# Paint Booth Performance

# FILTER CHANGING PROCEDURES

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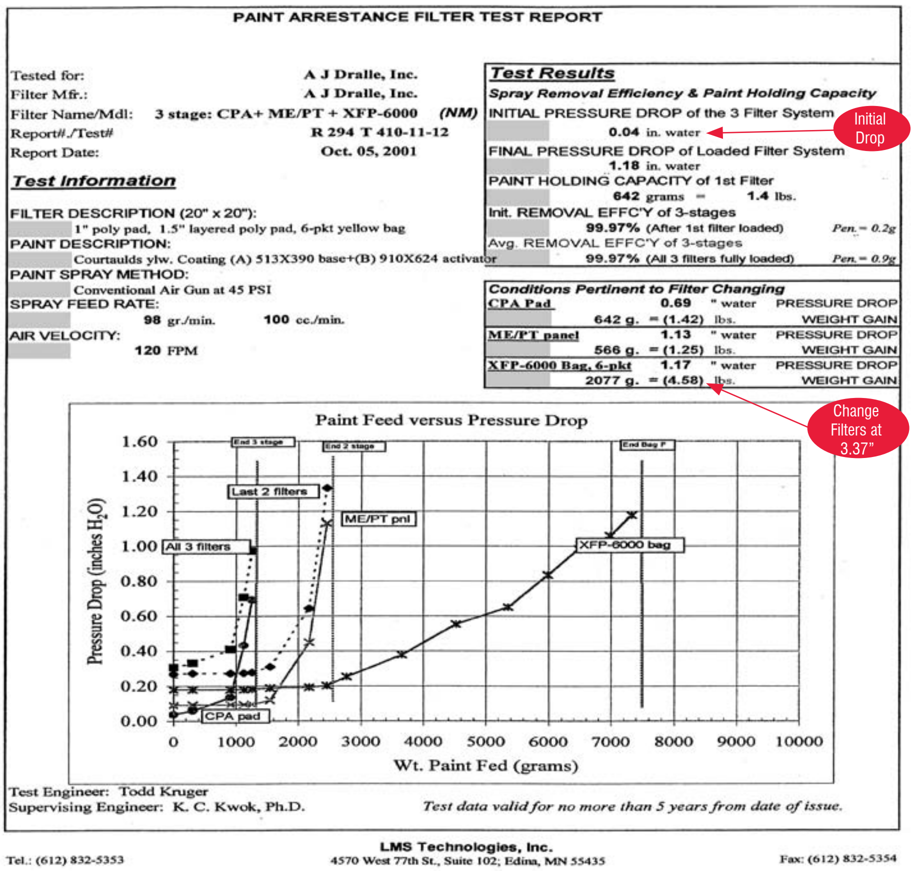
What is the best rule for signaling the time to change filters? This question has been asked of spray booth manufacturers, as well as filter manufacturers. There is not an easy answer.  Let's look at filtration, fans and chamber design.

## FILTRATION

This discussion will concern itself with 3-Stage NESHAP filters as mandated in CFR 40 part 63. This is the aerospace NESHAP regulation that mandates the use of 3-Stage filters. Please note that the 3-stages of filtration must meet testing in accordance with Method 319 (Figure 1) which is explained in the regulation (see tables 3 and 4 of article 63.475).

Filter manufacturers have tests that show that their filters will perform over a very great range of pressures. One manufacturer says that you should change your filters when the first stage is 0.50 inches water column (WC) above the initial pressure drop as measured by a manometer. The second and third stages should be changed when they are at 0.75" WC above their initial pressure drop.



PAINT ARRESTANCE FILTER TEST REPORT

| | |
|---|---|
| Tested for: | A J Dralle, Inc. |
| Filter Mfr.: | A J Dralle, Inc. |
| Filter Name/Mdl: | 3 stage: CPA+ ME/PT + XFP-6000 (NM) |
| Report#./Test# | R 294 T 410-11-12 |
| Report Date: | Oct. 05, 2001 |

***Test Information***

FILTER DESCRIPTION (20" x 20"):
1" poly pad, 1.5" layered poly pad, 6-pkt yellow bag
PAINT DESCRIPTION:
Courtaulds ylw. Coating (A) 513X390 base+(B) 910X624 activator
PAINT SPRAY METHOD:
Conventional Air Gun at 45 PSI
SPRAY FEED RATE:
98 gr./min. 100 cc./min.
AIR VELOCITY:
120 FPM

