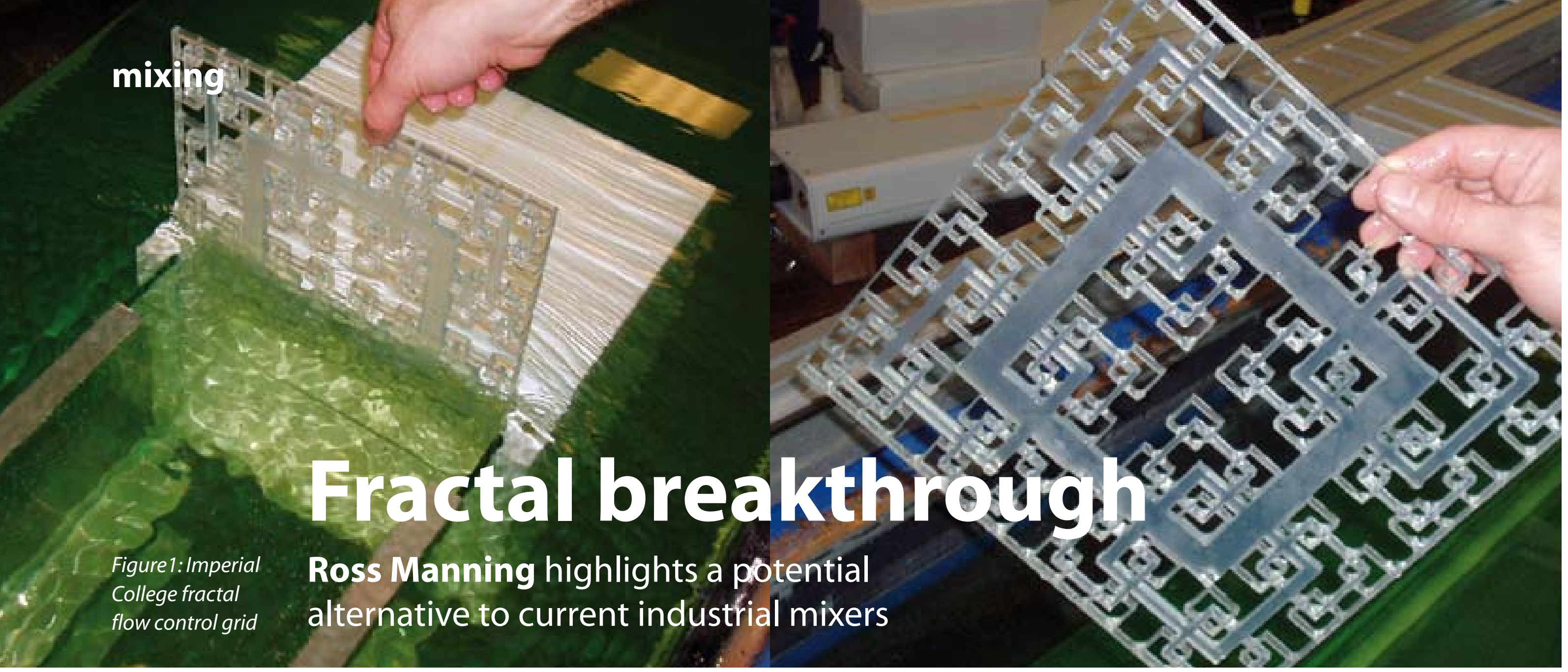

Fractal breakthrough

Ross Manning highlights a potential alternative to current industrial mixers

Figure 1: Imperial College fractal flow control grid

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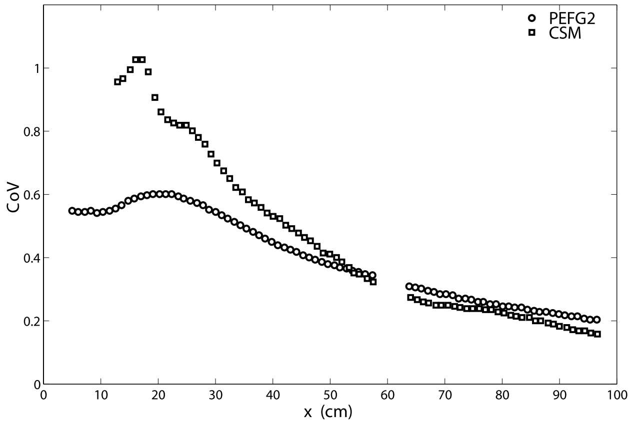
FLUID mechanics experts at Imperial College London have had a breakthrough in fluid mixing based on the turbulence created by fractal meshes, which they say could result in substantial energy savings, greater control and more effective mixing than the kind of industrial mixers currently used in the process industries.

