Appliances

Dishwasher particle handling optimization

The second part of this article looks at critical design parameters in prototypes of dishwasher filtration systems to increase particle handling capability and reduce water and energy usage. A simple test compares filtration system performance to optimize dishwasher design.

In dishwashers, particles typically travel along the path of movement from dishware, through the tub and sump, to the drain. This defines three particle handling capacities of the dishwasher:

- washing capacity from dish to tub;
- filtering capacity from tub to sump; and
- draining capacity from sump to drain.

The design of dishwasher wash, filtration and drain systems must therefore adopt a systematic point of view, since the overall particle handling capacity is determined by the lowest one of the three. In a well-designed, optimized dishwasher, the particle handling capacity should gradually increase at each step along the cycle. This will ensure that particles coming from upstream will always be transmitted to the downstream without creating bottlenecks where accumulation and blockage may interrupt or even force the termination of wash cycles. This article concentrates on the second path, which involves the particles accumulated on, and removed from, both coarse and fine filter surfaces.

Water and particle distribution

A general purpose filtration system test rig shown in Figure 1 was built to study the coarse and fine filter flow rates (Qc and Qf), distribution, water pressure/head variation, particle accumulation and removal, etc. The test rig is highly flexible to enable assembly of various filtration/washing system designs. The coarse filter of different hole internal diameter (ID), open ratio (OR), gauge, surface roughness, area and materials can be placed at a different inclination angle, as can the fine filter.

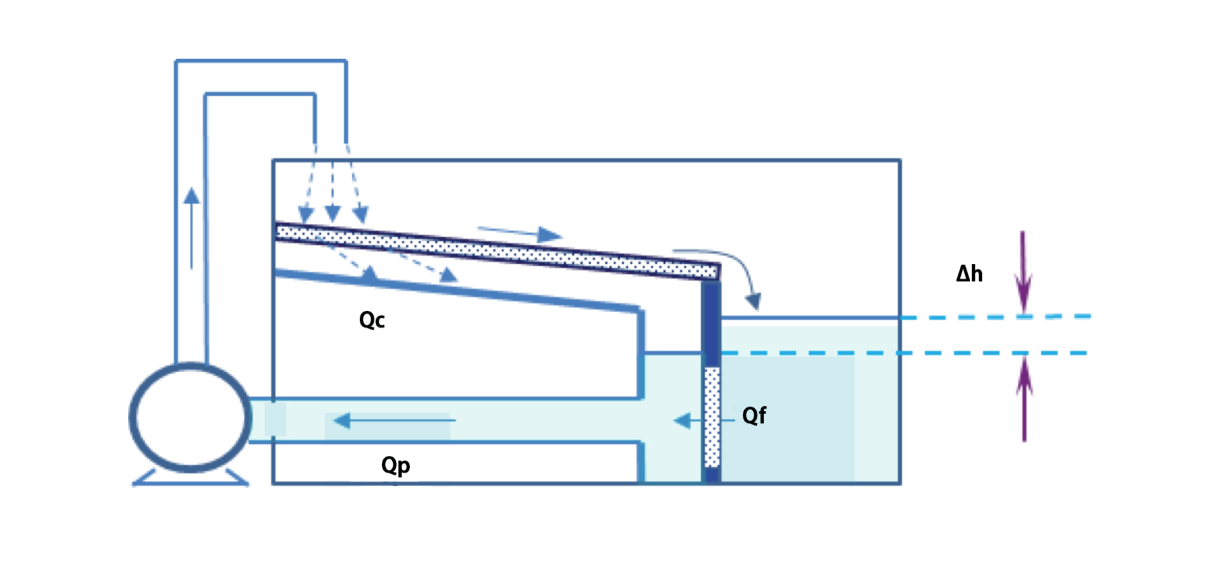

Figure 1: Test rig schematic for water/particle distribution analysis.

