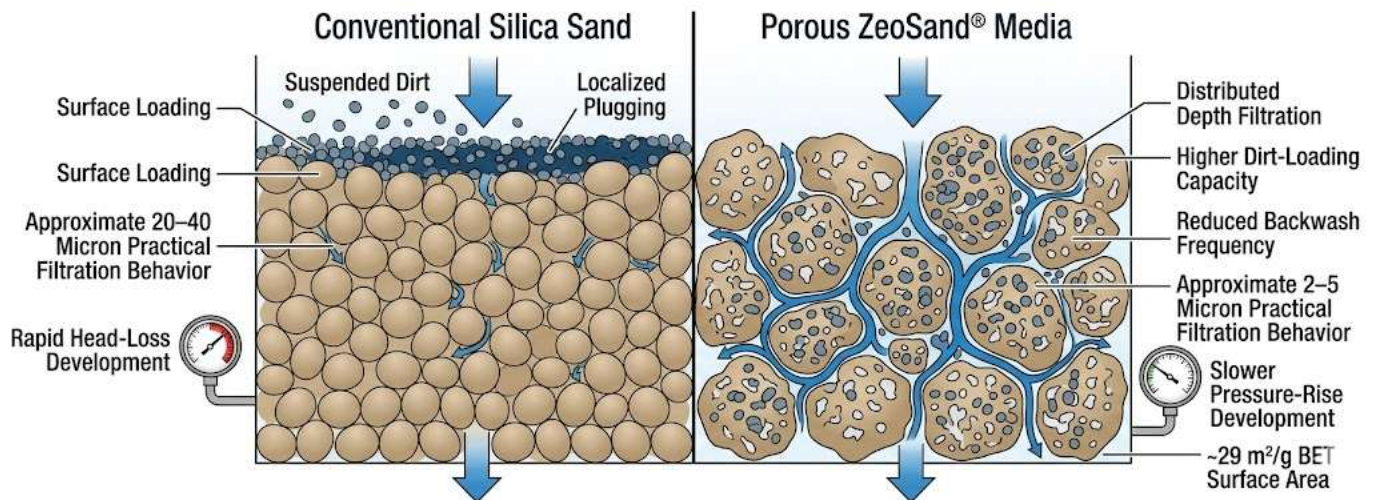


# Fine-Particle Filtration in Granular Media Systems

## Improved Small-Particle Removal, Higher Dirt-Loading Capacity, and Reduced Hydraulic Resistance Using ZeoSand® Filter Media

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### Introduction

Granular media filtration remains one of the most widely used technologies for suspended solids removal in recreational water, drinking water, industrial process water, and wastewater treatment systems. Conventional silica sand has historically served as the standard filtration media because of its low cost, chemical stability, availability, and acceptable hydraulic performance.

Although filtration media are frequently compared primarily on particle size, actual filtration behavior is governed by substantially more than nominal effective size alone. Media characteristics, including:

- internal porosity,
- surface area,
- bulk density,
- particle morphology, and
- pore structure

can significantly influence:

- fine-particle retention,
- dirt-loading capacity,
- head-loss development,
- depth filtration behavior,
- hydraulic resistance, and
- backwash performance.

Porous natural zeolitic filtration media differ substantially from conventional dense silica sand in these physical characteristics. These differences may significantly influence practical filtration performance under comparable operating conditions.

Conventional silica sand filters are commonly associated with practical particulate removal in the approximate 20–40 micron range. Porous zeolitic filtration media, due to their substantially greater surface area, internal porosity, depth filtration characteristics, and distributed solids-loading behavior, may demonstrate significantly improved fine-particle retention into the approximate 2–5 micron range while simultaneously exhibiting

substantially greater dirt-loading capacity under suitable operating conditions.

Based on differences in porosity, internal surface area, and solids distribution behavior, porous zeolitic media may exhibit practical dirt-loading capacities estimated at approximately two to four times those of conventional silica sand under comparable hydraulic operating conditions.

These characteristics may contribute to:

- extended filtration cycles,
- slower head-loss development,
- reduced backwash frequency,
- lower pumping energy demand,
- reduced water consumption, and
- improved long-term hydraulic performance.

This paper examines the engineering basis for these performance differences.

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## Engineering Summary

Compared to conventional silica sand, porous zeolitic filtration media such as ZeoSand possess:

- substantially greater BET surface area,
- higher internal porosity,
- lower bulk density, and
- enhanced depth filtration characteristics.

These physical differences may contribute to:

- practical fine-particle retention in the approximate 2–5 micron range,
- dirt-loading capacities are estimated to be approximately two to four times greater than silica sand,
- slower head-loss development,
- reduced backwash frequency,
- and lower hydraulic energy demand under suitable operating conditions.

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## Granular Filtration Fundamentals

Granular media filters remove suspended solids through multiple mechanisms, including:

- mechanical straining,
- interception,
- sedimentation,
- adsorption,
- diffusion, and
- depth loading.

