The Costs of wiper-based cleaning in large Cleanroom-facilities

A Cost Analysis of Cleaning by Wiping

by Win Labuda et al. in Lübeck

In the cost analysis of cleanroom wipers, only analyzing the cost of the wipers alone leads to significant assessment errors. The material costs for such a product must be seen in the context of the production process in which the wiper is utilized. It is therefore meaningful to consider such costs which a wiper *causes* or which it *influences*, too. These cost segments can far exceed the material cost segment. In the end, the most economical wiper for a production process is seldom the cheapest one available. Ultimately, the wiper used should always be the one which upon consideration of all of the cost segments listed below turns out to be the least expensive.

The nine cost segments of cleaning by wiping

1. Cost of the cleaning time up to the required degree of surface purity including folding and saturating with solvent
2. Cost of providing the wipers at the place of use (material-dispensers, refilling the dispensers, refilling the cleaning fluid, disposing of the used wipers)
3. Cost of access to the wipers (times for distance covered by the operator between the place of use and the place of supply, searching times if the product is often not on hand, disposal times at the workplace)
4. Cost of the proportionate production rejects caused by the use of wipers (e.g. defects caused by particle release)
5. Cost of double and multiple withdrawals with simply stacked wipers in comparison to single-wiper dispensers or boxes
6. Cost of the total disposal of the used wipers
7. Material cost of the product wipers
8. Material cost of the solvent
9. Cost of providing the solvent (e.g. isopropanol)

The costs named above vary depending on the different qualities and brands of the wipers. They also vary considerably according to the dispensing system which is used in production.

The cleaning, providing, access, search, and disposal times, which at present amount to costs of DEM 2.32 per minute per operator/workplace, are quite substantial cost segments. They exceed the material costs significantly. In order to set up an overall view of the costs, the workplace costs have to be calculated first.

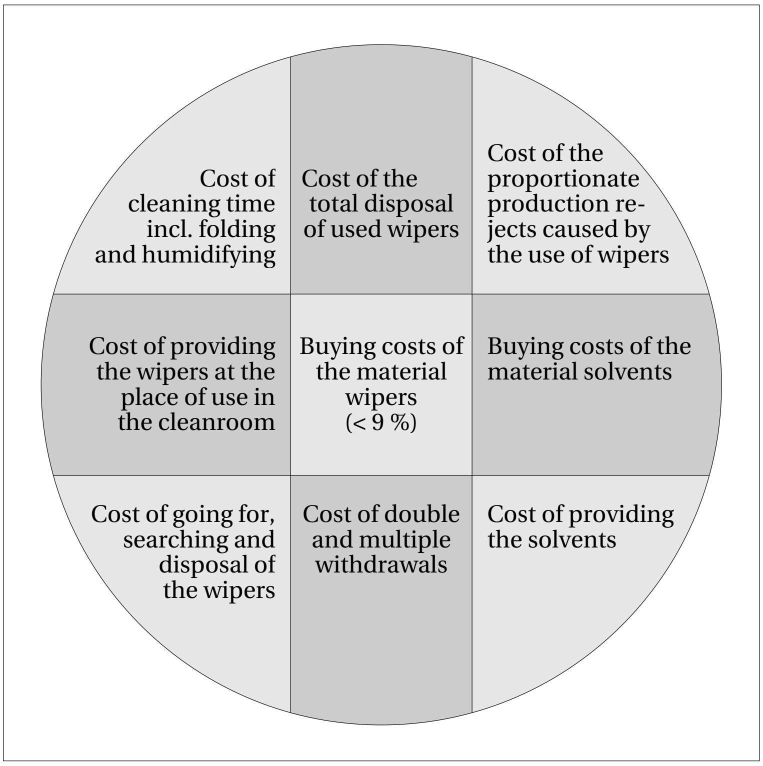

Fig. 1 - The nine Cost-Blocks of Cleaning by Wiping

Calculating the workplace costs

The workplace costs of a typical large company of the semiconductor industry comprise the total costs of the company divided by the number of employees, that is the number of workplaces. The workplace costs consist of the following cost segments:

- Δ Wage costs
- Δ Management costs
- Δ Investment depreciation
- Δ Operation maintenance *and*
- Δ Capital expenditure

In Table 1 the calculation of the workplace costs for 1997 consisting of wage costs, investment depreciation, operation maintenance, and capital expenditure is shown.

