# Interaction of polyvinylpyrrolidone with small cosolutes in aqueous and non aqueous media

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The properties of dilute solutions of polyvinylpyrrolidone (PVP) in aqueous and non-aqueous solvents in the presence of small molecules are studied by measurements of intrinsic viscosity, $[\eta]$. The unperturbed dimensions are determined in pure solvents and in solvent mixtures. There are different unperturbed states, depending on the solvent and the solvent/cosolute mixture. These results are discussed on the basis of the nature of the side group interaction with the solvent and the cosolute. The role of the preferential adsorption of one of the cosolute on the polymer was considered. It would seem that the solvent plays an important role in the type of interaction.

**Keywords** Polyvinylpyrrolidone; cosolutes; conformational parameter; preferential adsorption; conformational transition; hydrophobic effect

## INTRODUCTION

The interaction of polyvinylpyrrolidone (PVP) with aromatic and aliphatic compounds in aqueous solution has been widely studied[1-5]. Polyvinylpyrrolidone has the ability to bind reversibly to small molecules forming association complexes, which is very important from several points of view, in chemistry, biochemistry, pharmaceutical sciences, etc. Molineux *et al.*[1] have investigated the interaction of PVP with small cosolutes in aqueous solutions taking into account thermodynamical aspects of the binding process with several kinds of cosolutes (ionic, non-ionic, aromatic, aliphatic, etc.).

Bandyopadhyay *et al.*[6] have studied complexes between PVP and phenolic materials in aqueous and non-aqueous media and they found that the intrinsic viscosity of the polymer is reduced by the addition of hydroquinone and other phenols, and if the solvent is propan-2-ol the interaction is weaker than in water, and too small to be measured in dimethyl sulphoxide. Since the polymer is soluble in a variety of solvents it is possible to study the interaction of small molecules with PVP in several solvents of different solvating power because the solvent could play an important role in the type of interaction. Therefore, it is of interest to study the effect of the interaction of small molecules with PVP in different solvents from the unperturbed dimensions point of view because the interaction could affect the conformation of the chain due to electrostatic or hydrophobic effect, i.e., if we consider that PVP can be viewed as composed of two kinds of groups, dipolar imide group on the pyrrolidone rings and hydrophobic groups as methine and methylene in the backbone and the methylene in the same ring, which is one of the reasons of the ability of PVP to bind cosolutes[1,2].

The interpretation of configurational properties of polymer solutions is based on the assumption that the ideal unperturbed dimensions of the chain depends only on intramolecular forces and that these forces are not affected by the solvent nature[7,8]. Further, the molecular dimensions of a polymer in binary solvents are regarded as being influenced by the excess free energy $G^E$ of the mixture[9-11].

The aim of the present work is the study of the solvent and the solvent/cosolute mixtures effect on the chain dimensions, and the influence of the cosolute–PVP interaction on the unperturbed dimensions of the chain.

## EXPERIMENTAL

PVP fractions, obtained from a commercial sample* by fractional precipitation with chloroform–petroleum ether 60°–80°C as solvent–precipitant pair at 25°C, were studied. The polyvinylpyrrolidone samples are fractions with narrow molecular weight distribution $(\bar{M}_w/\bar{M}_n < 1.4)$[12]. The number average molecular weights of the fractions in propan-2-ol at 25°C were determined in a Hewlett–Packard 502 high speed membrane osmometer. Viscosity measurements were carried out at 25°C in a flow-capillary viscosimeter of the Desreux–Bischoff type[13]. Neither kinetic energy nor non-Newtonian corrections were found to be necessary. The temperature control was better than ±0.2°. Intrinsic viscosities $[\eta]$ were obtained from Huggins–Kraemer treatment of the data, and linear plots were obtained for all solvents and mixtures. The error in the intrinsic viscosity was not greater than ±1%.

Equilibrium dialysis experiments were carried out in a dialyser with a total volume of about 15 ml. The semipermeable cellophane membrane was conditioned in each of the solvent mixtures before use. Dialytic equilibrium was obtained in 6 h.

