Natalia Shevchenko

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PROBLEM OF GREASE AND ITS SOLUTIONS IN COMMERCIAL KITCHENS.

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MIKKELIN AMMATTIKORKEAKOULU
Mikkeli University of Applied Sciences

DESCRIPTION

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Problem of Grease and its Solutions in Commercial Kitchens

Abstract

The field of this work is the ventilation system of commercial kitchens. This type of ventilation differs a lot from any other because of grease problem: Grease accumulated in the ducts. It leads to numerous serious risks which are discussed in this thesis. In this work you can also find information about grease construction and its sources. The main idea of the thesis is finding out the better solution of grease problem in commercial kitchens.

There are two ways of solving grease problem in pro-kitchens: grease filter installation and duct cleaning. Different types of grease filters are compared during this work. The better efficiency among baffle filter, cyclonic filter and Turbo Swing filter is found out. The Turbo Swing filter operational work principle and the gap influence on the efficiency of Turbo Swing filter are studied in the MUAS (Mikkelin University of Applied Sciences) laboratory. The results and analyses of these measurements are presented in this thesis.

The ways of duct cleaning are also compared in this work. The information about frequency of pro-kitchens duct cleaning in different countries are presented and compared in this thesis.

Subject headings, (keywords)

Commercial Kitchen, Ventilation, Grease, Turbo Swing Filter, Duct Cleaning

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CONTENTS

1 INTRODUCTION

The ventilation system of commercial kitchens differs from the other type of ventilation systems. The Standards for commercial kitchens are more stringent. In comparison with others places, in professional kitchens there are such problems like different impurities generated during the cooking process, excess of humidity, excess of heat from special kitchen equipment. All these factors should be taken into account when designing ventilation system of commercial kitchens. But the main design challenge is grease.

Grease is a complex of chemical compounds. Grease composition and amount of emitted grease depends on the type of cuisine. But anyway grease will be accumulated in the ducts in a short time. Accumulating of grease has a lot of consequences. Grease can cause a big fire, diseases of the kitchen staff, reduces the ventilation efficiency and damage the roof of restaurant. The discussion about grease sources and risks are written in detail in the first two chapters of this thesis.

The solution of grease problem in commercial kitchens is a filtration of exhausted air flow. A lot of grease filters has appeared on the market of special equipment for commercial kitchens during last two decades. There are two standard types of grease filters on the market: baffle and cyclonic filters. But such world famous manufactures like Jeven and Halton can offer the new technology filters, for example Turbo Swing Filter from Jeven Company.

The main aim of this thesis is to find out the most effective grease filter. In this work I will compare efficiencies of three grease filters:

- Baffle filter
- Cyclonic filter
- Turbo Swing filter

After comparison I will recommend in what kitchens what filter should be installed.

The efficiency of turbo swing filter will be studied by means of practical case. The idea is to find out how air flow rate and the gap between the filter and the ceiling influence on the filter extraction efficiency. The measurements will be done in MUAS (Mikkelin University of Applied Sciences) laboratory by counting amount of particles before and after the filter. The results will be analyzed. The recommendation for choosing the better gap between the turbo swing filter and the ceiling to achieve better efficiency will be given. This information is necessary for equipment manufacturer, so that they could evaluate efficiency of their products. Therefore, achieving better efficiency can reduce the duct cleaning frequency. This help to save money for the restaurant entrepreneurs.

In this thesis I will also discuss ways of duct cleaning as the final step of grease problem solution. There are ways of duct cleaning from grease:

- Ice Blasting Technology Robot
- Rotating Brush Robot with active foam
- Manually by using scrapers and caustic chemicals.

I will compare these ways and will also present advantages and disadvantages of each way. In the end of this thesis I will also give information about frequency of filter and duct cleaning. I will discuss the role of standards in duct cleaning and will compare the standards in different countries. This information is interesting for restaurant owners. By using this information they can check the duct cleaning frequency in their own restaurant.

2 GREASE EMISSIONS AS A CHALLENGE FOR PRO KITCHENS

Grease is the main design and maintanence problem for ventilation of commercial kitchens. Grease emissions appears during the cooking process and can have different composition. It depends on type of cooking. The composition of grease emmisions and kitchen work time influence the rate of duct clogging. The concequences of clogging of ventilation system with grease emissions are very serious.

In the next two chapter I will discuss the grease composition, grease emissions sources and risks caused by grease.

2.1 Grease composition. Grease emissions and their sources.

Grease is a complex of chemical compounds. It consists of grease and water vapors, particles of grease and grease gases. Grease gases include such compounds like nitrogen oxides, carbon dioxide and carbon monoxide. Grease in gaseous form is much easier than grease vapor (with content of liquid particles) and grease particulate. That’s why grease gases are considered to be non-condensable. Grease vapour in comparison with grease gas may condensate when compounds of grease vapour achive the size of 10-20 microns /1/. They become too heavy and as a consequence are transformed into drops. Grease vapour include hydrocarbon compounds which can transform into VOC (volatile organic compounds), ROC (reactive organic compouns) and SVOC (semi-volatile organic compounds) during the cooking process . Grease particulate can be in liquied ans solid form of particles which are in the size from 0.01 to 100 microns.

Grease particles in the size from 0.03 to 0.55 microns are called smoke or submicron particles. They are produced by burning of grease during the very quick contact of grease with hot surface. Compounds of grease with moisture content which are more than 0.55 microns but less than 6.2 microns are called steam. It is emitted from the hot cooking surfaces during the burning of frozen and cold products. Other grease particles produced during the cooking and larger than 6.2 microns are called spatters. Spatters can achieve the size of 150 micron. The composition structure of grease is shown in figure 1.

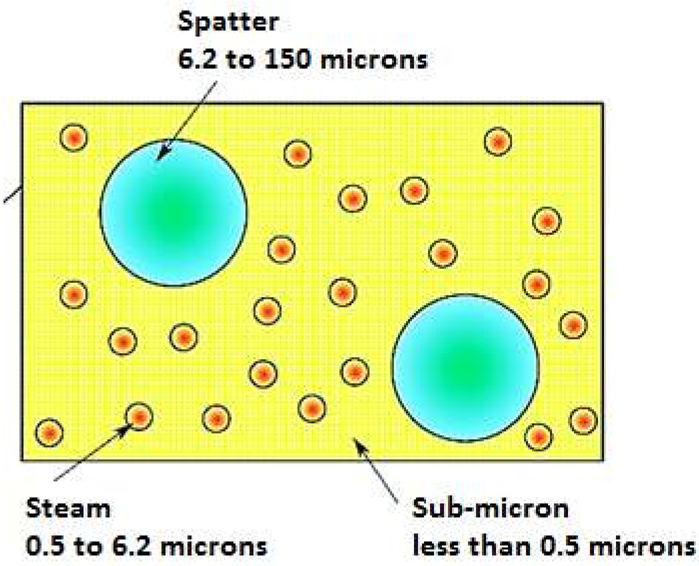


Figure 1. Grease construction /1/

Amount of grease emissions in the air depends on kitchen equipment, style of cooking and type of food. Figure 2 and table below show the mass of vapor and particulate emissions produced during the cooking of 1kg of food in different equipment (gas and electric ovens, griddles, fryers, broilers and ranges).

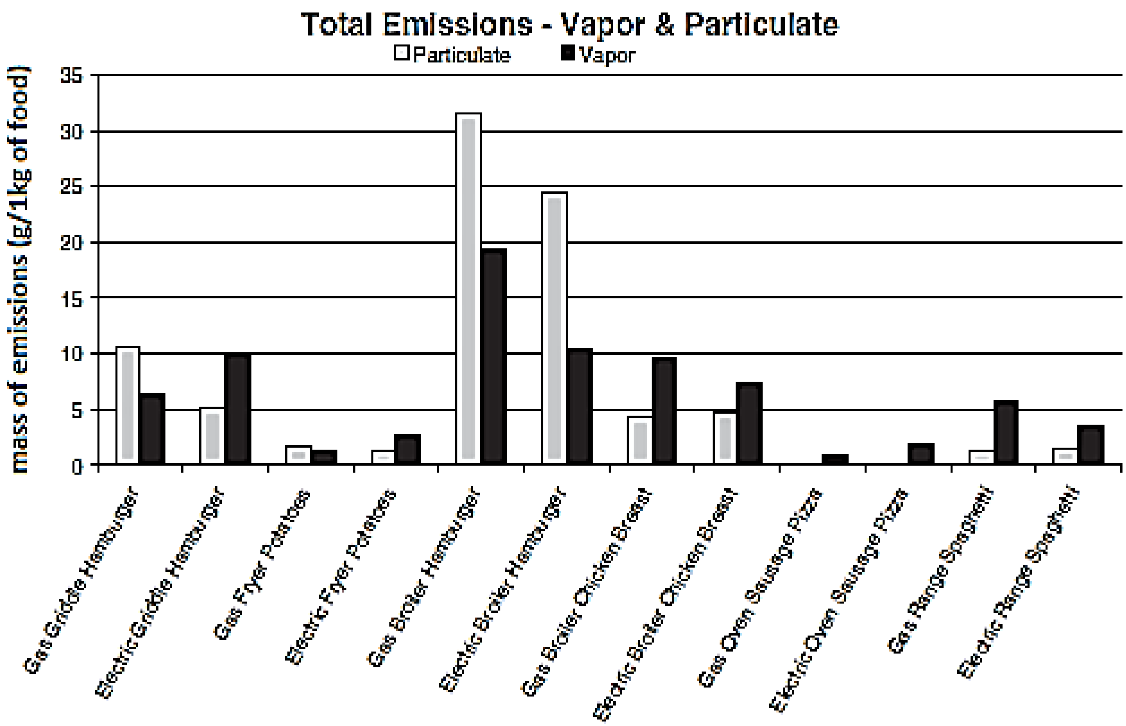


Figure 2. Grease mass emissions in
the exhaust duct without grease filter installation /2, p. 7/

Figure 2 shows that the biggest mass emisions are during the cooking hamburgers by using gas broiler. The mass emissions of vapour in this case is 32 gramm per 1 kg of cooking food. The particulate mass emissions of hamburgers prepared in gas broiler are 19 gramm. On the second place for amount of emissions is preparing hamburgers on electric bloiler. The vapour emissions of electric broiler hamburger is 24g. It is less than for gas broiler but difference is not very big. The particulate emissions of electric broiler is in two times less than for gas broiler hamburger and don't differ a lot from the particulate emissions of electric griddle hamburger; gas and electric broiler chicken breast. The lowest mass emissions are during the pizza cooking in gas and electric ovens. There are no vapour emissions and only 2g of particulate emissions during pizza preparing in electric oven. There is also a very small amount of vapour emissions during the cooking potatoes in gas and electric fryers and spaghetti in gas and electric ranges. The particulate mass emmisions of 1kg of potatoes and spaghetti cooking vary from 2g to 6g.

