ISSN: 3068-2789

Review Article

Journal of All Physics Research and Applications

Layered-frame Fabrics as an Innovative Alternative to Traditional Multilayer Filters in Mechanical Engineering

Safarova Terane Qasim*

Associate Professor, Azerbaijan State University of Economics, Department of Engineering and Applied Sciences

***Corresponding author:**
Safarova Terane Qasim, Associate Professor, Azerbaijan State University of Economics Department of Engineering and Applied Sciences. Tel: +994 55 777 53 30.

ABSTRACT

Filtration of working fluids in mechanical engineering is a key element in ensuring the reliability and longevity of equipment by preventing accelerated wear and system failures caused by contamination. Traditional multilayer woven filters, where each layer is manufactured separately and then assembled into a single structure, offer high filtration efficiency but have several technological and operational limitations related to the strength of interlayer bonds and manufacturing complexity.This work examines the development and application of layered-frame filter fabrics produced on modern weaving machines that form a multilayer structure in a single technological cycle, physically integrating the layers through a primary yarn framework. This approach enhances mechanical strength, shear resistance, and thermal and chemical durability of the filter structure, which is especially relevant for use in aggressive and highly loaded industrial environments. Additionally, the layered-frame fabric allows for zonal assignment of filtration and mechanical properties within a single fabric piece, opening new prospects for adapting filters to specific technical conditions. Despite increased production complexity, this solution contributes to improved filter durability and reliability, reducing overall operating costs. Thus, the development and implementation of layered-frame filter fabrics represent a relevant and promising direction, capable of replacing traditional multilayer constructions while improving the functional and operational performance of filters used in mechanical engineering and related industries.

Keywords: Filtration, Mechanical Engineering, Layered-frame Filter |Fabrics, Multilayer Structure, Durability, Industrial Applications.

Received: July 24, 2026;
Accepted: August 01, 2026;
Published: November 25, 2026

Introduction

The problem of liquid filtration affects almost all branches of industry. One of the main issues is filter clogging. The gradual accumulation of solid particles on the filtering element reduces its permeability, which leads to an increase in pressure drop and requires frequent cleaning or replacement of filters, resulting in decreased productivity in mechanical engineering. Therefore, the filtration of these liquids plays a key role in ensuring the efficient operation of equipment [1].

Filters are integrated into various machine circuits — supply, return, or circulation lines — through which process fluids flow. For example, in the hydraulic drives of metal-cutting machines, fine filters are most often installed in the drain line after hydraulic motors or cylinders. This allows for the effective removal of particles generated during operation, preventing contamination of the reservoir and the re-entry of abrasive materials into the pump. Replaceable filtering elements made of metal or polymers are used, capable of retaining particles as small as 10 micrometers [2].

In engine and gearbox lubrication systems, filtration is carried out at the outlet of the oil pump, that is, in the pressure line. The most commonly used are full-flow filters with paper elements, which provide continuous cleaning of the oil supplied to friction parts and bearings. In diesel fuel systems, a pre-

Citation: Safarova Terane Qasim (2026) Layered-frame Fabrics as an Innovative Alternative to Traditional Multilayer Filters in Mechanical Engineering. J All Phy Res Appli 2: 1-4.

filter equipped with a water separator is installed before the high-pressure pump. It removes water and solid impurities, protecting the fuel injection system components from damage. Additionally, a fine filter is placed directly before the injectors, capturing particles between 2 and 5 microns in size [1,3].

Cooling systems of industrial equipment and temperature-controlled installations also include filters, usually located in the return circulation line. Mesh or cartridge filters are typically used here to prevent rust, scale, and other contaminants from entering pumps and heat exchangers.

An improper choice of filter material can also negatively affect equipment performance, as the filter material may be incompatible with the chemical composition of the liquid (causing corrosion, swelling, or degradation, etc.). Furthermore, errors in selecting pore size may lead either to insufficient filtration or to excessive flow resistance. In many filtration systems, filters are washed or blown through, but this process does not always completely remove contamination [1,4].