Preferential adsorption coefficient $\lambda^*$ was determined

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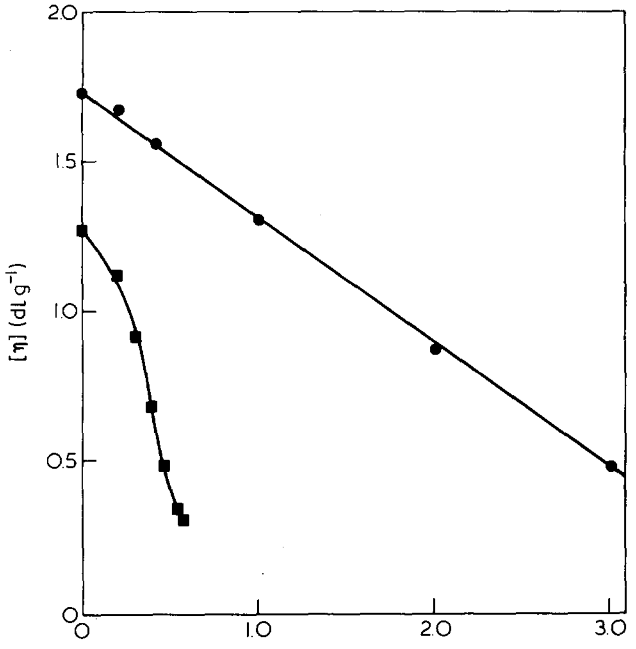

***Figure 1*** Variation of intrinsic viscosity $[\eta]$ of PVP with mixed solvent composition in % (v/w) in the systems propan-2-ol/hydroquinone (●) and water/hydroquinone (■)

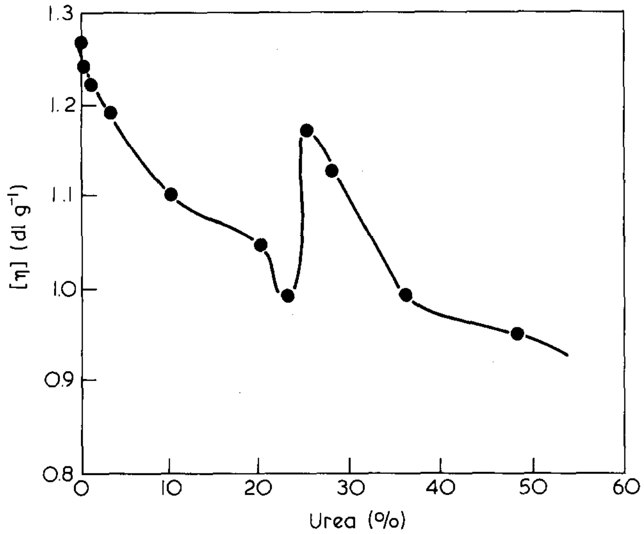

***Figure 2*** Variation of intrinsic viscosity $[\eta]$ of PVP with mixed solvent composition in % (v/w) in the system water/urea

by the relation:

$$\lambda^* = \frac{(\mathrm{d}n/\mathrm{d}c)_\mu - (\mathrm{d}n/\mathrm{d}c)_k}{\mathrm{d}n/\mathrm{d}k}$$

where $(\mathrm{d}n/\mathrm{d}c)_k$ is the polymer refractive index increment in the solvent mixture, $\mathrm{d}n/\mathrm{d}k$ is the variation of the refractive index of solvent mixture as a function of volumetric composition and $(\mathrm{d}n/\mathrm{d}c)_\mu$, i.e. the polymer refractive index increment after establishing dialysis equilibrium. The precision in the determination is about $\pm 0.01$.

All reagents were analytical grade purity. Mixtures of solvent–cosolute systems were made by % v/w. When working on solvent cosolute mixtures, the polymer was always dissolved in the mixture. The composition of a polymer solution was never adjusted by addition of a single constituent.

