Al-Mustansiriyah Journal of Science
ISSN: 1814-635X (print) 2521-3520 (electronic)

ORIGINAL ARTICLE

OPEN ACCESS

Effect of Changes in the Concentrations of Sodium Chloride, Sodium Bicarbonate, and Citric Acid on the Surface Tension and Viscosity of Solutions of Certain Polymers

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ARTICLE INFO
Received: August 27, 2024
Revised: December 22, 2024
Accepted: January 05, 2025
Published: March 30, 2025

ABSTRACT: ***Background:*** *The polymer's improved properties enable its application in numerous fields. Different concentrations of sodium chloride (NaCl), citric acid ($C_6H_8O_7$), and sodium bicarbonate ($NaHCO_3$) were added to aqueous solutions of the following polymers: Polyacrylamide (PAM), Polyanionic cellulose low viscosity (PACLV), Carboxymethylcellulose low viscosity (CMCLV), and Polyethylene glycol (PEG) and Polyvinylpyrrolidone (PVP), It was added to know the effect of the additives on the polymers of the samples studied and which ones improve the properties of the polymers more than others.* ***Objective:*** *The objective of this work is to improve certain physical properties of the polymers used in the samples.* ***Methods:*** *The weights of the droplets of the solutions were measured, and the time of its flow. Surface tension and surface tension force and energy were calculated, and relative viscosity, specific viscosity, reduced viscosity, inherent viscosity, and intrinsic viscosity were calculated.* ***Results:*** *The results obtained indicate an increase in the surface tension, where the change in concentrations of citric acid $C_6H_8O_7$ caused the largest increase to the surface tension of the solutions, while the surface tension of the solutions increased less when changing the concentrations of $NaHCO_3$ and the increase in surface tension in the case of changing the concentrations of NaCl was less than changing the concentrations of both $C_6H_8O_7$ and $NaHCO_3$. Also, the relative viscosity of the polymer solutions increased.* ***Conclusions:*** *The effect of increasing concentrations of NaCl and $C_6H_8O_7$ and $NaHCO_3$ in the solutions were in different quantities depending on the polymer they affect, and this diversity and difference in the effect of the additives can be used in many fields such as those in the medical or industrial field, scientific research and oil fields.*

KEYWORDS: *Citric acid; Polymers; Sodium bicarbonate; Sodium chloride; Viscosity*

INTRODUCTION

Polyacrylamide has wide applied interest and unique characteristics, including high water solubility, high viscosity, and efficient flocculation capabilities. These properties make them valuable in various sectors, such as agriculture, wastewater treatment, mineral processing industries, water treatment, enhanced oil recovery (EOR) technologies, nanoparticle stabilization, and electrophoresis-induced sputtering separation purification. [1], [2]. Polyacrylamide is a carbon chain polymer with a side amide group, it is a water-soluble synthetic polymer that has useful properties such as good adhesion, good hygroscopicity, high hydrophilicity, and non-toxicity [3].

Polyethylene glycol (PEG) is a versatile polymer with exceptional properties that favor its abundant use in different applications. It is widely used in the food industry, various biomedical and pharmaceutical applications, and many everyday products such as cosmetics [4]. Polyvinylpyrrolidone (PVP) known as polyvidone or povidone is a synthetic polymer made of linear 1-vinyl-2-pyrrolidone groups, it is an amorphous polymer of high molecular weight, high melting point, thermoset, easily soluble in water, many solvents organic, non-toxic, biocompatible, chemically inert, temperature resistant, pH stable, colorless non-ionic polymer and has been widely used in nanoparticle synthesis

[5]–[7]. PVP can be used as a brace component for gene delivery, orthopedic implants, and tissue engineering applications. Depending on different molecular weights and modified forms, it can produce outstanding beneficial characteristics with distinct chemical properties [8].

Carboxymethylcellulose (CMC) is an anionic, water-soluble derivative of cellulose, a linear anhydrous glucose polysaccharide. The main difference between CMC and cellulose is only the presence of some anionic carboxymethyl groups (-CH_2COOH) in the CMC structure which replace the hydrogen atoms of some hydroxyl groups present in the virgin cellulose infrastructure [9]. Polyanionic cellulose (PAC) has high substitution capacity and purity and is often used as a rheumatism modifier. At the same time, polyanionic cellulose has excellent thermal stability, salt resistance, and strong antibacterial properties. It is widely used in high-temperature deep wells [10]. Sodium chloride (NaCl) is the most common and essential salt used in chemical industries, food production, and medical applications. The chemical industry consumes more than 60% of the total production, making it the largest user of salt. This industry is mainly concerned with the transformation of salt into chlorine, caustic soda, and sodium carbonate, which are used in various applications such as oil refining, petrochemicals, organic synthesis, glass manufacturing, etc. [11]. Sodium bicarbonate ($NaHCO_3$) plays an important role in emulsion meat products by improving the functional properties of proteins, enhancing flavor, and inhibiting the growth of microorganisms, all of which determine the color, water holding capacity, texture, flavor, and shelf life of the final product's meat. $NaHCO_3$ is a food ingredient that contains a synergistic anion, HCO_3 [12]. Citric acid is a weak organic acid that is naturally found in all citrus fruits. Citric acid in its pure form is easily soluble in water and is colorless. It is solid at room temperature [13]. Citric acid is an organic, non-toxic, and biodegradable acid, that is widely used in the food industry and many other industries, such as biomedical, pharmaceutical, leather, and textile [14].