Management costs vary greatly and can seldom be ascertained. For this reason we do not want to consider them in this framework.

We have based the depreciation costs on an investment value minus government subsidies of DEM 950 million. The duration of the depreciation amounts to 120 months. Up to that time a full depreciation of the equipment and a 50% depreciation of the investment in the building ensues.

The costs of maintaining the investment and of the capital expenditure are assumed to be a trifling DEM 36 million per year or DEM 3 million per month.

Cleaning times

Work studies have shown that wiping the work surface of a cleanbench of 62.5 x 120 cm once with a polyester cellulose wiper requires a minimum of 12.1 seconds and a maximum of 20.1 seconds of pure wiping time.

With preparation times for folding, saturating, and disposing of the wipers, the time needed to complete the task increases to a minimum of 27 seconds and a maximum of 50 seconds. The workplace costs which arise for this activity for the polyester cellulose wiper are between DEM 1.04 and 1.93 per wiping procedure. The mean for 6 test persons is exactly 40.6 seconds = DEM 1.56 per wiping procedure.

But the wage costs of the wiping procedure alone amount to DEM 0.33 - more than double the material costs. The total costs for the wiping procedure amount to almost 10 times the material costs.

With that the access times (fetching and bringing times) have not yet been considered, which can comprise a substantial item in the cost calculation depending on the production environment. These access times decrease with the degree of availability of the wipers near the workplace.

The defects caused by textile fibres for 0.4 µm-structures amount to < 0.5% of the total defects, including overalls and masks, according to concurring reports of a smaller and a larger German wafer manufacturer. One can thus assume a guideline value of 0.25% for cleanroom wipers alone.

The average production yield at present in the production of semiconductor chips is in the range of 90%. With a yearly turnover of DEM one thousand million, the assumed material and production costs amount to about DEM 400 million. Thus, the total cost of rejects would amount to DEM 40 million. For wipers the share would be 0.25% = DEM 100,000. Assuming a demand for 800,000 standard wipers per year, a product-specific reject share would amount to DEM 0.125 per cleanroom wiper.

workplace costs per wiping procedure (time 40,6 sec.)	DEM 1.56
product-specific reject share	DEM 0.12
material costs of the wiper	DEM 0.16
mean cost of each cleaning operation	DEM 1.85

Tab. 2 -calculating the average mean cost of each cleaning operation

Tab. 1 - Calculating the workplace costs (1997) for a semiconductor FAB with 700 operators

	per month	per hour	per minute
Wage costs			
operator-before-tax wages per month	DEM 2600.-		
tax-free shift bonus	DEM 400.-		
additional wage costs	DEM 546.-		
holiday/Christmas bonus	DEM 296.-		
value for paid vacation days, holidays, and continued payment of wages (48 days)	DEM 709.-		
total wage costs	DEM 4551.-	DEM 29.20	DEM 0.486
Depreciation costs			
total remaining value = 12,5%			
depreciation	DEM 6,9 million		
divided among 700 workplaces = investment depreciation per workplace and month	DEM 9857.-		
depreciation costs		DEM 77.-	DEM 1.28
Cost of maintaining the investment and capital expenditure (at 128 effective hours per month):			
per workplace	DEM 4285.-	DEM 33.48	DEM 0.55
Total costs			
workplace costs		DEM 139.68	DEM 2.32

If one sets the price of a standard cleanroom wiper with DEM 0.12 to 0.20 - that is a mean price of DEM 0.16 - and then if one adds the items (see Table 2 and Fig. 2), the mean cost of each cleaning operation amounts to a total of DEM 1.85. However, neither the access times (fetching, bringing, and searching times) nor the management costs have been considered in the assessment. Thus, one can assume a rate for each cleaning procedure of 2 DEM.

