max. 0.30	IP 336
Sulfur Mercaptan	%m/m	0.0005	Max. 0.0030	Doctor / ASTM D3227
Doctor test		Negative	Doctor. Negative	IP 30
Refining components at point of manufacture:				
Hydroprocessed components	%v/v	-	Report	
Severely hydroprocessed components	%v/v	-	Report	
Volatility:				
Distillation: Initial Boiling Point	°C	148	Report	
10% recovery	°C	161	Max. 205.0	
50% recovery	°C	175	Report	IP 123/ASTM D86
90% recovery	°C	201	Report	
End point	°C	232	Max. 300.0	

Table 2. Continues.

Residue	%v/v	1.0	Max. 1.5	
Loss	%v/v	1.0	Max. 1.5	
Flash point	°C	39	Min. 38.0	IP 170
Density at 15°C	kg/m <sup>3</sup>	788.7	Min. 775.0 Max. 840.0	IP 365/ASTM D 4052
Fluidity:				
Freezing point	°C	Minus 57	Max minus 47.0	IP 16/ASTM D 2386
Viscosity at minus 20°C	Mm <sup>2</sup> /s	2.9	Max. 8.0	IP 71/ASTM D445
Combustion:				
Smoke point	Mm	26	Min. 25.0	IP 57/ASTM D 1322
Smoke point	mm	-	Min. 19.0	IP 57/ASTM D 1322
And Naphthalenes	%v/v	-	Max. 3.0	ASTM D1840
Specific energy	MJ/kg	43.29	Min. 42.80	
<u>Corrosion:</u>				
Copper Strip	Class	1	Max. 1	IP 154/ASTM D130
Thermal stability. JFTOT at control temperature of 260°C:				
Tube rating visual		0.0	no. Less than 3 No peacock (P) or Abnormal(A) deposits	IP 323/ASTM D3241
Pressure differential	mm Hg	0.0	Max. 25	
Contaminants:				
Existent gum	mg/100 ml	1.4	Max. 7	IP 131/ASTM D381
Water separation characteristics				
Water reaction Interface	Rating	lb	Max.lb	IP 289/ASTM D1094
Microseparometer, at point of manufacture:				
MSEP Without SDA	Rating	98	Min 85	
MSEP With SDA	Rating	-	Min 70	ASTM D3948
Conductivity:				
Electrical Conductivity	pS/m	9	Min 50 Max 450	IP 274/ASTM D2624
Lubricity:				
Wear scar diameter	mm	-	Max 0.85	ASTM D5001

which solid hydrocarbon crystals, formed on cooling, disappear when the temperature of the fuel is allowed to

rise under specified conditions of test. A sample is placed in a jacketed tube fitted with a string rod and

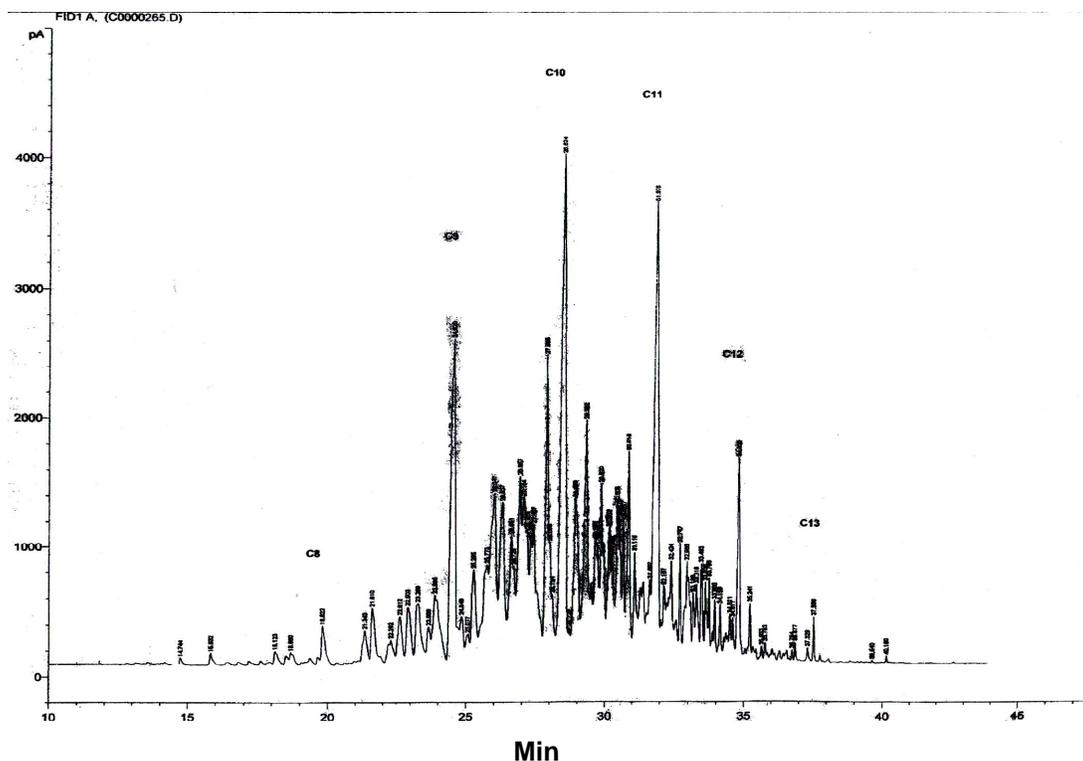


Figure 1. GC. for jet fuel A1.

