



Efficiency of Fuel Filters for Residential, Liquid Fuel-Fired Heating Systems

Dr. Thomas A. Butcher, Ryan Kerr,
Michael Persch, Neehad Islam,
and Robert O'Brien

Project Report
July 2023

National Oilheat Research Alliance
Research and Education Center
Plainview, N.Y.

Introduction

In residential, liquid fuel-fired heating systems, filters are commonly used between the fuel storage tank and the fuel pump. These filters serve to protect the fuel pump and to prevent blockage of the atomizing nozzles. The smallest part of these nozzles are the swirl slots with a cross sectional width of 150 microns or greater. These nozzles have added protection with a small, sintered metal inlet filter with a pore size of about 40 microns or greater, depending on the firing rate.

Gear type pumps, the most commonly used fuel pumps, also have further protection in the form of inlet screen strainers with opening sizes in the 100-micron range.

The filters most often used in the fuel line between the tank and the burner are listed to filter 10-micron particle sizes.

In 2007, at Brookhaven National Laboratory, [1] a study of the factors that cause failure by blockage of these pressure swirl nozzles at very low firing rates was completed. In this study, it was concluded that the current level of filtration was adequate to protect nozzles from blockage and that the greater threat to reliability is fuel coking internally to the nozzle, particularly when fired in hot, refractory lined combustion chambers.

The liquid heating fuel industry is now making a transition from fossil fuels to renewable biofuels with the most important fuel being biodiesel [2]. To aid in this transition, NORA is conducting fuel quality field tests of homes that are using blends of biodiesel—even up to B100. One of the measurements is of filterable particulates from fuel samples taken from the pump bleeder port downstream of the in-line fuel filter. To-date, over 100 field tests have been completed and, in many cases, the measured filterable particulate level was found to be extremely high – reaching over 500 mg/L

In addition, NORA has been addressing field concerns that have been raised about frequent and repeated “sticking” of fuel pumps where the fuel pump shaft will not rotate during startup leading to a burner failure to start. While exploring solutions, NORA has found that improving filtration can effectively resolve the situation in nearly all cases.

The removal efficiency of filters is expressed in various ways. A nominal efficiency is the percentage of particles (by count) removed at a specific cut size. An example of this would be a rating of “98% removal at 10 microns”. Often, in product literature, filters are simply said to be “10-micron filters” which does not provide clear information on actual performance.

“Beta Ratio” is also used to provide information on filter efficiency. This is simply the number of particles over a specific size per unit volume upstream of the filter divided by the number per unit volume downstream. This can be reported at a specific target size or data can be provided over a range of particle sizes.

There are generally two types of fuel filters used in residential heating systems. One is a canister/filter cartridge arrangement. The metal filter canister contains a replaceable cartridge insert, usually made of woven fiber or cellulose acetate “foam”. The other is a “Spin-on” filter in which the filter and metal canister is integrated and replaced together. The spin-on filter element is a coated, pleated paper element. The details of the paper element are often proprietary.

The filtration testing evaluated the actual filtration efficiency for the most commonly used filters in the residential heating sector. Note: all the filters tested, except one, are described as “10-micron” filters by their respective manufacturers.

Experimental

Testing of filtration efficiency was conducted by Southwest Research Institute (SwRI), Fuels and Lubricants Division. The test method involves a defined suspension of particles in a test fluid with initial measurement of filtration efficiency and then, the change in filtration efficiency and pressure drop over time as the filter blocks.

In the testing, only the initial filtration efficiency could be measured because the lowest flow rate at which this test is defined is near the upper limit of the nominal maximum flow rate of the filters tested. This is approximately 18 gallons per hour and would represent the flow rate associated with a two-pipe system. At this low flow rate, it would simply take too long for the filters under test to have a large rise in pressure drop and achieve blockage.

During the filter test, particle concentration is measured simultaneously upstream and downstream of the filter using an optical particle count instrument. This instrument reports particle count/ml of sample larger than or equal to specific sizes. With this information both upstream and downstream of the filter, removal efficiency can be determined.

In addition to the test using the known suspension of particles in a test fluid, samples of fuel from field testing were sent to SwRI for measurement of particle size distribution. The purpose of this measurement is to enable at least initial evaluation of the fraction of the particles in a typical oil sample that would be removed by the different commercially available filters tested. To expand on this point: if all of the particles in typical field fuel samples were very large, a small difference in filter efficiency at very small sizes would not be expected to have practical impact on system performance.

The specific fuel samples tested for size distribution are listed in Table 1, below.