***Test Results***

***Spray Removal Efficiency & Paint Holding Capacity***
INITIAL PRESSURE DROP of the 3 Filter System
0.04 in. water
FINAL PRESSURE DROP of Loaded Filter System
1.18 in. water
PAINT HOLDING CAPACITY of 1st Filter
642 grams = 1.4 lbs.
Init. REMOVAL EFFC'Y of 3-stages
99.97% (After 1st filter loaded) *Pen. = 0.2g*
Avg. REMOVAL EFFC'Y of 3-stages
99.97% (All 3 filters fully loaded) *Pen. = 0.9g*

***Conditions Pertinent to Filter Changing***

| | | | |
|---|---|---|---|
| CPA Pad | 0.69 | " water | PRESSURE DROP |
| | 642 g. = (1.42) | lbs. | WEIGHT GAIN |
| ME/PT panel | 1.13 | " water | PRESSURE DROP |
| | 566 g. = (1.25) | lbs. | WEIGHT GAIN |
| XFP-6000 Bag, 6-pkt | 1.17 | " water | PRESSURE DROP |
| | 2077 g. = (4.58) | lbs. | WEIGHT GAIN |



Test Engineer: Todd Kruger
Supervising Engineer: K. C. Kwok, Ph.D.
*Test data valid for no more than 5 years from date of issue.*

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*Figure 1: Typical Method 319 testing report (Published with permission from AJ Dralle Co.).*