Although granular filtration is often simplistically described as a “screening” process, actual filtration behavior is considerably more complex. Granular filters do not function as absolute membrane barriers. Instead, practical particulate removal reflects the combined effects of:

- particle interception,
- flow-path tortuosity,
- contaminant adsorption,
- solids distribution within the media bed, and
- depth filtration behavior.

As suspended solids move through the filter bed, particles are progressively captured throughout the media depth. The effectiveness of this process depends strongly on:

- media effective size,
- hydraulic loading rate,
- porosity,
- surface characteristics,
- internal surface structure, and
- contaminant distribution throughout the filter bed.

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## Effective Size and Filtration Fineness

### Effective Size Fundamentals

Effective size ( $D_{10}$ ) is defined as the particle diameter at which 10% of the media by weight is finer.

Typical pool and process filtration sands commonly have effective sizes of approximately 0.45 to 0.55 mm. Effective size strongly influences:

- pore spacing,
- hydraulic resistance,
- pressure loss, and
- practical particulate retention.

As the effective size decreases:

- pore openings become smaller,
- fine-particle interception generally improves,
- but hydraulic resistance increases.

Conventional sand filtration, therefore, involves a tradeoff between filtration fineness and head-loss development.

### Effective Size Alone Does Not Predict Filtration Performance

Although effective size remains important, actual filtration behavior cannot be predicted solely from particle diameter.

Two filtration media may possess similar effective size, similar bed depth, and similar uniformity coefficient, yet demonstrate

substantially different filtration performance because of differences in:

- internal pore structure,
- surface area,
- particle morphology,
- solids-loading distribution, and
- depth filtration behavior.

This distinction is particularly important when comparing dense silica sand with porous zeolitic media.

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### Surface Area, Internal Porosity, and Fine-Particle Retention

One of the most significant engineering differences between porous zeolitic media and conventional silica sand is the presence of extensive internal surface structure and interconnected pore systems.

Typical BET surface areas are approximately:

Media	BET Surface Area (m <sup>2</sup> /g)
Silica sand	~0.5
Crushed glass	<0.1
Other zeolite	~12
ZeoSand	~29

Surface area among natural zeolitic materials can vary substantially depending upon mineral composition, deposit origin, purity, and processing methods. Porous zeolitic filtration media such as ZeoSand may exhibit BET surface areas of approximately 29 m<sup>2</sup>/g, while some natural zeolitic materials may possess substantially lower surface areas and correspondingly different filtration behavior.

Because surface area strongly influences particle interaction, contaminant retention, and depth filtration behavior, zeolitic media should not be assumed to exhibit equivalent hydraulic or filtration performance solely based on mineral classification.

Silica sand particles are relatively dense and non-porous. Suspended solids are therefore captured primarily near the upper surface of the filter bed.

Porous natural zeolite media contain interconnected internal void structures, tortuous flow pathways, and substantially greater internal surface area.

These characteristics may promote:

- increased particle interception,
- longer particle residence time,
- enhanced depth loading,
- improved distributed solids retention,
- and greater interaction between suspended solids and media surfaces.

As a result, porous zeolitic media may exhibit substantially improved practical retention of fine particles compared to conventional silica sand, despite similar nominal effective sizes.

Conventional silica sand filters are commonly associated with practical particulate removal in the approximate 20–40 micron range. Porous zeolitic media may demonstrate improved particulate retention into the approximate 2–5 micron range under favorable operating conditions.

Importantly, these values represent practical operating behavior rather than absolute filtration ratings.

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### Surface Loading Versus Depth Filtration

Conventional silica sand frequently behaves primarily as a surface-loading filtration media.

As suspended solids accumulate near the upper surface of the filter bed:

- permeability decreases,
- localized plugging develops,
- pressure differential rises rapidly, and
- filtration cycles shorten.

Filtration efficiency often becomes increasingly dependent upon the formation of a surface cake layer.

Porous zeolitic media may behave differently because suspended solids can penetrate farther into the media depth before retention occurs.

This distributed loading behavior may:

- reduce localized plugging,
- distribute solids throughout a greater portion of the bed depth,
- delay terminal head loss, and
- maintain more stable hydraulic performance.

The result may be:

- finer practical filtration,
- increased dirt-loading capacity,
- improved water clarity,
- slower pressure-rise development, and
- extended operational cycles.

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### Dirt-Loading Capacity

Dirt-loading capacity refers to the quantity of suspended solids a filter bed can retain before excessive head loss or backwashing becomes necessary.

Several media properties strongly influence dirt-loading behavior:

- porosity,
- internal surface area,
- particle shape,
- solids distribution, and
- bed void volume.

Dense silica sand typically accumulates solids predominantly near the upper portion of the filter bed. These localized solid accumulations can result in relatively rapid development of pressure rise.