## RESULTS AND DISCUSSION

*Figure 1* shows the viscometric behaviour of one PVP fraction in the water/hydroquinone and propan-2-ol/hydroquinone mixtures. Intrinsic viscosity, $[\eta]$ decreases gradually in both cases and the cloud point ($\sim\theta$ condition) is reached at 0.56% and 3% of hydroquinone in water and propan-2-ol respectively. This result is similar to that of Bandyopadhyay *et al.*[6]

*Figure 2* shows the viscometric behaviour of one PVP fraction in the water/urea mixture. Intrinsic viscosity decrease sharply till 23% of urea and then increase till 25% of urea and then decrease again. The discontinuity in the curve could be attributed to a probable conformational transition of the chain due to the interaction of PVP with urea. Urea is a strong denaturating agent for proteins[14,15]. It is very probable that the action was similar for PVP, because PVP has certain similarities to that of the proteins, specially serum albumin and it has been used as a synthetic polymer model for proteins.

*Table 1* summarizes the number average molecular weight for PVP fractions and the viscometric data in pure solvents and solvent/cosolutes mixtures. Kuhn–Mark–Houwink relations were established by plotting the intrinsic viscosity against number average molecular weight to log–log plots (*Figure 3*). The experimental data show that $[\eta]$ of PVP fractions depends on the quality of the solvent and the presence of cosolutes decrease the slopes of the Kuhn–Mark–Houwink plots. *Table 2* summarizes, $K_a$ and $a$ values of the viscosimetric relations. It can be seen that the exponents of these equations are in accord with those usually found for flexible polymers, i.e., propan-2-ol is the best solvent for PVP[12] and $a = 0.85$ but when propan-2-ol have 3% of hydroquinone ($\sim\theta$ condition), $a = 0.51$. In water $a = 0.83$ and in water/hydroquinone 0.56% ($\sim\theta$ condition); $a = 0.50$ but in water/urea 23 and 35% mixtures $a = 0.71$ and 0.67 respectively. These results show that the polymer chain is more extended in pure solvent than solvent–cosolute mixtures, therefore it is necessary to know if this behaviour affects either conformational or thermodynamic parameters.

In order to find the value of the conformational parameter $K_\theta$, leading to the unperturbed dimension $\langle r_0^2\rangle^{1/2}$ given by: $K_\theta = \Phi(\langle r_0^2\rangle/M)^{3/2} = [\eta]_\theta/M^{1/2}$; and the thermodynamic interaction parameter $B$, the Stockmayer–Fixman equation[16] was employed.

***Table 1*** Intrinsic viscosity $[\eta]$ of PVP fractions in pure solvents and solvent mixtures, at 25°C and number average molecular weight of fractions

| | $[\eta]$/(dl g$^{-1}$) of fractions at 25°C | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Propan-2-ol | 1.71 | 0.62 | 0.60 | 0.50 | 0.45 | 0.29 |
| Propan-2-ol/hydroquinone 3% ($\sim\theta$) | 0.40 | – | – | 0.22 | 0.16 | 0.15 |
| Water | 1.27 | – | – | 0.45 | 0.30 | 0.23 |
| Water/hydroquinone 0.56% ($\sim\theta$) | 0.34 | – | – | 0.17 | 0.14 | 0.13 |
| Water/Urea 23% | 1.09 | – | 0.34 | 0.42 | 0.32 | 0.25 |
| Water/Urea 30% | 0.95 | – | 0.33 | 0.42 | 0.30 | 0.24 |
| $\bar{M}_n \times 10^5$ | 4.17 | 1.32 | 1.26 | 1.12 | 0.80 | 0.54 |

The plots are given in *Figure 4*. We can compare $K_\theta$ and $B$ for PVP in pure solvents and in solvent/cosolute mixture. The values of $K_\theta$ obtained by this relation are different for different solvents. The conformational parameter seems to be affected by the nature of the mixture when the solvent is water, but it remains constant when the solvent is propan-2-ol. The values of the long range interaction parameter $B$, change in the same way as the $a$ exponent of Mark-Houwink relationship with the solvent power. $B$ parameter is 0 in theta solvent. $K_\theta$ and $B$ values are summarized in *Table 3* for pure solvents and solvent/cosolute mixtures.

