# Flow Patterns of Polymer Solutions Injected into Dispersions of Bentonite

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**Abstract:**
The flow behaviour of colloidal dispersions is largely influenced by the interactions between the dispersed particles. We studied the influence of either natural or synthetic polyelectrolytes solutions on flow patterns within colloidal clay dispersion. For this purpose, highly diluted aqueous polymer solutions were intruded into a radial Hele-Shaw cell filled with montmorillonite dispersions. The developing flow patterns were recorded with a high resolution digital camera. The morphological parameters: fractal dimension, total number of branching, branching density of the patterns, *compactness* and *form* were obtained by digital image analysis. The results show that the patterns are largely affected by the different polymers.

**Zusammenfassung:**
Das Fließverhalten von kolloidalen Dispersionen wird in großem Maße durch die Wechselwirkungen zwischen den dispergierten Partikeln beeinflusst. Wir untersuchten den Einfluß sowohl von natürlichen, als auch von synthetischen Polymerlösungen auf das Fließverhalten von kolloidalen Tondispersionen. Zu diesem Zweck wurden stark verdünnte Polymerlösungen in eine, mit einer Montmorillonit Dispersion gefüllten, radialen Hele-Shaw Zelle injiziert. Mit einer hoch auflösenden digitalen Kamera wurden die sich entwickelnden Fließmuster aufgenommen. Die morphologischen Parameter: Fraktale Dimension, die Anzahl der Verzweigungen, die Verzweigungsdichte sowie *compactness* und *form* wurden durch digitale Bildanalyse bestimmt. Es konnte gezeigt werden, dass die unterschiedlichen Polymere die entstehenden Fließmuster in hohem Maße beeinflussen.

**Résumé:**
Le comportement en écoulement de dispersions colloidales est largement influencé par les interactions entre les particules dispersées. Nous avons étudié l'influence de solutions de polyélectrolytes soit naturels soit synthétiques sur le comportement en écoulement d'une dispersion colloidale d'argile. Pour ce faire, des solutions aqueuses très diluées de polymères ont été introduites dans une cellule radiale de type Hele-Shaw, remplie de dispersions de montmorillonite. Le développement de l'écoulement a été enregistré avec une caméra digitale de grande résolution. Les paramètres morphologiques: dimension fractale, nombre total de branchements, densité de branchements dans les images d'écoulement, les formes et leur étendue sont obtenus par analyse digitale des images. Les résultats montrent que ces images sont largement afectées par la nature des différents polymères.

**Key words:** clay dispersion, Hele-Shaw cell, polyacrylamide, polysaccharide, soil amendments

## 1 INTRODUCTION

Starting in the late fifties, polymeric substances have been used as soil conditioners or soil amendments. Natural as well as synthetic high molecular compounds have been applied for these purposes. These compounds act two fold: (i) the infiltration rate of water is increased and (ii) soil erosion and soil slacking is reduced. The reason for this activity is, that due to sorption of the polymers flocculation of the clay particles takes place which leads to large aggregates and to a reduced mobility of the clay particles. However, it can be observed that the selection of the polymers and of their application is done mainly on an empirical basis, i.e., under field trial conditions [1].

The goal of our investigation was to visualize, on a macroscopic scale, the result of the interactions of the clay particles with the different polymeric substances used in agriculture. We took clay, because these colloidal particles are







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circle respectively. These digital image analysis techniques are described in more detail in DATHE et al. 2001 [11].

## 3 RESULTS

Typical examples for the obtained flow patterns are shown in Fig. 5. As injection fluids distilled water (Fig. 5a), the polyacrylamide Praestol 630 BC (Fig. 5b) and the Gum Xanthan (Fig. 5c) solutions were taken. Already visual inspection shows the great differences in size and shape of the patterns obtained by the injection of different fluids. For all injected liquids, Tab. 2 gives the mean values and the standard deviation of the morphometric parameters measured by image analysis. The values of the morphometric parameters, especially the fractal dimension are in the range presented by TAKAYASU 1990 [12] for different systems. In addition the patterns formed in the water/clay system match with the structure found by STROBEL 1993 [3].

The use of the different types of polyacrylamides has led to different forms of patterns. The noniconic PAMs (Praestol 2300, Praestol 2500) show the highest values of fractal dimension of all synthetic polymers. The application of the anionic PAMs (Praestol 2350, Praestol 2530) led to a slight reduction of the fractal dimension. A more pronounced decrease is obtained with cationic PAMs (Praestol 630 BC, Praestol 852 BC). On the other hand, the cationic PAMs give rise to the highest values of the *form* parameter. The patterns formed by the intrusion show the most compact circle-like structure.