Surface tension is one of the parameters determining combustion efficiency. It is also an important property of new synthesized surfactants applied during fuel treatment. Furthermore, surface tension has an impact on the hydraulic characteristics of transport equipment. Since clouds contain extremely small water droplets and ice particles, surface effects must be taken into account [15] Viscosity, or the internal friction of fluid molecules, belongs to the class of transport phenomena associated with the motion of molecules in liquid or gas materials that create internal molecular resistance to motion [16] Al-Bakri *et al.* The surface tension of the cationic surfactant Benzyledimethylhexadecyl ammonium chloride (BAC) as a function of its concentration was measured. The effect of the addition of sodium chloride and Calcium chloride, at concentrations between 0.1-0.3 M and temperatures in the range of 10–50 °C was investigated. In addition, the surface tension of a mixture of BAC with different concentrations and a fixed amount of the anionic surfactant of sodium dodecyl benzene sulfonate (SDBS) was measured a maximum of the observed peak was found to decrease with increasing temperature and the addition of NaCl salt [17]. Metaxas *et al.* Microfluidic filament stretching studies demonstrate that extensional viscosity increased with increasing NaCl concentration [18]. Hussein *et al.* The viscosity of all uncured samples was measured using a viscometer. The density decreased as the content of sodium bicarbonate increased while the viscosity slightly increased as the blowing agent increased.[19] Libel *et al.* Electrospun fibers of poly(vinyl alcohol) (PVA) cross-linked with citric acid (CA) and incorporated with C16MImCl ionic liquid (IL) were successfully fabricated. The IL decreased the surface tension of the polymer solution from 47.40±1 mN/m for PVA/CA to 35.84±1 mN/m for PVA/CA/IL, also providing slight reductions in electrical conductivity and viscosity. Consequently, enhanced stability in the electrospinning process was achieved, resulting in homogeneous fibers without beads [20]. The aim of this work is to improve certain physical properties of the polymers used in the samples.

MATERIALS AND METHODS

Materials

The solutions of PAM (Mw (50% in H_2O), PVP, PEG, CMC LV, and PAC LV used in the present work were PAM, PVP, and PEG supplied by Sigma-Aldrich GMBH, but PACLV and CMCLV supplied by National Oil Corporation Jowfe Oil Technology. Sodium bicarbonate, sodium chloride, and Citric acid were used to prepare the samples for this article.

Manufacture of Citric Acid

Squeeze the lemon in a graduated laboratory, add the same amount of water, and then slowly add the soda. The mixture is filtered and a calcium chloride solution is added and a precipitate of calcium citrate is formed. Boil for two minutes and filter. Then sulfuric acid is slowly added, calcium sulfide precipitates, and citric acid is formed. It is filtered with filter paper and the acid is concentrated over low heat to form crystals that are dried in an oven [21].

Samples Preparation

To prepare the solution, dissolve 3 grams of polyacrylamide, polyethylene glycol, polyvinylpyrrolidone, carboxymethylcellulose, or polyanionic cellulose, then add citric acid, sodium bicarbonate, or sodium chloride to the solutions by weight (0, 1.5, 3.0, 4.5, 6.0, 7.5 grams) and stir solutions for one hour at room temperature (30 °C).

Measurements

1 Surface Tension

Using the droplet weighing method, a small amount of droplets was collected and the average mass of the droplet was found. The average radius of the drop was determined, then the surface tension (γ) relative to air was determined and expressed in measured values as follows [22]:

$$\gamma = \frac{\mathrm{m\ g}}{2\pi \mathrm{r}} \tag{1}$$

where m=average drop mass, g=9.8 ms^{-1} and r = inner radius of the tube used 5 mm. All measurements were carried out at room temperature (30 °C).