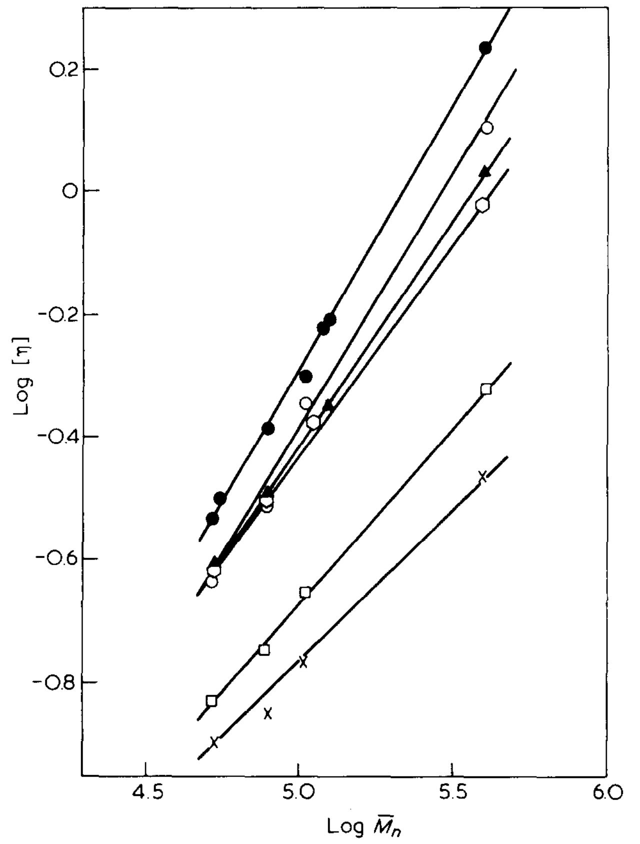

*Figure 3* Double log $[\eta]$-$\bar{M}_n$ plot for PVP in (●) propan-2-ol; (□) propan-2-ol/hydroquinone 3%; (○) water; (X) water/hydroquinone 0.56%; (▲) water/urea 23%; (x) water/urea 30%

*Table 2* Viscometric constant $K_a$ and $a$ at 25°C from Kuhn-Mark-Houwink relation

| Solvents | $K_a \times 10^5$ | $a$ |
|---|---|---|
| Propan-2-ol | 2.75 | 0.85 |
| Propan-2-ol/hydroquinone 3% (~θ) | 51.60 | 0.51 |
| Water | 2.78 | 0.83 |
| Water/hydroquinone 0.56% | 52.20 | 0.50 |
| Water/Urea 23% | 10.92 | 0.71 |
| Water/Urea 30% | 16.60 | 0.67 |

Taking for $K_\theta$ the values found by the Stockmayer–Fixman relation, we find the relation between the root mean square end to end distance for the unperturbed chain $\langle r_0^2\rangle^{1/2}$ and $M$, taking for $\Phi$ the theoretical value $2.87\cdot10^{21}$ without polydispersity corrections. The root-mean-square end to end distance assuming completely free rotation around the bond is $(\langle r_{of}^2\rangle/M)^{1/2}=290\times10^{-11}$ cm mol$^{1/2}$ g$^{-1/2}$ the value of $\langle r_0^2\rangle^{1/2}/\langle r_{of}^2\rangle^{1/2}$ ($\sigma$) that represents the effect of steric hindrance on the flexibility of the chain and the characteristic relation $(\langle r_0^2\rangle/M)^{1/2}$ is also given in *Table 3*.

The values of $(\langle r_0^2\rangle/M)^{1/2}$ and $\sigma$ remain constant in propan-2-ol and propan-2-ol/hydroquinone, the same behaviour is found in water and water/hydroquinone but when the cosolute is urea, the unperturbed dimensions of PVP are larger than in water or water/hydroquinone. This variation of $\langle r_0^2\rangle^{1/2}$ and the short-range