Interestingly, both the fractal dimension and the number of branches depend on the molecular weight of the polymers used. The increase of the size of the polymer molecules resulted in a decrease of these parameters, compare Praestol 2300 vs. Preastol 2500 and Praestol 2350 vs. Praestol 2530.

The natural polysaccharide Gum Xanthan leads to a rather high fractal dimension and to high numbers and density of branches. The values of the other parameters are in the range of distilled water as injection fluid. This might be due to the rather low concentration. In field studies with biopolymers it was found that much higher concentrations were necessary [13].

In order to explain these observations we suggest the following explanation. All PAMs act as flocculants with a flocculation capability decreasing from cationic over anionic to nonionic [14]. In the very first moments of the injection processes a flocculation of all dispersed clay particles takes place. This leads to an accumulation of flocculated clay particles at the interface between the injection fluid and the clay dispersion. This "clay wall" is moved by the continuously injected polymer solution and thus the "wall" is put under ever increasing mechanical stress. At a distinct critical stress and thus critical injection time, this wall breaks down. This time is dependent on the polymer and is positively correlated to its flocculating capability.

Furthermore the form of the break down is influenced by the polymer. Strong flocculating polymers and therefore strongly stabilizing agents lead to a destruction of the wall only at some sites, whereas with weak flocculating polymers the dam breaks down at numerous sites. When this decay has happened the solutions penetrate the dispersion. Because, due to the sorption of the clay particles this solution shows a reduced polymer content, the penetration patterns formed in this period resemble the patterns obtained with pure water.

| | Fractal Dimension | Number of Branches | Density of Branches | Compactness | Form |
|---|---|---|---|---|---|
| Water (dest.) | 1.59<br>($8.72*10^{-3}$) | 133.67<br>(21.78) | $5.152*10^{-4}$<br>($9.88*10^{-5}$) | 0.339<br>($3.27*10^{-2}$) | $1.27*10^{-2}$<br>($2.37*10^{-3}$) |
| Praestol 2300 | 1.64<br>($3.09*10^{-2}$) | 192.67<br>(24.48) | $4.417*10^{-4}$<br>($7.32*10^{-5}$) | 0.492<br>($4.09*10^{-2}$) | $1.25*10^{-2}$<br>($1.2*10^{-3}$) |
| Praestol 2500 | 1.61<br>($1.66*10^{-2}$) | 125<br>(10.56) | $3.425*10^{-4}$<br>($2.67*10^{-5}$) | 0.474<br>($2.95*10^{-2}$) | $1.91*10^{-2}$<br>($4.83*10^{-3}$) |
| Praestol 2350 | 1.57<br>($8.41*10^{-3}$) | 165.6<br>(40.41) | $2.870*10^{-4}$<br>($1.64*10^{-5}$) | 0.415<br>($5.23*10^{-2}$) | $1.28*10^{-2}$<br>($2.68*10^{-3}$) |
| Praestol 2530 | 1.54<br>($1.67*10^{-2}$) | 109.8<br>(17.5) | $2.743*10^{-4}$<br>($3.36*10^{-5}$) | 0.399<br>($3.30*10^{-2}$) | $1.88*10^{-2}$<br>($1.52*10^{-3}$) |
| Praestol 630 BC | 1.48<br>($3.58*10^{-2}$) | 110.8<br>(12.91) | $2.794*10^{-4}$<br>($3.71*10^{-5}$) | 0.448<br>($3.91*10^{-2}$) | $2.99*10^{-2}$<br>($3.23*10^{-3}$) |
| Praestol 852 BC | 1.48<br>($3.79*10^{-2}$) | 98.6<br>(11.15) | $2.58*10^{-4}$<br>($5.92*10^{-5}$) | 0.475<br>(0.11) | $3.43*10^{-2}$<br>($8.78*10^{-3}$) |
| Gum Xanthan | 1.63<br>($3.48*10^{-2}$) | 203.17<br>(37.72) | $4,831*10^{-4}$<br>($3.84*10^{-5}$) | 0.38<br>($4*10^{-2}$) | $9,93*10^{-3}$<br>($6.74*10^{-4}$) |

First number: Mean value, from 5 parallels (Water, Praestol 2300 and Gum Xanthan 6 parallels)
Second number: Standard deviation

*Table 2: Mean values and standard deviation of fractal dimension, number of branches, density of branches, compactness and form.*


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