The surface tension force (F) and surface tension energy (E) can be calculated respectively by the following equations [23], [24].

$$F = 4\pi\ r\ \gamma \tag{2}$$

$$E = \gamma\ A \tag{3}$$

and A is a surface area

2 Viscosity

To determine the flow time of the solutions, the methodology presented in ASTM was used. The flow times of the samples were measured using a glass capillary viscometer at room temperature (30 °C), and then the measured values were expressed in terms of relative (η_r), specific (η_{sp}), reduced (η_{red}), inherent (η_{int}) and intrinsic (η) viscosities of all samples as follows [25]–[29]:

$$\eta_r = \frac{t_{solution}}{t_{solvent}} \tag{4}$$

$$\eta_{sp} = \eta_r - 1 \tag{5}$$

$$\eta_{red} = \frac{\eta_{sp}}{C} = \frac{\eta_r - 1}{C} \tag{6}$$

$$\eta_{inh} = \frac{Ln\ \eta_r}{C} \tag{7}$$

$$[\eta] = \frac{(2(\eta_{sp} - \ln \eta_{rel}))^{\frac{1}{2}}}{C} \tag{8}$$

where C is the mass concentration of ZnO nanoparticles, a solvent is the flow time of the pure solvent, and a solution is the flow time of the samples. Then, the Schulz-Blaschke constant ($\mathrm{K_{sb}}$) is calculated by the equation (9) [10], [30]:

$$\eta_{red} = [\eta] + K_{sp}[\eta]\eta_{sp} \tag{9}$$

RESULTS AND DISCUSSION

Surface Tension

Figure 1 represents the relationship between surface tension and concentrations of citric acid, sodium bicarbonate, and sodium chloride for solutions of all polymers used in this manuscript. Figure 1(a) shows that all additives caused an increase in the surface tension of the solutions of PAM, where sodium bicarbonate had the largest increase in the surface tension of the PAM solutions, then citric acid increased the surface tension in lower quantities than sodium bicarbonate and greater than sodium chloride, which had the least increase in the surface tension of the solutions. The effect of changing the concentrations of (NaCl), ($C_6H_8O_7$), and ($NaHCO_3$) in the solutions of (PACLV) is observed in Figure 1(b), where (NaCl) led to the largest increase in the surface tension of the solutions, followed by the increase came from($C_6H_8O_7$) and the smallest increase came from ($NaHCO_3$). It is observed in figures 1(c), 1(d), and 1(e), which show the surface tension of the solutions of (CMCLV), (PEG) and (PVP), respectively, and the concentrations of additives, that change in concentrations of ($C_6H_8O_7$) caused the largest increase to the surface tension of the solutions, while the surface tension of the solutions increased less when changing the concentrations of ($NaHCO_3$) and the increase in surface tension in the case of changing the concentrations of (NaCl) was less than changing the concentrations of both ($C_6H_8O_7$) and ($NaHCO_3$).

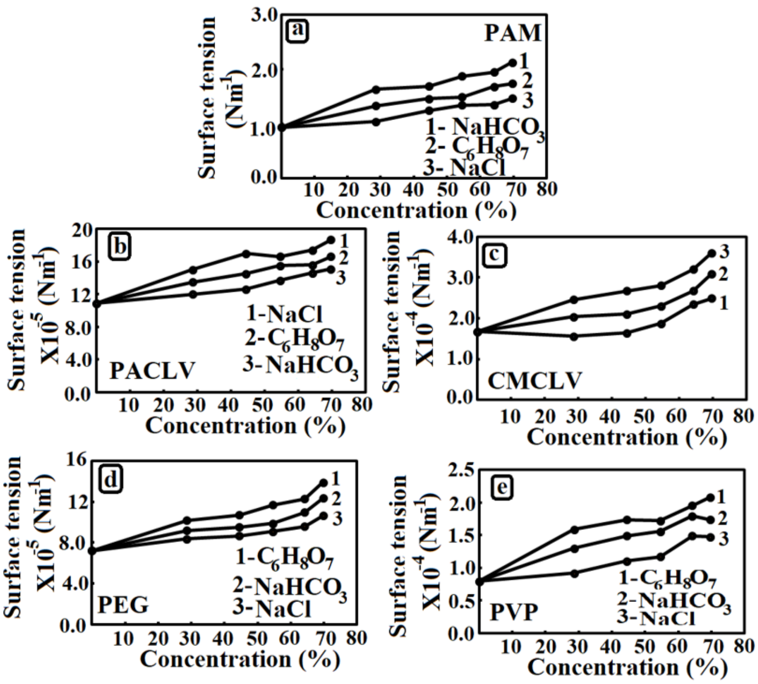

Figure 1. Surface tension vs concentrations of citric acid, sodium bicarbonate, and sodium chloride in solutions

The concentrations of ($NaHCO_3$), ($C_6H_8O_7$), and (NaCl) vs the surface tension forces of the polymer solutions are represented in Figure 2. Figure 2(a) represents the changing of the surface tension force with the changing of the concentrations of additives in the solutions of (PAM), and it should be noted that the variation of the concentrations ($NaHCO_3$) gives a surface tension force greater than changing the concentrations of ($C_6H_8O_7$) and (NaCl), but ($NaHCO_3$) gives a greater surface tension force than (NaCl), whose gives less surface tension force to the solutions of (PAM). The change in the surface tension forces of solutions of (PACLV) with changes in concentrations of additives is seen in Figure 2(b), where the surface tension forces increase with increasing concentrations of (NaCl), ($C_6H_8O_7$), and ($NaHCO_3$), respectively. Figure 2(c) shows that the difference in the surface tension forces of the solutions of (CMCLV) increases with increasing concentrations of (NaCl), ($NaHCO_3$), and ($C_6H_8O_7$), respectively. The surface tension forces for the solutions of (PEG) and (PVP) were plotted with changing concentrations of additives in Figures 2(d) and 2(e) respectively. The effect of concentration on the solutions for both polymers was similar since the surface tension forces for both increased with increasing concentrations of ($C_6H_8O_7$), ($NaHCO_3$), and (NaCl) respectively.