Each wiping operation in the cleanroom costs > 1 US $.

The distribution of costs

The distribution of costs for the total complex *cleaning by wiping* in a manufacturing plant with an annual demand for e.g. 800,000 wipers can be subdivided into a commercially modifiable and a technically modifiable cost segment. The resulting distribution is shown in Table 3. With a demand for 800,000 wipers a year the total cleaning costs in a manufacturing plant comprise 1.472 million DEM.

Here a general problem becomes evident.

While the technically modifiable cost segment amounts to DEM 1.344 million (91.3%), the commercially modifiable cost segment amounts to only DEM 128,000 (8.7%). Even a 30% reduction of material costs effectuated by the pur-

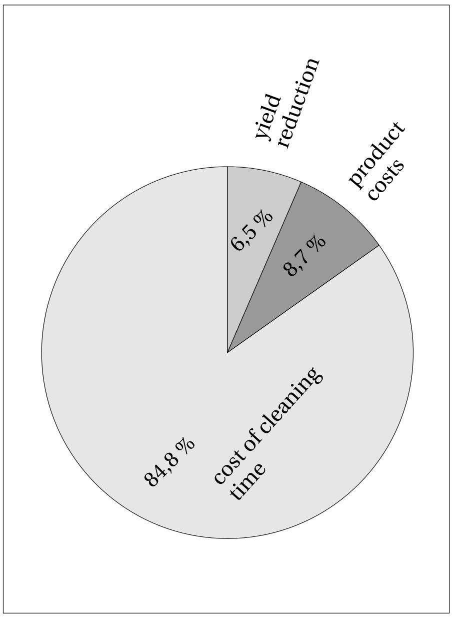

Fig. 2 - Distribution Cleaning by Wiping

Tab. 3 - distribution of costs for cleaning by wiping in a FAB with an annual demand of 800,000 wipers

commercially modifiable cost segment (modifiable through buying)	product costs	DEM 128,000.-	8.7 %
technically modifiable cost segment (modifiable through production control)	yield reduction	DEM 96,000.-	6.5 %
	cleaning time costs	DEM 1,248,000.-	84.8 %
total costs		**DEM 1,472,000.-**	**100 %**

chasing department would bring a modification (price reduction) of only DEM 38,400 per year. A reduction of the technically modifiable cost segment of 30% would, however, result in a cost reduction of DEM 403,200 - almost ten and one-half times as much!

From the point-of-view of the user it would make sense to motivate appropriate specialized companies to make certain innovations. By means of an improved wiper more suitable for the production process and or more efficient in cleaning, for example, a reduction in the technically modifiable cost segment could be achieved. Instead, it often happens that companies use pressure in purchasing. By withdrawing profit resources, such specialized companies make "peanuts" while the cost segments in the technical area are only slowly reduced.

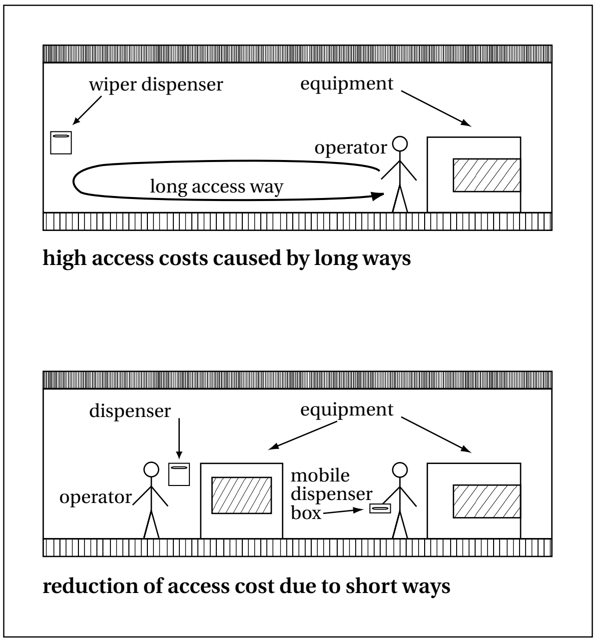

Fig. 3 - reduction of access times for wipers in a cleanroom caused by increased material presence (dispensers and mobile dispenser boxes) close to the workplace

The problem is that there is no form of organization for the suggested kind of innovation motivation. Because the framework of organization and the defined tasks for purchasing departments are so narrow, they are often forced to show successful buying results in the sense of reduced prices. They are not motivated for tasks that go beyond that and do not have the personnel for it.

