Investigation on Novel Polymer Filter Medium for Filtration of Automotive Lubricants

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Dissertation Submitted to the Department of Mechanical Engineering, University of Sheffield in Partial Fulfilment of the Requirements for the Degree of

Master of Philosophy

May 2016

Abstract

At present in all countries with developed automotive industry a lot of attention is given to the improvement of the efficiency of automobile engines. The continuous increase in the power output of the engines along with the introduction of turbo-supercharging have significantly affected the loading on moving parts of engines and their sensitivity from the abrasive polluting impurity. Ensuring necessary resource and reliability of engines, the application of the engine oil with the high level of operation characteristics have imposed increased requirements for lubrication systems of engines.

Work on further improvement of lubrication systems includes optimization of hydraulic and design features of units of lubrication systems and the increase in the efficiency of oil filters. Economic, regulatory and environmental concerns are forcing vehicle operators to re-evaluate oil filtration practices. Fleet operators can choose from various options, including conventional disposable paper oil filters, centrifugal separators and in-line cleanable oil filters. To guide decisions about filtration practices, this research compares the performance, serviceability, economics and environmental impact of these options.

The aim of this research is to investigate the influence of the polymer filter media on the quality of filtration of automotive lubricants and to demonstrate advantages and unique features of the polymer filter media. The outcome of this research establishes relevant characteristics of the novel polymer filter media, extensively tested for filtration of automotive lubricants.

It demonstrates different impacts on oil filtration provided by the polymer filter media used in oil filters and compares its performance against the paper filter media used in tests of oil filters and also in both polymer and paper oil filtration systems. The application of the polymer filter media results in a significant reduction of the wear of engine moving parts and an extended oil drain intervals. The analysis of laboratory tests and obtained data, demonstrate that polymer oil filters have greater filtration efficiency and also greater contaminant retention capacity in comparison with conventional paper oil filters.

Based on the knowledge gained here various recommendations have been given on the potential future work related to this topic.

Acknowledgements

I wish to express my sincere appreciation to my supervisors, Professor Chris Wilson and Doctor Robert Woolley for their patience, guidance and support through my time at the University of Sheffield. I appreciate the opportunities they provided for me to be involved in a number of relevant research projects.

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X_0 and $X_к$ concentration of contamination impurity in oil before and after tests;

$G_м$, $G_{уг}$, G_n weight of the oil being in crankcase, burned and taken during tests;

g_m quantity of contamination impurity in oil;

g_{yr} quantity of contamination impurity in burned-down oil;

g_n quantity of contamination impurity in samples of oil;

X_{cp} average concentration of contamination impurity in oil;

X_3 concentration of dry phase of contamination impurity;

G_3 quantity of products of contamination retained by filters and centrifuges;

g_3, $g_3 \sum$ quantity of contamination impurity (dry phase), retained by each filter and all filters;

g_1 total of contamination impurity found in oil;

R_p radius of internal surface of rotor;

r_0 internal radius of layer of liquid in rotor;

ω angular speed of rotation of rotor;

Ω the working volume of the rotor ($\Omega = Ph\left(R_p^2 - r_0^2\right)$), where h - average height of rotor);

δ size (diameter) of impurity particles;

$\rho_1 u \rho_2$ density of particle and oil ($\rho_1 - \rho_2 = \Delta$);

Q volume of oil consumption through centrifuge per min/hrs;

μ dynamic viscosity of oil.

Chapter 1 – Introduction

1.1. Background and Motivation

At modern rates of engine oil consumption there is need to achieve the extended use of the engine oil. Along with an improvement in design of engines, optimization of capacity of a filtration system and reduction of oil consumption in oil smoke, considerable reduction of the oil use could be achieved through the application of highly effective combined oil filtration systems, leading to extended oil life cycles.

It was found that properties of the engine oil do not considerably change chemically and worsen as a result of the use of the engine oil. In fact there is an increase in content of the following pollutant substances: soot, water, sulphur, metallic and non-metallic particles, which result in fast ageing of the engine oil and therefore its replacement and it was also concluded that the application of existing methods of oil filtration and improved oils with high content of additives do not allow to significantly increase lifespan of the engine oil.

There have been a number of large scale field trials carried out in Europe and USA funded by respective governments and the objectives of these trials were to validate efficiency of various oil filtration systems and filters as well as demonstration of the engine oil being used for significantly longer periods of time.