thermometer. The tube is placed in a low-temperature bath and stirred as the sample cools. When crystals of hydrocarbon appear, the tube is removed from the cooling bath and allowed to warm up slowly with continuous stirring. The temperature at which the hydrocarbon crystals completely disappear is the freezing point (Figure 2). Because it is a mixture of more than a thousand individual hydrocarbons, each with its own freezing point, jet fuel does not become solid at one temperature the way water does. As the fuel is cooled, the hydrocarbon components with the highest freezing points solidify first, forming wax crystals. Further cooling causes hydrocarbons with lower freezing points to solidify. Thus, the fuel changes from a homogenous liquid, to a liquid containing a few hydrocarbon (wax) crystals, to a slush of fuel and hydrocarbon crystals, and, finally, to a near-solid block of hydrocarbons. The freezing point of jet fuel (Esaton, 2005) is defined as the temperature at which the last wax crystal melts, when warming a fuel that has previously been cooled until wax crystals form. Thus the freezing point of fuel is well above the temperature at which it completely solidifies. The primary criterion for fuel system performance is pumpability – the ability to move fuel from the fuel tank to the engine. Pumpability is influenced both by fuel fluidity and fuel system design. In lieu of a fuel system flow simulation test, the industry uses freezing point as an indicator of a fuel's low-temperature pumpability. Jet fuel typically remains pumpable approximately 4 to 15°C (8 to

27°F) below its freezing point.

### Electrical conductivity

Picosiemens per metre, n—the unit of electrical conductivity is also called a conductivity unit (CU). A siemen is the SI definition of reciprocal ohm sometimes called mho.  $1 \text{ pS/m} = 1 \times 10^{-12} \Omega^{-1} \text{ m}^{-1} = 1 \text{ cu} = 1 \text{ picomho/m}$ . Rest conductivity the reciprocal of the resistivity of uncharged fuel in the absence of ionic depletion or polarization. It is the electrical conductivity at the initial instant of current measurement after a dc voltage is impressed between electrodes. Static electrical charge can be generated when dissimilar surfaces move across each other, for example, when fuel moves through a pipe, hose, valve, or fine filter. The rate at which the static charge dissipates is proportional to the liquid's ability to conduct electricity (electrical conductivity). Pure hydrocarbons are essentially nonconductors. While jet fuel is composed of hydrocarbons, it is a slightly better conductor because it contains trace amounts of ionizable compounds, e.g., water, phenols, and naphthenic acids. Ions are electrically charged species. Water ( $\text{H}_2\text{O}$ ), which is electrically neutral, can dissociate to form charged species.  $\text{H}_2\text{O} = \text{H}^+ + \text{OH}^-$ . Conductivity of fuels is usually expressed in conductivity units (CU),  $1 \text{ CU} = 1 \text{ pico Siemens/meter}$  ( $1 \text{ pS/m} = 1 \times 10^{-12} \text{ ohm}^{-1} \text{ meter}^{-1}$ ).