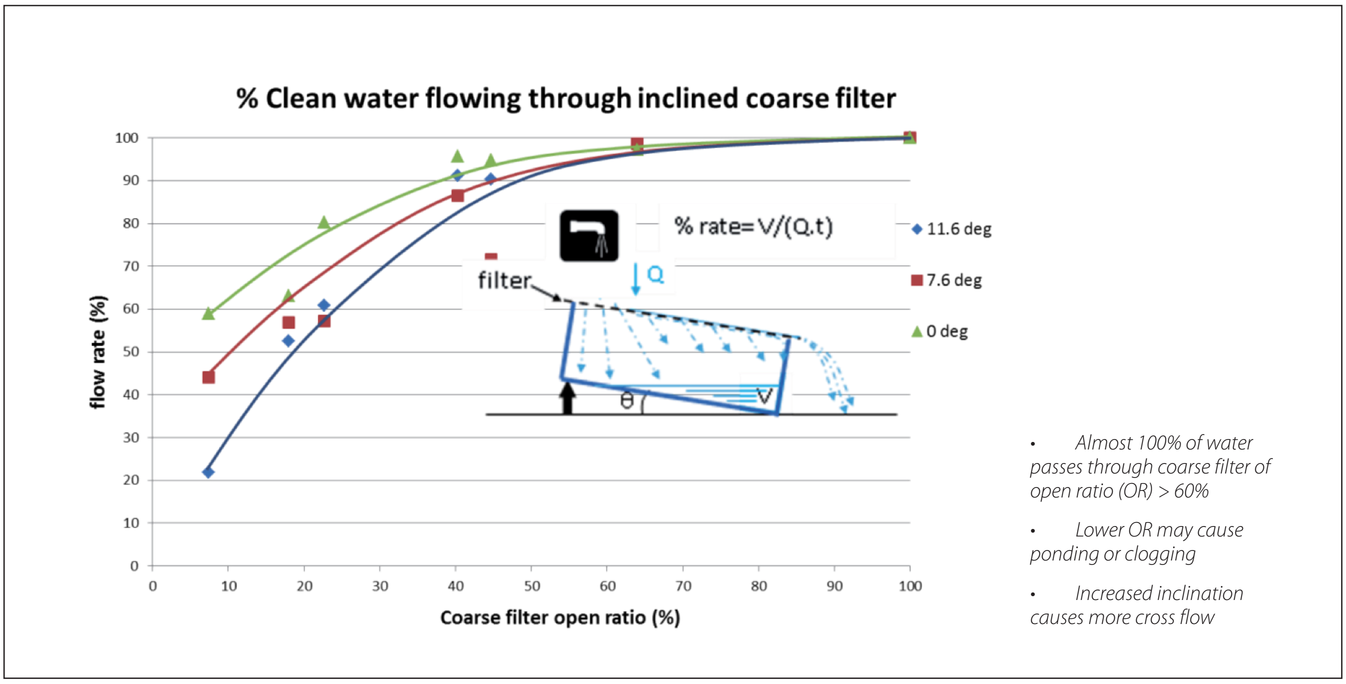

Figure 2: Clean water filter flow rate through inclined coarse filter.

The pump flow rate Qp can be changed by a switch in the outlet pipeline, and measured/monitored by a magnetic flowmeter. Clean, soiled or detergent-containing water of different fill levels can be used in the test. Various food particles can be added on the coarse filter surface to quantify the particles remaining on the filter surface or pushed into the sump under various conditions. The transparent box which encloses part of the dishwasher body and sump provides convenient visualisation and evaluation of the test results.

Coarse filter performance

Figure 2 shows that the percentage of water passing through the coarse filter increases with the filter open ratio and decreases with filter inclination angle. While a large open ratio is beneficial in allowing higher through-flow rate, it may decrease the integrity and rigidity of the coarse filter structure and hence has to maintain a certain level. On the other hand, the inclination angle could affect the ratio between the surface flow or cross-flow rate, and the through-flow rate of the coarse filter, with the net water supply equaling the sum of these two.

With larger inclination angles, the cross-flow rate will increase and help clean the filter surface to maintain a large clean area. At the same time, the unit through-flow rate and the coarse filter efficiency will decrease. More clean water will have to be provided by the fine filter and thereby its work-load is increased.