Christos Vassilicos, professor of fluid dynamics in Imperial's department of aeronautics has been conducting research into turbulence in mixing and flow control for around 20 years. An understanding of turbulence is of enormous importance in environmental studies, meteorology and oceanography, but it also plays a vital role in many industries wherever fluid flow is critical, such as the chemical, processing, automotive, aerospace and naval industries. For example, the cost of pumping oil through pipelines is largely proportional to the frictional losses caused by turbulence. Understanding turbulence can lead to flow control schemes for reducing skin friction drag. Even a small percentage reduction in frictional losses would mean huge cost savings for worldwide industries that consume vast quantities of oil, such as ocean shipping and air transportation, along with impressive reductions of pollutants. Improvements in turbulence management can also be brought to combustion engines and mixing devices leading to further energy gains and emission reductions.

Figure 2: The coefficient of variance (CoVx) when the dye source is upstream of the grid (PEFG2 = Imperial College fractal flow control grid; CSM = commercially available top-performance industrial mixer – current standard of mixing)



Researchers at Imperial have been using wind tunnel experiments to understand the turbulence dynamics of fluids flowing through fractal grid structures. The term "fractal" was coined by Benoît Mandelbrot in 1975 to describe geometric shapes that are self-similar in that a similar structure can be observed at different levels of magnification. In a fractal grid each section of the grid can be viewed as a smaller scale replica of the whole. Imperial's wind tunnel tests were the first to examine the turbulence generated by such grids and showed that the grids could be used to subtly control and manage the transition from laminar to turbulent flow.

The scaling and decay of turbulence generated was investigated downstream of different two-dimensional fractal grids. The research team found that slight alterations in the grid's dimensions (fractal parameters such as bar thickness and fractal dimension) related directly to the turbulence intensity generated by the fluid's impact with the grid, as well as on the pressure drop across it. This showed that it should be possible to independently set the levels of turbulence intensity and pressure drop. Further to this, fractal grids could be designed to generate high turbulence intensities with low pressure drops – creating optimised energy-efficient mixers.

fractals for fluid mixing

Engineering with fractals started in the 1990s and the US-based process R&D company Amalgamated Research was the first to use fractals in fluid mixing. It developed a fractal fluid distribution system, designed to exhibit extreme symmetry from large to small scale. Since 1997, Amalgamated Research's fluid transporting fractals have been used in a diverse range of industrial applications.

The technology developed at Imperial College London takes a different approach to applying fractals to the process of fluid mixing. The so-called Fractal Flow Control (FFC) Grids are fractal-patterned meshes which are designed to be immersed in any fluid flow (eg flow in pipes, tunnels, tanks) where controlled mixing of fluids is necessary. The grids generate a bespoke turbulence to control fluid flow and reduce friction drag.

Fluid mixing is central to the majority of industrial processes and the control of fluid mixing is vital for process efficiency and yield. The grids provide an elegant alternative to current static in-line mixers for fluid mixing and can be used across all industries for mixing fluid process materials such as oil and water or mixing a fluid and a gas like water and air to create a homogenous end product.

FFC Grids could be used in a wide range of applications spanning many sectors. They may in particular be used in the chemical and petrochemical industries for additive mixing, dilution of acids and bases, chlorination or oxidation; in waste and water treatment for aeration, sludge mixing and chemical addition and other key industrial areas such as pharmaceuticals for generating powders.

fractal flow control grids

Vassilicos and his team conducted experiments to compare the mixing and drag performances of FFC Grids with those of a commercially available top-performance industrial mixer (referred to as CSM, for current standard of mixing). The experiments used a dye attenuation technique to make synoptic and non-intrusive measurements of the concentration field downstream in a water pipeline, and drag measurements were made in a wind tunnel at Imperial College.

The tests were a success, with initial findings showing that FFC Grids have several advantages over the CSM. The team found that replacing a CSM with FFC Grids would have a major impact on aspects of mixer performance, which are outlined below and include substantial energy savings and more controlled and effective mixing requiring minimal effort or cost.

homogeneity and less downtime

Figure 2 shows how the coefficient of variance (CoVx) varies when the dye contaminant is released upstream of the grid. The CoVx values for the FFC grid were smaller than those for the CSM, and the results show the FFC grid mixes as well as the CSM in the far field and better than the CSM in the near field! In terms of spatial distribution of mixing the FFC grids kept the mixing activity away from the walls of the pipeline, which is not the case of CSM.

