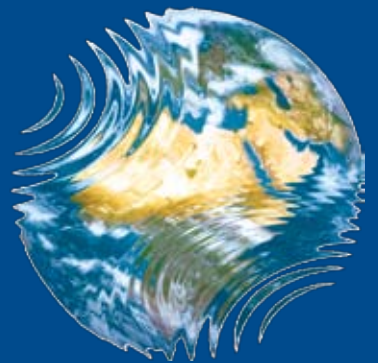


FLOPAM DR

Drag Reduction



SNF OIL DIVISION

Polymer Drag Reduction Effect

During the 1970s and 80s when the cost of energy was high, there was a large research effort to study drag reduction and EOR within the petroleum industry. There is a large volume of literature on drag reduction with polymer and there are many commercial applications, especially in the oil industry where it is used to aid in the transport of crude oil through pipelines, to increase waterflood injection rates and for fracturing fluids. In this document the topic of drag reduction relative to pipe flow of aqueous fluids is presented.

When a fluid moves relative to a solid surface, frictional drag is created which results in a corresponding dissipation or loss of energy. Scientists in many industries have studied methods to minimize this effect.

Reducing the amount of friction in pipeline flow leads to reduced energy consumption or increased flowrate for the same pump pressure. The benefit is improved performance and economics and in a global sense, a more efficient and environmentally sensitive use of energy resources.

Drag reduction

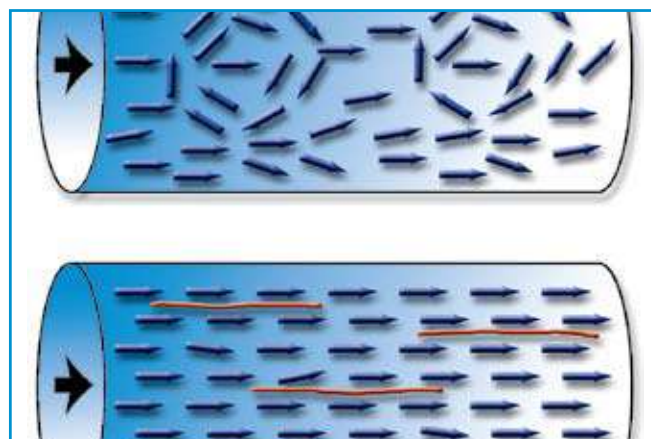
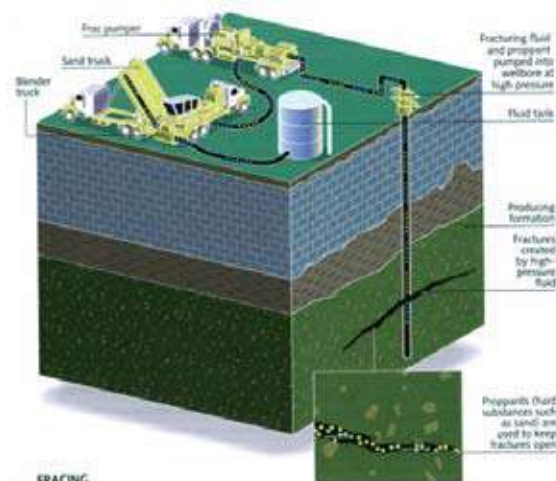
Drag reduction can be defined as an increase in pumpability due to the addition of polymer to a fluid in turbulent flow. Polymers added for this purpose are called drag reducer additives commonly referred to as DRA. For pipe flow conditions the effectiveness of DRA can be calculated as follows:

$$DR (\%) = \frac{(\Delta P_{\text{without DRA}} - \Delta P_{\text{with DRA}})}{\Delta P_{\text{without DRA}}} \times 100$$

In turbulent flow the simple relationship between shear stress and rate of strain through viscosity is no longer valid and the velocity profile, head loss and friction factor, etc. cannot be derived analytically and must be found experimentally. These quantities are functions of both Reynolds number and the relative roughness (e/D) of the pipe wall.