Figure 3 describe the size distribution of particles in mass emissions during cooking of 1 kg of food. The particles are described in four sizes:

- condensable vapour particles
- particles less than 2.5µm
- particles bigger than 2.5µm but less than 10µm
- particles bigger than 10µm

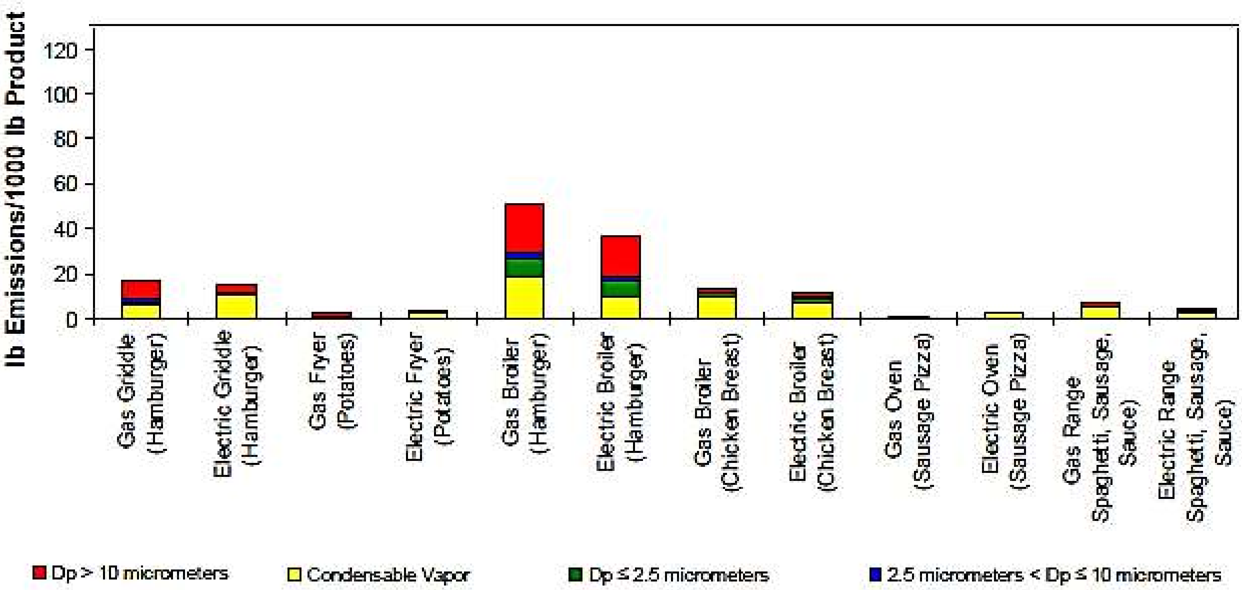


Figure 3. Grease mass emissions in the exhaust duct without grease filter installation. Distribution of different size particles /2, p. 8/

On figure 3 you can see that the biggest part of mass emissions for all types of food and appliances is the part of condensable particles and the part of particles bigger than 10 μm. This is the result of what is termed "homogeneous nucleation" where vapor condenses onto small nuclei and these droplets continue to grow until they reach about 100 nm in size. The mass emissions of particles which are bigger than 2.5 μm but less than 10 μm is very small /2, p.6/.

Figures 2 and 3 show that the peak of emissions of big size particles and condensable vapor is produced during the hamburger cooking. The minimum emissions are produced during the pizza cooking.

2.2 Risks caused by grease

The consequences of grease problem are very serious. Grease accumulating can cause fire and staff diseases, reduce efficiency of ventilation system and damage the roof of restaurant. In this chapter I will discuss these risks caused by grease.

Grease is the main reason of fires in commercial kitchens. According to National Data Fire Center of U.S.A., 64% of fires in restaurants had occurred when the flame from the cooking process reacted with the grease inside the hood /3, p.2/. Thus fire spread to the exhaust duct. From the duct fire can spread to the roof. If there are grease buildups on the roof, the fire will be very serious. An example of fire caused by grease is shown on figure 4. The consequences and damages after such kinds of fires are more serious and extensive because:

Figure 4. Firemans on the restaurant roof try to extinguish fire caused by grease ignition /4/

- Grease can burn for a long period of time.
- Difficulty of fire extinguishing. There is poor access to the system for fireman.
- Such fires start inside the ventilation systems and very quickly fire can spread over to other rooms through the ducts.

The fire safety in commercial kitchens is regulated by local legislation and fire codes. For example, fire code in U.S.A is NPFA 96 (Standard For Ventilation Control and

Fire Protection of Commercial Cooking Operations). According to this standard commercial kitchen must have independent and separate extract systems to prevent fire spreading over to other rooms. The fire dampers must not be installed in extract duct system because their effectiveness is questionable as grease on the downstream side would ignite before damper closure.

There are also some international codes such as IBC (International building Code), IMC (International Mechanical Code), and UMC (Uniform Mechanical Code). The commercial kitchen extract ductwork should be tested in according with these codes. These codes also require ducts to be tested according to ASTM E 2336 (Standard Test Methods for Fire Resistive Grease Duct Enclosure Systems), UL 1978, or UL 2221. The main point of these methods is to check the availability of enclosure materials to resist flaming (combustion).

Grease also can cause health problems of restaurant staff. Grease in the ducts is a good media for mold, fungus, bacteria, virus and microbs growth. After the appearance of each of these negative things in one place in ventilation systems, it will very quickly spread over the whole builing. Such dirty places also can be visited by cockroaches and rats. All these things can cause different allergies, intoxication, lungs and infectious diseases. It can also be a reason of serious epidemic of flu.

The exhaust ventilation efficiency is reducing because of grease accumulating in the ducts. Accumulated grease on the inner surface of the exhaust duct leads to

- Reducing of the inner diameter of the duct. As a result the load of the fan increases and fan is overheated. The life cycle of fan reduces a lot. The air flow rate reduces and efficiency of ventilation system reduces too.
- Reducing of efficiency of heat recovery as vaporized grease could clog the energy recovery core. As a result the heat transfer of heat recovery reduces too.

A part of grease impurities, which didn't settle on the duct surface and wasn't filtrated, goes through the ventilation system and moves out of the atmosphere. From atmosphere grease can settle on the roof of the restaurant. From the roof grease can also flow on the walls to the ground.

Such grease buildup is the reason of swell, crack, blister and deterioration of the restaurant roof. These can cause serious problems:

- Leaks of the roof
- Damage of the restaurant roof
- Cosmetic problem as grease leakages are visible
- Fines of local occupational safety and health administration codes.
- Very expensive reconstruction of the roof
- Unsafety of work areas on the roof. Access is difficult.
- Pollution of ambient and ground water.

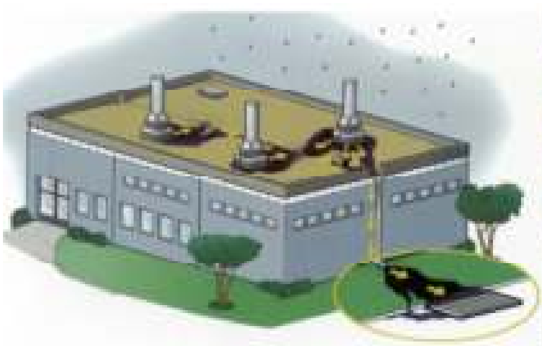


Figure 5. Grease buildups on the roof flow on the building walls and pollute ambient and ground water /4/

Figure 6. Grease buildups on the restaurant roof /4/

3 GREASE FILTERS AS A SOLUTION OF GREASE PROBLEM

Nowadays the installation of grease filters is the best solution of grease problem in commercial kitchens. All over the world there are appeared a numerous companies which produce grease filters and other special equipment for commercial kitchen ventilation. There are two standard types of grease filters on the market: baffle and cyclonic filters. Such famous manufactures like Jeven and Halton can offer different modifications of cyclonic filters. They can also offer the new technology patent filters, for example so called Turbo Swing filter from Jeven Company.

In this chapter I will explain the construction, work principles and efficiencies of three different filters: the baffle, cyclonic and Turbo Swing filter. I will also present and analyze efficiency of turbo swing filter in practical case. Finally I will compare the efficiencies of these three filters.

3.1 Baffle filters.

Baffle filters are widely spread in commercial kitchens all over the world. According to the history of developing grease filtration in kitchens baffle filters are improved versions of mesh filters. Accumulated grease in mesh filters was the main reason in most fire cases in pro kitchens according to the USA National Fire Protection Agency report. Initially baffles were designed to provide fire safety of commercial kitchens.

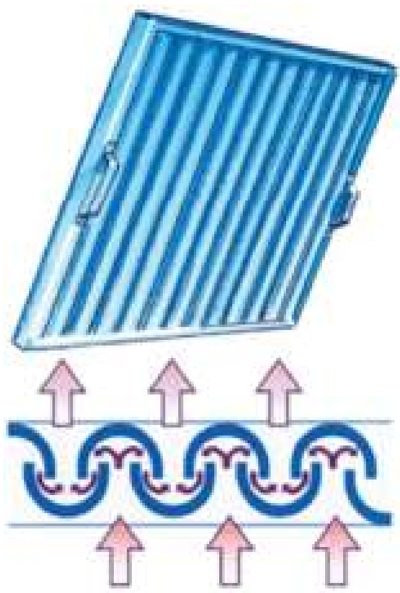


Figure 7. Construction of baffle filter /5, p. 7/

Baffles filters work on the principle of grease particles colliding with the filter surfaces and as a result settling on the bottom of the filter. There are staggered steel plates in the construction of baffle filter. They are installed in that way to allow the air with grease impurities to flow through the filter slits where it changes the direction 180° two times. Because of this abrupt direction changing of grease extraction, grease collides with the filters' surface and settles. The distance between the filters' steel plates designed to provide optimal grease capture velocity. The main aim of this is to avoid clogging up with grease and to provide fire safety. The grease capture velocity influences mostly on filter efficiency. The construction of a baffle filter you can see on figure 7.

The efficiency of baffle filter is presented on the figure 8 below. You can see that efficiency of grease filter is not very high. The maximum extraction efficiency of particles bigger than 10μm achieved 35%. The particulate efficiency for particles smaller than 4μm is almost zero. Baffle filters are usually used for light dirty commercial kitchens for pizzas, potatoes and spaghetti cooking.

