Fractal Structures for Uniform Fluid Distribution in the Sugar Industry

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Introduction

In most cases better fluid distribution benefits the performance of any chemical heat- or mass transfer unit operation. However, for some applications the benefits are not as pronounced as for the others. For example, fluid distribution is crucial for packed distillation towers and not as important for tray distillation towers[1].

Although the problem of fluid maldistribution is frequently addressed in the chemical and petrochemical industry or general chemical engineering publications[2,3], the sugar industry literature remains almost free of references on this important subject. Nevertheless, significant economic benefits can be achieved by optimizing conventional fluid distributors or designing new equipment utilizing the advantages of improved distribution systems. A clear understanding of shortcomings of the existing distributors will help elucidate the benefits provided by more efficient fluid distribution systems.

Existing and potential applications in the sugar industry

A review of unit operations currently utilized by the sugar industry indicates that processes involving liquid flow through a column filled with granulated material are among the most sensitive to fluid distribution. Efficiency of these unit operations is dependent on the uniformity of the concentration front of dissolved components. Any deviation from "plug" flow reduces performance separation efficiency of a column. Following are the processes used in the beet industry, cane sugar mills and refineries, for which fluid distribution is of crucial importance.

Industrial chromatography for syrup or molasses desugarization
Juice and water softening
Carbon or ion exchange decolorization columns

For some other processes the effect of fluid distribution is less obvious, but the optimization may result in significant savings. Use of fractal structures for air distribution in sugar conditioning silos may serve as a good example of such application[4]. A similar concept has been applied for turbulence reduction in a pilot clarifier design.

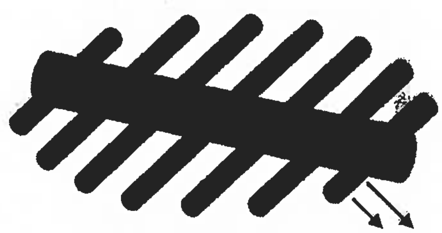
Once the importance of fluid distribution is understood and the damage from maldistribution evaluated, the corrective action should be taken. Existing fluid distributors can be modified or new equipment can be designed providing improved fluid distribution. Amalgamated Research Inc. (ARi) is currently exploring both alternatives.

Disadvantages of conventional distributors.

Most common distributors used in chromatographic, softener, decolorization applications are quite simple in design. When these processes were transferred from pilot to industrial scale the fluid distribution issue was obviously overlooked. The major drawback of common types of distributors roots in the lack of symmetry, which makes a scale-up task very complicated.

An example of a conventional lateral pipe distributor is shown in Figure 1. Typically the centrally located inlet is connected to a series of interconnected pipes with outlet holes. The residence time from the inlet to each hole varies depending on the distance from the inlet. For the same reason the pressure drop is different for each path from an inlet pipe to an outlet hole. Since the concentration of dissolved components changes continuously, different residence time leads to spreading or "smearing" of the concentration front and therefore to loss of separation efficiency.

Figure 1
An Example of a Conventional Distributor



Conventional practice of distributor design based on high pressure drop or variable outlet hole size leads to another set of problems. Among them is dependence of distribution quality on the feed rate. This problem is sometimes addressed as a turndown ratio. The ability of a distributor to convert fluid from a feed pipe into a uniform two-dimensional surface inside the column is extremely important for many industrial applications. For example in simulated moving bed (SMB) chromatography recirculation flow varies significantly during an operation cycle. Obviously, variable distribution quality in each step results in reduction of overall process efficiency.