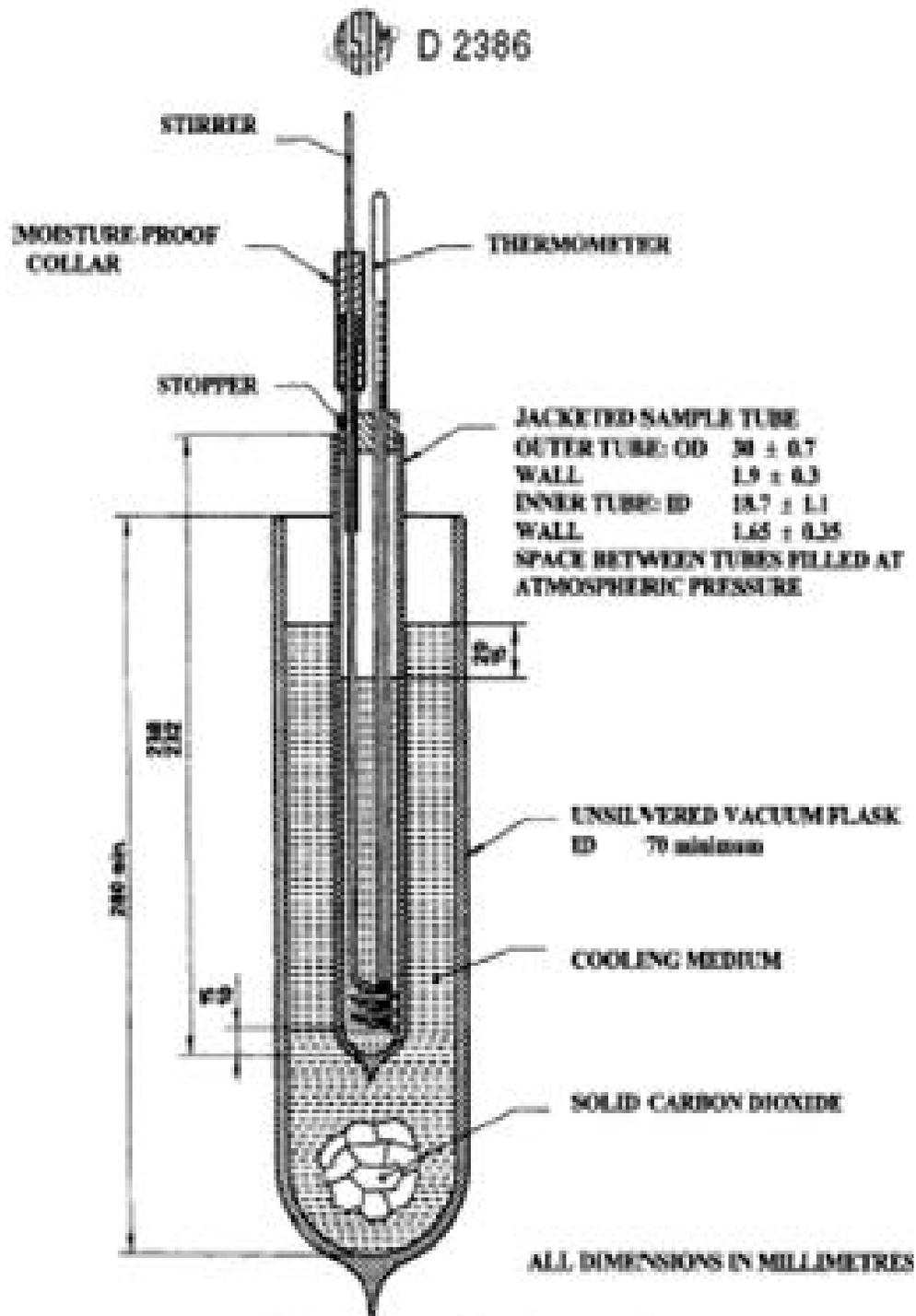


Figure 2. Freezing point apparatus.

Kerosenes may have conductivity ranging from less than 1 CU to perhaps 20 CU. For comparison, deionized water has a conductivity of about 10 million CU. Filtering or rapidly pumping a liquid that is a relatively poor electrical conductor, like jet fuel, can result in a static charge being created much faster than it dissipates. When the

accumulated charge exceeds the ionization potential of the air above the liquid, it can discharge from the liquid surface as a spark (Esaton, 2005). The energy of the spark can initiate an explosion if the liquid is flammable and the composition of vapor and air in the vicinity is in the flammable range. To prevent explosions triggered by

**Table 3.** Chemical structure and molecular weight of polyalkylphenol formaldehyde.

Polymer name	Chemical structure	Abb.	M.wt	n
Polynonyl Formaldehyde	<p style="text-align: center;"><math>C_9H_{19}</math></p>	PNPF <sub>1</sub>	843	3.43
		PNPF <sub>2</sub>	1057	4.35
		PNPF <sub>3</sub>	2044	8.6
Polydodecyl Formaldehyde	<p style="text-align: center;"><math>C_{12}H_{25}</math></p>	PDDPF <sub>1</sub>	1879	6.68
		PDDPF <sub>2</sub>	1980	7.1
		PDDPF <sub>3</sub>	2178	7.77
Poly technical dodecyl phenol formaldehyde	<p style="text-align: center;">R</p>	PTDDPF <sub>1</sub>	2047	7.5
		PTDDPF <sub>2</sub>	2327	8.5
		PTDDPF <sub>3</sub>	2556	9.3

R = alkyl group, n = degree of polymerization (repeating unit).

**Table 4.** Designation of ethoxylated polyalkylphenol formaldehyde.

Polymeric surfactant	Designation	Total no. of (en)*	Total M.Wt
EPNPF	NP <sub>1</sub>	40	2600
	NP <sub>2</sub>	40	2820
	NP <sub>3</sub>	40	3800
EPDDPE	DDP <sub>1</sub>	40	3640
	DDP <sub>2</sub>	40	3740
	DDP <sub>3</sub>	40	3940
EPTDDPF	TDDP <sub>1</sub>	40	3810
	TTDP <sub>2</sub>	40	4110
	TDDP <sub>3</sub>	40	4306

\* en = Ethylene unit.

a static discharge, well designed fuel handling systems use bonding and grounding (or earthing), pumping rate limits, and time for charge dissipation (relaxation time), before the fuel is exposed to air. Military jet fuels and international Jet A1 require the use of an additive to increase the electrical conductivity of the fuel. Conductivity improving additives are also called anti-static additives or static dissipator additives. Use of the additive reduces the hazard of charge accumulation for

handling situations that are less than optimum. The additive does not prevent charge generation, rather it increases the rate of charge dissipation by increasing fuel conductivity. The probe of a portable conductivity meter is immersed in a fuel sample and the conductivity is read from a meter or digital display. A voltage is applied across two electrodes in the fuel and the resulting current expressed as a conductivity value. With portable meters, the current measurement is made almost instantaneously

upon application of the voltage to avoid errors due to ion depletion. Ion depletion or polarization is eliminated in dynamic monitoring systems by continuous replacement of the sample in the measuring cell. The procedure, with the correct selection of electrode size and current measurement apparatus, can be used to measure conductivities from 1 pS/m or greater. The commercially available equipment referred to in these methods covers a conductivity range up to 2000 pS/m with good precision, although some meters can only read to 500 or 1000 pS/m. The CRISON Meter is available with expanded ranges but the precision of the extended range meters has not been determined. If it is necessary to measure conductivities below 1 pS/m, for example in the case of clay treated fuels or refined hydrocarbon solvents, Test Method D 4308 should be used.

### **Gross heat of combustion, Qg (MJ/kg)**

The quantity of energy released when a unit mass of fuel is burned in a constant volume enclosure, with the products being gaseous, other than water which is condensed to the liquid state. Gross heat of combustion is expressed as megajoules per kilogram. The gross heat of combustion at constant volume of a liquid or solid fuel containing only the elements carbon, hydrogen, oxygen, nitrogen, and sulfur is the quantity of heat liberated when a unit mass of the fuel is burned in oxygen in an enclosure of constant volume, the products of combustion being gaseous carbon dioxide, nitrogen, sulfur dioxide, and liquid water, with the initial temperature of the fuel and the oxygen and the final temperature of the products at 25°C. Gross heat of combustion is represented by the symbol Qg.