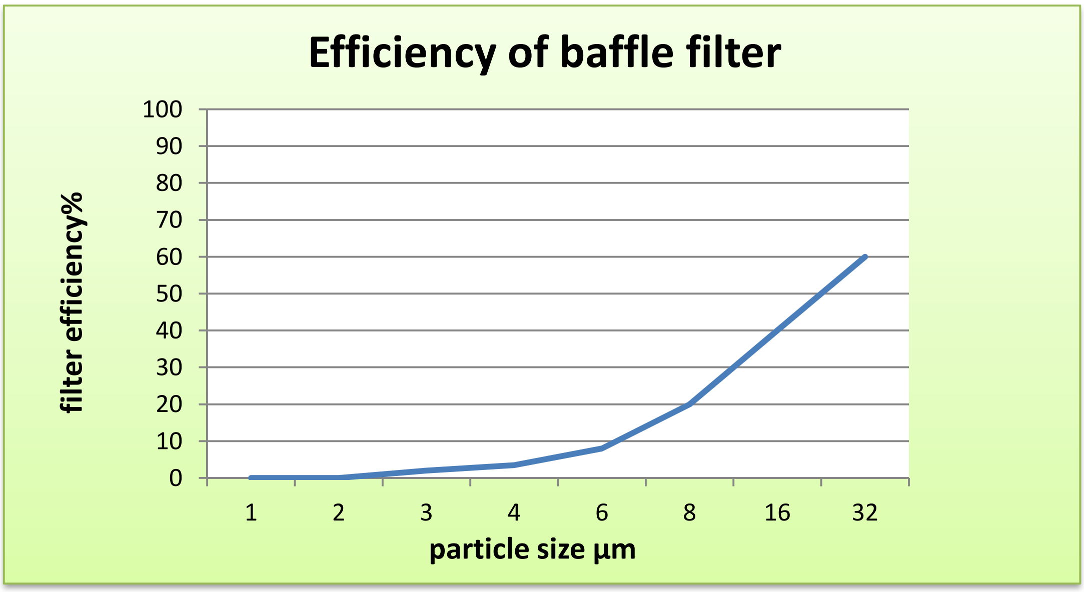


Figure 7. Efficiency of baffle filter /5/

3.2 Cyclonic filter.

Cyclonic filters appeared on the market of commercial kitchen filters later than baffle filters. The filtration principle of cyclonic filters is based on centrifugal force. Air with grease impurities enters the filter slots and after that spins through the filter. During spinning grease particles are impinging the filter walls and accumulating on the filter inner surface and on the bottom of filter. The clean air exits from the top and the bottom of the filter.

There are different modifications of cyclonic filter depending on manufacturer. Two different types of cyclonic filters are shown on figures 8 and 9.

The efficiency of cyclonic filters is shown on figures 10 and 11. These graphics show that the efficiency of particles in the size of more than 10μm is almost 100%. Efficiency of cyclonic filter is much higher than efficiency of baffle filter, especially for the bigger particles. The efficiency of smaller particles (< 6μm) is from 3 to 25 %. This value is also higher than for baffle filter, but anyway not very high. Thus, in comparison with baffle filters, cyclonic filters are installed over the appliance where mass emissions of grease is higher, for example: over the gas and electric broiler for chicken breast cooking; over gas and electric griddle for hamburger cooking.

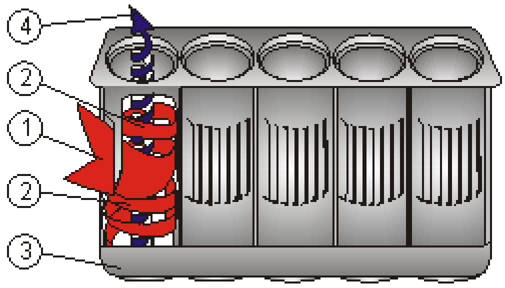


Figure 8. Construction and operation principles of cyclonic filter from Jeven Company /6/

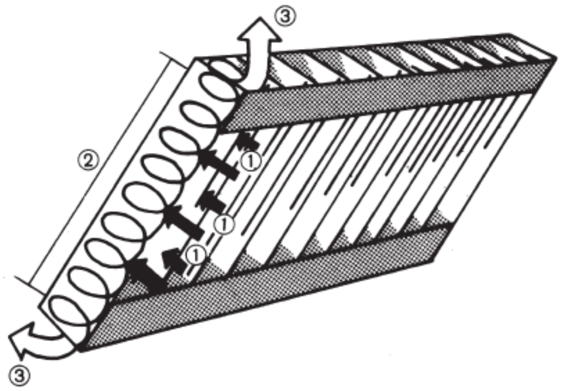


Figure 9. Construction and operation principle of cyclonic filter from Halton Company /7/

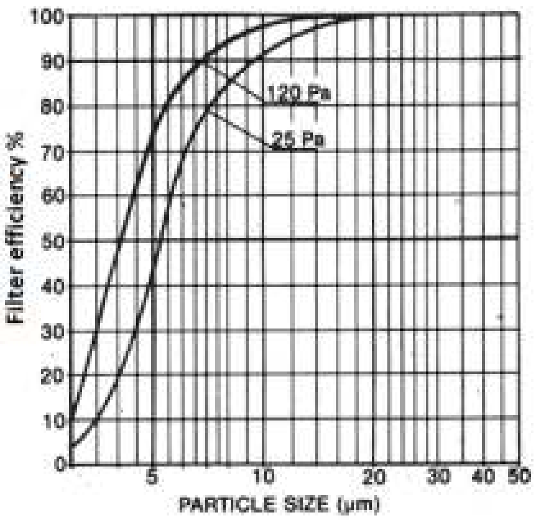


Figure 11. Construction and operation principles of cyclonic filter from Halton Company /7/

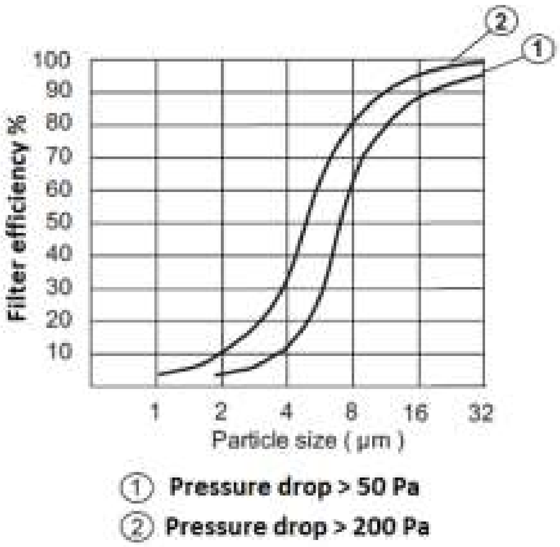


Figure 10. Construction and operation principles of cyclonic filter from Jeven Company /6/

3.3 Turbo swing filter.

Turbo Swing filter is a breakthrough of Jeven Company. It is a new kind of filter that provides the most effective grease filtration of particles in the size between 1 to 10μm. Turbo Swing has absolutely different operation principle in comparison with other kind of filters.

The construction of turbo swing filter is shown on figure 12. In construction of this filter is a metal separation plate 7 (plate with many holes) which is operated by motor 3. Filtration of Turbo Swing is based on rotating of separation plate of Turbo Swing filter.

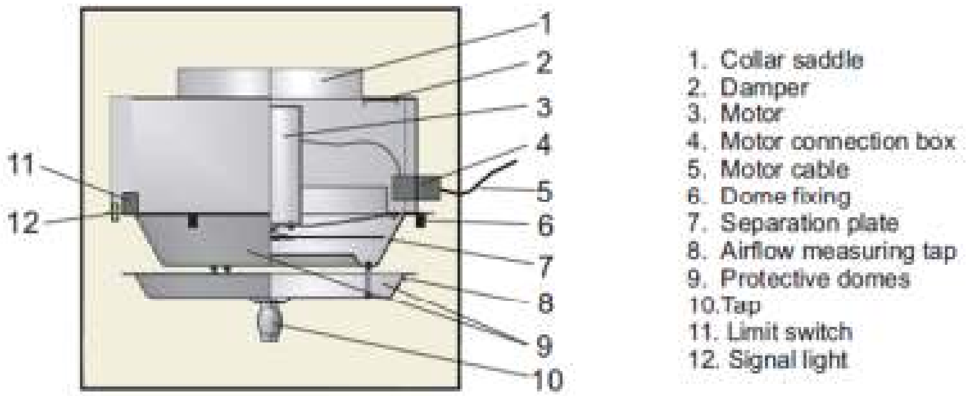


Figure 12. Construction of Turbo Swing filter /8/

The operational principle of Turbo Swing is shown in figure 13. On this figure you can see that air enters to the filter (process 1 on the figure 13) and flows through the holes of fast rotating separate plate (process 2 on the figure 13). During this process impurity particles collide and adhere to the walls of the protective domes (process 3 on the figure 13). After that collided particles of liquid grease swing by centrifugal force (process 4) to the separate chamber so called protective domes (process 5 on the figure 13). From this chamber grease is removed through the tap opening (process 6). The cleaned air exits to the ducts (process 7).

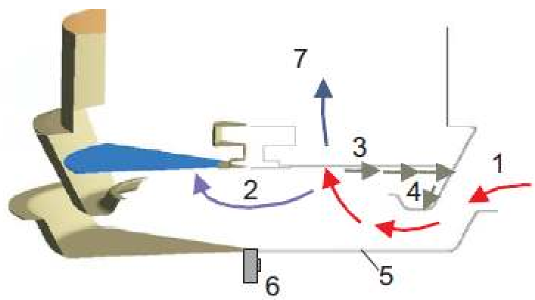


Figura 13. Operation principle of Turbo Swing filter /8/

Theoretical efficiency of turbo swing filters depends on exhaust air flow rate, on amount and the size of liquid grease particles. The graphic below shows the theoretical efficiency of turbo swing filters.

In figure14 you can see that the extraction efficiency of small diameter particles is higher in comparison with cyclonic filter. For example, 3µm particles extraction efficiency is 55%. The extraction efficiency of larger particles is also higher than in previous two filters. In practice efficiency of Turbo Swing filter depends also on the gap between filter and ceiling. How the gap and air flow rate influence on turbo swing efficiency in practice I will tell in the next paragraphs according to results of measurements which were done as a practical part of this thesis.

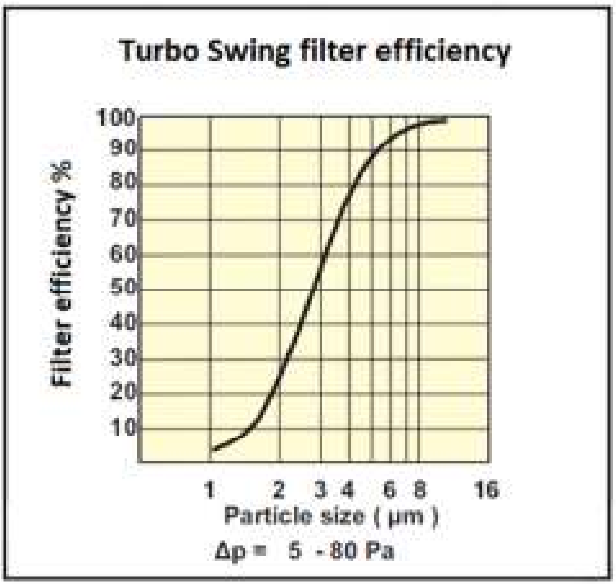


Figura 14. Operation principle of Turbo Swing filter /8/

3.4 Efficiency of Turbo Swing filter measured in practical cases.

The efficiency of filter increases because of the leakage of dry and vapour particles of grease through the gap between turbo swing filter and ceiling. When grease vapour particles are separated from the air, some part of filtrated air with dry particles flows into the duct. Another part of particles outgoes through the gap between filter and ceiling by centrifugal force. The amount of the escaping dry particles through this gap depends:

- on gap width between filter and ceiling
- on the air flow rate

The aim of the laboratory measurements were:

- To find out the influence of gap width on the filters efficiency.
- How Turbo Swing filter works with dry dust particles.