Thus, the choice of filter type and installation location depends on the properties of the liquid and the design features of the system. Reliable filtration directly affects the service life of machinery and its stable performance under high loads and exposure to aggressive environments

In modern engineering systems, filter selection takes into account not only the properties of the working medium but also the operating conditions, equipment specifications, and the required level of filtration. Practice shows that even minor deviations from cleanliness standards can cause serious malfunctions, especially in complex and high-precision mechanisms [4]. Therefore, special attention is paid to the choice of filters with verified characteristics and proper labeling.

For example, in the hydraulic systems of metalworking machines and presses, the Bosch Rexroth 1.0250H10XL-A00-0-M model is widely used. It is installed in the pressure line after the pump and provides filtration of particles down to 10 microns, effectively protecting sensitive components such as valves, distributors, and actuators from abrasive wear [2].

In lubrication systems of diesel power units, full-flow oil filters such as the Mann W 940/44 are used. These devices are installed in the pressure line after the oil pump and ensure effective filtration of the oil from wear particles and contaminants, thereby supporting stable operation of bearings and friction elements. Fuel filtration is particularly critical for diesel engines equipped with high-pressure injection systems. In such cases, fine filters are installed before the high-pressure fuel pump (HPFP) to prevent micro-contaminants and moisture from entering the injectors, maintaining fuel delivery precision and extending the service life of the fuel system [3].

In large hydraulic systems typical of metallurgical and heavy engineering industries, replaceable filter elements such as the Hydac 2600 R 010 BN4HC are used. These are generally installed either in the return line or directly in the tank. Such filters have a high dirt-holding capacity and filtration efficiency of $\beta \geq 200$ for particles sized 10 micrometers, which is especially important given the large volume of circulating hydraulic fluid [2].

Cooling systems also require reliable filtration, particularly when using process water in heat exchangers and cooling channels of equipment. In such cases, it is advisable to install main coarse filters such as the Siemens VAG DUO-FIT 200, equipped with a durable stainless-steel mesh. These devices are mounted at the system inlet and prevent large solid particles from entering, which could otherwise damage pumping equipment or clog pipelines [1].

Thus, proper selection of filtration equipment in accordance with the requirements of a specific machine plays a crucial role in ensuring reliability, efficiency, and durability of its operation. Using filters with verified technical specifications guarantees stable filtration performance and reduces the risk of breakdowns and unplanned shutdowns.

In industrial practice, technical filter fabrics with multilayer structures are increasingly being used. Due to their chemical resistance and high mechanical strength, these materials demonstrate excellent performance in removing solid particles, oils, and other contaminants from liquid media. They are widely used across various industries -from food and chemical processing to mechanical engineering and water treatment [5].

Modern multilayer filter materials are composite systems that include several functionally distinct layers. This multilayer design significantly improves filtration efficiency and allows the filter element to be adapted to specific process conditions and requirements. Each layer performs a particular function: the top layer traps larger particles, the middle layer performs fine filtration of small dispersed impurities, and the bottom layer acts as a supporting base, providing structural stability and mechanical strength. Depending on the filter's purpose and operating conditions, both natural and synthetic fibers-such as polypropylene, polyester, polyamide, PTFE, or cellulose-may be used in manufacturing the different layers [5].
In another study, dedicated to the analysis of two- and three-layer depth filters, aerosols based on potassium and sodium salts (KCl and NaCl) were used. The results showed that multilayer filters provide a more uniform distribution of contaminants throughout the material thickness and have increased dust-holding capacity. Three-layer configurations achieved the best performance in capturing the most hazardous fine particles, while maintaining air flow resistance within acceptable limits. This indicates that increasing the number of filtering layers has a positive effect on the durability and efficiency of the filter under high-contamination conditions [5].

Analysis and comparison of the presented studies suggest that multilayer and composite filters offer significant advantages for both liquid and aerosol filtration. The use of fibers of different scales-from nanofibers to macrofibers-ensures a high level of purification, resistance to clogging, and stable permeability even during prolonged operation [5,6].

Multilayer woven filtering materials are filters in which each layer performs a strictly defined function. Such a structure is designed with consideration of load distribution and step-by-step purification, which allows achieving high filtration efficiency, mechanical resistance, and reliability during operation in industrial systems.

