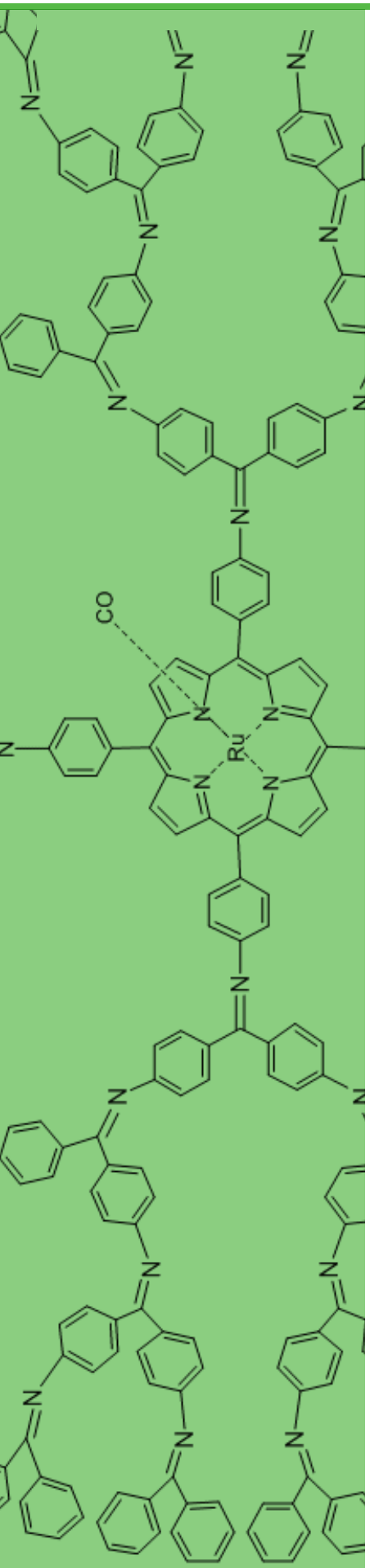
Dendrimer-Based Chemistry Offers Challenging Alternatives



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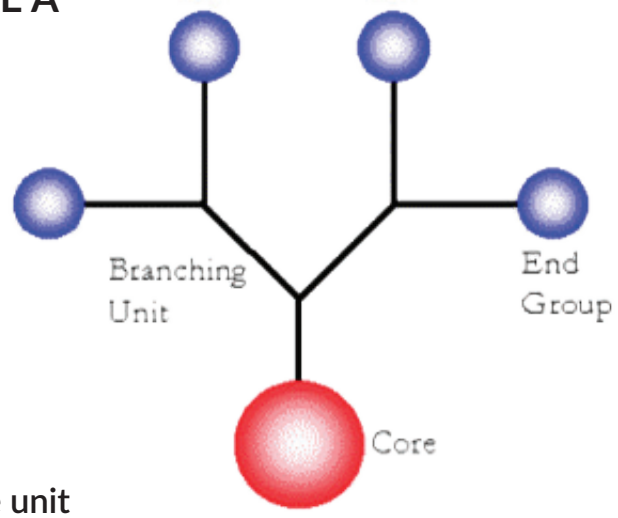
A newly refined patent-pending dendrimer chemistry challenges conventional crystal modifier chemistries, which include phosphonates, phosphates, acrylates, maleic, and carboxylic acid as pretreatment in reverse osmosis systems. The unique performance, handling, and logistics advantages of dendrimers are particular to the molecular structure and it's application as pretreatment in membrane processes. This paper discusses the chemical and practical attributes of dendrimer-based scale inhibitors in reverse osmosis applications.

Dendrimer Architecture:

The term dendrimer refers to the highly branched structure of the macromolecule. They are synthesized in a stepwise fashion resulting in molecules that are highly branched and of a precise molecular weight. Unlike most polymers, dendrimers are three-dimensionally layered. This unique characteristic provides a preferable combination of high complexity and sound structural integrity.