Here management is challenged to change its views, to create organizational forms which make the possibilities of reducing costs in the technically and commercially modifiable cost segments transparent, and to realize these possibilities in an appropriate way.

Reducing technically modifiable costs

At present, the purchasing prices of cleanroom wipers can only be modified to a small extent by reducing the material costs. However, there is a possibility of saving by reducing access times in production, use of improved handling systems, other delivery forms, etc. These can be subdivided as follows:

- reduction of access times
- prevention of multiple withdrawals
- special wipers customized to the application
- wipers with reduced liquid residue
- improved standard wipers in homogeneous presaturated quality

Reduction of access times

If the next available wiper is only 10 meters away from the place of use, the access time (fetching and bringing time) when going at an average, cleanroom-appropriate speed is 22 seconds. This corresponds to access costs for each wiping procedure of DEM 0.85. These times are not yet included in the cost calculation listed above of DEM 1.85 per wiping procedure.

In a large cleanroom production operation in Germany one had the idea to reduce the access costs by packing and folding the cleanroom wipers in a special way so that they could be hung on the unused sides of equipment with self-adhesive hooks. Thus the work surface was kept clear. That is workplace-close material access in the best production-technical sense. The increased material availability also reduces the time needed to search for the wipers.

Prevention of multiple withdrawals

When using simply stacked packages (Fig. 5 and 6), several wipers are often taken at once, although only one of them is needed. That occurs even more often when working with protective gloves. Putting the excess wipers back into the package is tedious and more expensive than throwing them away. For this reason they are used unnecessarily in the subsequent wiping operation. To save costs, cleanroom wipers should be made available in easy-to-withdraw dispensers which make multiple withdrawals impossible. Closely stacked, unfolded individual wipers in a plastic bag do not belong any longer in a modern cleanroom production process. Sometimes the objection is raised that one has the impression that more particles are released when withdrawing from a single-wiper interfold dispenser than from a simply stacked package. However, tests have repeatedly shown that the amount of particles released is about the same (Ref. 1). The use of single-wiper dispensers in several large German cleanrooms has shown no negative effects during the last five years.

Special wipers customized to the application

For the tasks of cleaning equipment and in optics, the highest quality wipers often save the most money. It does not matter if a wiper costs DEM 2.50, if through its use the downtime in the production of a plasma- etching system can be reduced by only 10 minutes.

Today's special wipers in Hi-Tech production are *precision instruments in a cost-conscious production environment.* The costs for their utilization must al-

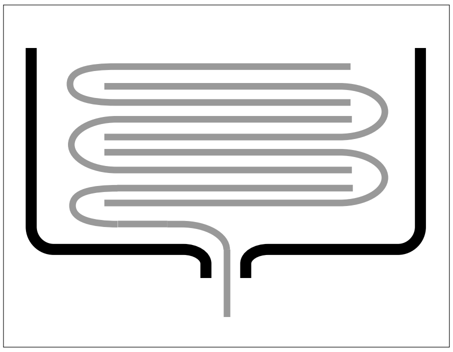

Fig. 4 - cross-section of a dispenser filled with interfolded wipers

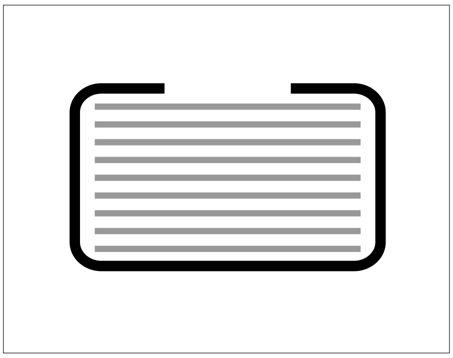

Fig. 5 - cross-section of a foil package, withdrawal from the top (flatly stacked wipers)