For instance in 2003 in USA under the U.S. Department of Energy FreedomCAR & Vehicle Technologies Program "Oil Bypass filter Technology Evaluation" the field trials were conducted by Idaho National Engineering and Environmental Laboratory Transportation Technology and Infrastructure Department.

Their published "Oil Bypass Filter Technology Evaluation" report details the completed fleet evaluation of an oil bypass filter technology. Eight four-cycle diesel-engine buses used to transport INEEL employees on various routes have been equipped with oil bypass filter systems from the puraDYN Corporation. The bypass filters were reported to have engine oil filtering capability of <1 micron and a built-in additive package to facilitate extended oil-drain intervals. Tested eight buses have accumulated 259,398 test miles. This represented an avoidance of 21 oil changes, which equates to 740 quarts (185 gallons) of oil not used or disposed of. Results of the trials allowed to validate the extended oil-drain intervals, an oil-analysis regime evaluated the fitness of the engine oil for continued service by monitoring the presence of necessary additives, undesirable contaminants, and engine-wear metals.

Similarly in Germany field trials were conducted under the programme "Tribology" related to research projects aiming to increase the engine oil change interval with inclusion in the oil filtration system of the additional by-pass filter with a high retaining capacity. These trials were carried out using public buses over a few years. Public buses were operated in "stop and go" heavy duty conditions with installed additional by-pass filters and obtained results demonstrated that inclusion of by-pass filters allows to improve technical condition of engines and also significantly increase engine oil change interval up to 60-70 thousand km.

Clean oil is vital to an engine performance and its durability. The engine oil must lubricate, cool and clean the inner engine components as it circulates. However in order to remain effective it must be continuously filtered. Most engines are fitted with spin-on filters which were introduced to the market in1960. Since then spin-on filters have been used in most of automobile engines as they have been designed to be rugged, durable and inexpensive it is mainly due the fact that only paper filter media has been used, however these oil filters do not provide sufficient level of the engine oil filtration and therefore the engine oil has a limited lifespan and typically replaced every 10,000-12,000 miles, while in USA the engine oil, for instance in PLG cars, is replaced every 3,000-5,000 miles.

Published results of field trials in Europe and USA clearly demonstrated that the engine oil has capacity to last significantly longer, provided the efficiency of filtration exceeds performance of conventional paper filtering media used in oil filters and therefore there is need for introduction of advanced filtering materials, improved filters or filtration systems.

Ideally it should be an oil filter with superior filtering ability and retaining capacity, has the ability to improve engine longevity, increase maintenance intervals and results in significant financial savings over the life of the vehicle. Extending an engine's oil drain interval while maintaining the same engine wear resolves around the durability of the engine oil additive package, retaining capacity and micron filtering ability of an oil filter.

This requires development of novel types of filtering media with greater filtration capabilities of providing extended use of the engine oil and outperforming existing filtering media in all other technical aspects, which is the main motivation driving this work.

1.2 Aims, Objectives and Methodologies

The aim of this project is to investigate the influence of the combined polymer oil filtration system on cleaning of automotive lubricants, used in internal combustion engines. Several key objectives need to be achieved, which are:

1. to analyse existing experience related to the methods of researches and features of design of oil filtration systems used in internal combustion engines;
2. to carry out laboratory and engine bench tests of various oil filtration systems, in order to obtain the reliable assessment of the influence of the oil cleaning system on the wear and contamination of moving parts, physical and chemical indicators of engine oil and service life of filters;
3. to determine and demonstrate the possibility of the use of polymer full-flow oil filters in internal combustion engines, resulting in improved oil filtration, extended life span of engine oil and reduced wear of moving parts of the engine;

4. to determine reliability of protection of bearings of the engine in different operating modes using various oil filtration systems, including paper and polymer full-flow filters, by-pass filters and by-pass centrifuge;
5. to investigate the structural change in balance of components of contamination impurity present in the engine oil retained by oil filters, tested in diesel and petrol engines, using various oil filtration systems;
6. to demonstrate by results of this research the efficiency of combined polymer oil filtration system and its suitability for the application in full-flow and by-pass oil filters.

For engine bench tests of paper and polymer oil filters and filtration systems the following types of the internal combustion engines were used: diesel engine Cummins ISB e-4 and petrol engine VW 1.2 TSI.