Dendrimers may be described as covalently bonded structures around a molecular core, using repeating chemical reaction sequences to develop mathematically precise functional groups and mass at its terminus. The dendrimer consists of four main components (see figure A):

FIGURE A



1. A central core unit
2. Arms of the identical size
3. Linking or branched points
4. End functional groups

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Naturally existing dendritic architecture is commonly observed in nature. It is evident in lightning patterns, snow crystals, tree branches, and vascular systems. The synthetically engineered dendrimer molecule is utilized in many chemical applications such as drug delivery systems using proteins in dendritic form.

Dendrimers are preferred in such high-tech applications because of their structure and integrity. Such traits are also highly desirable in water treatment applications.

Dendrimers have two major chemical environments in their structure. These include the exterior surface chemistry with functional end groups (see figure B), and the sphere's interior (or voids) which are largely shielded from the exterior environment due to the spherical shape of the dendrimer structure (see figure C). Dendrimers accept guest elements or molecules in the dendritic voids, which can introduce the guest molecule into an environment (as with pharmaceutical delivery systems). In the application of water treatment the guest molecule can be a dissolved ion, or an organic molecule (humic acids, etc.). A dendrimer antiscalant 'host' may control the ions or organic molecule in the exterior groups or interior voids, depending on the characteristics of the targeted constituent.

FIGURE B

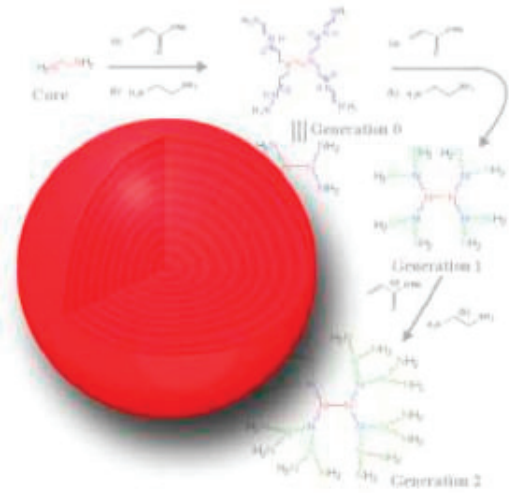

FIGURE C

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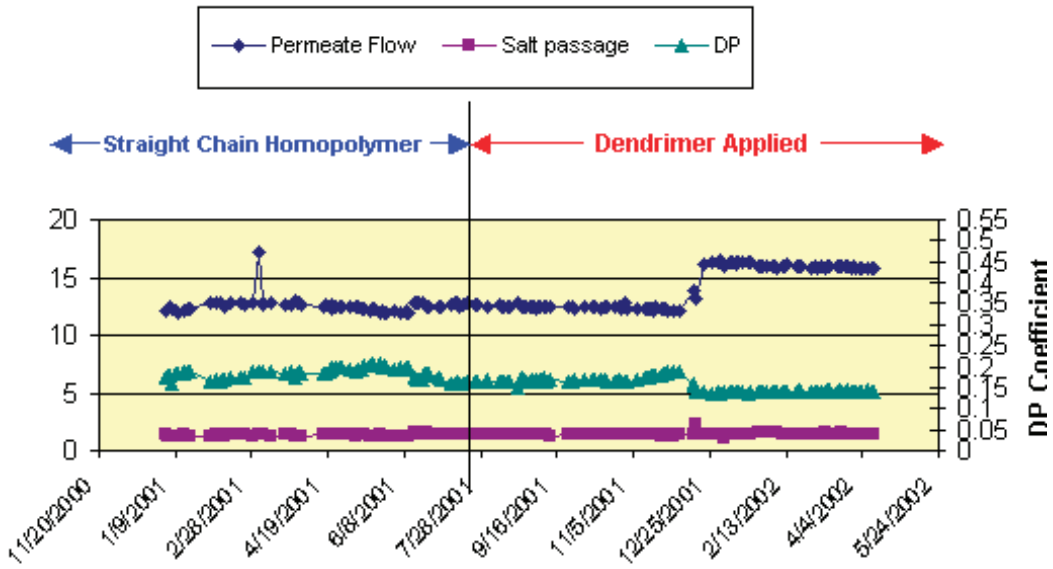
Comparison of Dendritic Molecular Strategy and Conventional Crystal Modification in RO