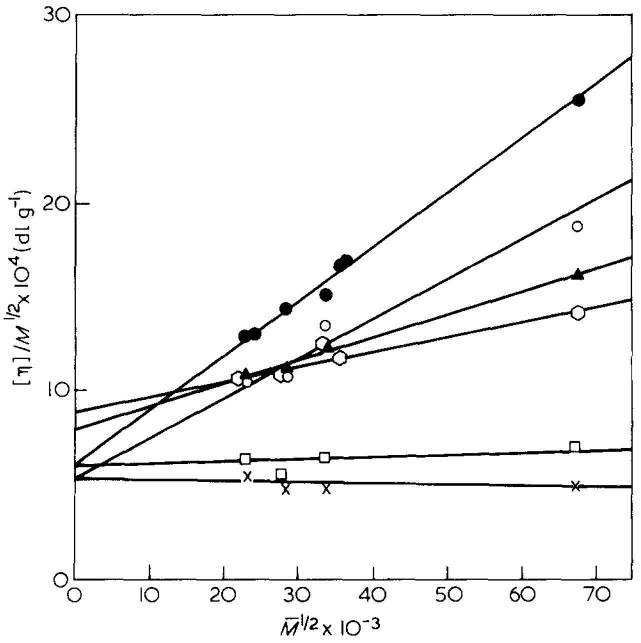

*Figure 4* Stockmayer-Fixman plot for PVP in (●) propan-2-ol; (□) propan-2-ol/hydroquinone 3%; (○) water; (X) water/hydroquinone 0.56%; (▲) water/urea 23%; (○) water/urea 30%

*Table 3* Conformational and thermodynamics parameters $K_\theta$ and $B$, from Stockmayer-Fixman relation in pure solvents and solvent mixtures at 25°C and the characteristic ratio and the rigidity coefficient $\sigma$

| | $K_\theta\times10^4$ (dl g$^{-1}$) | $B\times10^{28}$ (cc mol$^2$ g$^{-1}$) | $(\langle r_0^2\rangle/M)^{1/2}\times10^{11}$ (cm mol$^{1/2}$ g$^{-1/2}$) | $(\langle r_0^2\rangle/\langle r_{of}^2\rangle)^{1/2}$ |
|---|---|---|---|---|
| Propan-2-ol | 6.0 | 21.63 | 593 | 2.04 |
| Propan-2-ol/hydroquinone 3% (~θ) | 6.0 | 0.00 | 593 | 2.04 |
| Water | 5.2 | 15.27 | 565 | 1.95 |
| Water/hydroquinone 0.56% (~θ) | 5.2 | 0.00 | 565 | 1.95 |
| Water/Urea 23% | 8.0 | 9.33 | 653 | 2.25 |
| Water/Urea 30% | 8.8 | 7.63 | 674 | 2.32 |

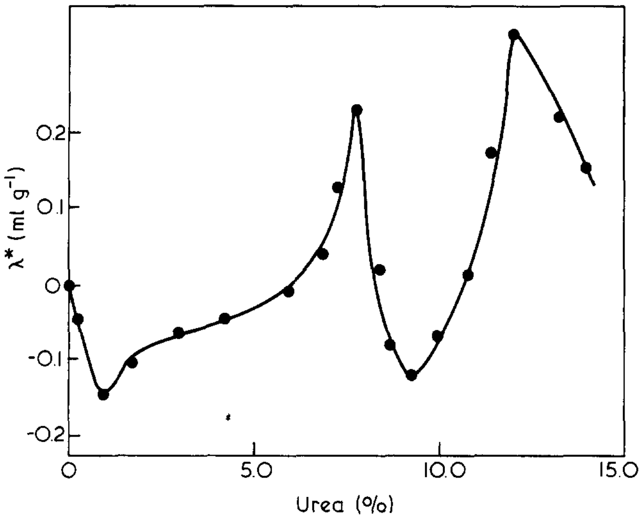

***Figure 5*** Dependence of the preferential adsorption parameter λ* on mixed solvent composition for the ternary system PVP/urea/water

interactions must be related to variations of internal rotations around the main chain. There would be an extra short range interaction in water/urea than in water/hydroquinone. This could be due to the fact that urea breaks the water structure and furthermore the hydration of PVP side-group, which is capable of hydrogen bonding, must be taken into account. The bulky side group is more hydrated so the monomeric unit is bigger than the real monomeric unit, increasing the hindrance of the internal rotations, and as Dondos and Benoît[17] have pointed out, the association of the side-groups of the monomer unit with solvent molecules would result in a higher apparent molar volume of the monomer, which is reflected in the unperturbed dimension, therefore, it could be interpreted in terms of a conformational transition of the chain due to the presence of urea.