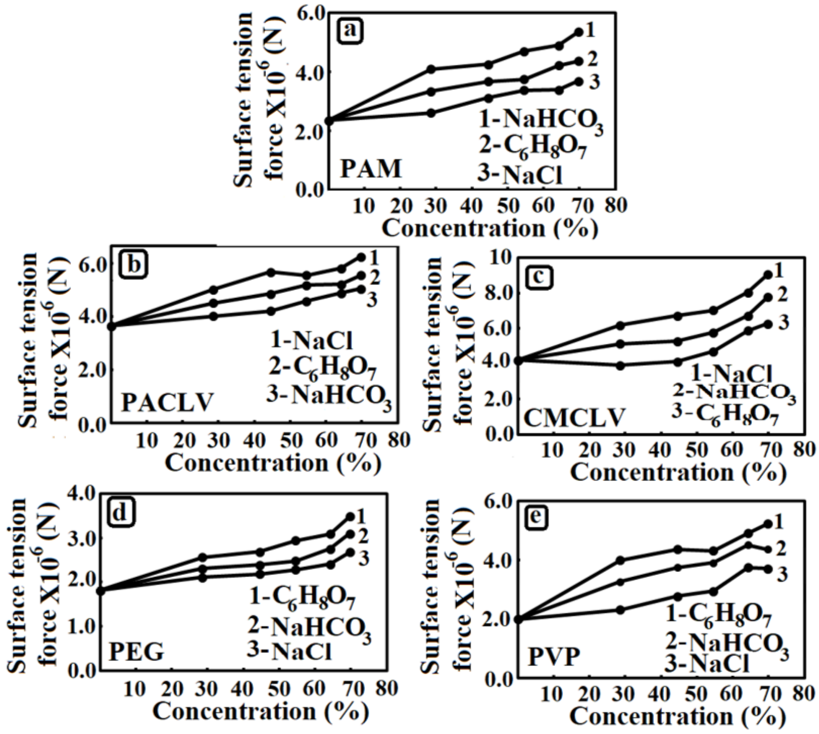

Figure 2. Concentrations of ($NaHCO_3$), ($C_6H_8O_7$), and (NaCl) vs the surface tension forces of the solutions

Figure 3 represents the change in surface tension energies of solutions with changing concentrations of additives, and shows an increase in surface tension energies with increasing concentrations in the same manner as the surface tension forces in Figure 2 increased with increasing concentrations.

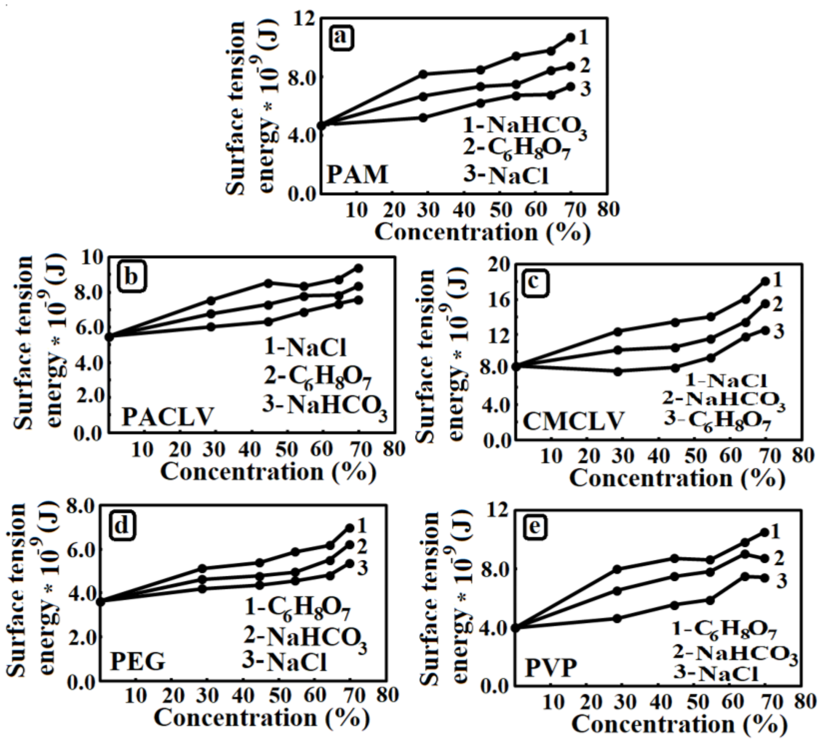

Figure 3. The concentrations of ($NaHCO_3$), ($C_6H_8O_7$), and (NaCl) vs the surface tension energies of the polymer solutions

Table 1 shows the amount of increase in the surface tension of solutions, as it includes its lowest and highest values according to Figure 1.