1.3 An overview of the Research

The dissertation begins with an in-depth literature review to provide extensive background information to support the topic discussed throughout the research. Necessary laboratory and bench tests are conducted as part of the project to generate a comprehensive data set to characterize performance of various oil filtration systems under operating conditions. Detailed discussion and analysis are presented based on the results of carried out various tests via analytical methods. Finally appropriate conclusions are drawn with regards to future work. The whole dissertation is divided into the following chapters:

- Chapter 1: A brief introduction is given to a practical problem faced in the automotive industry, which also highlights the importance of this study. Detailed objectives and methods used, along with the structure of the dissertation are presented.
- Chapter 2: This chapter provides a comprehensive literature review with regards to the following key topics: theory and application of the engine oil filtration and lubrication systems, oil contamination and its influence

on reliability of engine operation, bases of theory and calculation of filtering systems.

- Chapter 3: Details about the experimental setup are presented in this chapter. Principles, functions, working procedures, modification of polymer composition and chemical formulation of the polymer media are introduced respectively. An overview is given to the filtering materials tested with respect to their pores structure and types of filter media.
- Chapter 4: In this chapter, results obtained from a series of laboratory tests are presented. Results are divided into two parts regarding two filtering materials tested. Filtering characteristics of each material in various conditions of tests are compared and summarised.
- Chapter 5: Analytical researches of various oil filtration systems and researches of the efficiency of oil filtration are presented in this chapter.
- Chapter 6: This chapter presents the results obtained from engine bench tests of oil filters in the various conditions and from engine cycling tests to see the impact of filtering materials on the quality of oil filtration.
- Chapter 7: Conclusions are drawn based on the results and discussions in previous chapters. This chapter also provides recommendations for the future work in this area.

Chapter 2 – Literature Review

2.1 Engine oil and lubrication system, classification of lubrication systems of internal combustion engines

In recent years along with further improvements in design of automobile engines, an increase of their technological level and reliability, there has been a substantial increase in quality of the engine oil, which is one of the basic functional elements of the internal combustion engine. Irrespective of the type of the engine and its design features, the main functions of the engine oil are [1]:

- lubrication of internal parts
- providing cooling of the engine by transferring heat
- sealing piston ring - cylinder bore interface
- absorbing contaminants
- suspension of wear particles
- protection of engine parts from corrosion
- suspension of soot that forms as a result of combustion.

The engine oil should also have the high stability at oxidation and watering and provide reliable start-up of the engine in low temperatures conditions.

Compliance of the oil quality to ISO Standards and OEM requirements specifically related to the engine oil, which are aggravated by the presence of various types and designs of internal combustion engines. The design of the sleeve assembly of the engine and especially value of its average effective pressure, defining break of crankcase fumes, is decisive in definition of level of the oil antioxidant ability.

For instance, for diesel engines the engine oil is required with significantly improved detergency–dispersing properties, than for the petrol engines. The conditions of engines operation and a quality of diesel and petrol fuels have an extensive impact on the quality of the engine oil, other factors which should be considered are: an increase in speed of movement of the vehicle and its loading, as the oil temperature in the sump of the engine reaches 120-150^{0}C [2].

Improved engine oils are available on the market and typically these oils have a wide range of properties and consist of a large number of various additives that leads to an increase in their cost. Engine oils are a blend of two components - base oils and additives [3]. Every type of engine oil is blended in order to meet the required lubricant performance of relevant ISO standards and specific requirements of particular application. As a rule the choice of base oil can be mineral, semi-synthetic or synthetic. Normally off-road diesel engines use mineral engine oil. Semi-synthetic and synthetic engine oils are used in petrol engines, found in PLG cars, where longer service intervals and higher operating conditions require more refined oil. Formulated mix of additives is the difference between producing specific type of engine oil which meets ISO standards and other type of engine oil that offers significant performance advantages. Additional additives also enhance the chemical and physical properties and as a result enable to achieve significant performance benefits from the engine oil. Various additives used in engine oils are a complex mix of 10 to 15 different types, they can make up to 25 percent of the formulation, depending on its quality and application [4].

It was noted [5] [6] that the main criterion determining the life span of the oil is the content of insoluble in n-Pentane substances.