It is observed experimentally that viscous turbulent flow in pipe can be subdivided into three layers: a very thin layer near the pipe wall where the flow is essentially still laminar in which the adjacent pipe wall suppresses turbulence, a turbulent boundary layer existing in the transition from the laminar wall layer to the fully turbulent layer, and the fully turbulent layer.

Scientists have studied fluid flow characteristics with soft compliant surfaces, suction to control boundary layer growth, heat transfer through pipe, multi-phase flow and a wide array of conditions.



Drag Reduction

Numerous techniques for reducing friction at the pipe wall have been proposed and studied for several decades but since most of the pressure loss occurs in the turbulent boundary layer it is the most interesting to study and has the greatest potential for reducing friction loss with additives.



History

Researchers discovered that certain fluid additives modify the structure of the boundary layer and cause a reduction of skin friction during turbulent flow. These may be either insoluble particles (clays) or fibers, associated colloids or soluble long chain polymers. Studies have shown that skin friction on marine animals was reduced by viscous secretions. The first record of drag reduction was in 1883 but not until 1948 was the mechanism of drag reduction first studied by B.A. Toms, who saw that polymethyl methacrylate could lower the pressure gradient compared to the solvent alone for the same flow rate in turbulent flow.

The first field applications of drag reducer were made in oilfields in Texas in 1950 where fracturing with guar gum was established.

In 1961 the US Navy Research Laboratories began studying drag reduction with a rotating disc apparatus. They investigated a wide range of water soluble polymers and saw that in some cases very large friction reduction was possible with just a trace amount of polymer added to the solution. Some very dilute polymer solutions had viscosities only slightly greater than water and did not behave like pseudo-plastic polymer fluids.

Additives for drag reduction

Numerous synthetic and natural polymers have been proven to reduce frictional drag in turbulent flow conditions; the ones that achieve the best drag reduction effect have the following properties:

- very long chain, flexible molecular structure.
- very high molecular weight (MW) molecules.
- rapid solubility in water.
- solutions exhibit viscoelastic properties.

In the early studies of synthetic polymers, polyethylene oxide having a MW around 4 to 8 million was widely used. Since then, Polyacrylamide became the most widely used polymer for drag reduction due to its low cost, good mechanical stability, and high MW. The SNF emulsion drag reducer polymer, called DR7000, has a molecular weight in the range of 15-17 million.

Associative colloids produced by mixing anionic and cationic polymers can be more stable to shear degradation but require very specific conditions for dispersion.



Drag reduction in pipe flow

Pipeflow can generally be described as laminar or turbulent based on the flow structure. In the laminar flow regime, the fluid moves in laminae or layers and the flow velocity profile can be predicted analytically. In turbulent flow, the fluid particles move in a random 3 dimensional motion superimposed on the average motion of flow and the frictional pressure loss must be determined based on experimental results. The pressure loss can be calculated once the friction factor, f , is determined from the Moody plot which shows the data for friction factor as a function of Reynolds number. The Reynolds number is calculated with the following equation:

$$Nre = 928.d\rho v/\mu$$

d = diameter (inches)

v = velocity (ft/sec)