The upper (outer) layer serves as a pre-filtration barrier and protects the inner layers from rapid clogging. It captures large particles of mechanical impurities and reduces the load on subsequent filtration stages. This layer is usually made from synthetic fibers such as polyester (PET), polypropylene (PP), or polyamide (PA), with possible inclusion of antistatic additives. Typical characteristics include a thickness of 200–400 μm and a surface density of 150–250 g/m². The most commonly used weaving patterns—plain or twill—ensure high air permeability and the formation of pores with diameters ranging from 50 to 100 μm, which is effective at the coarse filtration stage [5].

The middle layer performs the main filtering function, providing retention of fine-dispersed particles. It is manufactured from multicomponent fibers, including combinations of polyester and polyamide, as well as microfibers and nanofibers deposited onto a woven substrate using the electrospinning method. The weave structure-satin or sateen-gives this layer density and uniformity. The thickness ranges from 300 to 800 μm, and the surface density varies from 250 to 400 g/m². The pore size typically lies within the range of 10–40 μm. According to experimental data, the middle layer determines the key filter parameters such as purification efficiency, dust-holding capacity, and hydraulic resistance [6].

The inner (supporting) layer is responsible for the structural stability of the filter, especially under high pressure and during backwashing. It is made of strong, chemically resistant materials such as PET, fluoropolymer-modified polyesters, or fiberglass components. Typical thickness ranges from 400 to 600 μm, with a surface density of up to 500 g/m². The weave structure has high rigidity, providing the filtering element with the necessary mechanical strength and resistance to tearing and stretching under cyclic loading conditions [5].

The technology for manufacturing multilayer woven filters is implemented primarily through two approaches. The first, classical method involves sequential production of each layer on weaving equipment with specified warp and weft parameters, followed by their integration into a single structure. Methods such as thermal bonding, lamination, ultrasonic welding, or needle punching are used to join the layers. The weave type is selected according to the functional purpose of each layer: plain weave is used to provide strength, twill weave to enhance filtering capacity, and satin weave to ensure uniform flow distribution [5].

An experimental study conducted by our team using the modular laboratory stand LFMT-02 made it possible to investigate the properties of the filtering material "Filtrodiagonal, art. 2074". This setup is designed for testing filters used in liquid purification systems. The equipment allows for the evaluation of filtration efficiency, permeability, and several performance characteristics under various operating conditions. The LFMT-02 can operate across a wide temperature range (from –34 °C to –67 °C), which enables simulation of real operating environments [6].

The applied method was vacuum filtration, in which the test liquid passes through the filtering material under negative pressure. This makes it possible to determine the particle retention efficiency and the filter's limiting operating parameters. The installation is widely used in laboratory practice and certification centers to assess filter compliance with industrial standards. The reliability of the obtained results is confirmed by adherence to international norms and requirements.

The laboratory unit is equipped with a tensioning system, a digital dynamometer, and a deformation gauge, which made it possible to conduct comprehensive tests of the filtering material "Filtrodiagonal, art. 2074". The study focused on a material made entirely of cotton fibers, examining its mechanical, geometric, and filtration characteristics.

Based on the results of the conducted tests, it was found that the average surface density of the examined fabric was approximately 576 ± 25 g/m², with an average thickness of about 1.5 ± 0.2 mm. Geometric parameters were determined using a digital micrometer and a fabric density tester. The warp thread density was recorded at 222 ± 4 threads per 10 cm, and the weft thread density at 110 ± 4 threads per 10 cm.

Tensile strength tests were performed using a universal testing machine Instron 3365, designed for analyzing the mechanical properties of materials under tension, compression, and fatigue loading. The samples measured 5 × 20 cm. The results showed a breaking strength of approximately 183 kgf in the warp direction and about 88 kgf in the weft direction. Elongation at break was also determined: about 25 % along the warp and around 9 % along the weft, indicating good elasticity of the material while maintaining structural strength.

An alternative to the traditional method is three-dimensional weaving, which allows the formation of a multilayer structure in a single manufacturing process. This approach requires the use of specialized multilayer weaving machines with independent yarn feed systems for each structural level. It ensures high interlayer bonding strength, eliminating the need for adhesive layers. Filtration parameters are significantly influenced by the pore size, which is determined by the density and structure of the yarns as well as the weaving technique. Depending on the filter's purpose, pore sizes may range from 5 to 100 μm. Both smooth and textured fibers are used, including monofilament and multifilament yarns, which provide different levels of retention efficiency and mechanical strength.