Table 1. Lowest and highest value of surface tension of polymers solutions

Polymers	**$NaHCO_3$**		**NaCl**		**$C_6H_8O_7$**	
	Lowest value ($\times10^{-5}$)	Highest value ($\times10^{-5}$)	Lowest value ($\times10^{-5}$)	Highest value ($\times10^{-5}$)	Lowest value ($\times10^{-5}$)	Highest value ($\times10^{-5}$)
PAM	9.40	21.0	9.40	14.6	9.40	17.0
PCALV	11.0	15.0	11.0	19.0	11.0	17.0
CMCLV	7.20	12.4	7.20	10.7	7.20	13.9
PEG	7.9	17.0	7.9	14.8	7.9	20.8
PVP	17.0	31.0	17.0	36.0	17.0	25.0

Viscosity

The relative viscosity of the solutions is plotted against the additive concentrations in Figure 4, where Figure 4(a) shows an increase in the relative viscosity of the solutions (PAM), with increasing concentrations of ($NaHCO_3$), (NaCl), and ($C_9H_8O_7$), respectively. Figure 4(b) represents the relationship between relative viscosity and concentrations for solutions of (PACLV), where the increase in viscosity with increasing concentrations of additives was in the following order ($NaHCO_3$), ($C_9H_8O_7$) and (NaCL). There was a decrease in relative viscosity with increasing additive concentrations, and this is evident in Figures 4(c), 4(d), and 4(e), which represent the relationship between viscosity and concentrations for solutions of (CMCLV), (PEG) and (PVP), respectively, and the decrease in viscosity by ($C_9H_8O_7$) was greater than the decrease caused by the concentrations of (NaCL) and the resulting decrease in ($NaHCO_3$) was smaller than all.

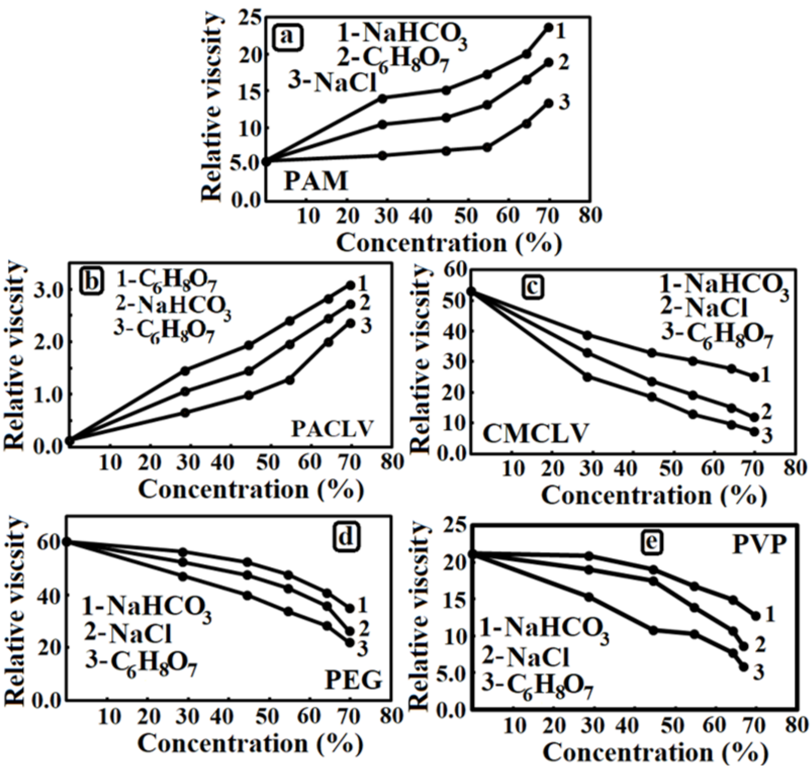

Figure 4. Relative viscosity of the solutions vs the additive concentrations

The specific viscosity is shown in Figure 5, where it becomes clear that the specific viscosity has changed in the same way as the relative viscosity of the solutions shown in Figure 4.