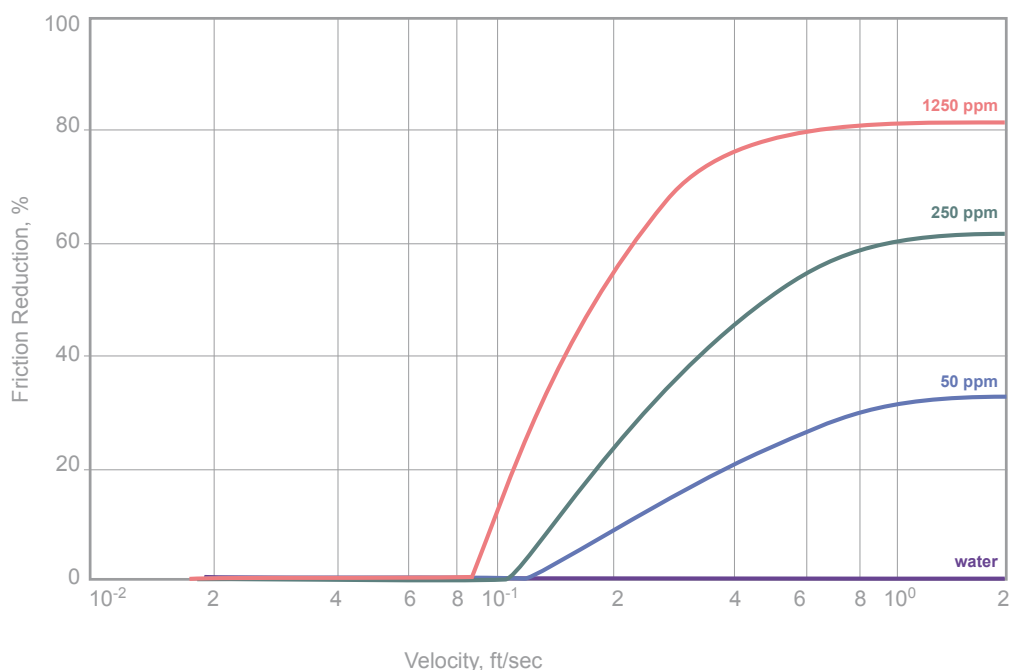
ρ = density (lb/gal)

μ = viscosity (cp)

For a Reynolds number less than 2000, flow is laminar and there is relatively little frictional pressure drop, but at higher Reynolds numbers there is a transition from laminar to turbulent flow and the pressure loss due to friction is large. This is where a DRA is highly effective i.e., fluids in the turbulent flow regime.



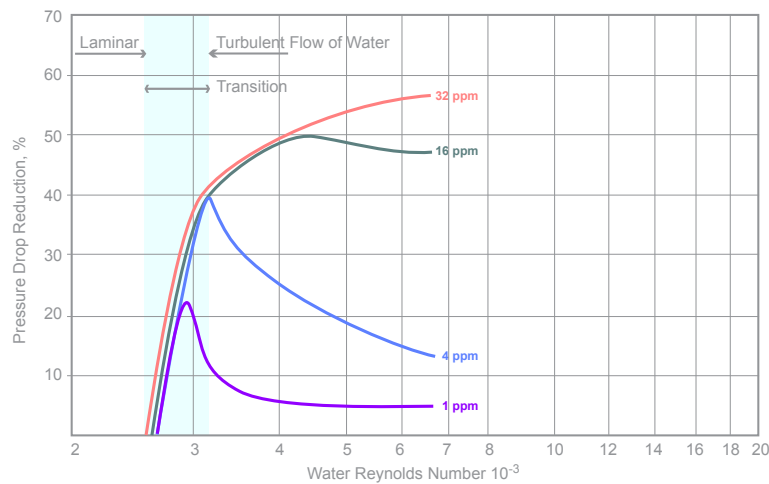
Friction Reduction vs Velocity and Concentration
for PAM with a Molecular Weight of 12 million



■ *Friction reduction as a function of velocity and concentration*

Drag Reduction

*Pressure Drop Reduction vs Reynolds Number
for PAM with a Molecular Weight of 12 million*



■ Pressure drop reduction as a function of the Reynolds number

This can be seen in the following curves.

At Reynolds numbers above 4000 the flow is fully turbulent and the effect of pipe roughness begins to influence the pressure loss. As the Reynolds number increases, the boundary layer thickness decreases and at extremely high Reynolds numbers the roughness elements protrude through the boundary layer into the turbulent core region. This is known as the fully-rough flow regime and the friction factor becomes a function of only the pipe roughness and no longer a function of the Reynolds number.

When a drag reducer polymer is added to a fluid in the highly turbulent fully-rough flow regime, one effect is to increase the thickness of the boundary layer which reduces the friction factor as if the pipe was smoother.