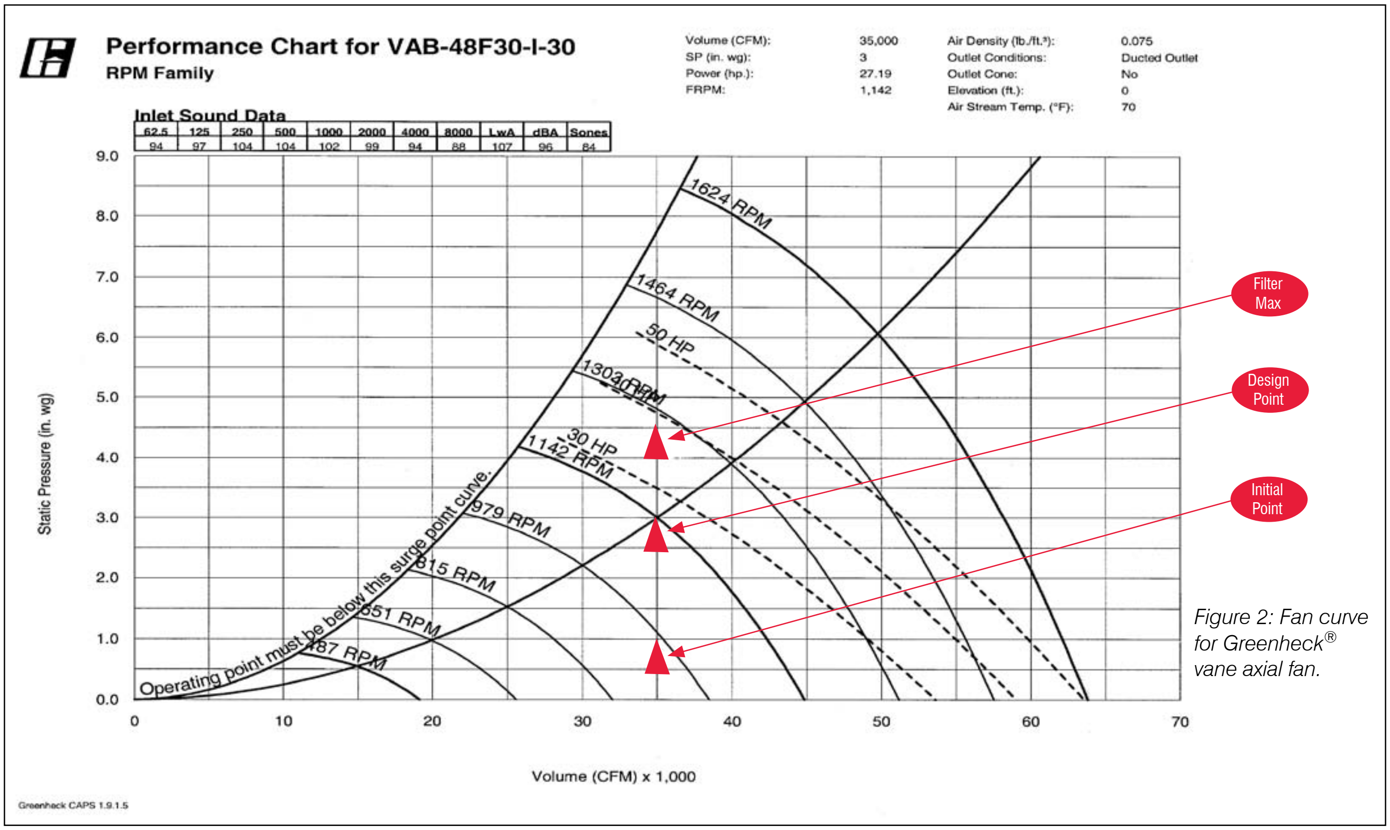


*Figure 2: Fan curve for Greenheck® vane axial fan.*

Users have different rules. Some users will tell you to change your filters after they are 1” WC above their initial pressure point. Still others have different rules involving filter loading from a visual standpoint. It is even possible to purchase a filter monitor for your filter system that will allow monitoring of the pressure drop across all three stages of filtration. Thus, you will be able to intelligently change just a single stage of filtration or two stages or any combination of all three. The monitor has magnehelic gauges that display the pressure drop of each stage.

## FANS

The answer is more complex than any of these rules. One must look at the entire system and review the fan curves.

Figure 2 resembles a typical fan curve for a vane axial fan. We will first describe the various elements of the fan curve. There solid blue line is the recommended design curve for a particular fan. Suppose the fan rotates at 979 RPM, then at zero pressure differential (ΔP) the air flow will be 42,000 CFM. If the fan rotates at 1,300 RPM then at zero ΔP the air flow will be approximately 57,000 CFM.

**Constant RPM:** As the ΔP across the filters and the exhaust ducting increases, the air output will decrease. For the fan rotating at 979 RPM and a ΔP of 1.0” WC the air flow will drop from 42,000 CFM to 35,000 CFM. If the ΔP across the filters exceeds 2.4” SP the fan will become unstable and you will not be able to predict the air output. Designers do not want to operate in the unstable range, hence for this fan and this RPM you would want to change the filters before they exceed 2.4” WC.

Spray booths that are fitted with fan controls can automatically increase the RPM when a sensor measures an increased ΔP. As you load the filters with overspray the RPM will continue to increase (see Fan Laws in the sidebar), thereby maintaining the same CFM output.

In practice the maximum ΔP will occur when the filters are loaded to saturation. This is the point at which any additional paint overspray will simply fall to the floor rather than adhere to the filters.

When fan curves are analyzed, the CFM delivered will vary as the pressure drop changes. The fan designer should make an effort to insure that from the initial starting point ΔP to the maximum anticipated ΔP, the fan should operate as far to the right of the surge (unstable) curve as possible. It is difficult to find a fan that will have stable performance over a static pressure range of 2-3 inches, and in the example that we will discuss below you will see why that is so.

**Example:** Using the same fan curve in Figure 2, let us look at the system

### Common Fan Laws - Simplified

| FAN LAW | FORMULA |
|---|---|
| 1. CFM varies Directly with RPM | (CFM 1 / CFM 2 = RPM 1 / RPM 2) |
| 2. SP varies with the SQUARE of the RPM | (SP 1 / SP 2) = (RPM 1 / RPM 2) 2 |
| 3. HP varies with the CUBE of the RPM | (HP 1 / HP 2 = (RPM 1 / RPM 2)3 |

characteristics of a typical airplane paint booth. It may require two fans of 35,000 CFM each with an initial pressure drop of 1.0" SP including filters and duct losses. The design fan curve shows that at 1.0" SP the fan is very stable (the point is to the right of the design fan cure.) At 3.0" SP it corresponds to the curve and is therefore stable, but at 4.5" SP the point falls to the left of the design curve, but to the right of the surge curve. Please note that above 3.37" SP the filters will no longer hold paint overspray, so operation above this pressure is not required. Ductwork losses may require the fan operate above this limit, but usually ductwork losses are in the range of .25 to .50" sp since the exhaust is just ducted immediately outdoors.

*Figure 3: 3-Stage Monitoring System, magnehelic gauges monitor the pressure differentials across each filter stage.*

In this range the fan is still stable, but the design engineer should be concerned that in the real world the final SP does not cross into the unstable range. For purposes of this example, at a $\Delta$P of 7.5" SP the point falls on the surge curve and there is a high potential for instability.

Using the fan curve we can see that at 1" SP we can operate the fan at 979 RPM and still achieve an output of 35,000 CFM. Referring to the dotted line that corresponds to the horsepower (HP) we see that approximately 10 HP (horsepower) is required by the motor to drive the fan. If we move along the y-axis that corresponds to 35,000 CFM, we see that to maintain this air flow we will need to increase the fan rotation 1150 RPM, and the motor will need to deliver 30 HP. Similarly, if we were to allow the filters to become excessively blocked with overspray, the $\Delta$P might increase to 4.5". To maintain 35,000 CFM the fan rotation would need to increase to 1,300 RPM and a motor capable of delivering 40 HP would be required.