With smaller inclination angles, the coarse filter through-flow rate will increase, bringing more particles onto the filter surface. At the same time, the cross-flow rate and the self-cleaning function of the coarse filter will decrease, resulting in a quick reduction of clean filter surface area and the water supply. This will eventually increase the workload on the fine filter.

"The percentage of water passing through the coarse filter increases with the filter open ratio and decreases with the filter inclination angle."

Sufficient self-cleaning

The inclination angle therefore has to be optimised and at a value between 5° and 10° sufficient self-cleaning effect is often established without decreasing the filter efficiency dramatically. It is worth noting that the tub surface can be designed to have a large inclination angle and a special profile to direct high velocity water towards the coarse filter surface where particles may be accumulated.

Besides inclination, the friction of the filter surface can also affect the water distribution and particle removal. Tests show that the cross-flow rate is reduced if the coarse filter surface is rougher. Some dishwasher manufacturers use a polished coarse filter to reduce clogging. Figure 3 illustrates the effect of friction on the particle movement is larger than that on the water.

While the percentage rate of water and particles travelling along the coarse filter surface are both increased with the inclination, the particle rate is consistently about 20% lower than that of the water. This may be explained by the fact that particles are carried over or pushed down by the cross-flow water, hence large and heavy particles subjected to higher friction force from the filter surface cannot move as fast.

Tests show that it is critical to form a continuous layer of cross-flow on top of the coarse filter surface of a depth

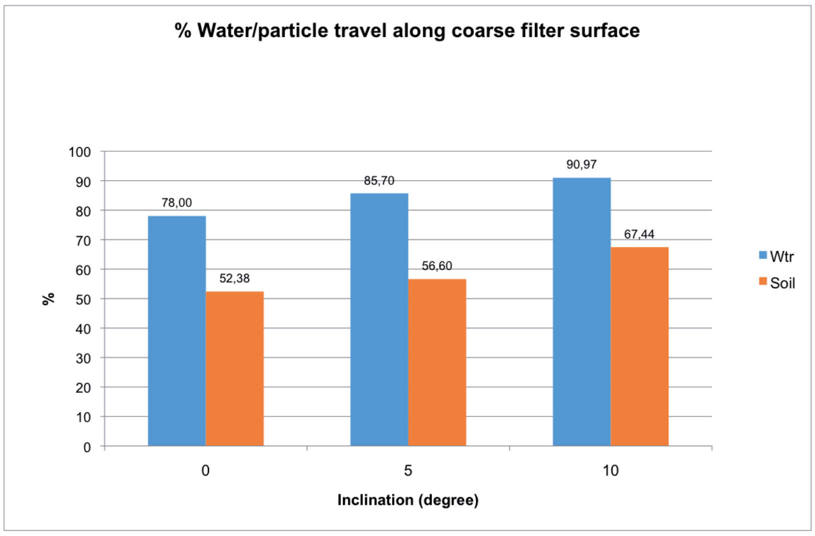

Figure 3: Test results for water and particles travelling along inclined coarse filter.

comparable with the largest particles in order to carry them all the way to the sump. If the water level in the sump is too low, the particles will stop on the filter surface where the cross-flow disappears completely. When the water level is too high, there is a thick wall of standing water which prevents the cross-flow from reaching and pushing the particles into the sump.

Either way, no continuous cross-flow is formed to carry particles all the way to the sump. Better particle removal performance can be achieved by adjusting the pump flow rate and optimising the water fill level to form a continuous layer of moving water on the filter surface.

Down jet

The down jet is often used to clear filter clogging more effectively. Down jet is generated with the downward orifice on the lower spray arm to clean particle accumulation on the coarse filter. It takes away a portion of clean water from washing the dishware to clean the filter surface. The number of down jet orifices, orifice profile and orientation may also be optimised to increase the effectiveness. This method however has shortcomings as it wastes valuable washing water and energy in rinse cycles when no filter blockage occurs.