### **Net heat of combustion, Qn (MJ/kg)**

The quantity of energy released when a unit mass of fuel is burned at constant pressure, with all of the products, including water, being gaseous. A weighed sample of fuel is placed in an oxygen bomb calorimeter under specific conditions. The fuel is ignited and the temperature increase of the calorimeter is used to calculate the heat of combustion (Griffith and Alexander, 1967). Net heat of combustion is expressed as megajoules per kilogram. The net heat of combustion at constant pressure of a liquid or a solid fuel containing only the elements carbon, hydrogen, oxygen, nitrogen, and sulfur is the quantity of heat liberated when a unit mass of the fuel is burned in oxygen at a constant pressure of 0.101 MPa (1 atm), the products of combustion being carbon dioxide, nitrogen, sulfur dioxide, and water, all in the gaseous state, with the initial temperature of the fuel and the oxygen and the final temperature of the products of combustion at 25°C. The net heat of combustion is represented by the

symbol Qn.

### **Density**

Density is the mass per unit volume at a specified temperature. Relative density is the ratio of the density of a material at a stated temperature to the density of water at a stated temperature. Density is a fundamental physical property that can be used in conjunction with other properties to characterize both the light and heavy fractions of petroleum and petroleum products. Determination of the density or relative density of petroleum and its products is necessary for the conversion of measured volumes to volumes at the standard temperature of 15°C. A small volume (approximately 0.7 ml) of liquid sample is introduced into an oscillating sample tube and the change in oscillating frequency caused by the change in the mass of the tube is used in conjunction with calibration data to determine the density of the sample (Esaton, 2005).

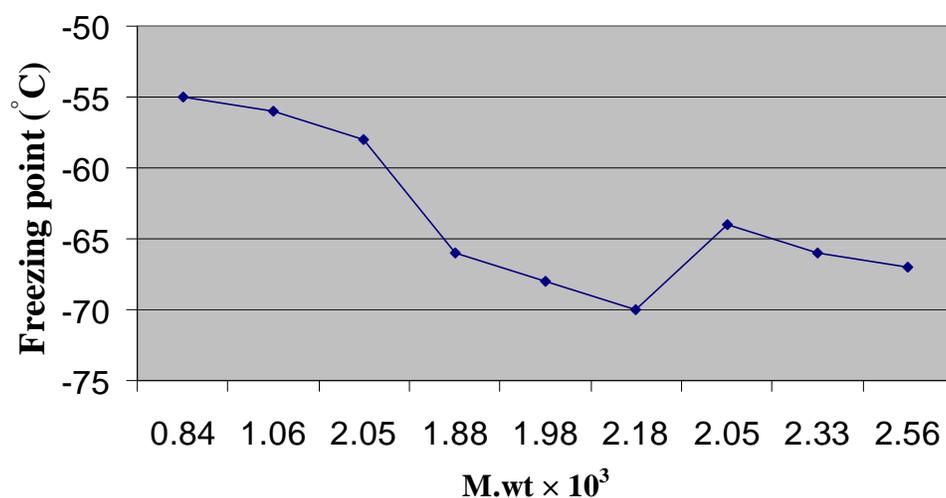
## **RESULTS AND DISCUSSION**

### **Effect of polymeric surfactant additives on freezing point**

Fuel for aviation turbine engines is extracted from crude oil. Molecules in the fuel are hydrocarbons, with a typical molecule containing between 9 and 16 carbon atoms. Jet A-1 (referred to as aviation kerosene), is defined by American Society for Testing and Materials standard (Esaton, 2005). Because it is a mixture of more than a thousand individual hydrocarbons, each with its own freezing point, jet fuel does not become solid at one temperature the way water does. As the fuel is cooled, the hydrocarbon components with the highest freezing points solidify first, forming wax crystals. Further cooling causes hydrocarbons with lower freezing points to solidify. Thus, the fuel changes from a homogenous liquid, to a liquid containing a few hydrocarbon (wax) crystals, to a slush of fuel and hydrocarbon crystals, and, finally, to a near-solid block of hydrocarbons. The freezing point of jet fuel is defined as the temperature at which the last wax crystal melts, when warming a fuel that has previously been cooled until wax crystals form. Thus the freezing point of fuel is well above the temperature at which it completely solidifies. The primary criterion for the fuel system performance is pumpability – the ability to move fuel from the fuel tank to the engine. Pumpability is influenced both by fuel fluidity and fuel system design. Jet fuel typically remains pumpable approximately at 4 to 15°C (8 to 27°F) below its freezing point. The use of additives may prevent the formation of large wax crystals that are responsible for reduced fuel flow.

**Table 5.** Freezing point of the prepared polymeric surfactant.

Polymeric surfactant	Freezing point (°C)	Density at 15°C
Blank Jet Fuel A1	-57	0.7883
NP <sub>1</sub>	-55	0.7893
NP <sub>2</sub>	-56	0.7900
NP <sub>3</sub>	-58	0.7927
DDP <sub>1</sub>	-66	0.7955
DDP <sub>2</sub>	-68	0.8011
DDP <sub>3</sub>	-70	0.8056
TDDP <sub>1</sub>	-64	0.7945
TDDP <sub>2</sub>	-66	0.7969
TDDP <sub>3</sub>	-67	0.8001