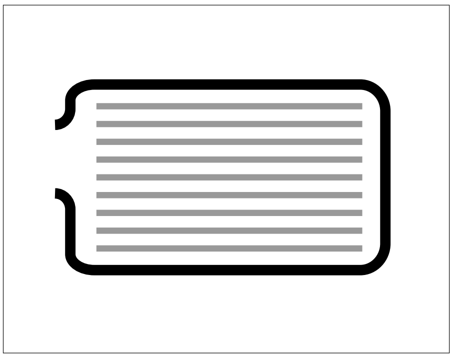

Fig. 6 -cross-section of a foil package, withdrawal from the side (flatly stacked wipers)

ways be seen in relation to how they can assist in saving. How different the surfaces of the various wipers are in design and thus, for example, how different the expected cleaning efficiency is can be seen in Figures 7, 8, and 9.

Example

A plasma-etching system with 4 chambers costs about DEM 2 million. With a 5-year depreciation time that is DEM 100,000 per chamber and year. When calculating an operating duration of 8760 hours per year, downtime costs amount to DEM 11.41 per hour plus cleaning costs of DEM 46.40 for 20 minutes of cleaning time. If the cleaning time can be reduced only 20% by using a more appropriate wiper, with each cleaning procedure DEM 11.56 minus DEM 2.50 = DEM 9.06 can be saved. In addition, the system is ready for use earlier, an advantage which gives far more profits. It has been reported, however, that using such wipers could partially reduce the cleaning time and post-cleaning time even further. If the whole system, that is all 4 chambers, has to be shut down for cleaning, the downtime costs increase from DEM 11.56 to DEM 46.24 plus the cleaning costs of DEM 185.60 for 80 minutes of cleaning time plus the lost profits.

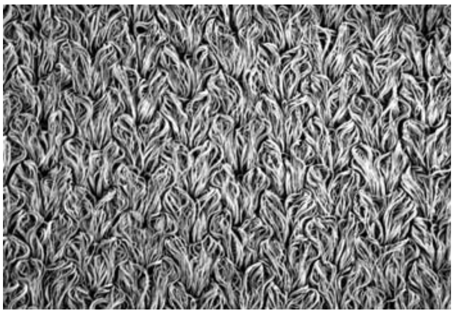

Fig. 7 - Surface of a wiper with the highest-level cleaning efficiency (SEM photo)

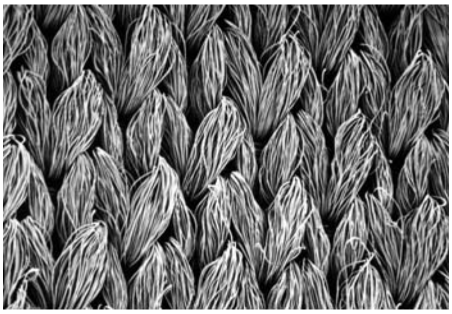

Fig. 8 - Surface of a wiper with high-level cleaning efficiency (SEM photo)

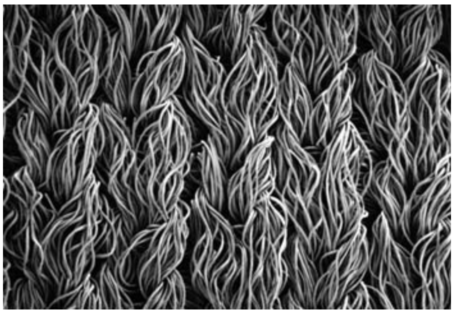

Fig. 9 - Surface of a wiper with lower-level cleaning efficiency (SEM photo)

Wipers with reduced liquid residue after wiping

One of the economically significant critical parameters of cleaning by wiping is the *liquid residue* on the surface after cleaning procedures with a damp cloth. This is true for the liquid absorption from surfaces with dry wipers. But it also applies to the taking up of dry contaminants with damp wipers. In both cleaning procedures a liquid film remains on the surface. This liquid film contains the following contaminants which have been transferred from the wiper into the liquid during the damp wiping procedure:

- Δ particles
- Δ fibre fragments
- Δ metallic salts
- Δ nonvolatile organic residues
- Δ surfactants

Moreover, the liquid residue contains components of the contamination which is or was on the surface. The larger the volume of the liquid residue is, the greater the potential contamination of the surfaces is with the above mentioned contaminants through the wiping process.