Table 1. Fuel Samples Submitted to SwRI for Size Distribution Measurements

Sample	Description
NF-1	B5, taken from mid tank position in the NORA lab
NF-2	B100 taken from mid tank position, in the field (“TB home”, Field Study)
NF-3	B100 taken from a sampling port in the field, tank bottom, pre-filter (TB home)

The first two samples in this table represent fuels that are expected to be fairly clean, as the particles have likely settled away from this sampling point in the tank. The third sample was taken at a special sampling tap which was added at one of the field sites. The sample at this last point could be expected to be less clean as it includes fuel plus some sludge from the tank bottom.

The filters sent for testing are shown in Figure 1.



Figure 1 Filters sent for testing

The filter labeled “Nora 1” is a common canister type filter and tests were done with two types of filter cartridge inserts. This included a woven “fabric” element and a common white “foam” element. The filter labeled “Nora 2” is a commonly used spin-on type filter. The filter labeled “Nora 3” is not a filter used in heating applications but rather a diesel engine filter. This specific unit is a high-performance filter with a nominal rating of 2 microns. The filter labeled “Nora 4” is a dual filter assembly with a common cartridge filter with a fabric element as the first stage and a different brand of diesel engine 2-micron filter as the second stage. This type of assembly has been used by NORA in resolving some field issues with pumps.

Results

Filtration Efficiency

Figure 2 shows, the filtration efficiency for all the tested filters and filter assemblies. There is one added curve labeled “dual spin-on”. This evaluates the possibility of two spin-on filters in a series configuration, but the results shown in this curve are simply calculated by combining the filtration efficiency of individual spin-on filters.

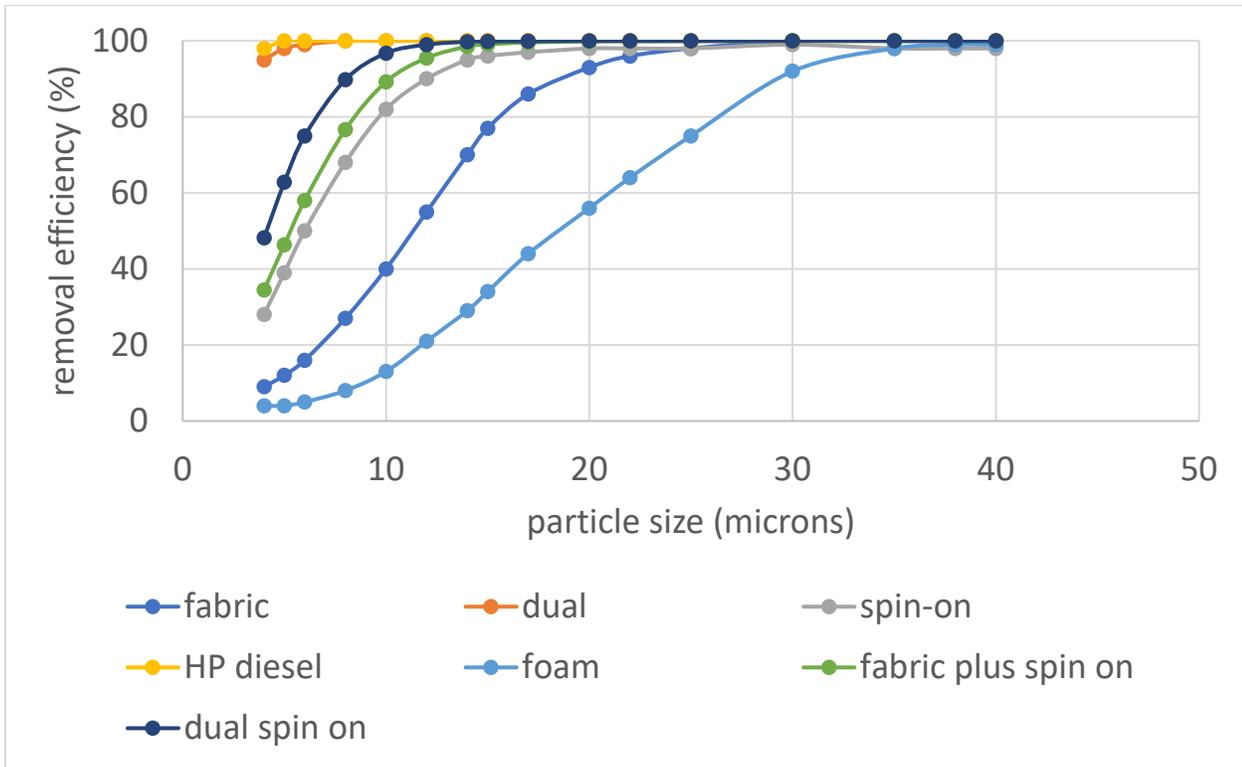


Figure 2 Filter removal efficiency measured at SwRI

Particle Size Distribution

The optical particle count instrument used cannot measure particles under 4 microns. For the analysis here, it is assumed that there are not particles smaller than 4 microns.