It is possible, though with added cost, to deploy a controllable down jet, e.g. by an on/off valve to re-direct flow where needed. It is worth mentioning that the washing algorithm is often a last-minute resource to accommodate poorly designed filtration systems. For example, temporary pulses in pre-wash cycles allow more time for water passing through the filter to supply the pump. Another example is to use one spray arm at a time to reduce the particle removal rate from dishes, hence reducing the overall particle load input to both filters.

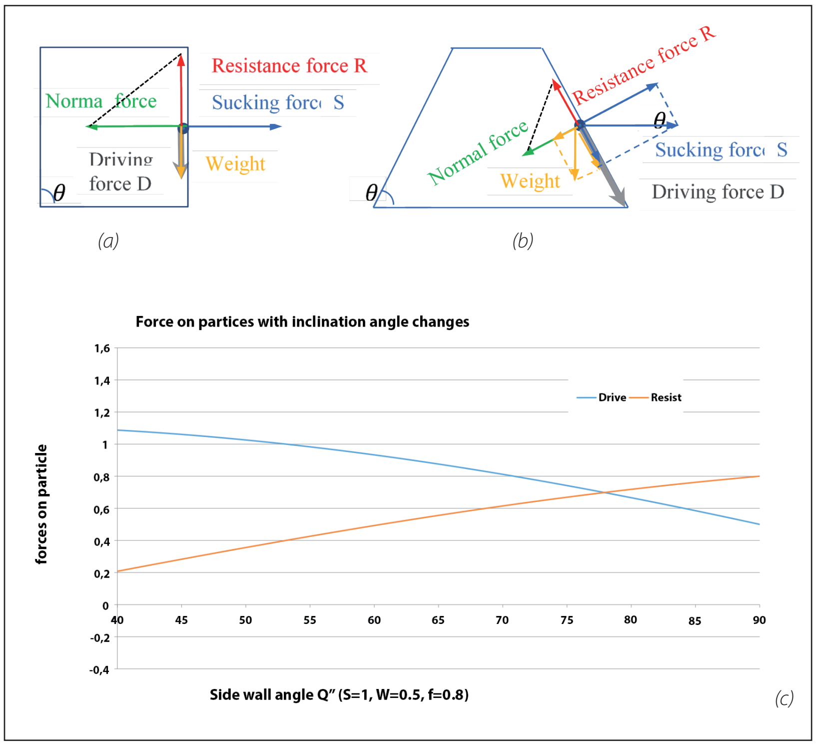

Figure 4: Comparison of self-cleaning between tube and cone shape fine filter forces: (a) tube shaped fine filter; (b) cone shape fine filter; (c) self-cleaning effect of inclination.

Fine filter performance

So far this analysis has focused on improving the coarse filter cleaning performance. In fact, the cleaning performance of the fine filter also contributes to the overall particle handling as the two filters work together to provide washing water to the circulation pump. The clogging of one filter will put the other under the full working load condition. It is therefore desirable that both filters have good self-cleaning capacity. Tests have shown that an inclined coarse filter could increase its self-cleaning capacity, but how about an inclined fine filter?

Miele has introduced a cone-shaped fine filter which has been reported to have little particle accumulation on the fine filter surface after months of operation. In contrast, the commonly used vertical tube fine filter surface can be clogged easily at washing and may have to be cleaned manually after operation.

To understand the mechanism of fine filter particle removal, two free body diagrams are shown in Figure 4 where a circulation pump (not shown) is located to the right of the fine filter, generating a sucking force S on the food particles. For the tube-shaped filter in 4(a), the driving force D which moves the particle downwards along the filter surface is its weight W, while the resistance force *R* equals the normal force *S* (sucking force) multiplied by the surface friction coefficient *f*. If the resistance force is greater than the driving force, or $W < S \times f$, the particle will remain on, and block, the filter surface. In contrast, the driving force *D* along the inclined fine filter surface in 4(b) is increased while the resistance force *R* is decreased.