The results show that the changes in $K_\theta$ and therefore in $(\langle r_0^2\rangle/M)^{1/2}$ with the solvent or with the nature of the solvent/cosolute mixture reflect types of polymer–polymer interaction, which might be competing with a solvent–small solute, solvent–solvent or polymer–solvent interaction.

It has been suggested that transitions from helicoidal chains to random coils can be induced by complex formation between polymer and hydrogen bonds which compete with intramolecular associations.

The high $K_\theta$ values for the PVP/water/urea system relative to the value in pure water must be due to a conformational transition of the chain. The negative contribution to the entropy associated to a disorder-order transition of the main chain is presumably balanced by a positive contribution due to a decrease in order of the water structure. This conclusion is consistent with the formation of hydrophobic bonds between side chains.

All these results show that changes in the solvent and mixture nature has a remarkable influence on the conformational and molecular parameter of PVP. In general the unperturbed dimensions would be medium-dependent when the polymer chains have polar and non polar groups readily associated with the solvent. On the other hand, the medium favours interactions between polar and non-polar sites of neighbouring side-groups in the polymer chain. The influence of the preferential adsorption of the solvent or cosolute on the macromolecule should be considered.

Preliminary results[18] about the preferential adsorption in PVP/urea/water, system shows that urea is preferentially adsorbed at low urea contents but when urea content increases water is preferentially adsorbed. *Figure 5* shows the variation of preferential adsorption coefficient $\lambda^*$ on function of urea concentration. $\lambda^*$ is defined as the difference in solvent composition (in volume fraction $\Phi_1$ of solvent 1) between the interior of the solvated coil and the mixture of pure solvents external to it per unity of polymer concentration $C$ in g ml$^{-1}$. It could be thought that at higher urea contents, water must be adsorbed by PVP, therefore increasing the hindrance of the internal rotations reflected in the unperturbed dimensions. Unfortunately it is very difficult to determine the $\lambda^*$ value at higher urea content than 15%.

The behaviour of this system is similar to that of lisozyme and albumin in urea/water mixture, studied by means of dilatometry and dialysis equilibrium-differential refractometry[19]. Further studies are in progress with different techniques.

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## REFERENCES

1 Molyneux, P. and Frank, H. P. *J. Am. Chem. Soc.* 1961, **83**, 3169
2 Molyneux, P. and Frank, H. P. *J. Am. Chem. Soc.* 1961, **83**, 3175
3 Molyneux, P. and Ahmed, G. S. *Kolloid-Z.u.Z. Polymere* 1973, **251**, 310
4 Molyneux, P. and Cornarakis-Lentzos, M. *Colloid Polym. Sci.* 1979, **257**, 855
5 Inoue, M. and Otsu, T. *J. Polym. Sci., Polym. Chem. Edn.* 1976, **14**, 1933
6 Bandyopadhyay, P. and Rodriguez, F. *Polymer* 1972, **13**, 119
7 Flory, P. J. and Krigbaum, W. R. *J. Chem. Phys.* 1950, **18**, 1086
8 Fixman, M. *J. Chem. Phys.* 1962, **36**, 3123
9 Dondos, A. and Patterson, D. *J. Polym. Sci.* 1969, **27**, 209
10 Dondos, A., Rempp, P. and Benoît, H. *J. Polym. Sci.* 1970, **C30**, 9
11 Gargallo, L., Radic, R. and Katime, I. *Eur. Polym. J.* 1980, **16**, 383
12 Meza, R. and Gargallo, L. *Eur. Polym. J.* 1977, **13**, 235
13 Desreux, V. and Bischoff, J. *Bull. Soc. Chim. Belg.* 1950, **59**, 93
14 Tanford, C. *Adv. Protein Chem.* 1968, **23**, 122
15 Anfinsen, C. B. and Scheraga, H. A. *Adv. Protein Chem.* 1975, **29**, 240
16 Stockmayer, W. and Fixman, M. *J. Polym. Sci.* 1963, **C1**, 137
17 Dondos, A. and Benoît, H. *Macromolecules* 1971, **4**, 279
18 Radic, D. and Gargallo, L. (unpublished data)
19 Abad, C., Trueba, M., Zaton, A. and Campos, A. *An. Quim.* 1979, **75**, 993