The amount of the liquid residue varies depending on the construction of the wiper. Top HiTech-wipers are constructed in such a way that only a small amount of liquid remains on the cleaned surface. Cheap wipers, but even some expensive wipers from the U.S. often leave large amounts of residue. The reason for that is to be found in the physical laws of capillarity of the textile materials used.

In the fundamental investigation into the hydromechanics of damp wipers it has been shown that three dynamic pro-

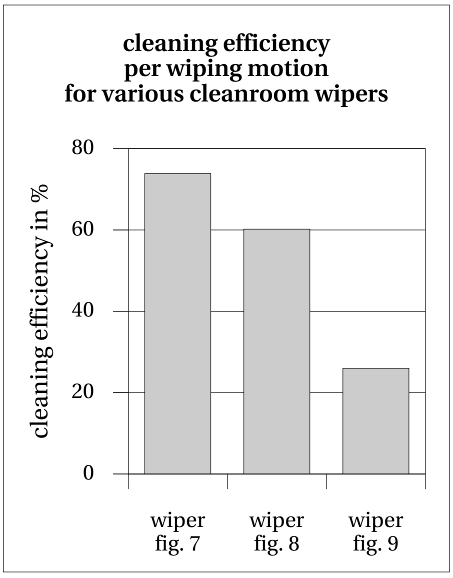

Fig. 10 - Diagram of the cleaning efficiency of various cleanroom wipers

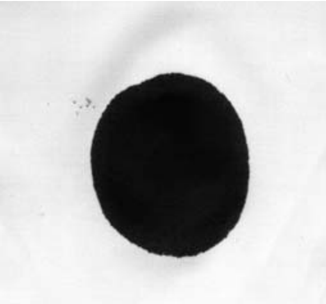
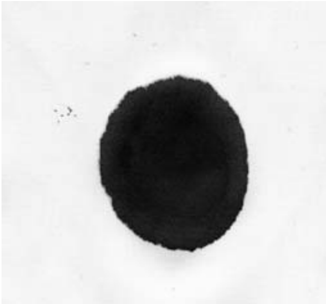
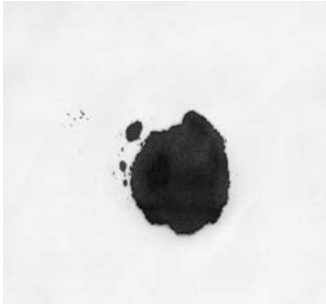
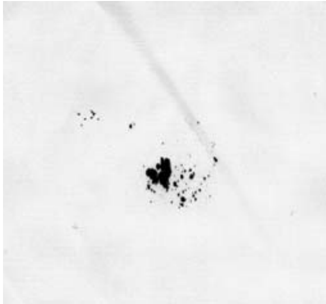

Fig. 11-14 - absorption of liquid of a wiper with highest-level cleaning efficiency (see fig. 7), layer 1 to 4

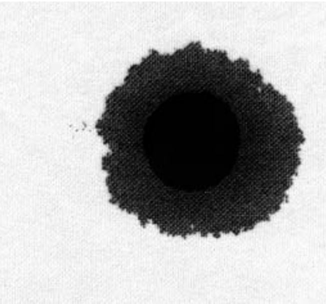
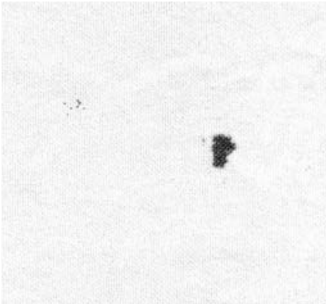