3.4.1 Method.

Construction with Turbo Swing filter was installed in MUAS (Mikkelin University of Applied Sciences) laboratory. Turbo swing filter was connected on the both sides with two ducts:

- Duct before the filter with dirty air
- Duct after the filter with filtered air.

The sizes of ducts were 315 mm according to the turbo swing technical brochure. In Jeven Turbo Swing technical brochure it is said that 315 mm is a standard and only possible duct size for connection with turbo Swing). On the end of the duct of filtered air the fan was installed. This connection is shown on figure 16. The air flow rate was regulated with the fan frequency. The (dirty air) duct was connected with the small room where smoke was generated. The connection between room and suction duct was isolated to avoid any smoke leakages. The construction with the turbo Swing filter is shown on figure 15.

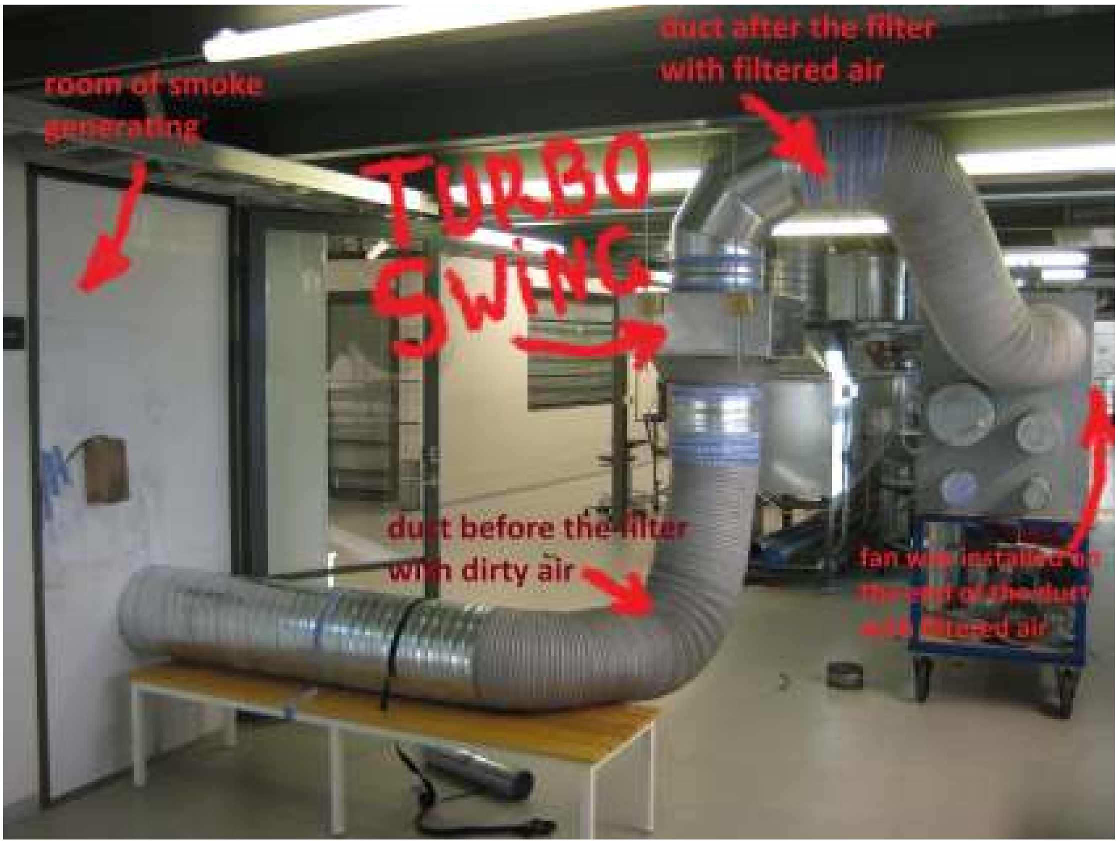


Figure15. Construction with the Turbo Swing filter in the MUAS laboratory.

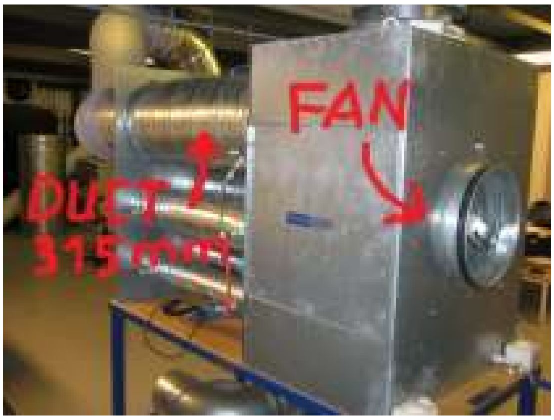


Figure 16. The fan connection with the duct of filtered air (in MUAS laboratory).

Figure 17. Smoke machine MAGNUM 1200 in MUAS laboratory.

The smoke was generated by the smoke machine MAGNUM 1200. It is shown on figure 17. The smoke machine was programmed to emit a certain amount of smoke every 20 seconds. Thus almost constant concentration of particles in the size between 0.3 µm to 10 µm was achieved in the room. The smoke generated by the MAGNUM 1200 imitates grease vapour that produced during the cooking process.

Figure 18. TSI AeroTrak 8220 Handheld Optical Particle Counter /9/

Concentrations of particles were measured with the particle counter TSI AeroTrak 8220 Handheld Optical Particle Counter. It is shown on the figure 18. In both suction and plenum ducts the hole was done for pipe of particle counter. The measurements were done in both ducts from 5 sample points. The holes were drilled in the ducts on the both sides of the filter. The particle counter was programed for a sample period 90 seconds in one point. The locations of sample points are shown on figure 19.

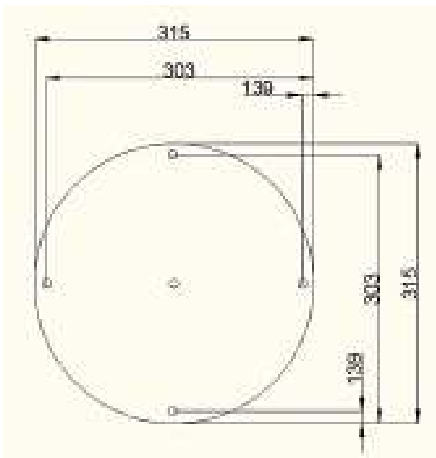


Figura 19. The locations of sample point.

Measurements were done by using three different gap widths between the Turbo Swing filter and ceiling: 0mm, 3.5mm, 10mm.

3.4.2 Results and analysis.

Actually in the beginning of my measurements I was engaged to find out the efficiency of filter and the leakage effect of dry grease particles from the gap. At the beginning the air flow was 200 l/s (this is the maximum air flow rate according to the turbo swing guidance).

During making measurements with 3,5 mm and 10 mm gap for 200 l/s flow there were no air leakages from the gap. It was found out that the air was sucked effectively into the filter. This was seen by using special smoke device, which visualizes air flows.

In additional measurements the influence was found out: the reducing of air flows leads to the increasing of leakages of air and particles leakages from the gap.

For 4 mm gap the 157 l/s was the highest flow on which the air was not totally sucked into gap from the room. This flow was installed in the duct before the filter. In this case the air flow after the filter was 152 l/s. Thus the leakage from the gap was 5 l/s. It's shown on figure 20.

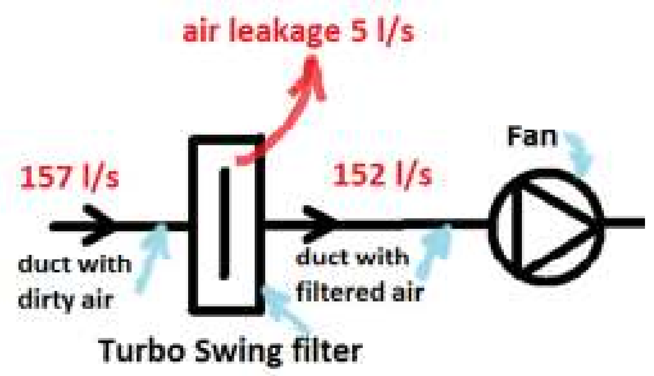


Figure 20. Gap width 4 mm, air leakage is 5 l/s.

After that I created a situation with almost the same flow for 10 mm gap. The air flow in the duct before the filter was 157 l/s. As a result the air was sucked from the ambient and the flow after filter was 194 l/s. So in this case there were no leakages of air and no particles leakages from the gap. The air flow rate increases on to 37 l/s. It is shown on figure 21. For

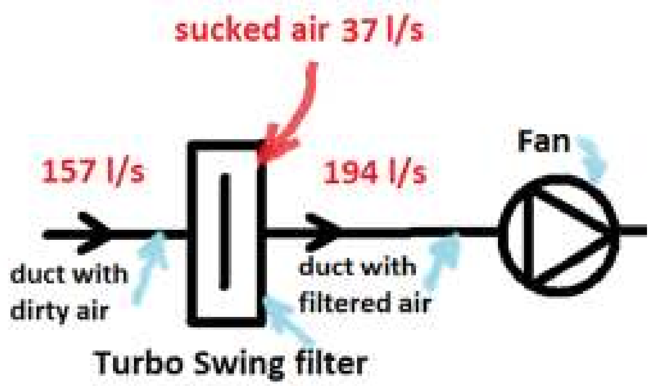


Figure 21. Gap width 10 mm, 42 l/s of air is sucked into the gap.

the same gap (10 mm) I found out that 135 l/s is the highest flow when air was not sucked into the gap.

The measurements results of particle concentrations before and after the filter are presented in the tables in the appendix in the end of the thesis. The example of results is presented in the table 2.