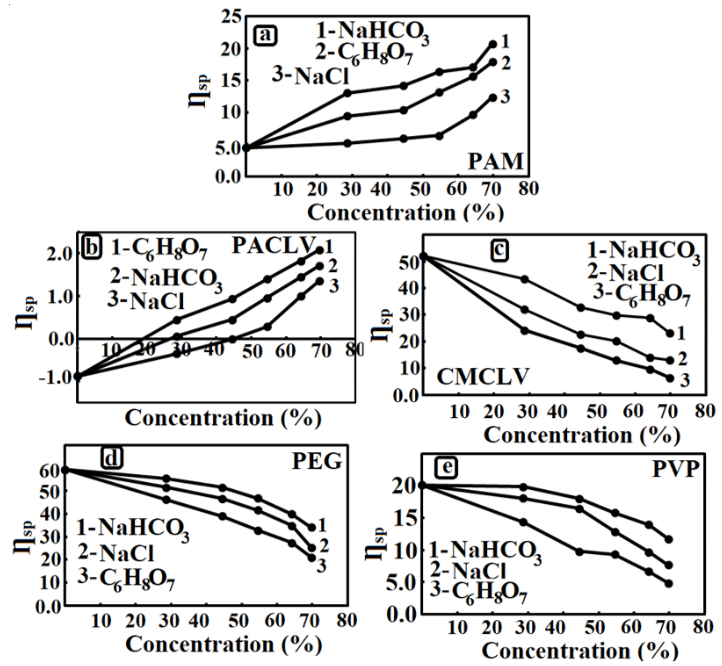

Figure 5. Specific viscosity of the solutions vs the additive concentrations

Figure 6 shows the decrease in inherent viscosities observed with increasing additive concentrations in solutions of all polymers. The change in concentrations of (NaCl) decreased the inherent viscosity to a greater extent than the change in concentrations of ($C_6H_8O_7$) in Figures 6(a) and 6(b), respectively, but the change in concentrations of ($C_6H_8O_7$) reduced the viscosity of solutions (PAM) is greater than the change in the concentrations of ($NaHCO_3$) as shown in Figure 6(a), while ($NaHCO_3$) reduces the viscosity of solutions of (PACLV) more than ($C_6H_8O_7$) as in Figure 6(b). Figures 6(c), 6(d), and 6(e) show that the concentrations of additives in the polymer solutions (CMCLV), (PEG), and (PVP), respectively, reduced the viscosity of these solutions. The effect of ($C_6H_8O_7$) was greater than the effect of (NaCl) and ($NaHCO_3$), as it reduced the viscosity more than (NaCl), but ($NaHCO_3$) had the least effect on the viscosity of the three polymers.

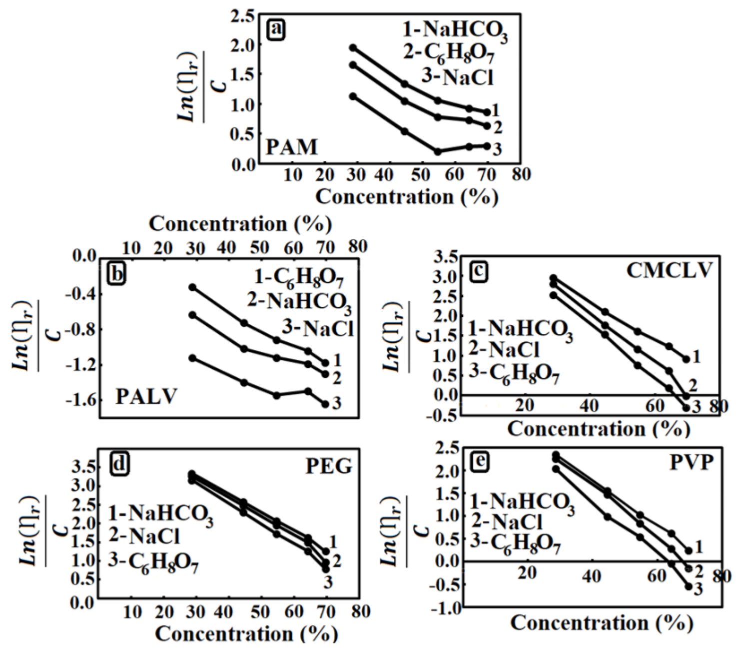

Figure 6. Inherent viscosity of the solutions vs the additive concentrations

The reduced viscosity decreased with increasing additive concentrations in Figures 7(a), 7(c), 7(d), and 7(e), but Figure 7(b) shows that increasing concentrations led to higher viscosity of the solutions (PACLV). Figure 7(a) shows that increasing concentrations of (NaCl) reduces the viscosity by (PAM) more than ($C_6H_8O_7$), while ($C_6H_8O_7$) reduces the viscosity more than ($NaHCO_3$), and Figure 7(f) indicates that ($C_6H_8O_7$) increases the viscosity of solutions (PACLV) more than it increases by ($NaHCO_3$). The effect of changing the concentrations of (NaCl) on the viscosity is smaller than the effect of ($C_6H_8O_7$) and ($NaHCO_3$) as in Figure 7(b). Increasing concentrations of ($C_6H_8O_7$) decrease the viscosity of polymer solutions (CMCLV), (PEG), and (PVP) more than (NaCl), as shown in Figures 7(c), 7(d), and 7(e), respectively, but increasing concentrations of (NaCl) in these figures show decreasing viscosity more than ($NaHCO_3$).