In order to achieve an increase in the engine capacity there is an increase in quantity of fresh charge being in the cylinder at the beginning of a compression cycle, known as pressurization application. However it leads to an increase in the mechanical and thermal loading and results in applying the following actions:

- increase in productivity of water and oil pumps;
- increase in efficiency of cooling system;
- improvement in the air filtration;

- application of combined oil filtration systems which provide effective separation of insoluble impurity.

At the same time, an improvement in oil filtration through an increase in completeness of elimination of the full-flow filter is restricted by an increase in its hydraulic resistance resulting in fast opening of the relief valve of the filter and therefore reduces reliability of protection of bearings, especially during cold start-up of the engine. Besides an increase in precision of elimination of the filter reduces the length of its service and increases the operational costs related to the replacement of filtering elements.

Overall performance of the filtration system depends on the following factors: structure and purposes of included in the system components and assemblies, their parameters and connection layout [7].

At present in diesel and petrol engines combined filtration systems are commonly used, in which under pressure, generated by the oil pump, all slider bearings are lubricated - radical and connecting rod cranked shaft, camshaft, valve lever, intermediate gear wheels of distribution of the drive of the oil pump, gear wheels, shaft of the drive of the high pressure fuel pump, regulator, turbocharger, etc. The engine oil under pressure is brought to bearings of shaft of the drive of the distributor of ignition and shaft of the drive of the water pump. Parts of the sleeve assembly group and others are lubricated through spraying [8].

In some engines auxiliary devices in form of nozzles or openings in parts are applied for additional supply of the oil through directed jet on various surfaces of friction such as walls of cylinders, couples valve lever of the drive bar, valve lever of the core of the valve, etc.

In designs of modern automobile engines, different oil lubrication systems are used. The knowledge of the general principles of construction, structure and ways of inclusion of components and assemblies of lubrication systems, enables to improve work related to modernization of existing and development of new types of engines which meet the requirements of the increased resource, minimum loss of power on bearings and the drive of various components and assemblies. Based on the analysis of lubrication systems of various engines it was concluded that systems variety can be classified by specific for each type characteristics [9].

The oil system flow diagram and the oil lubrication system of the engine, shown in figures 2.1-2.2 [10].

For normal functioning of lubrication systems there are subsystems which can be divided into the main system and the auxiliary system. Main subsystems consist of systems which provide cleaning and maintenance of oil temperature, cooling of pistons and management of hydraulic parameters through valves, while auxiliary subsystems provide reduction of delay of intake of engine oil to bearings, maintenance of oil level, control of parameters and diagnostic of lubrication system.

2.2 Oil contamination and its influence on reliability of engine operation

Advanced engine oils contain complex of additives and possess sufficient washing and dispersing properties therefore the bulk of contamination impurity has high degree of dispersion and particles sizes up to 2 microns [11]. The contamination impurity is divided into two main groups: organic and inorganic. Relevant processes of engine oil contamination in engines are extensively described in a number of researches [12].

The organic contamination impurity consists of products of incomplete combustion of fuel, products of thermal decomposition, oxidation, oil and fuel polymerizations. Besides water, sulphur and lead compounds which are found in the engine oil. The inorganic contamination impurity consists of the following: dust particles, products of operation of cindery additives, particles of the wear and technological contamination of the engine.

