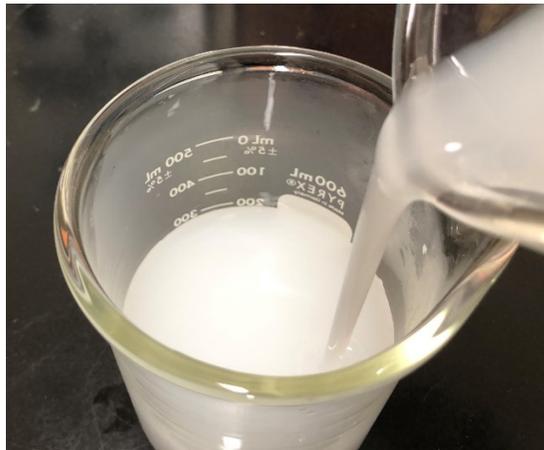


## UNDERSTANDING POLYMER FOR THICKENING AND DEWATERING PROCESSES

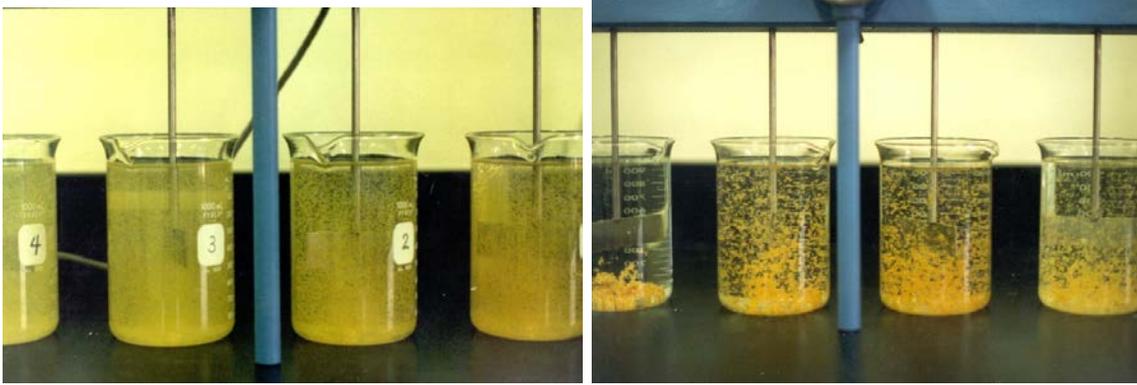
### INTRODUCTION

- The first thing an operator needs to know about polymer is that polymer creates a **dangerous slipping hazard** when introduced to water. Extreme caution should be exercised whenever working around, or especially when cleaning around, polymer.
  - Polymer in solution is very viscous (see Figure 1), which means it is “thick” and resistant to flowing.



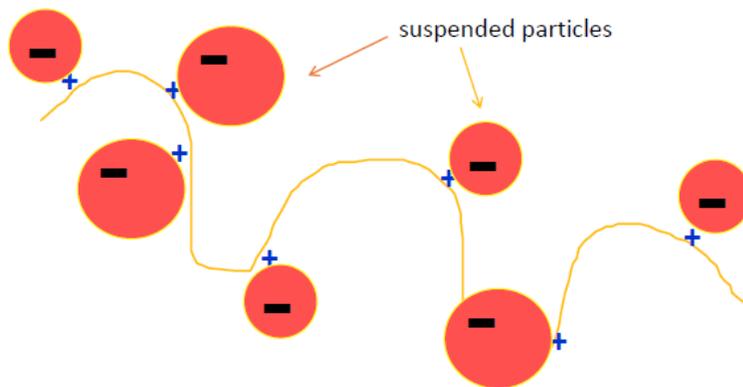
**Figure 1. Polymer Solution is Very Viscous.**  
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- Because polymer solutions may be clear (no color), slippery areas are even more difficult to detect.
- Do not use water to clean polymer spills because it will become more slippery. Use absorbent material such as cat litter. Always consult the Safety Data Sheets (SDS) and the manufacturer’s instructions on how to safely handle each type of polymer.
- Polymer is used as a flocculant for solids separation processes.
  - The aggregation of particles into larger and more easily removable forms by applying coagulants or flocculants is necessary for efficient separation by clarification, decanting, sedimentation, filtration, thickening, and dewatering processes.
  - The terms “coagulant” and “flocculant” are often used interchangeably; however, they are not the same (see Figure 2).
    - Coagulants neutralize the surface charge of particles, which allows them to create small clusters of particles, called flocs.
    - Flocculants make large flocs by bridging the small particles or flocs together.