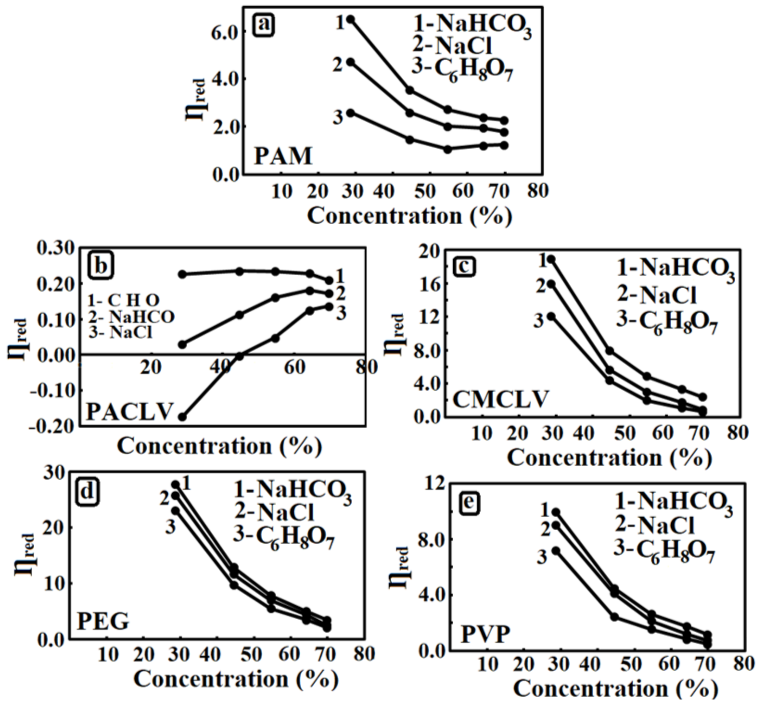

Figure 7. Reduced viscosity of the solutions vs the additive concentrations

Figure 8 represents the change in intrinsic viscosity with changing concentrations of additives, and the effect of these concentrations on the viscosity was identical to their effect on the reduced viscosity shown in Figure 7.

The Schulz-Blaschke constant versus the flow time of the solutions is represented in Figure 9. It turns out that the amount of constant decreases with increasing flow time in Figure 9(a), which shows solutions of (PAM), where solutions containing ($NaHCO_3$) saw the constant decrease more than solutions containing ($C_6H_8O_7$), while solutions containing (NaCl) have the lowest values for the constant. For the solutions of (PACLV) plotted in Figure 9(b), the values of the constant increased over time, because the constant increased more in solutions containing (NaCl) than in those containing ($NaHCO_3$), while solutions containing ($C_6H_8O_7$) had the lowest constant values. The constant in Figure 9(c) increases with increasing the flow time, this is because changing the concentrations of ($C_6H_8O_7$) results in an increase in the constant in solutions of (CMCLV) more than the increase in the constant in solutions containing (NaCl), while solutions containing ($NaHCO_3$) have lower values for the constant. The decrease in the constant for solutions of (PEG) is shown in Figure 9(d), where the constant decreased for solutions containing ($NaHCO_3$) more than for solutions containing (NaCl), while solutions containing (NaCl) had a decrease in constant values greater than that containing ($C_6H_8O_7$). There was a big difference in the change of the constant in Figure 9(e), which represents solutions of (PVP) compared to the rest of the figures, as the constant increased in solutions containing ($C_6H_8O_7$), while solutions containing ($NaHCO_3$) and (NaCl) decreased, and the constant in solutions containing ($NaHCO_3$) is greater than the constant in solutions containing (NaCl). The change in the Schulz-Blaschke constant indicates a change in the polymer chains [31].