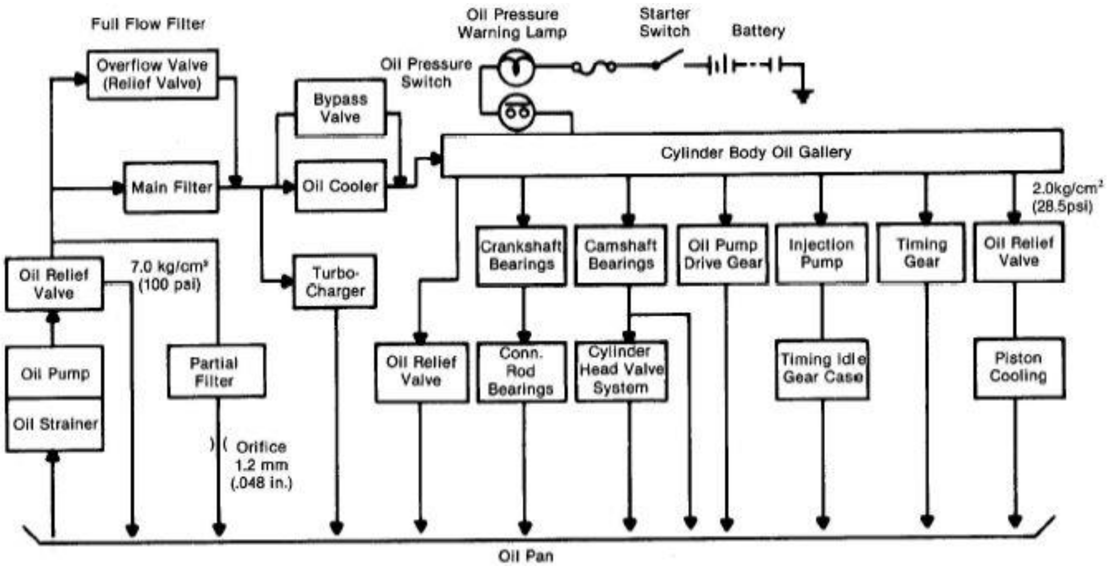


Figure 2.1 Oil system flow diagram

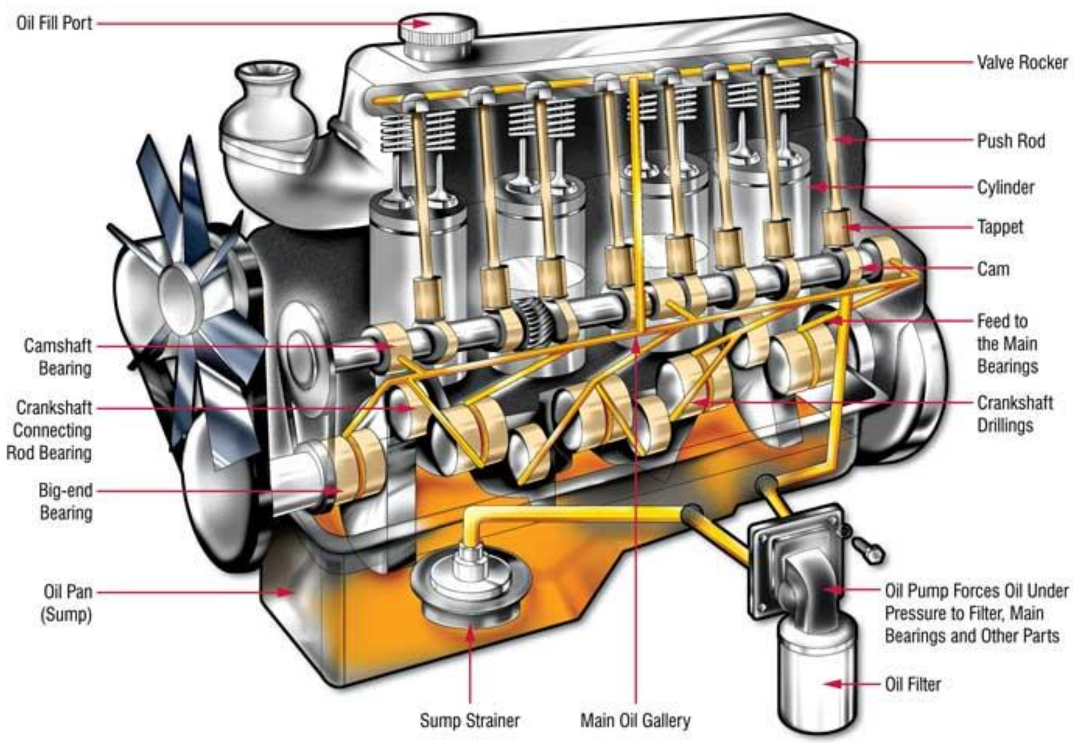


Figure 2.2 Engine lubrication system

Contamination of the engine oil in diesel engines differs from contamination of the engine oil in petrol engines, as diesel engines use diesel fuel which has higher soot content. It was demonstrated [13] that the fulfilled gases of diesel engines contain the particles with sizes of 0,006-0,5 micron, specific surface of which accounts for 70-90 sq.m/g thus assists the adsorption of products of decomposition of antiwear and anti-seize additives, reducing thereby antiwear properties of engine oils.