**Figure 2. Coagulants (on the Left) Produce Small Flocs, and Flocculants (on the Right) Bridge the Small Flocs Together. Reprinted with permission from UGSI Chemical Feed Inc.**

- Polymers are effective for use as flocculants because they consist of long chains of molecules called *monomers*. Monomers can create bridges between solids particles (see Figure 3). Polymers can have different charges, charge densities, and molecular weights. Polymers that have a positive charge (otherwise known as cationic) and a high molecular weight are typically used for thickening and dewatering solids separation processes.



**Figure 3. A Depiction of a Floc Formed by a Cationic Polymer Chain Bridging the Solids Particles. Reprinted with permission from UGSI Chemical Feed Inc.**

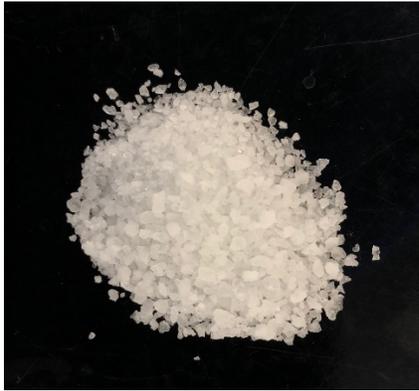
- Applying polymer prior to a thickening or dewatering process is also called “conditioning”. Conditioning with polymer is often a requirement for the thickening or dewatering equipment to successfully operate.

## POLYMER TYPE

Polymer is supplied in three different forms:

### ■ Dry (or Powder) Polymer (see Figure 4):

- Typically contains up to 90% active polymer. The remaining amount consists of residual water, buffers to control the solution pH, anti-caking additives to increase the shelf-life, anti-dusting agents, and small amounts of surfactants to facilitate the activation process.
- Requires more time for complete dissolution and activation than emulsion polymers.
- Can be delivered in 23 kg (50 lb) bags or “Super Sacks” that can be as large as 907 kg (2000 lb).

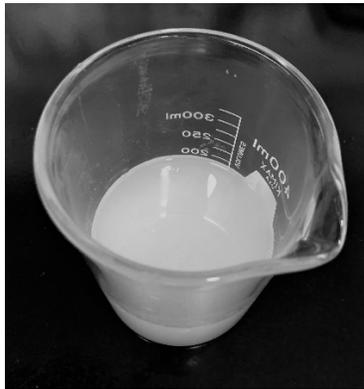


**Figure 4. Dry Powder.**

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■ Emulsion Polymer (see Figure 5):

- Consists of micron-sized polymer gels emulsified in 30% hydrocarbon oil.
- Depending on the amount of water in the polymer gels, the active polymer ranges from 20% to 55%, with the most commonly used being 40%.
- Can be delivered in 19 L (5 gal) pails, 208 L (55 gal) drums, 1022 L (270 gal) totes, or 11 400 to 18 900 L (3000 to 5000 gal) tanker loads.



**Figure 5. Emulsion Polymer.**

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■ Mannich Polymer (see Figure 6):

- Mannich polymer is typically custom blended for the specific application and can work very well.
- Mannich polymer has a low active polymer content of only 4% to 6%. Therefore, it is delivered in 11 400 to 18 900 L (3000 to 5000 gal) tanker loads, and the transportation costs are typically very high unless the Mannich polymer production facility is located close to the water resource recovery facility (WRRF).