The mixing systems had comparable homogeneity; however the CSM achieves homogeneity by deviating parts of the flow towards the walls of the pipeline in the near field, which may be undesirable in certain applications where the substances to be mixed are highly corrosive or persistently and/or recurrently hot. The FFC Grids mix by generating high levels of turbulence for relatively low levels of blockage without braiding different parts of the flow together, which is what the CSM mixer attempts to do with the result of throwing fluid at the walls. The high levels of turbulence generated by Imperial's Fractal Flow Control Grids means the grids can mix effectively at short stream wise distances, keeping the substances to be mixed clear from the walls, whereas the CSM achieves most of its good mixing far downstream. Using FFC Grids would therefore cause less damage to the pipeline, decreasing operational downtime and maintenance and extending lifetime.

power savings

The FFC grids were shown to be more efficient and effective mixers than the CSM. Mixing effectiveness is a function of both mixing quality and the necessary power input to achieve it. The normalised drag on FFC grids ranged between being significantly lower and comparable to that on CSM, implying that it is possible to save considerable amounts of power. Where many mixers are used in a pipeline, the economy in power input brought by replacing with fractal grids would be even greater.

optimal use of space

The physical footprint of an FFC Grid is much smaller than the CSM which has a complex three dimensional configuration, is made up of baffles and sits along the length of a pipeline. Imperial's FFC grids are more compact and thin with a simpler structure. The FFC Grids are valuable space savers, which enable effective use of plant floor area.

controlled and bespoke mixing

Different industrial applications may require different standards of mixing, and the adaptable FFC Grids can be designed to fit predefined requirements and specified mixing properties. Only small adjustments to a fractal grid are needed for significant effects on turbulence and drag. The experiments confirmed the roles for mixing effectiveness of two of the main design parameters of the fractal grids: the thickness ratio and the blockage ratio, which can be changed independently. The turbulence intensity generated by a FFC Grid increases with thickness ratio, and measurements suggest that the CoVx values are also increasing functions of thickness ratio. The drag increases nonlinearly with the blockage ratio.

FFC Grids offer the unprecedented possibility to independently control pressure drop and turbulence intensity. It is therefore possible to tune them as very efficient mixers by combining a very low pressure drop (by lowering blockage ratio) whilst turning up the turbulence by increasing the thickness ratio between successive fractal iterations.

Other design parameters could be experimented with, such as those which determine the distance from the grid where the turbulence intensity peaks. There are also many other patterns (beside the 'I' square and cross patterns used in the Imperial College tests to date), which can also be used for the design of fractal grids. There are therefore limitless possibilities and potential opportunities for effective mixing engineering and design, which are still to be explored.

used in combination

The most impressive results from the tests were obtained when a FFC Grid and CSM were combined in the pipeline. Mixing was several times better than the combination of CSM and CSM and than CSM and FFC Grids individually. This combination offers the very tangible possibility of setting an entirely new standard of high quality mixing with exceptionally low CoVx values, homogeneous concentration maps and profiles, as well as little action on the walls, and all this at a very short distance downstream from the mixing elements.

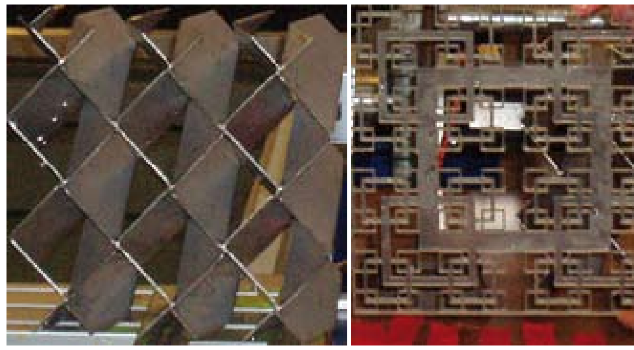


Figure 3: Commercially-available top-performance industrial mixer (a) compared with the Imperial College Fractal Control Grid (b)

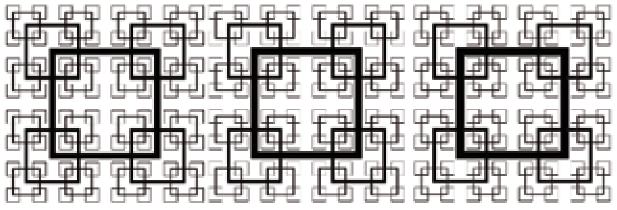


Figure 4: Fractal square grids for which all parameters are equal except for the thickness ratio – the differences between these three grids may be imperceptible to the eye but they generate very different turbulence intensities, which demonstrates how very sensitively the FFC grids can control mixing performance

further development

The FFC Grids in their current shape and form could potentially be competitive mixers by comparison to a commercially available top-performance industrial mixer, and could transform the mixing of fluids over a broad range of mixing applications. The technology is generic and could be adapted with different optimisations for different functions. FFC Grids offer process engineers an array of choices in fluid flow mixing, where blockage ratio, floor space, mixing intensity and mixer lifetime and maintenance are all constraints. The experiments conducted at Imperial suggest that the grids could increase both mixing efficiency and controllability over a wide variety of flow parameters, plus they are simple, cost effective and easy-to-install.

Building on existing work that established the mixing properties of the fractal grids, Vassilicos is currently running a proof of concept project development programme to test the technology in different operations and work is ongoing. Patents on the technology have been filed by Imperial Innovations, the technology commercialisation company based at Imperial College London. tce

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