The high content of the soot in the engine oil of diesel engines leads to the suppression of antiwear properties of zinc dithiophosphate and strengthens the loss of low-temperature deposits [14] [15], especially as a cooling fluid enters the engine oil or during operation of engines in cold conditions on short routes with frequent stops.

Products of the wear of moving parts of the engine, present in the engine oil in the form of particles of metals, their oxides or metallo-organic compounds, which negatively influence the oxidizing stability of the oils, strengthen abrasive wear and suppress an effect of detergency-dispersing additives, assist the growth of acidity and formation of insoluble substances from hydrocarbons [16].

According to [17] the abrasive particles of the small sizes have the influence on wear of moving parts when the oil film thickness between parts more than the sizes of these particles.

Process of oxidizing polymerization of the engine oil and the products, which enter the engine oil as a result of incomplete combustion of fuel, proceeds with formation of acid and neutral products: acids, oxyacids, estolides, asphaltene acids, high-molecular interhalogen-isosteric compounds, asphaltenes, carbenes and carboides [18].

Contamination of the engine oil occurs in the engine continuously and depends on a number of factors, such as quality of fuel, oil, design of the engine, modes of its operation. Especially excessive process of the oil contamination [19] occurs in the engines working in lowered thermal modes and with a low frequency of rotation that is caused by poor conditions of combustion process and high access of gases to the base chamber of the engine. Other factors effecting intensity of the oil contamination are influenced by features of the engine design, engine operation process, malfunction of the fuel system and wear of parts of sleeve assembly [20].

A number of researches [21] are published and related to the reliability of engine operation along with the assessment of influence of the oil contamination.

The negative influence of the ageing oil and oil contamination processes have a negative impact on the following engine operations [22]:

- carburization and burning of piston rings and possibly of total loss of their mobility;
- increase in temperature of parts of sleeve assembly;
- jamming of valves in directing plugs;
- contamination of grids of engine oil receivers, filtering elements and channels of lubricant systems;
- increase in oil viscosity resulting in delay of intake of engine oil to bearings;
- abrasive wear of bearings by solid particles of contamination impurity.

Thus, the insoluble contamination impurity having the sizes exceeding the minimum thickness of the oil film, causes increased wear of moving parts of the engine and other negative impacts, which in turn reduce the reliability of the engine operation.

At the same time it is desirable to reduce the organic contamination impurity content in the oil that could considerably increase the length of oil replacement.

2.3 Filtration of oil, classification of methods and means of filtration

The reliable operation of the engine and a long service life of the engine oil cannot be achieved without the application of effective oil filtration systems.

Known methods of the oil filtration are divided into two groups: filtration in the porous medium and in the force fields. The means of the oil filtration are divided into two groups: filters such as full-flow, by-pass, combined and powered cleaners in which gravitational, centrifugal and magnetic force is used.

2.4 Bases of theory and calculation of filtering systems

Theories of calculation of filters and filtering systems are discussed in many reviews [23] and studies [24].

The pattern of the liquid movement in the porous medium is complex and tend to change in time in size. The speed of filtration is determined as correlation of consumption of liquid at rate of throughput to the area of filtering partition, expressed by the equation

(2.1) $$\omega = \frac{Q}{F}$$

where ω - speed of filtration

Q - consumption of liquid at rate

F - area of filtering partition

Hydraulic resistance of filtering partition thus becomes

(2.2) $$\Delta P = P_1 - P_2$$

where P_1 and P_2 - liquid pressure at the entrance and the exit, respectively.

The mode of the stream of liquid in channels of oil filters is characterized by Reynolds's number of Re<100 and is laminar and therefore according to Hagen-Poiseuille equation the speed of filtration is expressed by the equation

(2.3) $$\omega = \frac{\pi \cdot б_n^4 \cdot \Delta P \cdot m}{128\mu \cdot l_n} = K_{уд.} \frac{\Delta P}{\mu}$$

where $б_n$ - diameter of pore channel;

l_n - length of single pore channel;

m - number of pores channels;

One of the most important characteristics of the porous medium is the coefficient of porosity ψ determined as correlation of volume of pore V_n to volume of the porous medium $V_{n.c.}$

(2.4) $$\psi = \frac{V_n}{V_{n.c.}} = \frac{V_{n.c} - V_м}{V_{n.c.}}$$

where $V_м$ - material volume.

Methods of determination of porosity which were used in researches, presented in studies [25].