**Figure 6. Mannich Polymer.**

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# POLYMER ACTIVITY AND DOSAGES

- The polymer delivered to a WRRF is called “neat” and may include water, oil, surfactants, and other ingredients in addition to active polymer.
  - The active content is the portion that actually reacts with the solids.
  - The percentage of active content is what’s being referred to when expressing a concentration of polymer. For example, a 1% polymer solution has 1 gram of active polymer per 100 grams of polymer solution.
- Dry Polymer has the highest activity levels in its neat form, so it requires the smallest storage containers. This saves money in the cost to ship, and it requires the least space to store. However, this polymer type requires more equipment and time to prepare (or activate) the polymer.
- It is the active content that should be considered when assessing appropriate polymer dosages for solids processing systems.
- The best way to think of polymer dose for thickening and dewatering processes is in terms of active pounds of polymer per dry ton of solids (active lb/dry ton). In international standard (SI) units, active kilograms of polymer per dry tonne of solids (active kg/dry tonne).
  - A proper polymer dose for solids separation processes must relate the mass of the active polymer to the mass of the solids to which polymer is applied.
  - The calculation of polymer dose is as follows:

In international standard (SI) units:

$$\frac{\text{Active kg polymer}}{\text{dry tonne solids}} = \frac{1000 \left( \frac{\text{kg}}{\text{tonne}} \right) * \text{Polymer Flow Rate (L/m)} * \text{Active Polymer Concentration} \left( \frac{\%}{100} \right)}{\text{Solids Flow Rate (L/m)} * \text{Solids Concentration} \left( \frac{\%}{100} \right)}$$

In U.S. customary units:

$$\frac{\text{Active lb polymer}}{\text{dry ton solids}} = \frac{2000 \left( \frac{\text{lb}}{\text{ton}} \right) * \text{Polymer Flow Rate (gpm)} * \text{Active Polymer Concentration} \left( \frac{\%}{100} \right)}{\text{Solids Flow Rate (gpm)} * \text{Solids Concentration} \left( \frac{\%}{100} \right)}$$

- This calculation can be applied to either neat polymer or polymer solution. For example, in U.S. customary units:
  - If the desired polymer dose is 10 active lb/dry ton, the flow rate to a rotary drum thickener (Solids Flow Rate) is 350 gpm, the rotary drum thickener feed solids concentration (Solids Concentration) is 0.75%, and
  - If the active content of neat polymer (Active Neat Polymer Concentration) is 40%, then, using the equation provided, the Polymer Solution Flow Rate is calculated to be 0.03 gpm, or 1.8 gph.
  - Or, if the desired polymer solution (Active Polymer Solution Concentration) is 0.2%, then, using the equation provided, the Polymer Solution Flow Rate is calculated to be 6.6 gpm.