Distributors based on fractal geometry

A new generation of fluid distributors based on fractal geometry has been described extensively in the recent literature [5,6]. This innovative idea has resulted in a number of patents (issued and pending) on fluid distributors and engineered fractal cascades[7,8]. Fractal distributors originally installed in large-scale chromatographic columns (up to 7 meters in diameter), have been modified for ion-exchange and decolorization applications, air distribution in conditioning silos, gas-liquid systems, etc.[9]. A sample illustration of a fluid distributor for industrial chromatographic columns is shown in Figure 2. Seemingly complicated, the

Figure 2. Fractal Distributor for Industrial Chromatographic Columns

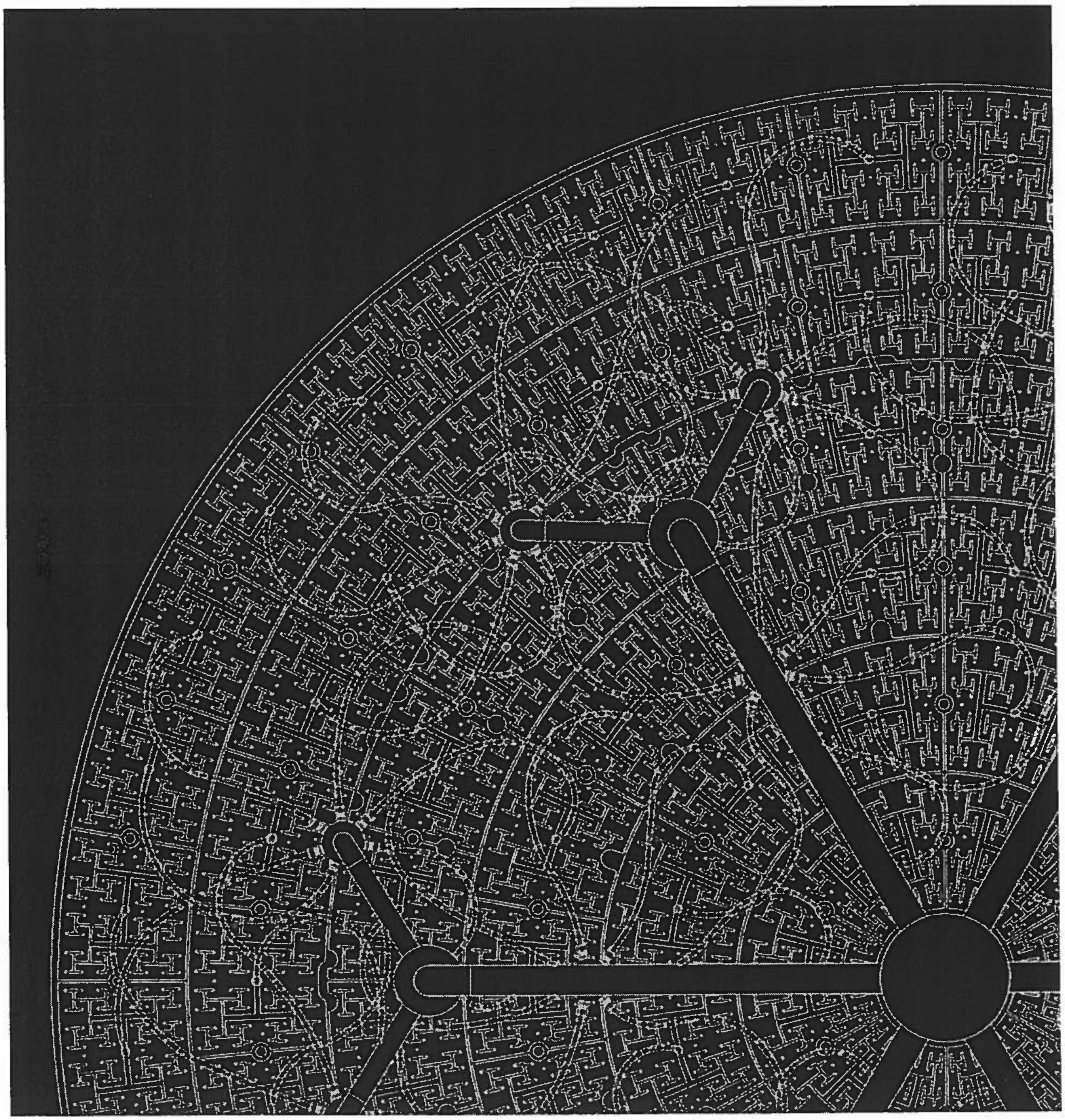


Figure 3. Fractals for Gas/Liquid Applications

Prototype testing:
Dr. Zarko Olujic
Delft University

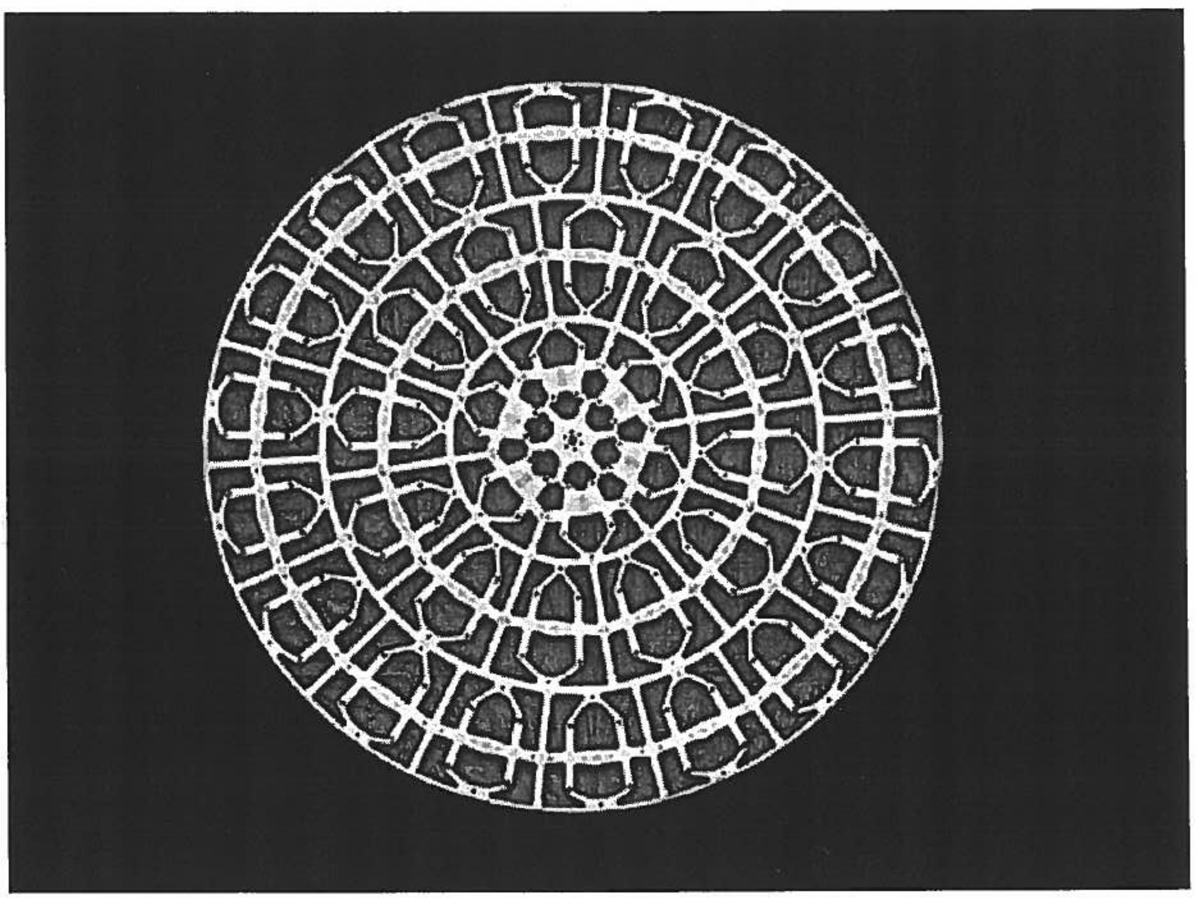
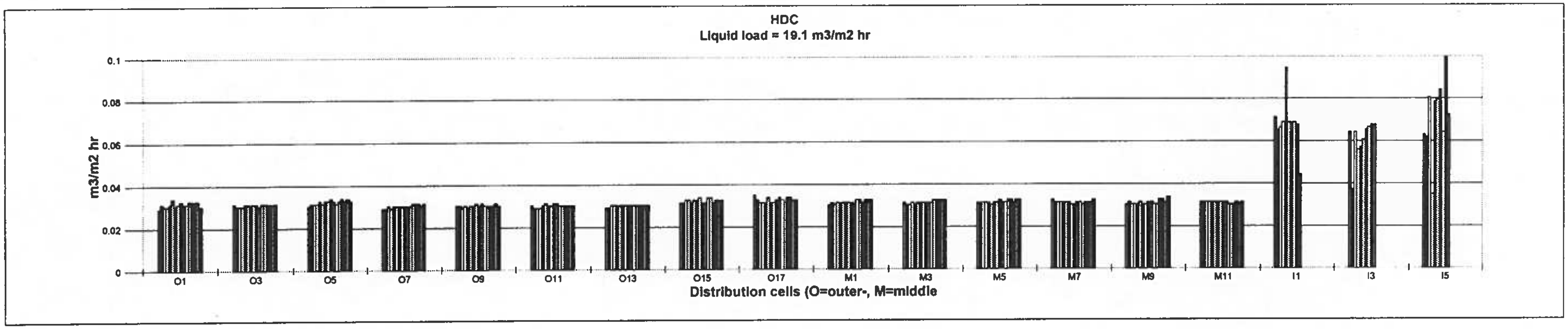
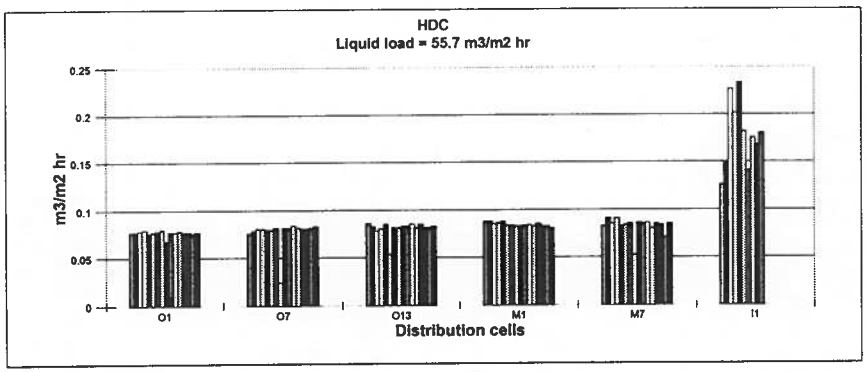