An additional advantage of this method of producing multilayer (three-dimensional) fabric is the ability to create zonal configurations within a single piece of material, where different areas can have distinct filtration capacities, mechanical support, and other properties. This allows precise adaptation of the filter to specific operating conditions. Table 1 presents a comparative analysis of this layered-frame fabric and the filtering fabric Filtrodiagonal art. 2074.

Table 1: The comparative analysis of the layered-frame fabric and the filtering fabric Filtrodiagonal art. 2074.

Parameter	Filtrodiagonal art.2074	Layered-frame 9-layer fabric
Type of composition	Single-layer fabric, diagonal (twill weave)	Multilayer (9 layers, frame structure)
Material	Cotton, polypropylene, polyamide	Composite (cotton yarn 50×3 tex for warp and weft), polypropylene 145 tex for the middle layer, polyamide 140 tex for the inner layer
Surface density	576 ± 25 г/м²,	Upper layer < 550 ± 25 g/m², middle layer 576 ± 25 g/m², lower layer > 574 ± 20 g/m²
Thickness	~1,5 ± 0,2 mm	~4,5 ± 0,2 mm
Weave	Diagonal (twill)	Plain weave
Tensile strength: Fabric density: threads per 10cm	Warp direction–183kgf, Weft direction – 88 kgf Warp–222 ± 4 threads/10 cm, Weft–110 ± 4 threads/10 cm	Warp–526kgf Weft – 273 kg Warp–222 ± 4 Weft – 110 ± 4
Elongation at break	Warp =25%, Weft = 9%	Up to 20% Up to 8%
Operating temperature	Up to 90-100 °C	Up to 90-100 °C
Maximum operating pressure.	Up to 50 kPa	Up to 80 kPa
Thermal resistance	Up to 100 °C	Up to 120- 150 °C

As we noted earlier, the production of such fabrics requires specialized equipment, in which the weaving machine provides independent yarn feeding and precise control of interlacing patterns. This increases the complexity and cost of the manufacturing process. However, these expenses are offset by the durability, reliability, and regenerability of the filter during operation-factors that are extremely important in mechanical engineering. After weaving, the filtering fabric may undergo additional processing, such as: Thermosetting, to stabilize dimensions; Plasma surface modification, to improve adhesion properties; Antistatic or hydrophobic impregnation, aimed at enhancing resistance to contamination and moisture.

Thus, the production of layered-frame filtering fabrics on weaving machines represents a promising direction that opens new possibilities for creating high-efficiency, durable, and adaptive filtering materials. These materials have the potential to replace traditional multilayer filters, improving their functional characteristics and operational performance.

Conclusion

Liquid filtration is essential for the reliable and efficient operation of industrial equipment. While traditional single-layer fabrics provide basic filtration, multilayer and composite filters-especially layered-frame fabrics with multiple functional layers-offer superior dirt-holding capacity, mechanical strength, and filtration efficiency.

These advanced fabrics enable stepwise particle retention, higher thermal and pressure resistance, and structural stability, making them ideal for hydraulic, lubrication, fuel, and cooling systems. Modern multilayer weaving technologies allow precise control of pore size, layer density, and material composition, ensuring long-term durability, reduced maintenance, and protection of sensitive components.

Overall, multilayer and layered-frame filtering fabrics represent a promising advancement in industrial filtration, offering enhanced performance, reliability, and operational safety in demanding environments.

References

1. Gerasimov VV (2018) Filtration and purification of process fluids: textbook. Moscow: Mashinostroenie 256.
2. Ivanov AP (2017) Hydraulic systems of metalworking machines: theory and practice. St. Petersburg: Piter 312.
3. Kuznetsov NI (2016) Fuel systems of diesel engines. Moscow: Transport 220.
4. Smirnov EV (2020) Reliability of mechanical engineering systems. Novosibirsk: NSTU 150.
5. Zhang S, Liu H, Li Q (2021) Study of the Filtration Performance of Multilayer and Multiscale Fibrous Structures. Materials 14: 580.
6. Salamatova VI (2022) Study of filtration properties of cotton and synthetic materials. Filtration and Purification 45–53.

Copyright: © 2026 Safarova Terane Qasim. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.