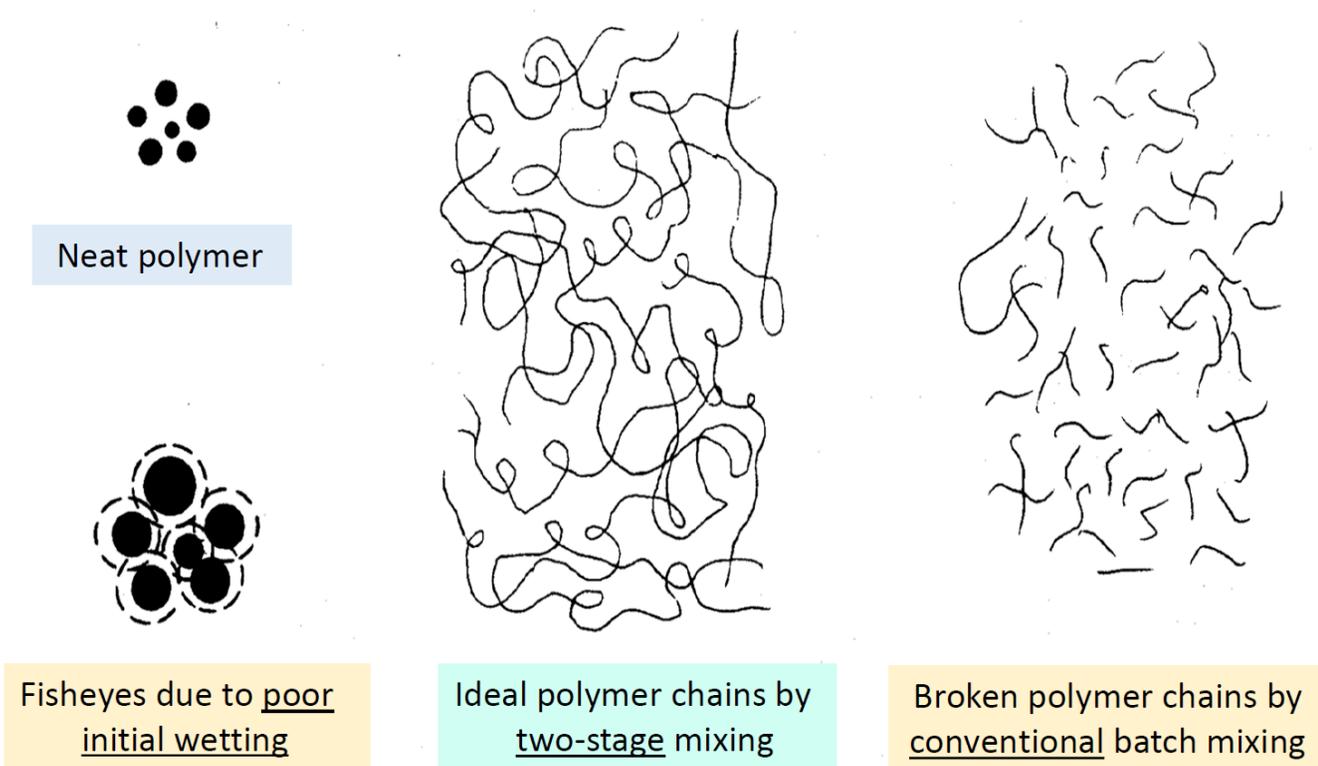
## HANDLING AND STORAGE

- Dry polymer is very *hygroscopic* (moisture-attracting), so care should be taken to store it in a cool and dry area (neither above 40 °C [104 °F] nor humid). Dry polymer has a shelf life of over 3 years if unopened and properly stored. Once a bag is opened, dry polymer can quickly clump and become unusable.
- Emulsion polymer tends to *stratify* (separate oil from water in the polymer gels) during storage, so a drum/tote mixer or recirculation pump should be used before the neat polymer is fed to the activation equipment. Emulsion polymer should be stored at the temperature range of 5 °C to 30 °C (41 °F to 86 °F) and dry conditions, preferably inside a building. If properly stored, emulsion polymer has a shelf life of 6 months. Should freezing occur, the product should be allowed to thaw thoroughly in a warm area and mixed well before use.
- Mannich polymer must be used within 4 weeks and should be kept away from both freezing and overly warm environments.