Figure 4. Distribution at Various Liquid Loads (high density - 576 exit holes).





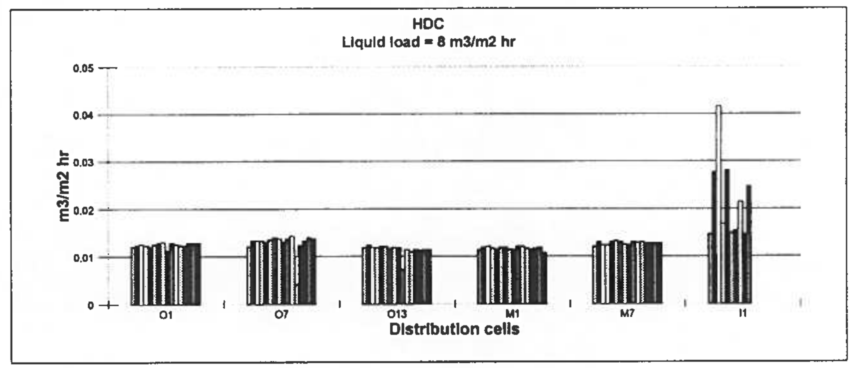


Figure 5. Distribution at Various Liquid Loads (low density - 144 exit holes)

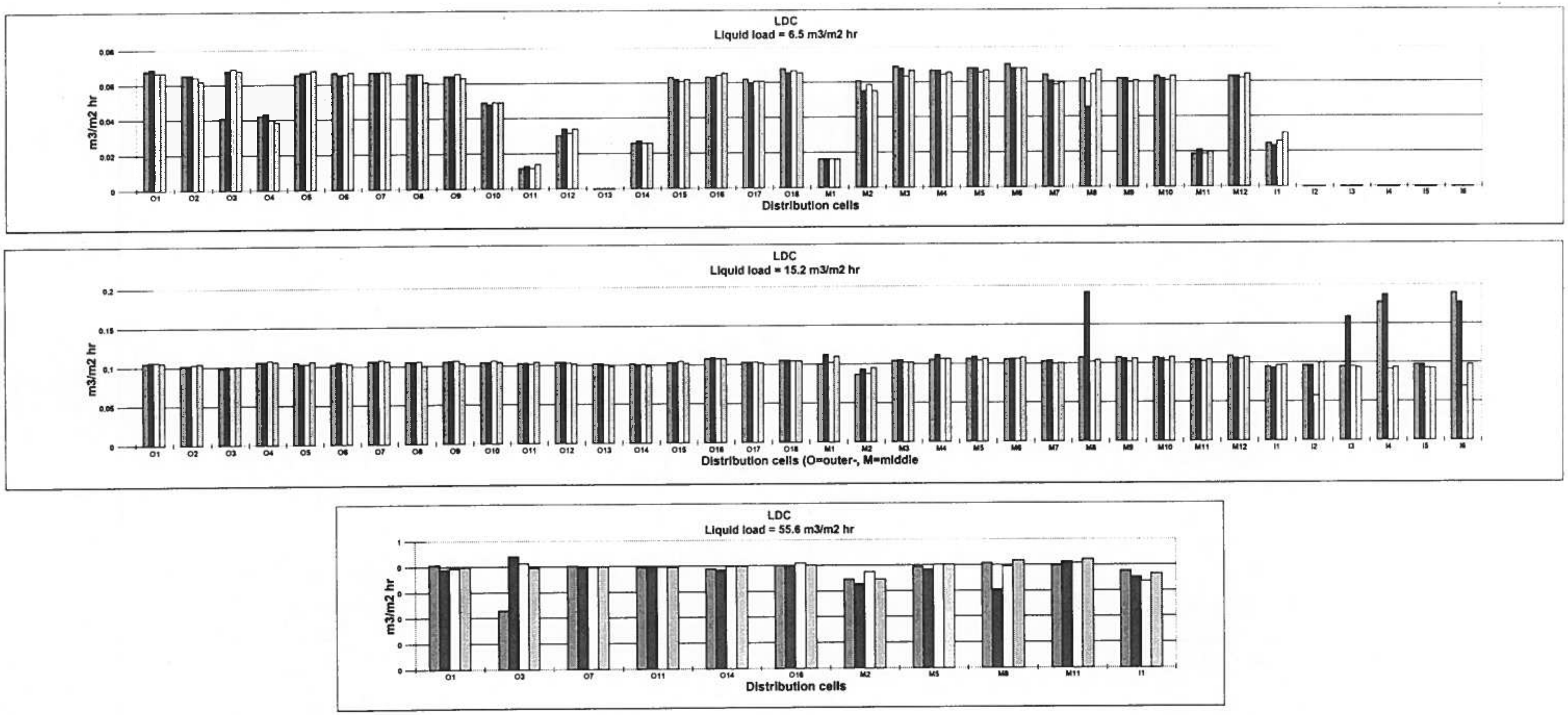
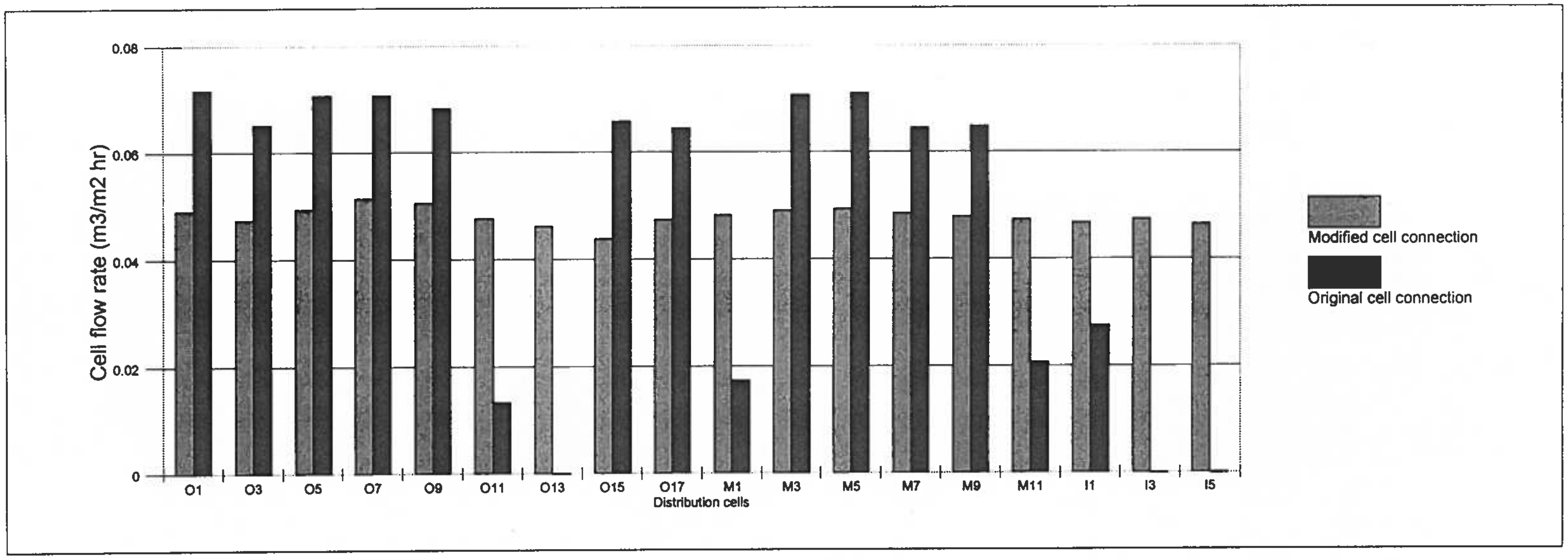