Older pipelines have scale buildup and corrosion which increase the roughness factor over time by as much as 2 or 3 times, causing the friction factor to increase by 50%.

The following conclusions can be drawn for pipe flow:

- drag reduction occurs only in fluids that are in the turbulent flow regime, above a Reynolds number of 2000.
- drag reduction is greater in small diameter pipe due to the roughness factor relative to the pipe diameter.
- drag reduction in dilute solutions increases with increasing polymer concentration up to a limit.
- at higher polymer concentrations the mechanism of drag reduction is complicated by the increase of viscosity and shear thinning properties.
- drag reducer polymers can lose their effectiveness due to shear degradation which occurs over time in the pipeline.
- the higher the turbulence, the higher the shear rate and the more degradation there is.





Polymer degradation

The shear degradation of the polymer is limited even at very high speed (25 m.s^{-1} or 75 ft.s^{-1}) on 3 to 6 inches pipes. The shear is lower very often than 2000 s^{-1} in the pipe.

But a part of the process is dependant on surface equipment sometimes not very adapted to the case of the polymer: high speed check valves, pressure control valves, restrictions...

On top of this, the study of the degradation of polymer by sand suspension in turbulent flow is very dependant on specific conditions of injection.

One other problem encountered in drag reduction is the mixing of the polymer and the water or the sand suspension. This is often a very rough method without use of specific equipment giving agglomerates of the size of a rice grain with a long dissolution time.

In many cases a pre-dilution of the polymer to 10000-15000 ppm through a static mixer improves the efficiency of the product.

Chemical degradation can occur very quickly with free radical formation between oxidizing and reducing species. In particular Fe^{2+} in presence of O_2 results in a rapid destruction of the MW of polyacrylamides and polyethylene oxides.

Polymer is removed from the fluid due to adsorption and flocculation with suspended solids. For use in slurries it is necessary to choose polymers that are non reactive with the solid being transported.

Polyacrylamide is more efficient in fresh water than in water with high salt or suspended solids levels. This is because in fresh water the polymer molecules uncoil and reach their full length, whereas in salt water the molecules tend to stay more coiled up. DRA is very efficient and most widely used in sea water injection.

Heat transfer with drag reduction

The increased wall layer thickness which accompanies turbulent drag reduction results in an increased thermal resistance between the wall and the bulk fluid and therefore a reduction in the rate of heat transfer.

This should not be confused with the entirely different application where polymer is injected into heat exchangers to flocculate the suspended matter to avoid scaling. This type of treatment is used periodically in power plants that use river or sea water.

Drag Reduction

Anomalous effects with dilute polymer solution

In addition to drag reduction, some DRAs also exhibit favorable side effects which are used in a number of applications.

Cavitation: polymer can inhibit the onset of cavitation which reduces noise. This can apply to propellers for torpedoes or submarines.

Flow through sinuous pipes: The pressure drop is increased compared with straight pipes.

Water jet cutting: With DRA the jet stream is kept in shape and more coherent, which gives a more focused circular jet, increasing the cutting efficiency.

Application of drag reduction in the oil industry

The biggest user of DRA is the oil industry, where there are multiple applications:

- Increasing water injection rates.
- Improved efficiency of water flooding.
- Drag reduction of produced fluids with a continuous water phase
- Increasing bottom hole pressure for hydraulic fracturing.
- Improvement of the clear fluids used in drilling through standard drill pipe and coiled tubing.

Transport of water

Large volumes of water are pumped through pipelines over long distances, from aquifers to injection wells, platforms to shore, production wells to water treatment facilities, etc. Operating cost can be high and in many fields the flowrate of water is limited by facilities.

Polyacrylamide DRA is supplied to the field in emulsion form and injected directly into the pipeline:

- to decrease the output pressure and the energy consumption of the water pump for the same flowrate,
- or to increase the flowrate through the existing pipeline for the same pump pressure.