№ point	1		2		3		4		5	
particle size µm	Before	after	Before	After	before	After	Before	After	before	after
	counts/m3									
0,3-0,5	$5{,}72\cdot10^8$	$5{,}82\cdot10^8$	$5{,}88\cdot10^8$	$5{,}96\cdot10^8$	$5{,}89\cdot10^8$	$5{,}62\cdot10^8$	$6{,}81\cdot10^8$	$6{,}44\cdot10^8$	$5{,}93\cdot10^8$	$5{,}61\cdot10^8$
0,5-1,0	$8{,}98\cdot10^8$	$10{,}07\cdot10^8$	$8{,}24\cdot10^8$	$8{,}26\cdot10^8$	$8{,}10\cdot10^8$	$7{,}07\cdot10^8$	$6{,}99\cdot10^8$	$6{,}46\cdot10^8$	$6{,}63\cdot10^8$	$6{,}01\cdot10^8$
1,0-3,0	$5{,}80\cdot10^7$	$6{,}88\cdot10^7$	$4{,}64\cdot10^7$	$5{,}61\cdot10^7$	$1{,}18\cdot10^8$	$6{,}07\cdot10^7$	$5{,}81\cdot10^7$	$4{,}11\cdot10^7$	$7{,}28\cdot10^7$	$5{,}55\cdot10^7$
3,0-5,0	$2{,}78\cdot10^6$	$8{,}70\cdot10^5$	$2{,}74\cdot10^6$	$1{,}41\cdot10^6$	$5{,}98\cdot10^6$	$1{,}12\cdot10^6$	$4{,}39\cdot10^6$	$1{,}05\cdot10^6$	$4{,}92\cdot10^6$	$1{,}07\cdot10^6$
5,0-10	$2{,}96\cdot10^5$	$1{,}49\cdot10^4$	$4{,}79\cdot10^5$	$4{,}07\cdot10^4$	$4{,}90\cdot10^5$	$2{,}91\cdot10^4$	$5{,}75\cdot10^5$	$4{,}04\cdot10^4$	$6{,}52\cdot10^5$	$4{,}62\cdot10^4$
10+	856	286	0	0	285	0	285	0	573	286

Table 2. Particles concentration of in 5 sample points before and after the filter for 3.5 mm gap.

For determine the filter efficiency the formula 1 was used. In this formula the average particles concentration was used. This was calculated by formula 2. The results of average particles concentration for different gaps are in tables below.

$$\text{filter efficiency} = \left(1 - \frac{\text{average particle concentration after the filter}}{\text{average particle concentration before the filter}}\right) \quad [1]$$

Formula 1. Filter efficiency. /10, p.15/

$$\text{average particles concentration} = \left(\frac{\sum \text{particle concentration in all sample points}}{\text{amount of sample points}}\right) \quad [2]$$

Formula 2. Average particles concentration.

Particle size µm	average concentration counts/m^3		efficiency of particles extraction %
	before	After	
>0.3	6,04·10^8	5,89·10^8	2,6
>0.5	7,79·10^8	7,58·10^8	2,74
>1	7,07·10^7	5,65·10^7	20,11
>3	4,16·10^6	1,11·10^6	73,47
>5	4,99·10^5	3,43·10^4	93,13
>10	399,8	0	100

Table 3. Turbo Swing filter efficiency when the gap is 3.5 mm, flow before the filter 157 l/s, flow after the filter 152 l/s, air leakage is 5 l/s.

The results of table 3 show that the filter efficiency for big particles (>5µm) is high (from 74 to 93 %). The efficiency of small particles (< 3µm) is also high. The reason of it is 5 l/s air leakage from the gap. The process is drawn on figure 20.

Particle size µm	average concentration counts/m^3		efficiency of particles extraction (filter efficiency) %
	before	After	
>0.3	6,07·10^8	7,29·10^8	-20
>0.5	7,58·10^8	8,53·10^8	-12,6
>1	5,58·10^7	5,78·10^7	-3,56
>3	3,18·10^6	1,056·10^6	66,8
>5	4,09·10^5	3,69·10^4	90,98
>10	285,8	16,6	94,19

Table 4. Turbo Swing filter efficiency when the gap is 10 mm, flow before the filter 157 l/s, flow after the filter 194 l/s, sucked air flow is 37 l/s.

Table 4 shows that extraction efficiency of big size particles (>3µm) is also very high (67-94 %). There is no filtration of particles smaller than 1 µm. It is caused by suction of air with small particles (<1 µm) into the filter gap. This is shown on figure 21.

Particle size µm	average concentration counts/m³		efficiency of particles extraction %
	before	After	
>0.3	$5{,}05\cdot10^8$	$5{,}01\cdot10^8$	0,8
>0.5	$9{,}65\cdot10^8$	$9{,}53\cdot10^8$	1,23
>1	$1{,}24\cdot10^8$	$1{,}16\cdot10^8$	6,7
>3	$6{,}41\cdot10^6$	$1{,}43\cdot10^6$	77,73
>5	$7{,}41\cdot10^5$	3	96,07
>10	119,2	0	100

Table 5. Turbo Swing filter efficiency when the gap is 10 mm, flow before the filter 135 l/s, flow after the filter 95 l/s, air leakage is 40 l/s.

Results of table 5 (for 10 mm gap) show that the reducing air flow up to 135 l/s lead to air leakage trough the gap (This process is shown on figure 22). As a result the extraction efficiency of particles smaller than 1 µm is increasing. The efficiency of bigger particles is also little bit increased in comparison with the table 4. The comparison of these filters efficiencies for 10 mm gap with the different flow (157 l/s and 135 l/s) is shown on figure 27.

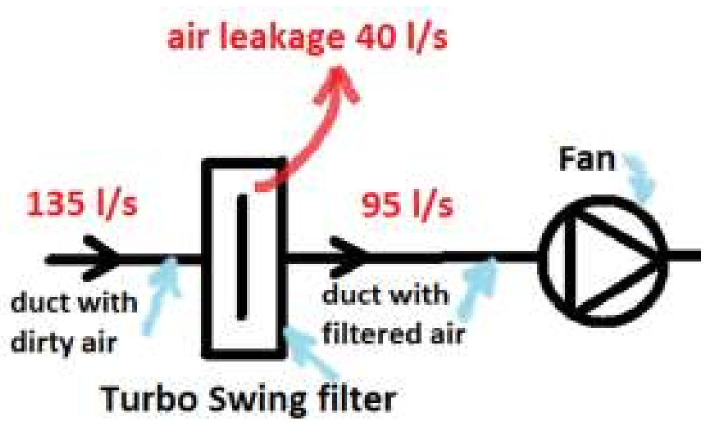


Figure 22. The gap is 10 mm, flow before the filter 135 l/s, flow after the filter 95 l/s, air leakage is 40 l/s.

Particle size µm	average concentration counts/m^3		efficiency of particles extraction %
	before	After	
>0.3	$4{,}76 \cdot 10^8$	$4{,}75 \cdot 10^8$	0,25
>0.5	$9{,}56 \cdot 10^8$	$9{,}43 \cdot 10^8$	1,44
>1	$1{,}16 \cdot 10^8$	$1{,}08 \cdot 10^8$	7,09
>3	$5{,}95 \cdot 10^6$	$1{,}08 \cdot 10^6$	81,9
>5	$5{,}52 \cdot 10^5$	$1{,}71 \cdot 10^4$	96,9
>10	170,8	0	100

Table 6. Turbo Swing filter efficiency when the gap is 0 mm, flow before the filter 108 l/s, flow after the filter 92 l/s, air leakage is 16 l/s.

The results of table 6 show that the extraction efficiency for all particles is very high. If compare this other gaps and air flows, filter efficiency is mostly high for particles in the size 3-10µm. the process is shown on figure 23.

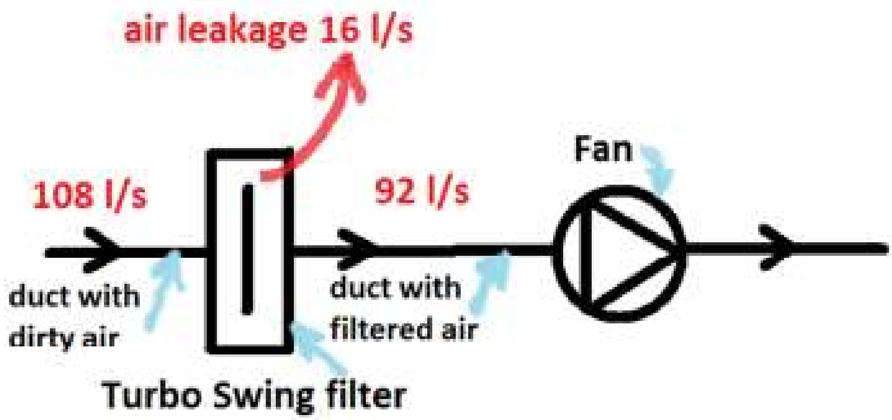


Figure 23. The gap is 0 mm, flow before the filter 108 l/s, flow after the filter 92 l/s, air leakage is 16 l/s.

Particle size µm	average concentration counts/m^3		efficiency of particles extraction %
	before	After	
>0.3	$6{,}57 \cdot 10^8$	$6{,}39 \cdot 10^8$	2,82
>0.5	$9{,}66 \cdot 10^8$	$9{,}40 \cdot 10^8$	2,7
>1	$9{,}05 \cdot 10^7$	$8{,}61 \cdot 10^7$	4,87
>3	$2{,}92 \cdot 10^6$	$1{,}04 \cdot 10^6$	64,29
>5	$3{,}21 \cdot 10^5$	$2{,}85 \cdot 10^4$	91,1
>10	57,2	0	100

Table 7. Turbo Swing filter efficiency when the gap is 0 mm, flow before the filter 205 l/s, flow after the filter 207l/s, sucked air flow is 2 l/s.

The process scheme of table7 results is presented on figure 24. These results show that increasing the air flow leads to the reducing of filter efficiency for particles bigger than 3 µm. The extraction efficiency of particles smaller than 0.5 µm is increased in comparison with the results of table 6. The comparison of filter efficiencies for the gap 0 mm with different flows (108 l/s and 205 l/s) is shown on figure 25.

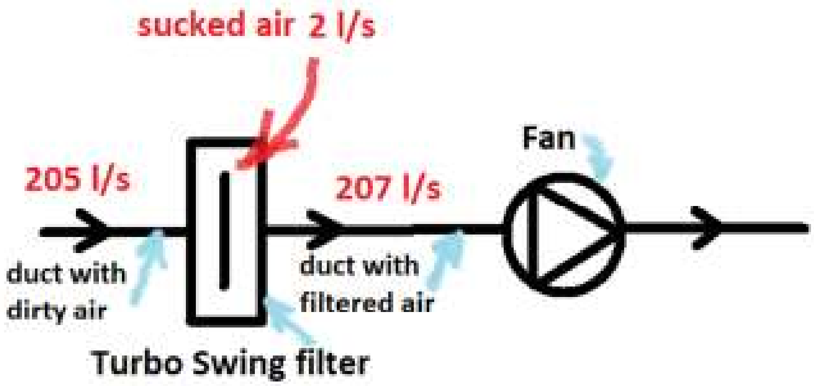


Figure 24. The gap is 0 mm, flow before the filter 205 l/s, flow after the filter 207 l/s, sucked air is 2 l/s.