## POLYMER MAKE-DOWN AND ACTIVATION

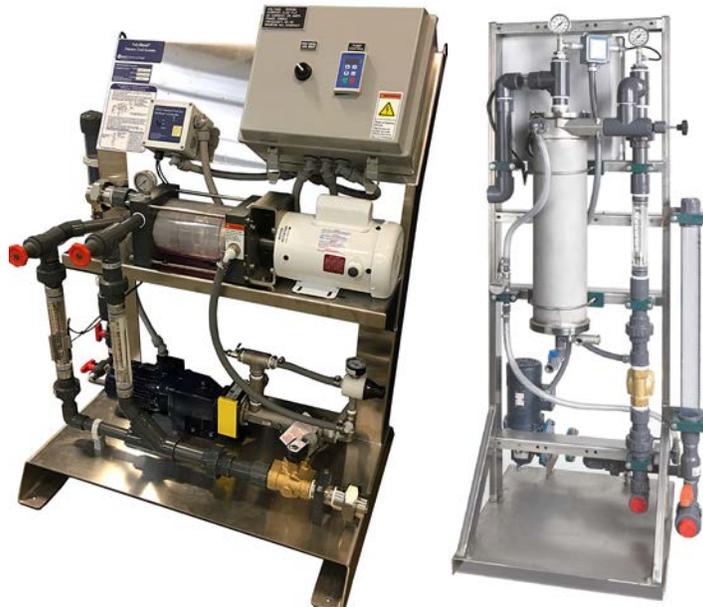
- Emulsion and dry polymer in their neat forms must be activated in a dilute solution before being applied to a solids stream for conditioning. Dilution water is mixed with neat polymer to produce this dilute solution in a “make-down” process (which can also be referred to as a “make-up” process).
- “Make-down” refers to the initial application of dilution water to neat polymer.
  - Dry: Dry polymers are typically diluted to 0.2% to 1% active solutions for activation.
  - Emulsion: The purpose of a surfactant provided in neat oil-based emulsion polymer is to facilitate activation of the polymer in an aqueous solution. Thus, the polymer concentration during make-down is often recommended at 0.5% in order to ensure a sufficient surfactant concentration.
  - Mannich polymers are delivered as activated compounds, so the only goal for its make-down process is to produce a dilute solution for injection.
- Aging after make-down: Often, additional time is desired or necessary after the make-down process to complete the activation process.
  - *Aging* (or, maturing) starts from the moment polymer solution is discharged out of the polymer make-down system. Sometimes, the detention time of the make-down solution in the polymer feed piping is sufficient to complete full activation prior to injection.
  - Other systems require a separate aging tank (for example, with a 30-minute detention time) to achieve full activation. Aging tanks are typically required for dry polymer systems.
- Post-dilution after activation: The optimal polymer concentration for activation is often not dilute enough to be the optimal concentration at the injection point, so it is helpful to have an additional post-dilution stage after the make-down and, if applicable, aging stages. Optimal concentrations for polymer injection solution can range from 0.1% to 0.25%, regardless of polymer type.
- Two-stage mixing for make-down: While polymers with higher molecular weights are more efficient in flocculation, they also present greater technical challenges in solution preparation than lower molecular weight polymers. The concept of two-stage mixing is well established in the polymer make-down process for dry and emulsion polymer (see Figure 7).

- First Stage, or initial mixing: Very high energy mixing at the initial stage. Proper wetting (for dry polymer) and very high energy mixing during this stage will prevent “fisheye” formation, including the prevention of fisheyes that occur on a microscopic level.
- Second Stage: Low energy mixing to minimize damaging the polymer molecules as they “uncoil” out of polymer gels/particles. Much longer residence time is required for the second stage than the first stage. Second stage mixing can occur in the same mixing chamber as the first stage mixing.
- Care must be taken to avoid breaking polymer chains through excessive mixing once activated. Damaged polymer chains will result in an increased polymer dose.



**Figure 7. A Depiction of Ideal Polymer Chain Activation Versus Common Pitfalls. Reprinted with permission from UGSI Chemical Feed Inc.**

- Emulsion make-down equipment: Although there are numerous emulsion polymer make-down systems available in the market (see Figure 8), they can be classified into two types which differ in how mixing energy is delivered for effective polymer activation:
  - Mechanical – An advantage of mechanical systems includes the ability to provide high mixing energy (ideal for first-stage mixing), regardless of the fluctuation of WRRF water pressure. However, they may require more maintenance than non-mechanical systems.
  - Non-mechanical (or hydraulic) – Easy to operate with fewer moving parts than mechanical systems. However, they require a dilution water booster pump to maintain the consistent incoming water pressure (minimum of 414 kPa [60 psi]) which is the source of the applied mixing energy.
  - Some make-down systems are designed to include both mechanical and non-mechanical mixing.