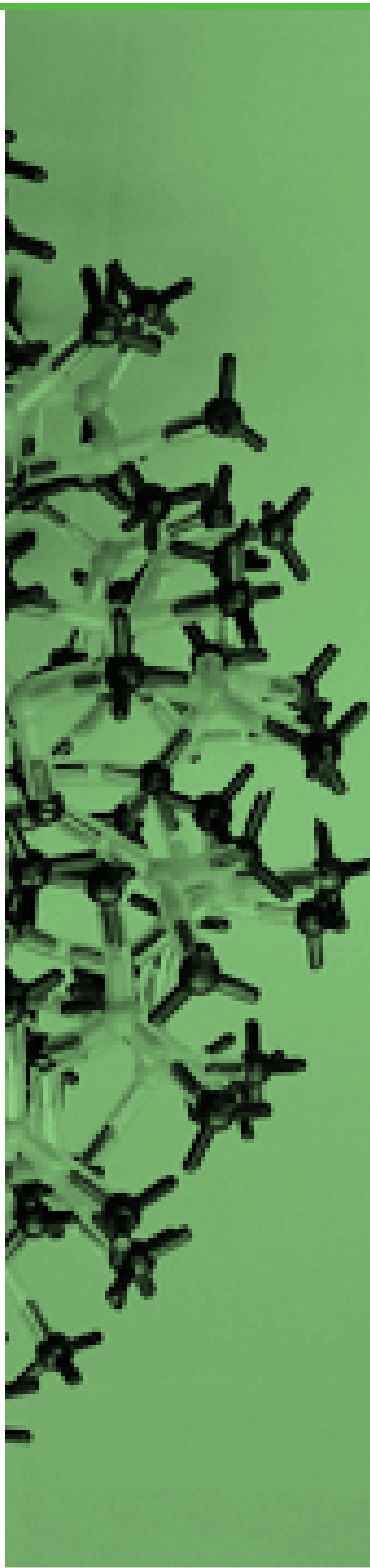
Because of their unique geometry, dendrimers behave differently from linear molecules. In solution, a dendrimer's occupied volume varies cubically with increasing size. However, the mass increases exponentially. This difference of density leads to enhanced solubility, reactivity and viscosity when compared to linear molecules. In fact, this increase in solubility greatly increases dendrimers' solubility in water as compared to a linear isomer. Since dendrimers are several orders of magnitude less in viscosity than the linear isomer, enhanced solubility is observed.

Traditional polymer science has evolved around the use of reactive modules to produce large one-dimensional molecules of various lengths. Such straight-chain molecular design, however, is inherently imprecise and critical variations in size, atom positions, covalent connectivity, or molecular shapes typically occur. By contrast, dendrimers have discrete, quantifiable bundles known to be mathematically precise. The result is more specific, predictable, and reliable dendrimer integrity, which is advantageous in controlling water chemistry.

Figure D is an example of improved membrane system performance using a dendrimer-based anti-scalant versus a straight-chain homopolymer to control inorganic constituents.