To maintain the flowrate in the laminar flow regime, the velocity of the fluid must be less than $2\text{--}3\text{ m.s}^{-1}$ ($6\text{--}9\text{ ft.s}^{-1}$). For higher velocity, turbulent flow, DRA should be considered. Polymer is added at 30 to 70 ppm which gives an average flowrate increase of 30% or a 30% reduction in pump pressure for the same flow rate.

For very long pipelines it is necessary to have multiple injection points along the pipeline where DRA can be added. In some cases, it may be possible to inject polymer that is not yet fully hydrated which would require 2 or more hours to fully hydrate (dissolve), generating high MW polymer all along the pipeline, keeping the drag reduction effect constant.

For example, polymer powder with a particle size of 1 mm (0.04 inch) will dissolve in 60 minutes at 20°C (68°F). At a flow velocity of 3 m.s^{-1} (9 ft.s^{-1}) the dissolution would be made over 10.8 km (6.7 miles).



Improvement of water flooding efficiency

In secondary recovery operations water is injected to maintain reservoir pressure or sweep oil towards production wells. Up to the fields' economic limit, the more water injected into the reservoir the more oil production. In most oil fields the produced water is reinjected into the reservoir to maintain a unit voidage ratio, so as the water cut increases, the demand for water injection increases.

High rate centrifugal pumps are used to inject water through wellbore tubing, which typically has a diameter of 4 to 8 inches. The injection rate is limited by the capacity of the injection pump, the diameter and length of the tubing and flowlines, and the reservoir permeability. With the use of DRA it's possible to reduce the frictional pressure drop in the flowlines and tubing and to increase the injection rate. For typical applications a 30% increase can be achieved with less than 100 ppm of DRA. In some field cases, the drag reduction effect can be as high as 60%.



DRA polymer is almost always used in emulsion form and injected into the high pressure pipeline with a triplex chemical dosing pump.

Additional benefits include:

- can be used temporarily to increase injection rate in parts or all of a field to make up voidage ratio lost during downtime or high production rate.
- reduced corrosion.
- polyacrylamide has no souring effect on the reservoir.
- reduced operating cost of water injection.
- reduce capital expense on new water injection facilities for brown fields.
- extension of the life of some fields.

Drag Reduction

Hydraulic fracturing

Hydraulic fracturing is a stimulation technique first developed in the 1940's to increase well productivity by fracturing the reservoir rock in order to increase the effective drainage area of a well. Fracturing has allowed low permeability formations to produce at economic rates. A fracturing (frac) fluid is injected at high rate and pressure into the wellbore to break the reservoir rock. Some fracture treatments have been injected at over 500 bbl/min which requires more than 10,000 hydraulic horsepower.

Frac fluids contain many additives such as DRA, biocide, scale inhibitor, surfactant, fluid loss additives and proppant. The fracture faces are held open by proppants such as sand, metals, plastics, etc. which provide long lasting high flow capacity for oil or gas production.

Achieving a high enough injection rate is a major problem in deep wells. Both the bottom hole pressure required to fracture a formation and the pressure loss due to friction increase directly

with well depth. This is due to the cumulative effect of the overburden pressure and the length of tubing or casing the fluid has to travel through to reach the bottom hole. If the injection rate is below a critical value, the proppant may fall out of the frac fluid and cover the perforations forcing the treatment to be stopped.

DRA is widely used to reduce the frictional pressure loss so that a higher bottom hole pressure and injection rate can be achieved. The drag reduction effect can be as much as 50 to 75% during a fracturing treatment.

Typically, the process has the following characteristics:

- high injection rates: 10 m³/min (65 bbl/min)
- fluid velocity in wellbore: 15-25 m.s⁻¹ (49-82 ft.s⁻¹)
- most often 2-4% KCl to inhibit clay swelling
- emulsion polyacrylamide such as DR6000 and DR7000
- concentration range: 200 – 2000 ppm

Clear fluid drilling

Drilling fluids that do not contain any solids are known as clear fluids and they are used to maximize formation productivity. Polymer is added to clear drilling fluids which contain CaCl₂, KCl or Na-formate, to viscosify and help remove drill cuttings, and improve bit lubrication which gives faster penetration rates. Polymer can also provide improved wellbore stability, and it used at around 1000 – 3000 ppm.