Referring to the free body diagram, $D = S\cos(\theta) + W\sin(\theta)$ while $R = (S\sin(\theta) - W\cos(\theta)) \times f$, giving arbitrary values to *S*, *W* and *f* shown in 4(c), the value of forces *D* and *R* will change with the inclination from 90° to 40°. The driving forces become larger than the resistance force when (θ) is below 77°, pushing the particles downwards along the filter surface to achieve self-cleaning. In another design, Bosch has used a tube-type fine filter although its cross section profile on a horizontal plane is of a circular sinusoidal waveform. According to the inventor, it is difficult for particles to stay on peaks of the undulating surface and they remain in the valley floors, resulting in the peak portion of the filter surface becoming unclogged during washing.

New test procedure

Through preliminary analysis and the rig test, a number of critical parameters having a positive impact on filter cleaning capacity have been identified. The standard controlled soil tests were conducted on prototypes where these parameters were implemented both individually and as a group for further verification in the dishwasher.

Due to a long lead-time and low repeatability of the standard test, a new dishwasher test procedure was developed in house where the mixed food particles are prepared, applied directly to the tub surface and each test is conducted only for a few minutes. During the test, only the lower spray arm is used to clean the applied particles on the tub surface. The amount of particles applied and the length of time clogging the filtration system are recorded for each test. The test is repeated, with the amount of particles reduced and the time to clog the filtration increased, until the filtration system is no longer clogged in two minutes. The amount of particles in this condition may be referred to, for example, as the particle handling capability of the filtration system.

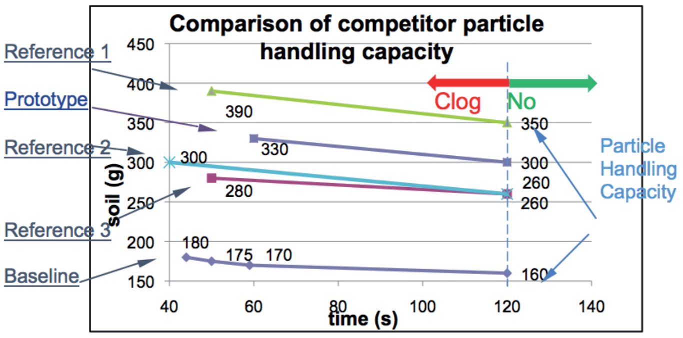

Figure 5

Figure 5: Comparison of clogging performance of prototype and competitor.

Thanks to the high repeatability and short turnover time of the new test procedure, many different design parameters, prototypes and dishwashers of various manufacturers were tested, evaluated and compared quickly and accurately in a short period of time during the project, making it possible to provide valuable input to the final design parameters for future dishwasher products.

In Figure 5, the results of the new test procedure on various dishwashers were compared with the prototype, which has a coarse filter with 5° inclination angle, an optimised water fill level, a re-adjusted down jet position/orientation, and a modified sump design to compensate for the clean water volume lost due to filter inclination. Its particle handling capability, or the anti-clogging performance, is almost double that of the baseline, becoming the second best after the industry leader.

The test results correlate well with that of the controlled soil test, where the total amount of particles collected at the end of pre-wash one by the prototype is more than double the baseline product, and comparable to the top level achieved by the industry leader. This is significant because of the improved self-cleaning performance, but also the potential improvement in washing quality and savings in water and energy.

As more particles have been removed from the dishwasher in pre-wash one, fewer washing cycles will be needed to remove the remaining particles with the same washing quality, or the same number of washing cycles will achieve much better washing quality.

Conclusions

Systematic analysis has been conducted on parameters which have potential impact on particle removal performance, particularly from tub to sump where the core dishwasher operation of filtration and separation is taking place. Design and process changes have been identified, implemented, prototyped and validated, resulting in significant improvement in particle handling performance from the baseline, and within reach of the industry leader.

A reliable, representative and simple particle handling test procedure has been developed to supplement the traditional controlled soil test. The new test procedure takes minutes to prepare and execute, offers high repeatability and accuracy, and significantly speeds up the new product introduction process.

Further information

Part 1 of this article, 'Filter cleaner improves dishwasher performance', was published in *Filtration+Separation*, September/October 2016. ●

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