**Figure 3.** Freezing point against molecular weight.

The temperature of the fuel in the aircraft tank normally falls during flight depending on aircraft speed, altitude, and flight duration. The freezing point of the fuel must always be lower than the minimum operational tank temperature. Freezing point is a requirement. The freezing points of the undertaken polymeric surfactants are listed in Table 5. The values of freezing points decrease with decreasing surface tension, interfacial tension and dynamic surface tension. As indicated in Table 5 the values of freezing points ranging from  $-55$  to  $-70$ . It was noticed that the polymeric surfactants improved the freezing point of jet fuel A1. The minimum value of freezing point was obtained by DDP<sub>3</sub> which exhibited freezing point;  $-70^{\circ}\text{C}$  which pronounced the minimum value of surface tension as indicated in Table 5. Cyclo paraffin is considered one of the major components in jet fuel A1 (Esaton, 2005), which increases its density and reduces the freezing point up to  $-57^{\circ}\text{C}$ . The prepared polymeric surfactants were screened as freezing point depression agents, after adding polymeric surfactants, the freezing point was

enhanced and decreased up to  $-70^{\circ}\text{C}$  which has a marvelous industrial reflection and enables us of using it for military use the polymer molecular weight play an important role in enhancement the depression of freezing point of Jet Fuel A1 as shown in Figure 3. From the data plotted in this figure, it is clear that the most effective molecular weight of the freezing point was situated between 3640 and 4306. This may be due to a positive synergetic effect caused between the exothylated polymeric surfactants and the cycloparaffin in the jet fuel A1, which decreased the freezing point. Three of these surfactants [NP<sub>1</sub>, NP<sub>2</sub>, NP<sub>3</sub>] exhibited freezing point nearly close with the blank freezing point (F.P =  $-57^{\circ}\text{C}$ ) as shown in Table 5. From this table, it was found that the maximum value of freezing point depression was obtained with DDP<sub>3</sub> (F.P =  $-70^{\circ}\text{C}$ ). Meanwhile the minimum value of freezing point depression was exhibited with TDDP<sub>1</sub> (F.P =  $-64^{\circ}\text{C}$ ). This means that the used polymeric surfactants DDP<sub>1</sub> to DDP<sub>3</sub>, TDDP<sub>1</sub> to TDDP<sub>3</sub> can be used as freezing point depression of the Egyptian jet fuel A1.

**Table 6.** Electrical conductivity of the prepared polymeric surfactants in jet fuel A1.

Polymeric surfactant	Electrical conductivity, pS/m	$\gamma_{J_{cmc}}$ , mNm <sup>-1</sup>
Blank Jet Fuel A1	9	40
NP <sub>1</sub>	13	40
NP <sub>2</sub>	15	38
NP <sub>3</sub>	16	38
DDP <sub>1</sub>	15	37
DDP <sub>2</sub>	18	35
DDP <sub>3</sub>	20	34
TDDP <sub>1</sub>	14	38
TDDP <sub>2</sub>	14	37
TDDP <sub>3</sub>	17	36

### Effect of polymeric surfactant on electrical conductivity

Jet fuel, can result in a static charge being created much faster than it dissipates. When the accumulated charge exceeds the ionization potential of the air above the liquid, it can discharge from the liquid surface as spark. The energy of the spark can initiate an explosion if the liquid is flammable and the composition of vapor and air in the vicinity is in the flammable range. Military jet fuels and international jet A1 require the use of an additives or static dissipater additives. Use of the additive reduces the hazard of charge accumulation for handling situations that are less than optimum. The additive does not prevent charge generation; rather it increases the rate of charge dissipation by increasing the fuel conductivity. Electrical conductivity (pS/m) for the prepared polymeric surfactants are listed in Table 6. The values of electrical conductivity increase with decrease in the surface tension. The static electrical charge can be generated (Heimenz, 1986) when dissimilar fuel surfaces move across each other, for example, when fuel moves through a pipe, hose, valve, or fine filter. The rate at which the static charge (Groves and Scarlett, 1965) dissipates is proportional to the liquid ability to conduct electricity (electrical conductivity). As indicated in Table 6, the values of electrical conductivity, was situated between 13 and 20. The maximum value of electrical conductivity was obtained by DDP<sub>3</sub> (20 pS/m) which exhibited the lowest surface tension (34 mNm<sup>-1</sup>) as indicated in Table 6. Where the minimum value of electrical conductivity was obtained with NP<sub>1</sub> (13 pS/m) which pronounced the highest value of surface tension (40 mNm<sup>-1</sup>) as indicated in Table 6. This observation reflects that the electrical conductivity increases with reducing of the surface tension, further enhances the electrical discharges of jet fuel during refueling the tanks and transportation through the chain. It is very important to discharge of the fuel discharge of the fuel static charges to prevent collision of charges and repulsion. This means that the surfactant undertaken cause enhancement of the fuel electrical

conductivity to avoid the self ignition and explosion (Esaton, 2005).

### Effect of polymeric surfactant additives on density and calorific values

The density and net heat of combustion are important parameters in determining the performance of any aviation fuel. The ASTM standard (Esaton, 2005) for jet A/jet A1 specifies a density, at 15°C, in the range 775 to 840 kg/m<sup>3</sup>, and a net heat of combustion not less than 42.8 MJ/kg. For jet fuel fuels, the net heat of combustion is found to be approximately correlated with density (Akkermans and Briels, 2002). The data in Table 5, show that the density of jet fuel A1 increases by adding the polymeric surfactants. The density was increased by increasing both of molecular weights and the alkyl chain length. The quantity of energy released when a unit mass of fuel is burned in a constant volume enclosure, with the products being gaseous, other than water which is condensed to the liquid state, is gross heat of combustion, Q<sub>g</sub> (MJ/kg). The quantity of energy released when a unit mass of fuel is burned at constant pressure, with all of the products, including water, being gaseous, is named as a net heat of combustion, Q<sub>n</sub> (MJ/kg). The net heat value of the fuel is an important property in relation to its utilization; it is also a difficult property to measure accurately. The gross heat value must first be determined in a bomb calorimeter by an extremely exacting and time consuming technique. Water formed in the calorimeter is condensed and consequently the heat required to transform it and is subtracted from the gross heat to obtain the net heat of combustion.