Drag reduction in extreme pressure systems

Polyacrylamides are widely used to improve the efficiency of water jet cutting processes, where pressures are as high as 4,000 bar (58,000 psi). Polymer makes the water jet more cohesive and focused which produces a finer cut and reduces cutting time.

Civil work application

The polymer jet solution has a higher pressure and is more focused even to a distance near one meter. This property has been used in civil work applications such as:

1.1- Concrete drilling: water jets with 3000 ppm of polymer were used in Los Angeles after the 1989 earth quake to drill 6.4 cm (2.52 inch) holes through bridge pilings to reinforce them with steel bars. The cost was 100 times lower than conventional diamond bit drilling.

1.2- Concrete, marble, brick cutting: Polymer is used alone or in a mixture with abrasives or stainless steel shot which allows precision cutting even in thickness of 25 to 75 cm (10 to 30 inches).

1.3- Concrete removal: It's possible to remove concrete during demolition or restoration work with hydro-demolition which removes concrete and leaves the steel reinforcement bars for recovery or for reconstruction.

1.4- Tunnel drilling / quarrying / mixing: Water jets are used for tunnel drilling, replacing explosives. It's also used for quarrying blocs of marble or granite or in mining operations such as coal mining.

Miscellaneous applications

DRA is used in numerous other high pressure applications such as:

- Breaking up very hard deposits in refinery heat exchangers.
- removal of sludge from nuclear power steam generators which consists of magnetic, metallic copper and oxides.
- submerged water jetting to cut away dangerous rock outcrops or concrete blocs in harbors.
- precise cutting in the manufacturing of clothes, leather, metal, ceramic tiles, etc.
- Cleaning boat hulls.



Other applications

There are a variety of other specialty applications for DRA where technical knowledge is still limited. Research and development will increase in these and other areas due to the increasing energy cost.

■ Storm sewer flow augmentation

Increasing the flow capacity of storm sewers can reduce flooding and avoid large capital expenditures for pumping or infrastructure. In some locations, years of continued development have increased the flow capacity requirements of existing storm sewers. By providing 20-30% increase of flow capacity during the periods actually needed, polymer drag reduction can provide a cost effective way to solve flooding problems.



The need for construction of larger sewers, at least in a short-medium term may be avoided. Economic feasibility studies together with 5 years of data from an automatic dosing station demonstrate that this is a practical solution to many flooding problems. Today, totally automatic systems are available in USA and UK.

This has not been applied to large zone flooding but can bring in the future a solution to increase the speed on the bottlenecks which limit the flood.

The use of large amounts of emulsion polymer can be organized very quickly with a pre-dilution and multiplication injection in the flow of water.

■ Fire fighting

Water flow rates can be increased, smaller hose lines used, and nozzle pressures raised by the addition of DRA to firefighting water. Polymers have been tested in fire fighting lines in Hamburg and Paris and the New York City fire department has used it for several years.

■ Energy storage

One way to efficiently use nuclear energy is to store water in two lakes. When the demand for electricity is high the upper lake is flowed through a turbine into the lower level lake and it produces electricity. When the need for electricity is low, a pump transfers the water back to the upper lake. Polymer can reduce the energy consumption by 30%.

■ Marine applications

Drag reducer can increase the speed of torpedoes and boats, reduce the noise produced by submarines, and reduce the energy consumption of large tankers. There has been an intense amount of study over the last 40 years in this area but only a few known commercial applications.

■ Irrigation

Polymer is injected into irrigation water downstream of the pumps to increase the flowrate and it also improves consolidation of the soil by flocculation.

■ Biomedical applications

Polyacrylamides have been tested to improve blood flow in restricted arteries and decrease blood pressure, reducing the amount of stress on the heart.





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