Figure 3, below, shows the distribution of measured particles (by count or number) in the size ranges reported. This shows most of the particle count is in the 4-6-micron range for samples NF-1 and NF-2 and split between this range and the 6-14-micron range for the NF-3 sample.

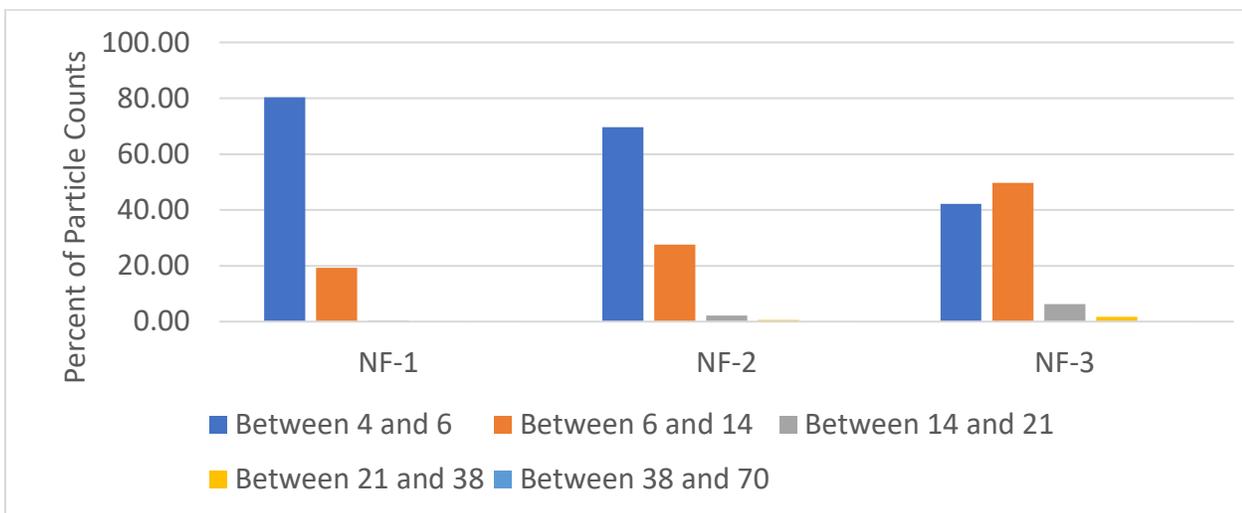


Figure 3 Results of heating fuels particle analysis by SwRI. Size ranges are in microns.

Discussion

The filtration efficiency curves clearly show that the cartridge insert elements have much lower removal efficiency for sizes of 30 microns and less than the spin-on filters. The high performance 2-micron diesel engine filters show the best removal efficiency, as expected.

The results in Table 2 show several things. First, the fuel delivered from the tank to the filter is much dirtier than the fuel in the middle of the tank (Compare NF-2 and NF-3). Second, as the fuel is dirtier the size of the particles is larger. Third, for all fuels, a significant percentage of the total mass is smaller than 20 microns. Based on this, the poor performance of some of the filters under 20 microns means the pump and nozzle will be exposed to high particulate content fuel. This is likely contributing to pump seizing and other problems which have been reported in the field.

Table 2. Total Particle Count and “Mass” Percentage Under 20 microns

Fuel Sample	Total Count	“Mass” Percentage Under 20 Microns
NF-1	13,918	89
NF-2	4,072	59
NF-3	52,639	42

Conclusions

The key conclusion from this study is that the cartridge insert type filter elements in common use in residential liquid fuel heating systems has markedly lower removal efficiency than spin-on type filters. Further, a significant fraction of the particles is within the size range where the cartridge insert filter efficiency is low, leading to the potential for high particulate loading at the pump inlet.

It should be noted that this study is based on a limited number of filter and fuel samples and the authors would like to see added testing to support these conclusions, which we feel have very important implications for the industry. In the case of the cartridge inserts it is not known if the lower removal efficiency is due to the elements themselves or due to bypassing at the element gaskets.

References

1. McDonald, R. Durability of Very Low-Capacity Pressure Atomized Fuel Nozzles Used with Low Firing Rate Residential Oil Burners, Brookhaven National Laboratory Report BNL-79185-2007-IR, May 2007.
2. Butcher, T. Decarbonization of liquid heating fuels, Conference paper presented at the ASHRAE Winter Meeting, Atlanta, 2023, Paper AT-23-C074.
3. Worldwide Fuel Charter, Sixth Edition, 2019, published by the Worldwide Fuel Charter Committee, accessed 6/28/2023.