The usefulness of the net heat value, in combination with difficulty of its determination, gives considerable incentive to the development of methods for estimating the net heating value for simpler properties preferably from the properties that are usually measured as inspection tests on a fuel. Relationships for estimating the net heating value from physical tests have been

**Table 7.** Calorific value of the prepared polymeric surfactants fuel A1.

Polymeric surfactant	Calorific value, MJ/kg		$\gamma_{J_{cmc}}$ , mNm <sup>-1</sup>
	Gross	Net	
Blank jet fuel A1	46.06	43.70	40
NP <sub>1</sub>	44.90	42.80	40
NP <sub>2</sub>	45.40	43.70	38
NP <sub>3</sub>	45.64	43.70	38
DDP <sub>1</sub>	46.37	44.40	37
DDP <sub>2</sub>	47.10	44.80	35
DDP <sub>3</sub>	47.70	45.30	34
TDDP <sub>1</sub>	45.67	43.90	38
TDDP <sub>2</sub>	46.00	44.11	37
TDDP <sub>3</sub>	46.24	44.21	36

developed previously. The values of the calorific values (MJ/kg) are listed in Table 7. The maximum value of gross heat of combustion of the polymeric surfactant was 47.70 MJ/kg against DDP<sub>3</sub> (the net heat of combustion was 45.30 MJ/kg). Meanwhile the minimum gross calorific value was obtained by NP<sub>1</sub> (44.90 MJ/kg) and the net calorific value was (42.80 MJ/kg). The minimum and the maximum exhibited net calorific value were enumerated enhancement with all the used polymeric surfactants except with NP<sub>1</sub>. The gross and net calorific value of NP<sub>1</sub> was smaller than that obtained by the blank jet fuel A1 (43.70 and 42.90 MJ/kg, respectively). By inspection the data of surface tension, it was found that there is a strong relationship between the depression of surface tension and increase of calorific values. Generally, decrease of surfactant tension was accompanied with the increasing both of the gross or the net heat of combustion (calorific value). Addition of these polymeric surfactants to the jet fuel may cause decrease of the fuel surface tension, and further increases atomization (decreasing of fuel droplet size). Hence, the complete combustion could be obtained to increase the net calorific values in comparison to the blank jet fuel A1.

### Effect of polymeric surfactant additives on emulsion stability of jet fuel A1

Emulsification is one of the most important characteristic of the surfactant. Therefore, the emulsifying tendency of the prepared compounds was examined by using water/jet fuel system. Emulsion stability is an important quality creation. Oil phase and water phase is a solution of highly functional hydrocolloids. However, these types of oil in water (o/w) emulsion are inherently unstable due to the difference in specific gravity between the oil droplets and the water medium (Hernandez et al., 1991). Oil can be emulsified and uniformly dispersed, the large difference in the density between the two phases (oil and aqueous) can cause atomization. Reducing the

particle size along with increasing density of oil droplet and viscosity of water phase can enhance the stability of emulsion density of oil can be determined after addition of polymeric surfactants in order to maintain a stable dispersion of the oil (Chanamai and McClements, 2000b). The surface tension( $\gamma$ ) and interfacial tension (IFT) is regarded as the factor playing an important role in emulsion stability (Sherman, 1968; Rousseau, 2000; Sullivan and Kilpatrick, 2002; Marzall, 1976). Low surface tension ( $\gamma$ ) or interfacial tension (IFT) is necessary for emulsion formation but it is not the only factor for emulsion stability (Marzall, 1976). The stability of this emulsion is not conditioned to be high as the Zeta potential (O'Brien and White, 1978; Hunter, 1981) is small and the stability of emulsion require high value of Zeta potential to make stabilize of the electrical double layer (Tocanne and Teissie, 1990; Bivas, 2006). The average droplet size was, thus, affected by the components in the water phase/oil phase system. These findings suggest that an explanation is that the dynamics of the necking and droplet formation is an important and sometimes determining factor (Zhang and Stone, 1997).. The force imposed by the interfacial tension dynamically interacts with the viscous forces in the rapid event of the necking of the droplet. One common way to characterize the size distribution of the emulsions is the use of the parameters that indicate the dispersion, such as droplet size (Ruiz et al., 2002). The average droplet size varied from 17 to 23  $\mu\text{m}$ , and was affected by the characteristics of the surfactant and the viscosities of the oil and water phases (Ruiz et al., 2002). The average droplet size decreased with increasing size of the hydrophobic group of the surfactant. The emulsions were formed using the polymeric surfactant at 0.1% conc. The stability and droplet size are shown in Table 8.

The jet fuel A1 was emulsified in water and the pronounced milky emulsion was remarked by minutes. From the presented results, it was found that the emulsion stability and droplet size decreases by increasing the molecular weight of surfactants. The