Fig. 15 - 18 - absorption of liquid of a wiper with lower-level cleaning efficiency (see fig. 9), layer 1 to 4

cesses are at work in the absorption of liquid:

1. lateral liquid absorption during the wiping process
2. the subsequent longitudinal distribution of the liquid in the wiper because of its capillarity
3. the distribution of the liquid in layers in those wipers which have layers because of folding

These mechanisms can be clearly depicted by pressing a textile piece flat against a black-coloured drop of liquid (Indian ink). Two rings form on the surface. The inner ring has a darker colour. It develops because the capillaries of the wiper are filled with the liquid in direct contact. An almost concentric lighter outer ring forms around the darker inner ring. This develops because of the longitudinal spreading of the liquid in the wiper due to its capillarity. The size of the two rings is dependent on the surface energy of the textile materials and of the liquid, the viscosity and the temperature.

The inner ring contains a greater amount of liquid than the outer ring. During the wiping process the liquid from the wiper is deposited onto the wiped surface. The amount of this residue is in direct correlation to the number of capillaries per area unit in the wiper as well as to the parameters mentioned above and to the amount of liquid on the surface relative to the volume of the wiper.

The economic significance of the liquid residue

The liquid residue after cleaning-by-wiping processes has a great economic significance. It can influence the costs per wiping procedure considerably. The reasons for this are the following:

1. An employee performing a cleaning procedure has the unconscious desire to continue wiping until the surface is dry. That increases the time costs.
2. Depending on the amount of contamination transferred from the wiper to the surface, contamination can even increase during the wiping process instead of decrease.

Measuring the liquid residue

Measuring the liquid residue after damp cleaning has been difficult up to now because on smooth surfaces < Rz 5 µm HiTech-wipers leave residue of only 200 µl deionized water per cm^2. These thin water films with a thickness of only 10 nm vaporize relatively fast. Less efficient wipers, however leave ten times the amount of liquid residue and therewith a considerably greater remaining contamination as well. For measuring this important parameter Siegmann and Textor have suggested a method which is now in the test phase:

1. Apparatus requirements:
   - linear wiping simulator
   - wiper folded in 4 layers
   - weight for the wiper: 500 g weight
   - wiping-efficient wiper surface: 32.5 cm^2 (5 x 6.5 cm)
   - wiping speed: 40 mm/s

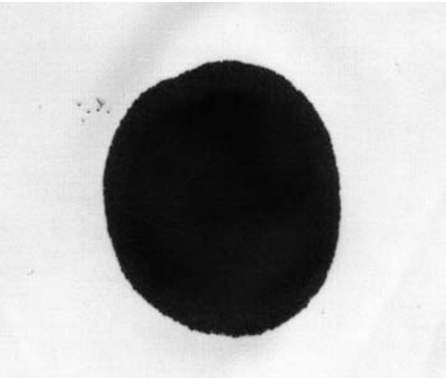

Fig. 19 - enlargement of fig. 11

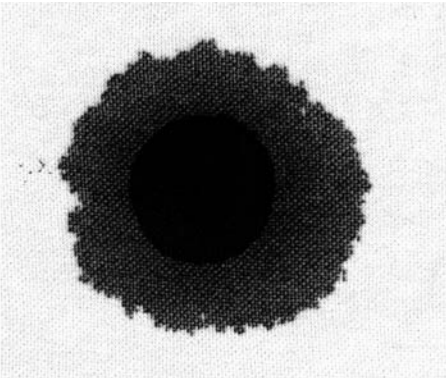

Fig. 20 - the inner and the outer ring can clearly be seen (enlargement of fig. 15)

Table 4 - Liquid residue (mg NaCl / l) after cleaning by wiping (Siegmann-Textor method)

	wiper 1		wiper 2	
	side A	side B	side A	side B
1	1,57	1,75	0,764	0,635
2	1,67	1,12	0,810	0,400
3	1,82	1,37	0,739	0,512
4	1,55	1,33	0,544	0,409
5	1,67	1,34	0,472	0,332
	8,28	6,91	3,329	2,288
$\bar{x}$	1,656	1,382	0,6658	0,4576
VK	6,47 %	16,5 %	22,3 %	25,8 %

- linear wiping distance: 330 mm
- amount of liquid for the test: 2 ml

2. Measurement of the liquid residue after wiping on a test surface by marking the test liquid with e.g. 10% sodium chloride, subsequent wiping off of the test foil and measurement of the NaCl residue remaining on the test surface by means of conductometry, ion-chromatography, capillary electrophoresis or AAS (atomic absorption spectroscopy).