FIGURE D





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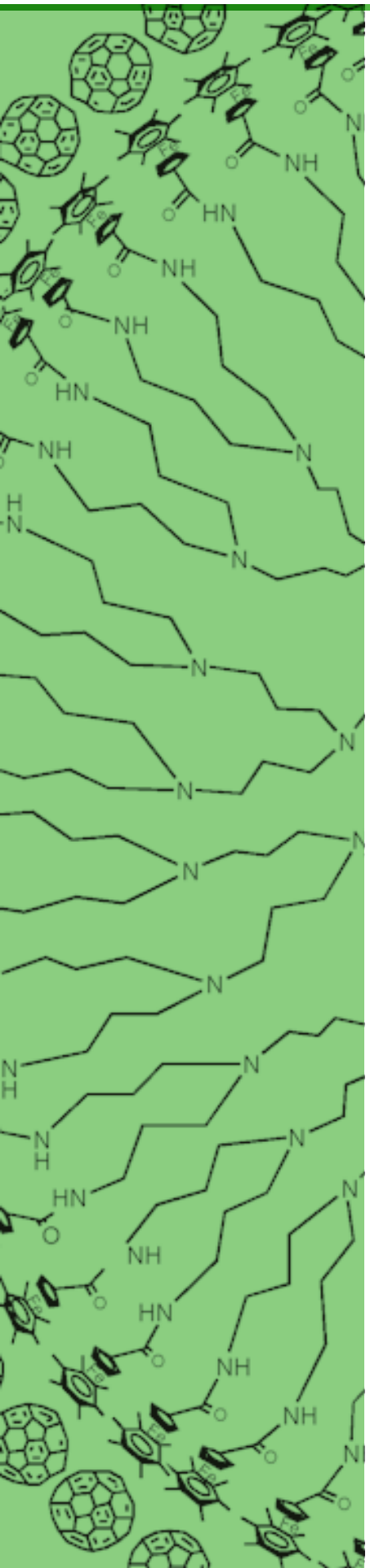

A municipal reverse osmosis system producing 950 gpm (216 m3/hr) operated with a straight-chain homopolymer from January 2001 until July 2001. During that period, the membrane system required cleaning on 6 occasions. In July 2001, the straight-chain homopolymer was replaced by a dendrimer-based antiscalant. As a result, the system required cleaning only one time during the subsequent 9 months. Further, after cleaning, the plant maintained a higher permeate flow and a lower differential pressure.

The geometric and chemical characteristics of dendrimers offer distinct advantages as compared to conventional crystal modifiers:

- Dendrimers have a greater surface area and a significantly greater quantity of functional groups for controlling inorganic constituents as compared to crystal modifiers. This greater surface area (internal and external) yields a higher loading capacity, which can control a wider range of metals, organic or inorganic molecules.

- Highly concentrated and intrinsically efficient by design, dendrimers may be used at the rate of one-eleventh the dosage of standard homo-polymers. This advantage allows users to reduce chemical handling logistics by eleven times compared to traditional scale inhibitors.

- Phosphate and phosphonates are not required in dendrimer formulations. In fact, these may be omitted to reduce risks of biological growth in the system and lessen environmental impact.

- Though dosages of linear homo-polymers are often increased to improve scale control, as with BaSO4 precipitation, their inherent instability may affect solubility. Such traditional scale inhibitors are twenty times less stable than dendrimers and will foul a membrane if overdosed. Dendri-mers, however, are stable at concen trations as high as 1,000 ppm which safeguards users in accidental overdose situations or in cases requiring higher dosages.

- The dendritic molecular structure has increased activity at higher TDS ranges due to a reduced impact of osmotic pressure based on their characteristic stability. Conventional scale inhibitors tend to lose solubility in higher TDS environments as the functional groups that maintain solubility become stressed.

- Most importantly, while traditional crystal modifiers adsorb onto developed inorganic crystals to destabilize crystal growth, dendrimers are unique in that they wholly prevent the formation of crystals by controlling the individual ions before crys tals form, using the dendritic structure. Such prevention (as opposed to modification) of crystal formation is characteristically more efficient, ultimately reducing membrane scaling.

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Summary

Dendrimers have demonstrated advantages in water treatment applications, utilizing an increased structural and functional area, a higher loading capacity, greater complexity, higher uniformity, lower toxicity, and multi-dimensional functionality, compared to straight-chain homopolymers. As such advantages obsolete straight-chain homopolymers in an increasingly competitive field, dendrimer-based pretreatments have a more active role in affecting the economy and feasibility of membrane plant operations.

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