**Table 8.** Emulsion stability of polymeric surfactants at 0.1% concentration.

Polymeric surfactant	Stability time, min	$\gamma_{J_{cmc}}$	$\gamma_{W_{cmc}}$	Droplet size ( $\mu\text{m}$ )
Jet	- ve	40	71.5	
NP <sub>1</sub>	37	40	36	20
NP <sub>2</sub>	26	38	34	18
NP <sub>3</sub>	18	38	33	15
DDP <sub>1</sub>	20	37	32	17
DDP <sub>2</sub>	15	35	31	14
DDP <sub>3</sub>	10	34	29	10
TDDP <sub>1</sub>	25	38	33	18
TDDP <sub>2</sub>	20	37	31	16
TDDP <sub>3</sub>	17	36	30	12

stability also decreased by the increasing of the alkyl chain length of the polymer skeleton. The stability of jet emulsion and droplet size were strongly related to the surface tension ( $\gamma$ ) of these surfactants in both jet and water media ( $\gamma_{J_{cmc}}$  and  $\gamma_{W_{cmc}}$ , respectively). The minimum emulsion stability was marked for DDP<sub>3</sub> (10 min.), which exhibited the minimum droplet size (10  $\mu\text{m}$ ) at the same time the maximum reduction of surface tension ( $\gamma$ ) for DDP<sub>3</sub> was obtained in both jet and water (34 and 29  $\text{mNm}^{-1}$ ). This observation is consistent with others (Sherman, 1968). Generally, the group DDP<sub>1</sub> to DDP<sub>3</sub> exhibited the minimum emulsion stability (20, 15 and 10 min), the minimum droplet size (17, 13 and 10  $\mu\text{m}$ ) and pronounced the maximum reduction of surface tension. Otherwise the maximum emulsion stability was remarked with group NP<sub>1</sub> to NP<sub>3</sub> (37, 26 and 18 min) and the maximum droplet size (20, 18, 15  $\mu\text{m}$ ), respectively, at the same time they exhibited the minimum reduction of surface tension. The minimized of IFT or surface tension ( $\gamma$ ) could be done good emulsion, but the O/W interface layer becomes very weak, so that the formed emulsion becomes unstable and is quickly resolved.

In the emulsion system, the ionic and nonionic surfactant layers adsorbed on the particle or droplet surfaces to modify the electrostatic, Vander Waals and steric interactions (Ruiz et al., 2002; Ivanov and Kralchevsky, 1997; Robins et al., 2002; Vincent, 1974; Ivanov et al., 1999), as well as the degree of hydrophobicity or hydrophilicity of the surfaces (Snoswell et al., 2003), so that their presence can strongly affect the rupture of the thin liquid films (Pugh, 1996). The influence of surfactants strongly depends on the length of hydrocarbon chains that changes the attraction dispersion and causes depletion flocculation (Leal-Calderon et al., 1997). Due to the multiple influences of adsorbed layers on the interfaces, they may give rise to both stabilization and destabilization of emulsions (Morrison, 1993). From emulsion formation of jet fuel, and depression of surface tension or interfacial tension, it can be concluded that the added polymers as a surfactants to

the jet fuel play an important role to modify the fuel particle size and enhances the atomization of fuel through spray. The modification of the fuel particles size (minimize the fuel particles) leads to complete ignition of the fuel in the ignition chamber. It is also necessary to stress that the notion about electrical double layer supposes that the charges on the droplet surface are smoothly distributed.

## REFERENCES

- Akkermans RLC, Briels WJ, 2002.** A structure-based coarse-grained model for polymer melts. *J Chem Phys*, 114: 1020-2001.
- Avedisian CT, Callahan BJ, 2000.** Experimental study of nonane/hexanol mixture droplet combustion without natural or forced convection. *Proc Combust Inst*, 28: 991-997.
- Bivas I, 2006.** Electrostatic and mechanical properties of a flat lipid bilayer containing ionic lipids: Possibility for formation of domains with different surface charges. *Colloids Surf A: Physicochem Eng Aspects*, 283: 423-434.
- Campanelli JR, Cooper DG, 1989.** Interfacial viscosity and the stability of emulsions. *Can J Chem Eng*, 67(5): 851-855.
- Canvari GP, 1982.** The formulation of an effective demulsifier for oil spill emulsions. *Marine Pollut Bull*, 13: 49-54.
- Chanamai R, McClements DJ, 2000b.** Impact of weighting agents and sucrose on gravitational separation of beverage emulsions. *J Agric Food Chem*, 48: 5561-5565.
- Dalton AB, Collins S, Munoz E, Razal JM, Ebron VH, Ferraris JP, Coleman JN, Kim BG, Baughman RH, 2003.** Super-tough carbon-nanotube fibres. *Nature*, 423: 703.
- Def-stan 91-91 Issue 4 (DerD 2494), 2002** Joint fueling systems "checklist" specification for jet A-1 Issue 19 Date Sept. 2002. (Except conductivity).
- Esaton MD, 2005.** Annual Book of ASTM Standards, Petroleum Products and Lubricants, D2386 Standard Test Method for Freezing point of Aviation Fuels, 5 (1).
- Esaton MD, 2005.** Annual Book of ASTM Standards, Petroleum Products and Lubricants, D2624 Standard Test Methods for Electrical conductivity of Aviation and Distillate Fuels, 5 (1).
- Esaton MD, 2005.** Annual Book of ASTM Standards, Petroleum Products and Lubricants, D 4809 Standard Test Method for Heat of Combustion of liquid Hydrocarbon Fuels by Bomb Calorimeter (Precision Method), 5 (2).
- Esaton MD, 2005.** Annual Book of ASTM Standards, Petroleum Products and Lubricants, D4809 Standard Test Method for Density and Relative Density of liquids by Digital Density Meter; 5 (2).
- Esaton MD, 2005.** Annual Book of ASTM Standards, Petroleum