A Variable Frequency Drive (VFD) changes the frequency of the electric alternating current, and is measured in Hertz (Hz).

Suppose the design engineer selects a 40 HP, 60 Hz motor that can drive the fan at 1,300 RPM against a $\Delta$P of 4,5" SP to give an air flow output of 35,000 CFM. Since there is a linear relationship between RPM and Hz, at the initial $\Delta$P of 1.0" SP the motor will only need 979*60/1,300 = 43 Hz, and the costs to operate the motor over 8 hours of spray booth operation will be fairly low. However, as the filters start to load with paint overspray and the $\Delta$P increases to 3.5" SP, the frequency required to drive the motor at 1,1500 RPM is 1,150*60/1,300 = 53 Hz. We see therefore that as the pressure $\Delta$P increases we need to increase the RPM of the fan, which understandably requires considerably more energy to drive the motor.

When the filters are fresh and new, the speed of the fan is low and the VFD is at a low frequency. As the filters become more dirty, the speed increases and the amperage (power requirement) increases. Finally we get to a point where the VFD is at its maximum setting and no further speed increase is possible. At this point the alarms sound and the system may shut down or begin a warning sequence.

What if the fan stayed at a fixed speed or if we did not have a variable speed system? Filters would continue to load and airflow in the booth would be reduced. It is possible to lower the airflow in the booth to levels that are unsafe from a fire risk standpoint. But, it is more likely that the painting performance of the booth would suffer causing blemishes in the surface that require rework. The painter would notice this and investigate the cause of the problem. He would soon see that the filter pressure drop is above the set point and that the fan speed is maxed out. He would then deduce that the filters require changing and take appropriate steps to remedy the situation.

Upon examining the state of the filters, he would see that the pressure drops across each stage of filtration are not to their effective limits. In other words, the filters had more life in them. This is not surprising when we look at this from a system approach. The filters are not the bottleneck in the system. The performance of the fan suffers long before the filters have been completely consumed.

The reduction in booth performance would be a vital telltale sign to the painter that he needs to change the filters.

## FILTER CHAMBER DESIGN

Now that we have learned about filter characteristics and Fan characteristics, let us look at the design of filter chambers (Figure 4). Chamber designed for high pressures have several common characteristics. They may contain structural elements such as I-beams and they may have heavier sheet metal panel elements. The design of a normal chamber

handling 1.25" static pressure is a trivial exercise and easy to accomplish. The design of a chamber for 3" static pressure must have some structural elements such as I-beams to prevent the suction from collapsing the walls.

In addition, the breaks on the panels themselves must be deeper to avoid the collapse. A designer must also look at the span of the panel and beam elements to assist in the load carrying duties. Obviously, structural design is beyond the scope of this article, so we will go no further into it.

It should be obvious that the three (filters, fans and chamber design) are interrelated and what affects one affects the others. If the filter changing pressure drop is set at 1.25" sp, then the horsepower will be low, the filter replacement cost will be high and the cost of the chamber will be low. With a chamber designed for 3" static pressure, the horsepower will be moderate, while the cost of the chamber will also be moderate. Filter replacement costs will also remain moderate.

*Pictures to the left are various views of a Filter Chamber:*

*Top picture, view from inside the filter chamber, shows the heavy sheet metal panels and I-beam construction.*

*Center picture, view from inside the booth shows paint filled air being pulled towards the filters.*

*Bottom picture, view from inside the filter chamber, shows the air improvement once pulled through the filters.*

For a chamber of 8" static pressure, filter replacement will be low, but horsepower and chamber costs will be extreme. For this reason, prudence suggests an optimal design of about 3" static pressure for the fan, chamber and the filter replacement.

## SUMMARY

Designing an optimal system of fans, filters and chambers is a difficult task and requires some trade-offs. But once the trade-offs are analyzed, an economical system is realized. We suggest that filters be replaced at a total filter pressure drop of 3" static pressure. This implies that the chamber is structurally designed to withstand this pressure. The filters will be able to hold all of the paint overspray without making a mess on the floor. The fan will be very stable over its intended range. The filter chamber can be economically designed to withstand the pressures.

Further, with a range as great as this it is essential that the prudent designer use variable speed fan motors to compensate for the wide range of paint booth air velocities that are possible. The paint booth airflow should be constant in the selected pressure range. Any attempt to operate above this range will result in alarms and attenuation of system performance and an ever noticeable performance drop-off from a painting standpoint.

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