The assessment of efficiency of purification of polluting impurity by porous partition is carried out based on some assumptions:

- the real partition is modeled on cylindrical channels of different diameter and identical length;
- nature of distribution of pores, doesn't depend on filter operating time;
- movement of working environment laminar for which Hagen-Poiseuille equation is correct. Provided that the consumption of liquid through pores will be proportional to fourth degree of its diameter.

With accepted assumptions the general initial coefficient of screening of porous partition becomes

(2.5) $$\varphi = \int_0^{X\max} \varphi_x d\Phi(x)$$

where x - particles size of contaminant;

$\Phi(x)$ - distribution of particles of contaminant;

φ_x - fractional coefficient of screening.

The assessment of form of experimental curve fractional coefficients of elimination of the filters, shown in [26] that they can be approximated by logarithmically normal distribution in integrated form

(2.6) $$\varphi_x = \frac{1}{\sqrt{2\pi}\lg\nu}\int_{-\infty}^{\lg б}\lambda - \frac{(\lg б - \lg б_o)^2}{2\lg^2\nu}(d\lg б)$$

where $l_g\ б_o$ and $l_g\ v$ - distribution parameters.

For the same filter the rate of coefficient of the elimination characterized by parameter, depends also on dispersion of the contaminant brought to the filter characterized by parameter. Therefore initial completeness of screening of the filter can be presented as

(2.7) $$\varphi = f(x, l_g\ б_o, l_g\ x_o)$$

In the equations 6 and 7 calculating distribution of particles is used, which doesn't coincide with their distribution by weight. Using the ratios [27] the mass completeness of elimination of filters is determined.

(2.8) $$l_g\ x_o = 0{,}163 + 0{,}388\ \ l_g\ x_{ом}$$

(2.9) $$l_g\ \beta = 0{,}069 + l_g\ \ \beta_м$$

The development of effective systems of engine oil filtration requires knowledge and application of bases of the theory of calculation of filtering systems and carrying out the analysis of features of designs of full-flow, by-pass and combined filters.

2.5 Features of design of oil filters

2.5.1 Full-flow oil filters

The analysis of design of full-flow oil filters, a diagram of a spin-on filter arrangement is shown in figure 2.3, show that filters can be divided into two main types: spin-on and cartridge (figure 2.4). The diagram (figure 2.4(1)) shows a typical spin-on oil filter. The oil flow through an oil filter is shown in figure 2.5. The full-flow oil filter is standard on most of modern vehicles. Most of oil filters use the paper filter media, traditional filtering material for full-flow design. The engine oil that goes through the full-flow filter and continues to lubricate the engine and the oil filter removes larger particles of contaminant from the engine oil harmful to the engine. The oil filter provides essential engine protection for maximum cold flow performance and filter's lifespan and designed to provide required level of oil filtration, handle the required flow rate when the engine oil is cold and provide sufficient dirt retaining capacity.

Mechanical designs employ an element made of the pleated filter paper to entrap and sequester suspended contaminants. Produced by filter manufacturers automotive oil filters vary in their design, materials, and construction parts. Full-flow filters that are made from completely synthetic material except the metal drain cylinders contained within are much superior and longer lasting than the traditional cellulose and paper type that still commonly used as filter media. These variables affect the efficiency, durability and cost of oil filters.