- Products and Lubricants, D4865-98 standard Guide for generation and Dissipation of Static electricity in petroleum fuel systems, 5 (2).
- Esaton MD, 2005.** Annual Book of ASTM Standards, Petroleum Products and Lubricants, D1298-99 Standard Test method for Density, Relative Density (Specific) Gravity, or API Gravity of Crude petroleum and Liquid Petroleum Products by Hydrometer Method, 5 (1).
- Ghaicha L, Leblanc RM, Villamagna F, Chattopadhyay AK, 1995.** Monolayers of mixed surfactants at the oil-water interface, hydrophobic interactions, and stability of water-in-oil emulsions. *Langmuir*, 11(2): 585–590.
- Griffith JC, Alexander AE, 1967.** Alexander, Equilibrium adsorption isotherms for wool/detergent systems: I. The adsorption of sodium dodecyl sulfate by wool. *J. Colloid Interface Sci*, 25: 311-316.
- Groves MJ, Scarlett B, 1965.** Polyhedral emulsion particles. *Nature*, 207: 288.
- Heimenz PC, 1986.** Principles of Colloid and Surface Chemistry. 2nd ed.; Marcek Dekker, Inc.: New York, pp: 385-398.
- Hernandez E, Baker RA, Crandal PG, 1991.** Model for evaluating turbidity in cloudy beverages. *J Food Sci*, 56(3): 747–750.
- Hughes JF, 1980.** Electrostatic charges on board ships. *Transactions of Institute of Marine Engineers*. 92: 38-44.
- Hunter RJ, 1981.** Zeta Potential in Colloid Science, Academic Press, London/San Francisco.
- Ivanov IB, Danov KD, Kralchewski PA, 1999.** Flocculation and coalescence of micron-size emulsion droplets *Colloids Surf, A Physicochem Eng Asp*, 152:161-182.
- Ivanov IB, Kralchevsky PA, 1997.** Stability of emulsions under equilibrium and dynamic conditions *Colloids Surf*, 128: 155-175.
- Jackson GS, Avedisian CT, Yang JC, 1991.** Soot formation during combustion of unsupported methanol/toluene mixture droplets in microgravity. *Proc Royal Soc London Ser A*, 435: 359–368.
- James RP, Charles RP, 1985.** Petroleum Spills. p. 3.
- Jerzy K, Bengt K, 1990.** On the formation and stability of concentrated water-in-oil emulsions, aprons. *Colloid Surf*, 50: 131–140.
- Leal-Calderon F, Mondain-Monval O, Pays K, Royer N, Bivette J, 1997.** Water-in-oil emulsions: Role of the solvent molecular size on droplet interactions. *Langmuir*, 13: 7008-7011.
- Lovstrand KG, 1981.** The ignition power of brush discharges — experimental work on the critical charge density. *J Electrostat*, 10: 161–168.
- Marzall L, 1976.** Adsorption of nonionic surfactants at the oil-water interface and emulsion inversion point. *Colloid Polym Sci*, 254: 674-675.
- Morrison ID, 1993.** Electrical charges in nonaqueous media. *Colloids Surf, A Physicochem Eng Asp*, 71: 1–37.
- O'Brien R, White LR, 1978.** Electrophoretic mobility of a spherical colloidal particle. *J Chem Soc, Faraday Trans 2*, 74: 1607-1626.
- Osipow LI, 1962.** Surface Chemistry. Reinold, New York, Chap. p. 11.
- Pugh RJ, 1996.** Foaming, foam films, antifoaming and defoaming. *Adv Colloid Interface Sci*, 64: 67-142.
- Robins MM, Watson AD, Wilde PJ, 2002.** Emulsions—creaming and rheology. *Curr Opin Colloid Interface Sci*, 7: 419–425.
- Rousseau D, 2000.** Fat crystals and emulsion stability — a review. *Food Res Int*, 33: 3-14.
- Ruiz MC, Lermada P, Padilla R, 2002.** Drop size distribution in a batch mixer under breakage conditions. *Hydrometallurgy*, 63: 65–74.
- Sherman P, 1968.** Emulsion Science. Academic Press, New York.
- Snoswell D, Duan J, Fornasiero D, Ralston J, 2003.** Colloid stability and the influence of dissolved gas. *J Phys Chem B*, 107: 2986-2994.
- Stiegler U, 2000.** An application of nuclear emulsions with automatic scanning. *Nuclear Instr Method Phys Res Sect A: Accel Spectromet Detect Assoc Equipm*, 454(1): 197– 200.
- Sullivan AP, Kilpatrick PK, 2002.** The effects of inorganic solid particles on water and crude oil emulsion stability. *Ind Eng Chem Res*, 41: 3389-3404.
- Tocanne JF, Teissie J, 1990.** Ionization of phospholipids and phospholipid-supported interfacial lateral diffusion of protons in membrane model systems. *Biochim Biophys Acta Rev Biomembr*, 1031: 111-142.
- Vincent B, 1974.** The effect of adsorbed polymers on dispersion stability. *Adv Colloid Interface Sci*, 4: 193–277.
- Von Pidoll U, Kramer H, Bothe H, 1997.** Avoidance of electrostatic hazards during refuelling of motorcars. *J Electrostat*, 41: 523–528.
- Washington C, 1996.** Stability of lipid emulsions for drug delivery. *Adv Drug Delivery Rev*, 20(2-3): 131–145.
- Yang JC, Jackson GS, Avedisian CT, 1991.** Combustion of unsupported methanol/dodecanol mixture droplets at low gravity. *Proc Combust Inst*, 23: 1619-1625.
- Zaki N, Schorling PC, Rahimian I, 2000.** Effect of asphaltene and resins on the stability of water-in-waxy oil emulsions. *Petrol Sci Technol*, 18(7): 945–963.
- Zhang DF, Stone HA, 1997.** Drop formation in viscous flows at a vertical capillary tube. *Phys Fluids*, 9: 2234-2242.

---

**Citation:** Sabagh AM-Al, Azzam E, Nasser NM, Abdel Haliem FT, El-Shafey AM, 2016. Using ethoxylated polyalkylphenol formaldehyde as additive to enhance some physical properties of Egyptian jet fuel A1. *Afr J Eng Res*, 4(2): 11-25.

---