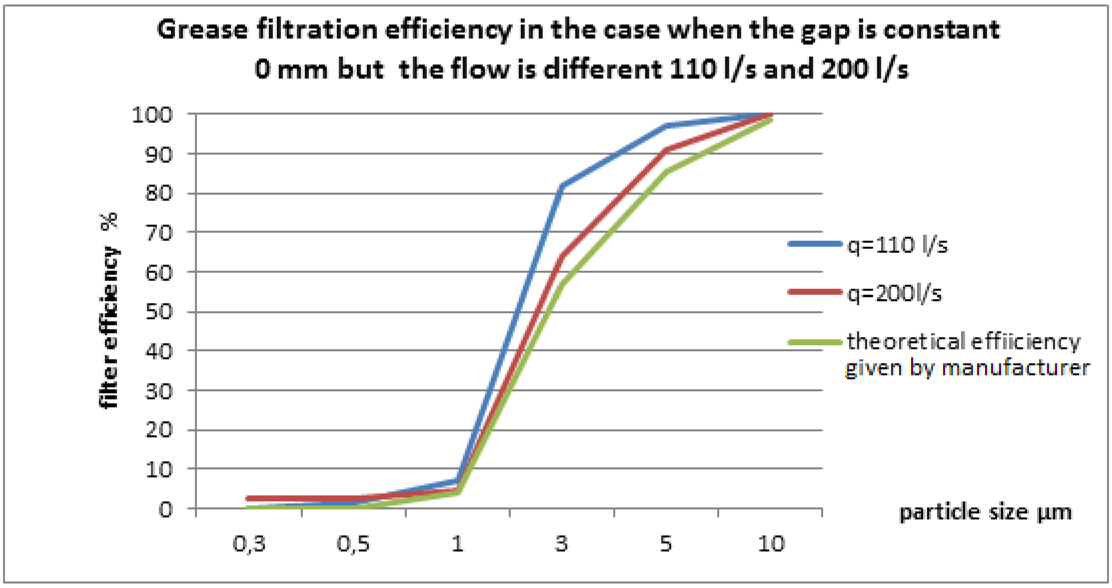


Figure 25. The grease filtration efficiency changes. The gap is constant 0 mm. Air flows are different.

The graphic on figure 25 is based on the results from the tables 6, 7. The figure 25 shows the filter efficiencies comparison when the gap is constant (0mm) but the suction duct flow is different (110 l/s, 200 l/s). On this graphic we can see that filter efficiency for particles between 1µm to 10µm is higher when the air flow in suction duct is 110l/s. This is a result of 16 l/s air leakage which is shown on figure 23. This air leakage also leads to leakage of particles in the size of 1-10µm, as a result to higher efficiency for 110 l/s flow.

During these measurements the filter was installed to the ceiling as closely as possible. But the leakage of air flow shows that there was small slot between filter and ceiling. Will air go into the duct through this small slot or not depends up to the air flow rate.

Figure 26 shows how the filtration efficiency changes in the case when the flow is constant (157 l/s) but the gap is different (3.5mm and 10 mm). The graphic on figure 26 is drawn on the results from tables 3 and 4.

For 3.5 mm gap the extraction efficiency of big diameter particles (> 5 µm) higher. This is the result of air leakage through the gap. This situation is drawn on figure 20. This air leakage leads to the leakage of particle smaller than 1µm. As a result filter efficiency was increasing.

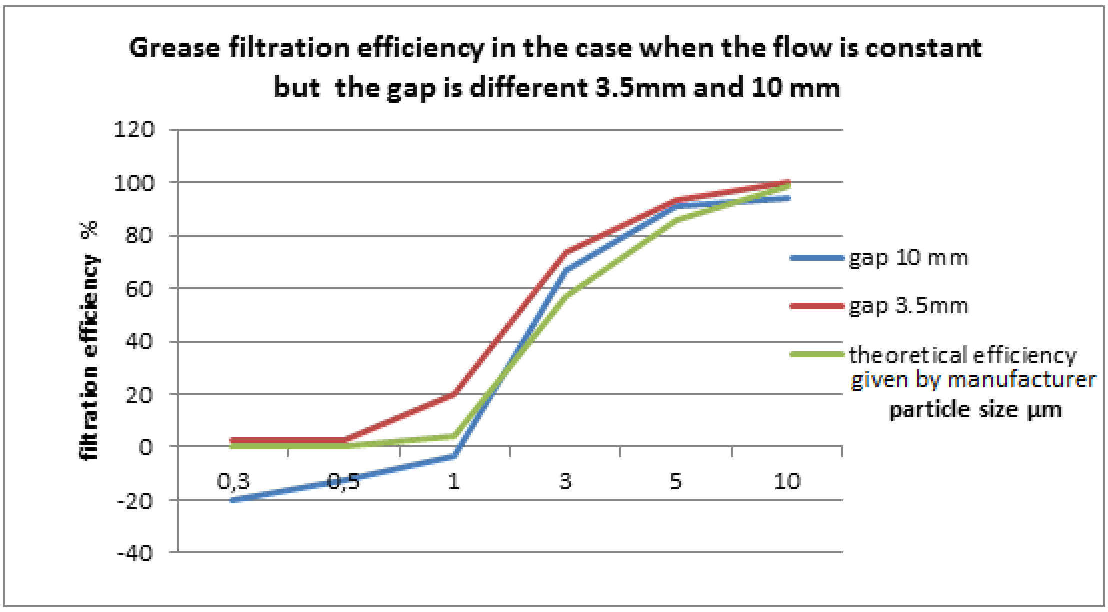


Figure 26. The grease filtration efficiency changes. The gap is different: 3.5 mm and 10 mm. Air flow in the suction duct is constant.

For the 10 mm gap the air is sucked into the gap. This process is shown on figure 21. As a result particles smaller than 1µm were sucked into the filter. The concentration of particles smaller 1µm after the filter was higher than before the filter. As a result there was not extraction efficiency of these small particles.

To achieve bigger efficiency in the case of 10 mm gap between filter and ceiling it is necessary to reduce the air flow.

Figure 27 shows how the filter efficiency changes when the gap is constant 10 mm but the flow is different: 157 l/s and 135 l/s. This graphic is based on the results from the tables 5 and 6. Figure 27 shows that for the reduced air flow (135 l/s) the extraction efficiency is higher for the all size particles. It was caused by the 40 l/s air leakage. The direction of air flow for 135 l/s flow you can see on figure 29.

Figure 27 shows also that for the bigger flow (157 l/s) there was not extraction efficiency of particles smaller than 1 µm. This is a result of air suction into gap (this process shown on figure 21 and on figure 28). This air suction was leading to the suction of particles smaller than 1µm.

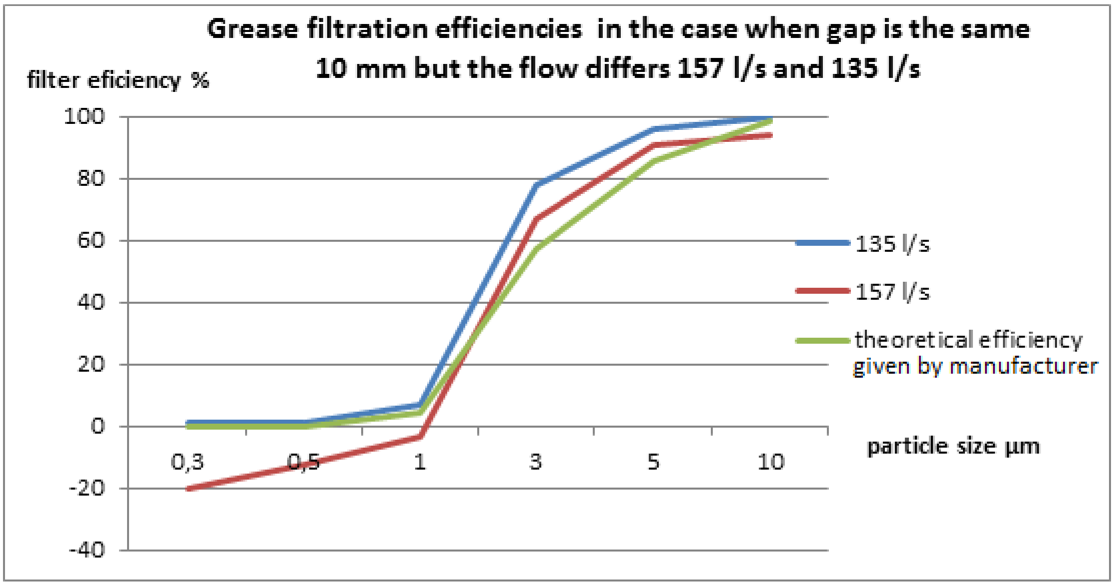


Figure 27. The grease filtration efficiency changes. The gap is constant: 10 mm Air flow in the suction duct is different: 135 l/s and 157 l/s.

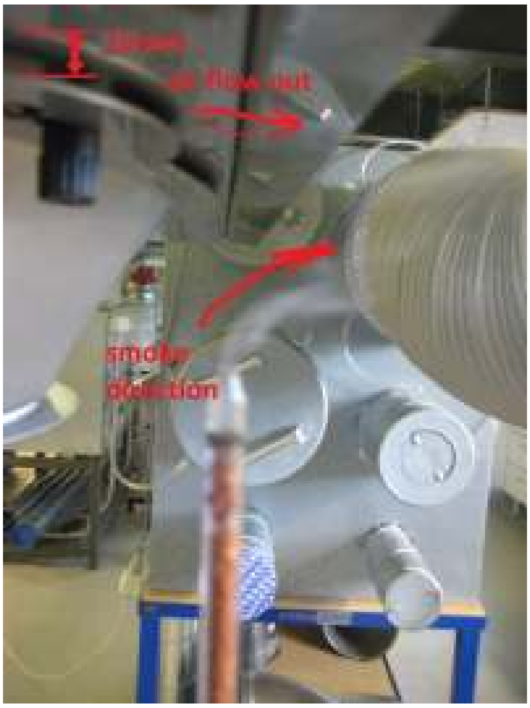


Figure 28. The air flow direction. Gap is 10 mm. air flow 157 l/s

Figure 29. The air flow direction . Gap is 10mm, air flow is 135 l/s.

The turbo swing filter after measurements is shown on figure 30. On this picture you can see that the vapour smoke particles after filtration are in drops form upper the line of separation plate.

Figure 30. Drops of liquid filtrated particles inside the turbo swing after the measurements.