**Figure 8. One Example of a Mechanical (on the left) and a Hydraulic (on the right) Emulsion Polymer Make-Down Systems Available on the Market. Reprinted with permission from UGSI Chemical Feed Inc.**

- Dry polymer make-down equipment: Dry polymer make-down systems (see Figure 9) typically include a wetting system (including dry polymer feeders and a rapid fill water dispenser), an aging tank, and a day tank for feeding the activated solution. A full batch system minimizes the number of tanks. For example, a mixer could be programmed to provide both the initial high-energy and the second-stage low energy mixing, and then the activated solution could be fed from this same tank. Other systems maintain separate tanks to optimize for each function.



**Figure 9. One Example of a Variety of Dry Polymer Make-Down Systems Available on the Market which Includes an Initial Wetting Device, Mix Tank and Post-Dilution. Reprinted with permission from UGSI Chemical Feed Inc.**

## INJECTION OF POLYMER SOLUTION

- Because polymer solutions are so viscous, they are difficult to inject and disperse rapidly into the solids flow stream, especially if the concentration of the solids receiving the polymer solution is thick.
- Different thickening and dewatering equipment units and applications require different polymer/sludge mixing mechanisms. Some equipment is designed with zones to accept the polymer solution and mix it with the sludge flow stream. However, some equipment and applications perform better when the polymer solution is injected in the upstream piping of the thickening or dewatering unit.
- There are many commercially available polymer–solids mixers with either static or mechanical mixing, so careful evaluation is required. Parameters to be considered include the type of dewatering equipment, solids concentration, solids to polymer contact time, and polymer solution viscosity.
- For example, if solids contains higher than 4% solids, the static polymer-solids mixer may not be able to disperse polymer solution rapidly and uniformly into the solids. This can cause over-dosing or under-dosing of polymer, ultimately leading to inefficient dewatering and wasted cost.

## DILUTION WATER

- The quality of dilution water has a tremendous effect on the efficiency of a polymer solution.
- Hardness, which represents a major portion of the ionic strength of dilution water, plays an important role in polymer activation. If hardness exceeds a certain level (such as 400 mg/L), it is strongly recommended to add a softening device to minimize the negative effect of hardness.
- It is essential to reduce the chlorine level of dilution water to below 4 mg/L to avoid damaging the structure of polymer molecules.
- When reclaimed water is used for the creation of polymer solution, it must be carefully evaluated. Chlorine, suspended solids, turbidity, and dissolved ions in reclaimed water react with polymer molecules and reduce the polymer's effectiveness.
- There is an optimal temperature range for dilution water. A water heater is recommended for dilution water below 4 °C (39 °F). Dilution water over 38 °C (100 °F) may damage polymer chains.

## SUMMARY

- Polymers are excellent flocculants and are critical for use as a solids conditioner prior to thickening and dewatering equipment.
- A summary of common ranges for active polymer content (otherwise known as polymer concentration) is provided in Table 1. Optimal make-down and feed solution concentrations vary by the polymer product, type of injection system, and the concentration and other conditions of solids in the solids flow stream. Conducting polymer optimization trials is recommended to determine the best concentrations for an individual system.