Figure 6. Improved Performance after Modification of pre-distributor Manifold.



distributors are rather easy to install. The original distributors have been in industrial operation for more that seven years. The cost compares favorably with conventional designs.

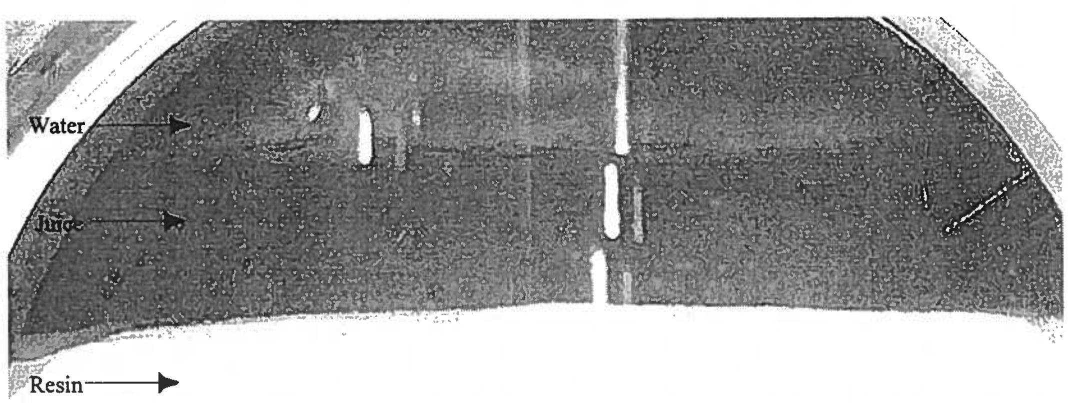
Experimental data

To confirm the quality of fluid distribution for gas-liquid systems (absorption and distillation applications) a 1.5 meter prototype fractal has been manufactured and tested at the Laboratory of Process Equipment of Delft University in the Netherlands. The fractal distribution network has remained unchanged and the open area was provided to allow the counterflow of gas. A prototype with more than 50% open area is shown in Figure 3. The quality of distribution was evaluated by physical measurement of flow out of each exit hole of a distributor. The results plotted in Figures 4 and 5 show the distribution of fluid at various liquid loads and density of exit holes. The surface of the distributor was divided into three areas (O-outer ring, M-middle ring and I-inner ring). The data have demonstrated superior distribution with the exception of the central portion of the distributor designated I1 through I6. At low liquid load the distributor was not completely full, therefore the distribution was partially distorted. We have found that the problem was caused by air entrapment in the pre-distributor manifold. After the problem was corrected the distribution improved drastically which is illustrated by Figure 6.

The test demonstrated high efficiency of fractal structures for uniform distribution across the column cross-sectional area. Results from fractal gas-liquid distributors have been confirmed by an alternative tracer injection test method. A pulse of food grade blue dye was injected in the chromatographic column and the samples were collected downstream at the exit. The response curve characterized the distribution quality in the column. It was shown that the distribution quality in a 4 meter-diameter column was equivalent to distribution in a 7.5 cm diameter pilot column. It may be impossible to achieve such a result without using a self-similar fractal structure. The experiments are described in more detail in our previous publications[10].

Another example of superior quality fractal distribution is demonstrated in Figure 7. An interface between water and 15 Brix sugar solution above the resin bed remained undisturbed at flowrates of 500 bed volumes per hour.

Figure 7
Interface between Water and 15 Brix Juice above the Resin Bed during Sweet-off Cycle



General benefits of fractal distributors

A few features of fractal fluid distributors will remain the same regardless of the application.

1. The self-similarity of fractals automatically implies easy scale-up from any size pilot installation. The manufacturing techniques may vary depending on the scale but the distribution quality does not change.

2. The uniformity of fluid distribution provided by fractals cannot be matched by using any conventional distributor. Each of the multiple pathways in a fractal distributor is hydraulically equivalent to all others. This guarantees superior fluid uniformity across the column.

3. Hydraulic equivalence also provides extremely wide turndown ratio without any loss of distribution accuracy.

4. As opposed to conventional distributors where uniformity is achieved by high pressure drop, fractals are very low pressure drop devices. Significant energy savings and reduced equipment cost may be realized through the use of fractal structures.

Specific benefits for various applications

The general features of fractal distributors bring out some benefits specific to certain applications. Some of the examples listed below illustrate the benefits of fractals mainly for applications where liquid flows through a granular bed , such as ion-exchange, decolorization, etc.

1. Because of better quality of fluid distribution, the concentration front will move through a resin bed uniformly. By-passes and stagnant zones will be essentially eliminated resulting in an overall increase of column efficiency. More complete utilization of resin or carbon exchange capacity can be achieved.

2. During the regeneration cycle a similar phenomenon can be observed leading to reduction of regenerant use, and more efficient regeneration. Water use (and hence evaporation load) can be reduced significantly during sweet-off cycles.

3. In unit operations with relatively fast kinetics, such as softening, higher overall throughput can be achieved by using short bed depth. This can only be accomplished with superb distribution quality. In conventional applications fluid maldistribution is usually compensated for with excessive bed depth, which in turn limits the column throughput.

Conclusions

– The sugar industry utilizes several unit operations that are very sensitive to efficiency of fluid distribution. A few examples include, but are not limited to chromatography, ion exchange and decolorization processes.

– Lack of uniform fluid distribution in existing systems results in low overall performance, high energy use and other associated costs.

– Fractal fluid distributors provide almost ideal fluid scaling and overcome the disadvantages of existing devices and open the opportunity for a new generation of industrial equipment.

– Since fractal distributors have been proven efficient in many industrial operations, the search for new applications and evaluation of the benefits should continue.

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