3.4.3 Recommendations for turbo swing filter installation.

The results show that the lower air flow and the more narrow gap between turbo swing and ceiling achieve the better extraction efficiency. The biggest difference is between the extraction efficiency of particles smaller than 2µm. When particles are bigger the extraction efficiency differs, but not so much. In all cases the extraction efficiencies of particles larger than 2µm are very high. The choosing of the air gap and air flow rate should be oriented first of all on the design flow of exhaust duct for a certain kitchen. The design hood exhaust air flow in commercial kitchens couldn't be low. It is usually not less than 200 l/s. The gap width should be adjusted in the limits from the 0 to 4 mm. The smaller gap should be chosen to increase the extraction efficiency of particles less than 2µm.

3.5 Comparison of filter efficiencies.

In this chapter I will compare the efficiencies of baffle, cyclone and turbo swing filters according to manufactures announcements. The graph of efficiency comparison is shown on the figure 31. It is easy to see that the Turbo Swing filter has the highest efficiency. That's why they should be installed over the most dirty places in the kitchen (over the gas and electric broilers for hamburger cooking or over the appliance for the Chinese wok cooking).

The cyclonic filters are on the second place. They have less extraction efficiency than turbo swing, but at the same time it is higher than baffle filter efficiency. The cyclonic filters are suitable for very dirty kitchens too. These filters should be installed over the griddles for hamburgers cooking, over the broiler for chicken breast cooking, over the potatoes fryers and over the spaghetti ranges.

The baffle filters are not very effective in grease filtration. This kind of filters should be used in light dirty places, for example over the ovens for pizza cooking.

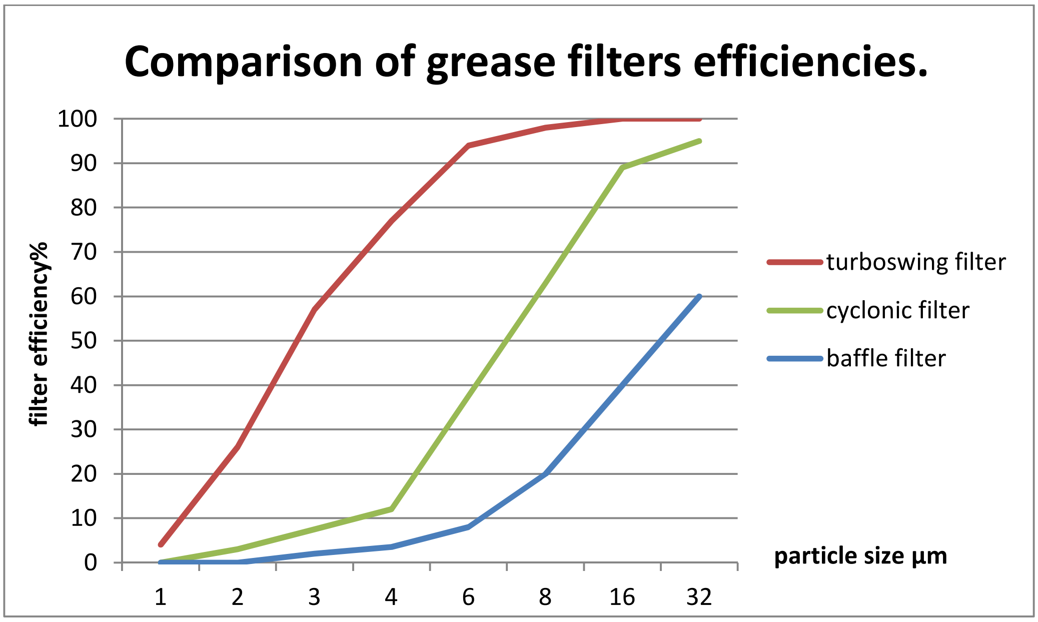


Figure 31. Comparison of Turbo Swing, cyclonic and baffle filters efficiencies according to manufactures announcements.

4 CLEANING OF VENTILATION SYSTEMS

4.1 Ways of duct cleaning.

Cleaning of ventilation systems in restaurants is compulsory anyway, even in the case when grease filters are installed. Grease filters very effectively reduce the demand of duct cleaning and as a result save money, but unfortunately couldn't totally prevent grease entrance into the duct. Filters should be also cleaned. In practice grease filters in commercial kitchens can be washed every week. They are usually washed in dish-washing machines. In comparison with the filters cleaning, the duct cleaning is a much more complicated and expensive process. Nowadays there are three ways of duct cleaning in professional kitchens

- By using the ice blasting technology with Danduct Ice Tech robot
- By using rotating brush robots with active foam
- Manually by using scrapers and caustic chemicals

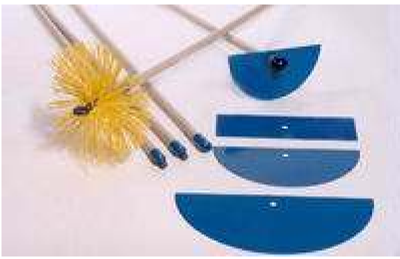
In this chapter I will tell the main things about these two methods. I will also compare them and will find out advantages and disadvantages of each method. Here you can also find some information about the frequency of duct cleaning and the role of standards in it.

4.1.1 Manually with caustic chemicals and scrapers.

Scraping and applying special detergents is considered to be the oldest method of duct cleaning. This kind of cleaning is fully done by workers. It is shown on figure 32. First of all the most rough grease impurities are removed from the duct by scrapers which are shown on figure 33 below. After that the grease is broken down by caustic chemicals and washed with hot water. It is really unpleasant work.

Figure 32. Manually duct cleaning by using scrapers and caustic chemicals. /11/

Not so far it was only the one way of duct cleaning. In fact this is cheaper than duct cleaning by using different robots. Manually cleaning doesn't need very expensive equipment, as only scrapers, detergents and worker hands are



used.

In Russia the average restaurant duct system cleaning by scrapers costs about 20000 rubles (it is about 470€).

Figure 33. Scrapers and brash for manually duct cleaning. /12/

4.1.2 Ice blasting technology (Danduct robot)

Dunduct Ice Tech robot breaks the grease and duct mixture down by using dry ice. This robot works on the sandblaster operational principle. In comparison with the sandblaster, result of cleaning by using Danduct robot is achieved due to the opportunity of dry ice sublimation. Sublimation is transforming solid form of substance into the gaseous form without the middle liquid form. In the moment when the dry ice grains collide with the duct surface, the dry ice grains immediately transform into car-

bon dioxide /3/. Because of the density of carbon dioxide is 800 times higher the density of dry ice grains, there is a micro explosion on the dirty duct surface and the grease is broken down. So the abrasive affect is avoided.

Figure 34. Danduct robot in the duct. /13/

The First step of the cleaning process by using Danduct robot is the installation of the special compressor with the pressure difference 7-10 bar on the external side of the building. This compressor connected with the dry ice device. It is used for the dry ice grains generating and supplying. The standard supplying horse of dry ice machine is 15 meters. Thus all length of vent ducts which should be cleaning need to be divided into 15 meters sections. Two inspection holes must be done in the duct system: one for the filter vacuum plant with grease capture filters and one for Danduct robot.

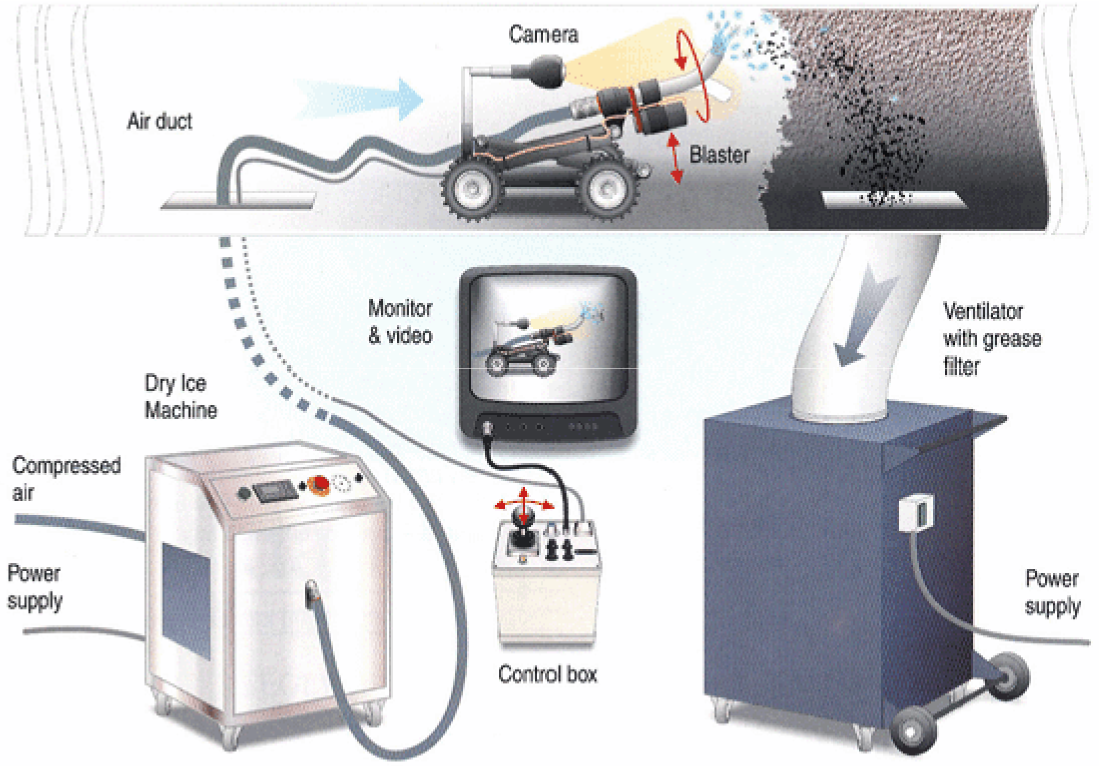


Figure 35. Process of cleaning by ice blasting technology /14/

From the chemistry point of view dry ice is a solid form of CO_2 carbon dioxide compound. The temperature of dry ice is -78.33°C. Thermo energy of dry ice is used in duct cleaning. The advantages of using this substance in duct cleaning is

- dry ice is nontoxic
- in liquid form dry ice can be stored for a long time
- relatively inexpensive
- easily and carefully can remove even very old and big grease impurities
- cleaning without chemicals and water.

4.1.3 Brush rotating robot with active foam.

Rotating brush technology is the most popular method of duct cleaning nowadays. In this duct cleaning method grease is broken down because of:

- Mechanical action of special brush rotating
- Chemical action of special active foam
- Temperature action (the temperature of active foam is about 60°C)
- Holding period of active foam in the duct (is about 15 minutes)

The cleaning process begins with the installation of special equipment: brushing robot, active foam and rinse generator, compressed air generator, duct inspection system.