Porous zeolitic media may permit:

- deeper particle penetration,
- distributed contaminant retention,
- greater utilization of the entire bed depth, and
- more uniform solids loading.

Because retained solids are distributed more uniformly throughout the media bed, porous zeolitic media may exhibit substantially greater dirt-loading capacity than dense non-porous silica sand under comparable operating conditions.

Although actual performance depends heavily on contaminant loading, hydraulic design, particle-size distribution, and operating conditions, the physical characteristics of porous zeolitic media support the engineering expectation of substantially greater solids storage capacity than dense silica sand.

Under comparable operating conditions, practical dirt-loading capacities for porous zeolitic media may be approximately two to four times greater than conventional silica sand due to:

- increased internal void volume,
- distributed contaminant retention,
- greater usable bed depth,
- and slower localized plugging near the upper filter surface.

Potential operational benefits may include:

- longer filtration cycles,
- slower pressure-rise development,
- reduced backwash frequency,
- reduced water consumption,
- and more stable filtration performance.

## Hydraulic Performance and Energy Saving

### Head-Loss Development

As solids accumulate within a filter bed, hydraulic resistance increases and differential pressure rises.

Surface-loaded sand filters often exhibit relatively rapid pressure-rise development because solids accumulate near the upper bed surface.

Depth-loading porous media may distribute solids more uniformly, reduce localized plugging, and delay terminal head loss.

Because porous natural zeolite has lower bulk density, higher porosity, and greater internal surface area, it may exhibit lower operating head loss during portions of the filtration cycle than dense silica sand.

### Pumping Energy Reduction

Lower sustained operating head loss may reduce pumping energy requirements because the circulation system operates against less hydraulic resistance.

Even modest reductions in differential pressure may become operationally significant in continuously circulating systems such as:

- commercial pools,
- aquatics facilities,
- industrial recirculating systems, and
- process-water treatment operations.

Because porous zeolitic media may delay pressure-rise development while simultaneously retaining greater quantities of suspended solids, the cumulative reduction in pumping demand over extended operating periods may become operationally meaningful.

### Backwash Energy Reduction

Lower-density media generally fluidize more readily during backwashing.

Typical bulk densities:

Media	Bulk Density (lbs/ft <sup>3</sup> )
Silica Sand	100
Crushed glass	75
ZeoSand	55

Because ZeoSand media has a substantially lower bulk density than silica sand, lower hydraulic velocities may be required to properly fluidize and expand the filter bed during backwashing.

Potential operational benefits may include:

- reduced backwash pumping energy,
- reduced water consumption,

- shorter backwash cycles,
- improved bed cleaning efficiency,
- and reduced mechanical stress on pumps and hydraulic components.

The combined effects of:

- finer practical particulate retention,
- increased dirt-loading capacity,
- slower head-loss development,
- reduced backwash frequency, and
- lower backwash velocities

may contribute to meaningful long-term reductions in operating costs and energy demand. In continuously operating commercial filtration systems, even modest reductions in average operating differential pressure and backwash frequency may produce meaningful long-term reductions in electrical consumption and water usage.

## Operational Considerations

Filtration media selection should consider:

- desired water quality,
- contaminant loading,
- hydraulic design,
- operating cost,
- maintenance requirements, and
- backwash capability.

Although effective size remains important, practical filtration performance is also strongly influenced by:

- surface area,
- porosity,
- internal structure,
- solids-loading distribution, and
- depth filtration behavior.

Porous zeolitic media may therefore provide advantages in applications where:

- improved water clarity,
- enhanced fine-particle retention,
- increased dirt-loading capacity,
- extended filtration cycles,
- reduced backwash frequency, and
- reduced hydraulic energy demand

are desirable operational objectives.

## Conclusions

Granular filtration performance is governed by substantially more than nominal particle size alone.

Media characteristics, including:

- surface area,
- internal porosity,
- bulk density,
- pore structure,
- and solids distribution

strongly influence:

- fine-particle retention,
- dirt-loading capacity,
- hydraulic behavior,
- head-loss development,
- and backwash performance.

Conventional silica sand filters are commonly associated with practical particulate removal in the approximate 20–40 micron range. Porous zeolitic filtration media, due to their substantially greater surface area, internal porosity, depth filtration characteristics, and distributed solids-loading behavior, may demonstrate significantly improved fine-particle retention into the approximate 2–5 micron range while simultaneously exhibiting increased dirt-loading capacity and extended filtration cycles under suitable operating conditions.

Based on differences in porosity, internal surface area, and solids-loading behavior, porous zeolitic media may exhibit practical dirt-loading capacities approximately two to four times greater than those of conventional silica sand under comparable hydraulic operating conditions.

Porous zeolitic media may therefore provide engineering and operational advantages in applications where:

- improved water clarity,
- fine-particle removal,
- increased solids-holding capacity,
- reduced hydraulic resistance,
- reduced backwash frequency,
- and lower operating energy demand

are important operational objectives.

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