Measuring the nonvolatile residue of organic contaminants (greases, surfactants) on surfaces after the wiping process is even much more difficult. These residues have thicknesses between 1 and 100 nm and are at present qualitatively hardly measurable (possibly by means of ESCA). However, very interesting insights can be gained quantitatively with the aid of *ellipsometry*.

With ellipsometric measurement technology one can measure thin layers from one atomic layer up to circa 200 nm as points. With the aid of computer technology one can measure surface thicknesses by means of adjustable measuring point grids. This gives interesting insights into the structure of nonvolatile residues after the wiping process. For a quick overview of the approximate thickness of such residue layers one can also work with the microscope with interference contrast according to Nomarski.

Standard wipers in homogeneously presaturated quality

With the standard wipers of polyester-cellulose type available today, too often fibres released in the wiping procedure have to be removed from the surface by wiping again. Thus the wiping procedures take up too much time. Moreover, most wipers are sprayed with a solvent from a spray bottle before use. Because of this, the middle of the wiper which has been folded in four layers usually becomes oversatuated in the middle zone. In the subsequent wiping procedure, the wiping efficiency is often so reduced that the surface is more contaminated than before (see Fig. 21). This speaks for the use of homogeneously presaturated wipers in a hermetically closed box with a lid (Fig. 22).

It is necessary to improve the standard wipers and provide them in a damp version in the future, so that the saturation process which takes up so much valuable production time can be eliminated. The damp wipers available on the market now do not yet meet the requirements of modern cleanroom production. One can, however, count on improved wipers within the next few years.

Disposal and ecological points of view

The question of disposing nonreusable wipers becomes more and more crucial worldwide. Many countries have already passed legislation on this or are about to do so. It is only a question of time until legislation is passed in Germany, too. In choosing cleanroom wipers at present one should take into consideration that the user will have to pay waste disposal charges for the materials polyester and polyamide in the future. This will add a new item to the cost calculation. Polypropylene and viscose or cellulose, on the other hand, are considerably easier to incinerate or to decompose. Also, the cost of cleanroom wipers varies according to the raw materials used. In the

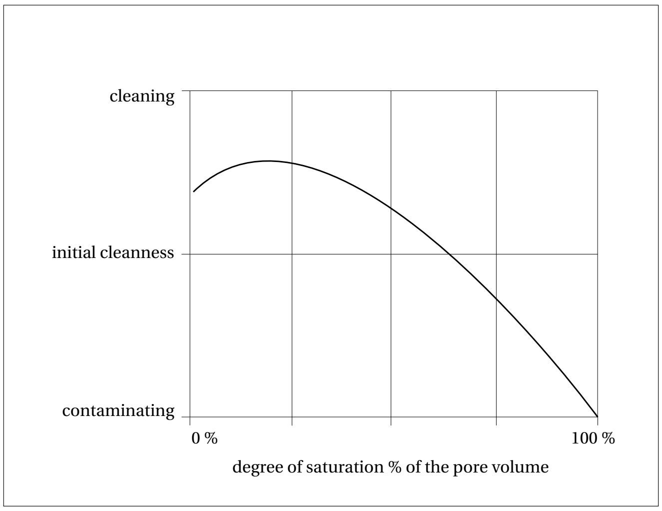

Fig. 21 - efficiency of cleaning by wiping with saturated wipers

Fig. 22 - hermetically closed dispenser box with a lid

Fig. 23 - mobile dispenser box

Fig.24 - dispenser box

future this trend will intensify significantly. At present fully decomposable wipers with very interesting particle release values (e.g. Viscot from Clear & Clean) are already available.

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