Duct cleaning robot has a special nylon or wire brushes. The type of brush is depends on the intensity of grease contaminations. The wire brush is usually used for more dirty kitchens, as it is very effective for removing even burnt grease from the duct. In all other cases nylon brushes are used. The diameter of brush varies from 100 -1000 mm. The brush rotates due to a special pneumatic motor installed in the robot. The robot also has a video inspection and a chemical product injector for the active foam.

The active foam is generated in a stainless steel container which is pressurized with compressed air. Its capacity varies from 25 to 50 liters. The compressed air produced by air generator, the flow of which obtains 240 liters per minute. The foam generator converts a solution of chemical degreasing product and water into highly alkaline foam for the removal of grease. This container is connected to the duct-brushing machine to inject active foam into the duct.

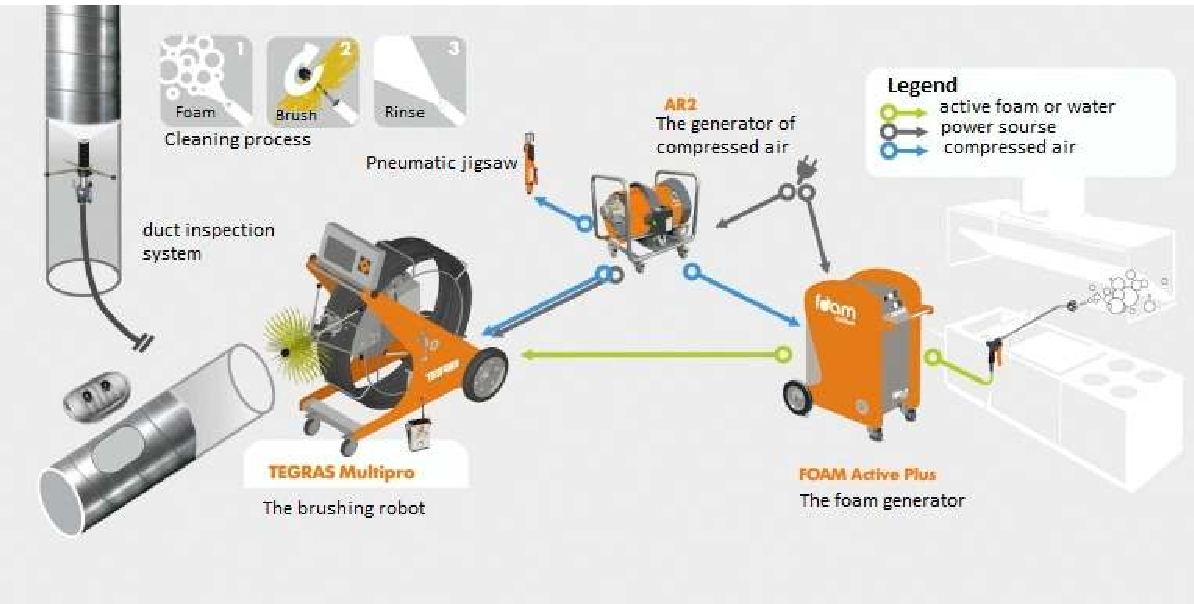


Figure 36. Process of cleaning by using brushing robot /15/

The cleaning process by using brushing robot is shown on figure 36. When all equipment is installed generated active foam is injected into the duct by brush robot. The foam adheres to the duct surfaces and breaks down the grease. The holding period of foam in the duct is about 15 minutes or more. The time period depends on the rate of contamination. After foam reaction with grease brushes start working. Brushes remove grease remains from the duct mechanically with rotary movements produced by robot. After all these processes the duct should be thorough rinsed by water. This water with admixtures of foam and grease duct is removed from the duct through drainage.

The advantages of this way of duct cleaning are:

- Short operational time
- Safety for ducts
- relatively inexpensive
- easily and carefully can remove even very old and big grease impurities

The disadvantages of rotating brush cleaning are:

- chemicals and solvents are relatively safe but can irritate lunge of sensitive or asthmatic persons

4.1.4 Comparison.

Cleaning by scrapers takes more time than ice blasting and rotating brush technologies. Of course the time of scraper cleaning depends on the rate of contaminants, the length of the ducts and the number of workers. In fact this problem can be solved by increasing the number of workers, but it will lead to the increasing of total cleaning price. In comparison with the scraping, ice blasting and rotating brush technologies are an automation process and takes maximum 2 days, while the scraping cleaning could take even a week. In many cases the commercial kitchens can not accept such long delay in operation. In the case when big restaurant with a lot of visitors is open 24 hours every day, a few days of restaurant closing are more expensive for the restaurant than the difference between the costs of scraping and the robot cleaning.

In comparison with the ice blasting and rotating brush, the main disadvantage of scraping cleaning is impossibility of cleaning the ducts of small diameters, because workers can not enter inside the duct. What about Danduct and rotating brush robot, it is quite little and can operate in the duct of small diameters.

In comparison with the scraping and rotating brush, the ice blasting cleaning is more reliable and guarantee of such cleaning is higher. In the case of scraping and rotating brush cleaning there is an opportunity of detergent leakages through the vent system to the kitchen room. It can lead to problems as special detergents for duct cleaning include different caustic chemicals and chemical biocides. In the case of ice blasting cleaning no water or any liquid are used and there will be no leakages. Also in comparison with the workers manually cleaning, robot doesn't break the duct surface during the cleaning.

4.2 Frequency of duct cleaning.

Frequency of duct cleaning is regulated by the local guidance, fire codes and legislation of the region. These vary from country to country. There are numerous air associations all over the world which advise and steer also the duct cleaning. Some countries have its own associations, for example

- NADCA (National Air Duct Cleaning Association) in USA,
- JADCA (Japan Air Duct Cleaners Association) in Japan.
- HVCA (Cleanliness of Ventilation Systems, Guide to Good Practice Cleanliness of Ventilation Systems TR/17) in UK
- SNBH (The Swedish National Board of Housing, Planning and Building) in Sweden
- FiSIAQ (Finnish Society of Indoor Air Quality and Climate) in Finland
- VDI (Hygiene requirements for ventilation and air conditioning systems and units) in Germany
- EHVA (European Hygienic Ventilation Association) in European countries.

There are also international non official guidebooks and regulations, for example:

- IKECA (International Kitchen Exhaust Cleaning Association)
- REHVA guidebook ”Cleanliness of ventilation systems”,

These standards and regulations give only some minimum or maximum values. These values can be used if they don't exceed the values of local standards, as local standards can be more strict in some countries.

Theoretically, frequency of duct cleaning depends on the type of cuisine, work time and amount of visitors. According to these parameters some restaurants need more often cleaning then others. Actually the owner of restaurant can take a decision to do cleaning of the restaurant ventilation system so often as he like, but it must be not less than the local legislation require.

For example, in the USA, according to the NADCA the restaurant kitchen exhaust system should be cleaned according to the NFPA 96 (International Standard for Ventilation Control and Fire Protection of Commercial Cooking Operations) and IKECA guidlines and Best Practices /15/.

Type or Volume of Cooking Frequency	**Frequency**
Systems serving solid fuel cooking operations	Monthly
Systems serving high-volume cooking operations such as 24-hour cooking, charbroiling, or wok cooking	Quarterly
Systems serving moderate-volume cooking operations	Semiannually
Systems serving low-volume cooking operations, such as churches, day camps, seasonal businesses, or senior centers	Annually

Table 8. Frequency of duct cleaning according to NFPA 96. /17/

Contamination level	Work time	Frequency of cleaning
Heavy Use	12-16 hours per day	3 monthly
Moderate Use	6-12 hours per day	6 monthly
Light Use	2-6 hours per day	12 monthly

Table 9. Frequency of cleaning kitchen extract system according to Guide to Guide to Good Practice Internal Cleanliness of Ventilation Systems [TR19] /18/

Frequency of cleaning kitchen extract system according to Guide to Good Practice Internal Cleanliness of Ventilation Systems TR/19 presented in table 9.

For example in Russia there is no regulation which says how often duct should be cleaned. But there is a standard which says that a certain rate of cleanness should be achieved inside the duct during all the time. In 2004 the order about “Organization of control over the cleaning and disinfection of ventilation and air conditioning systems” was established by the Russian Chief Medical Officer. According to this order the inspection and cleaning of ventilation systems should be done at least once for the 6 month.

In real life some restaurants ventilation systems should be cleaned more often than the standards recommend. In Russia in practice the restaurant are cleaning according to the table 10.

Type or Volume of Cooking Frequency	Frequency
The char broilers, wood burning stoves, 24 hour fast food place	Every month
Hamburger restaurant	Every 3 month
Small snack bar, pizza restaurant, oven hood every	Every 6 month
Hoods over steam kettles, dishwashers, soup vats	Once per year

Table 10. Frequency of restaurant duct cleaning in Russia in practice.

The comparison of tables 8, 9 and 10 shows that there are the most strict recommendations for frequency of duct cleaning in Russia. The duct cleaning frequency recommendations in USA and UK are almost the same. In comparison with Russia in the USA and United Kingdom heavy used kitchens such as 24-hour cooking kitchens are usually cleaned in 3 times rarely. The cleaning frequency of lightly use kitchens such as pizza restaurants in the USA and United Kingdom is in 2 times rarely than in Russia.

5 CONCLUSION

In this work I compared extraction efficiency of three different mechanical grease filters: baffle filter, cyclonic filter and Turbo Swing filter. The baffle and cyclonic filters are considered to be the basic grease filters for professional kitchens nowadays. The Turbo Swing filter is new technology patent grease filter of Jeven Company.

During my research it was found out that all of these grease filters have higher extraction efficiency for the bigger particles than for the smaller one. It was also find out that the Turbo Swing filter has the best extraction efficiency. The cyclonic filter is the second best. The baffle filter has the worst extraction efficiency in comparison with the two previous. The Turbo Swing filter extraction efficiency of small particles is in 3 times higher the cyclonic filter efficiency and is in 9 times higher the baffle filters efficiency. The Turbo Swing extraction efficiency for big particles is almost 100%. This figure is also very high for cyclonic filter. It is almost in 2 times higher the baffle filter efficiency.

According to this results of Turbo Swing filter measurements which were done in MUAS laboratory it was found out that the width of gap between ceiling and Turbo Swing does not influence the filter a lot. It was also found out that to achieve better efficiency of Turbo Swing filter it is necessary to reduce the air flow.

Relying on theoretical efficiencies and data about grease emission during different cooking processes I recommended which filter is good for which kind of cooking. I could say that the Turbo swing filter with the highest extraction efficiency should be installed in the dirtiest kitchens of hamburger and Chinese wok restaurants. The cyclonic filters are suitable for very dirty kitchens too. These filters should be installed over the griddles for hamburgers cooking, over the broiler for chicken breast cooking, over the potatoes fryers and over the spaghetti ranges. The baffle filters are not very effective in grease filtration. This kind of filters should be used slightly dirty places, for example over the ovens for pizza cooking.

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