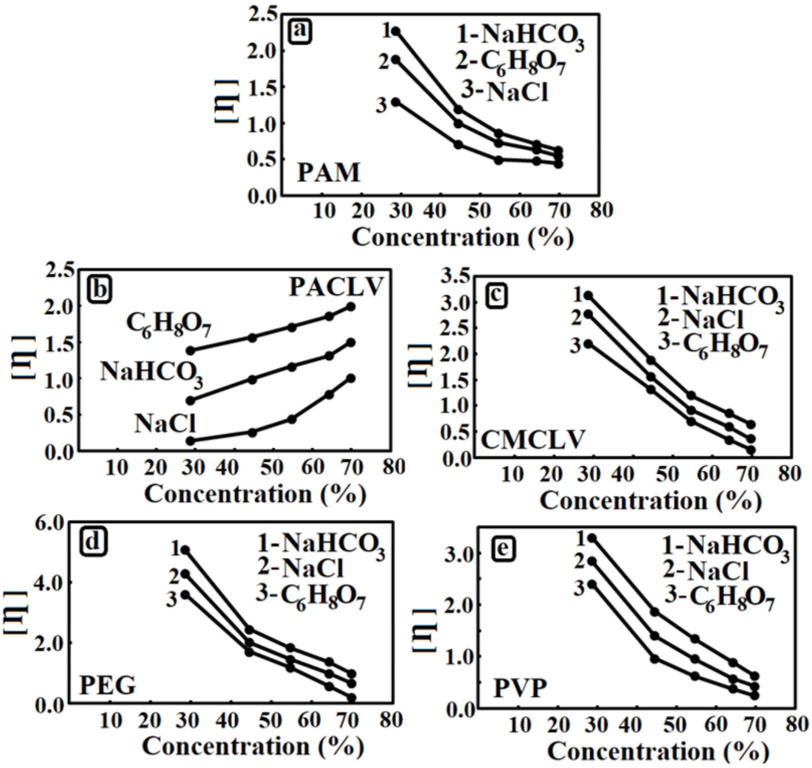

Figure 8. Intrinsic viscosity of the solutions vs the additive concentrations

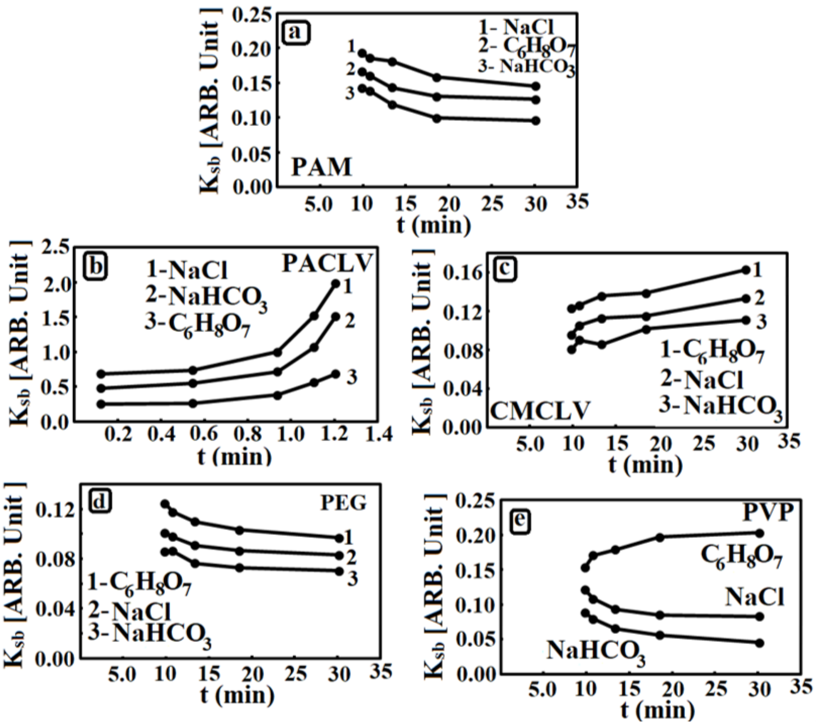

Figure 9. Schulz-Blaschke constant vs the additive concentrations

Table 2 shows the amount of increase in the relative viscosity of solutions, as it includes its lowest and highest values according to Figure 4.

Table 2. Lowest and highest values of the relative viscosity of polymer solutions

Polymers	$NaHCO_3$		NaCl		$C_6H_8O_7$	
	Lowest value ($\times 10^{-5}$)	Highest value ($\times 10^{-5}$)	Lowest value ($\times 10^{-5}$)	Highest value ($\times 10^{-5}$)	Lowest value ($\times 10^{-5}$)	Highest value ($\times 10^{-5}$)
PAM	9.40	21.0	9.40	14.6	9.40	17.0
PCALV	11.0	15.0	11.0	19.0	11.0	17.0
CMCLV	7.20	12.4	7.20	10.7	7.20	13.9
PEG	7.9	17.0	7.9	14.8	7.9	20.8
PVP	17.0	31.0	17.0	36.0	17.0	25.0

CONCLUSION

The results obtained in this work indicate an increase in the surface tension and relative viscosity of the polymer solutions, but the effect of increasing concentrations of (NaCl) and ($C_6H_8O_7$) and ($NaHCO_3$) in the solutions were in different quantities depending on the polymer they affect, and the change in the Schulz-Blaschke constant indicates a change in the polymer chains. This diversity and difference in the effect of the additives can be used in many fields, such as those in the medical or industrial field, and scientific research.

SUPPLEMENTARY MATERIAL

None.

AUTHOR CONTRIBUTIONS

Najla Ali Elgheryani: Writing–review & editing, Methodology, Visualization, Investigation, Conceptualization.

FUNDING

None.

DATA AVAILABILITY STATEMENT

None.

ACKNOWLEDGMENTS

I extend my sincere thanks and gratitude to those who helped me complete this research, especially National Oil Corporation Jowfe Oil Technology, which gave me the polymers, and Mr. Mohammad Bograd and Mr. Jamal Mohammad Al-Farjani.

CONFLICTS OF INTEREST

The author declares no conflicts of interest.

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