**Table 1. Common Ranges for Polymer Concentrations**

	Dry Polymer	Emulsion Polymer	Mannich Polymer
Neat (as delivered)	90%	22%–55% (commonly 40%)	4%–6%
Activation Solution	0.2%–1% (achieved by the make-down process)	0.5% (achieved by the make-down process)	Same as the neat solution because it is delivered as already activated compounds.
Injection (or Feed) Solution	Recommended: 0.1%–0.25%, achieved by post-dilution. However, can be the same as the activation concentration if post-dilution is not feasible.		Recommended: 0.1%–0.25%, achieved by the make-down process. However, can often be 0.2%–0.5% if the optimal concentration is not feasible.

- The type of polymer (dry, emulsion, or Mannich) will dictate the necessary systems and equipment for storage, handling, polymer solution make-down, and polymer solution injection.
- Due to the high viscosity, pumps that feed neat, activated, or post-diluted polymer solutions are typically high viscosity diaphragm pump, gear pump, peristaltic, or progressive cavity pump.
- Operators can save money on polymer by doing the following:
  - Helping to select a cost-effective polymer product,
  - Calculating and monitoring the polymer dose in terms of active lb/dry ton,
  - Appropriately handling and storing polymer in accordance with the polymer type,
  - Ensuring proper mixing energy and residence times for make-down and aging,
  - Experimenting with polymer activation and injection concentrations to find the optimal concentrations that minimize polymer dose, and
  - Measuring and monitoring hardness and other water quality parameters in the dilution water.

## DEFINITION OF TERMS

- Activation—Applying dilution water and time to neat polymer to allow the polymer chains to uncoil in order to be ready to create bridges between solids particles.
- Active content—The portion of polymer that reacts with the solids. For neat polymer, this represents the amount of monomer chains in relation to other necessary additives (such as oil, surfactants, water, pH buffers, anti-caking additives, and anti-dusting agents). For a polymer solution (such as polymer activation solution or polymer injection solution), this represents the amount of monomer chains in relation to the surrounding dilution water. In either case, the active content is given as a percent (more specifically, the percent by weight).
- Aging— Additional maturing time for polymer chains to be fully uncoiled, and therefore fully activated, after the preparation of the make-down solution.
- Coagulant—A chemical that neutralizes the surface charge of particles, allowing them to create small flocs.

- Conditioning—Applying activated polymer to a solids flow stream prior to a thickening or dewatering process.
- Day Tank—A tank used to make-down polymer solution from neat polymer, to age the make-down solution, to hold dilute polymer solution while it is fed to the injection point, and/or to serve all of these purposes sequentially in a batch operation system.
- Dilution Water—Water used for the creation of polymer solution, including for initial mixing, second stage mixing, or post-dilution.
- Floc—A cluster of particles.
- Flocculant—A chemical, such as polymer, that bridges smaller particles, allowing large flocs to be created.
- Initial (First Stage) Mixing—High-energy mixing stage of the make-down process to introduce dilution water to neat polymer, which initiates the activation process.
- Injection (or Feed) Solution—Polymer solution at the concentration being applied to the solids flow stream.
- Make-down—The initial application of dilution water to neat polymer. If only one dilution step is applied (i.e., for Mannich polymer, or if no “post dilution” is used), the resulting make-down solution is the same as the injection solution.
- Make-up—Same as “Make-down”.
- Neat polymer—Polymer in the form as delivered to a site, prior to any dilution.
- Polymer—A flocculant that consists of long chains of molecules.
- Polymer concentration—Same as “active content”.
- Polymer Injection—The introduction of dilute polymer solution to the solids flow stream.
- Post-Dilution—Additional dilution, beyond that needed for activation, to create a polymer solution with optimal concentration (of active content) for injection. Also called “push water” or “carrier water”.
- Second Stage Mixing—Low energy mixing stage of the make-down process with longer detention time than the initial (first stage) mixing designed to allow polymer chains to uncoil.
- Viscous, Viscosity—Resistant to flowing.

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## Recommended Reading

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Kim, Y. (2020). *Polymer 101: Chemistry, handling/storage, dilution water, and optimized mixing*. Water Environment Federation Webinar.