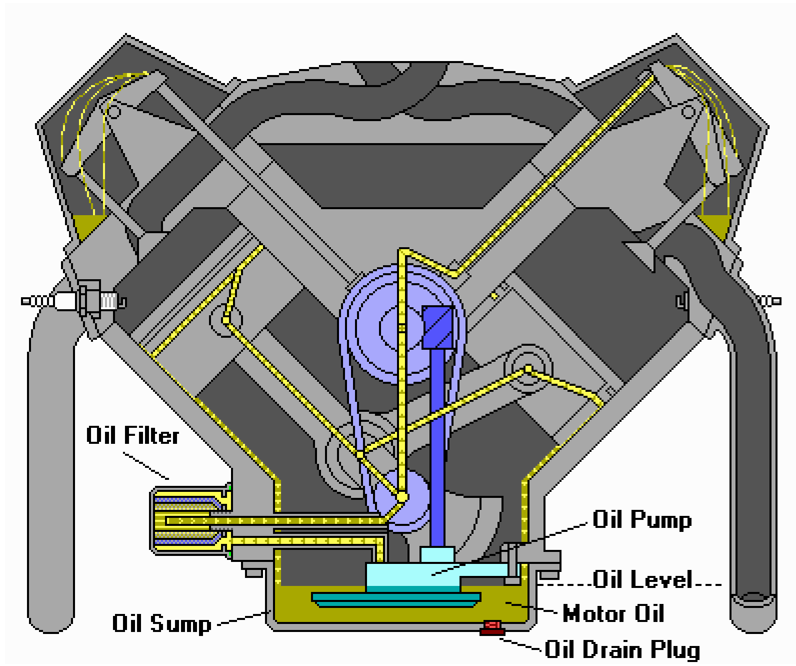
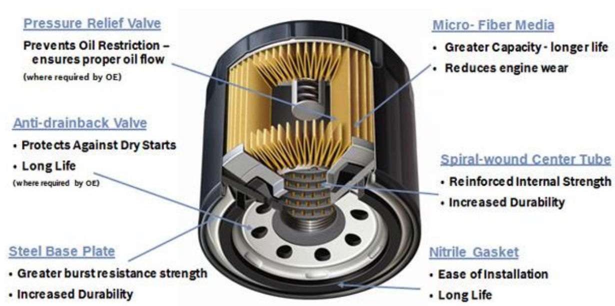


Figure 2.3 Diagram of spin-on filter arrangement



(1) Spin-on type

(2) Cartridge type

Figure 2.4 Main types of full-flow oil filters

Figure 2.5 Oil flow through a full-flow oil filter

Spin-on filters consist of a head mounted directly in-line with the return piping and a cartridge containing a paper filter element that screws onto a designed threaded post. This type of filter is an integral unit which cannot be dismantled once manufactured. The component parts are enclosed within the filter housing, known as canister, during production and assembly and seamed to the bottom assembly and for strength a double lockseam is featured in its design. The filter housing contains the filter along with any ancillary items such as cartridge relief valves etc. The retainer is fitted underneath the cartridge to act as a spring to hold all internal parts under tension and maintain the internal seals. The bottom assembly features the fixing thread, inlet ports and sealing gasket retaining pressing (bottom plate) and is seamed to the pre-assembled filter body to form an integral unit. These filters are used in engines of PLG and HG vehicles [28] [29].

Filters of cartridge type (figure 2.4(2)) have a removable module with the replaceable filter element installed in module (filter housing).

Most common designs of full-flow oil filters with various types of the springs condensing filtering elements, anti-drainage and relief valves, shown in figure 2.6-2.7. [30] [31]. In table 2.1 given the key parameters of full-flow oil filters and their filter elements produced by Baldwin Filters, Sogefi, Fleetguard, Caterpillar, Mahle and Donaldson companies for use in diesel engines [32]. While presented oil filters are all of the same type “spin-on” and have similar dimensions, their total surface area (cm^2) is different and therefore surface area of each filter determines the total volume of engine oil that enter the oil filter at a given flow rate, larger total surface area means that size of the pores of paper filter media tend to be smaller which is beneficial in order to achieve the greater level of oil filtration. These filters also have different surface area (cm^2) and it largely depends on the capacity of the engine for which a filter is produced.

In majority of filters traditional "star" laying design of the filtering curtain is used (figure 2.8-2.9-2.10).

In full-flow filters with elements of depth type (figure 2.11) the oil passes between layers of the filter paper winded in a roll [33] [34].

End caps of filter elements are produced, as figured stamped (cardboard or metal) and the flat cardboard. However the cardboard version does not provide tightness of glue connection of the cover and the element curtain because of the uneven thickness of the layer of glue in the curtain and periphery center.

Figure 2.6 Donaldson spin-on oil filter

Figure 2.7 Fleetguard spin-on oil filter

Figure 2.8 Mobil spin-on oil filter

Figure 2.9 Fleetguard oil filter (depth type)

Table 2.1

Key parameters of full-flow oil filters for diesel engines

Manufacturer of oil filters						
Filter parameter	Fram	Fleetguard	Donaldson	Baldwin Filters	Caterpillar	Mobil
Type of filter	spin-on	spin-on	spin-on	spin-on	spin-on	spin-on
Dimensions OD mm height mm	80 100	100 140	110 120	95 140	110 100	110 100
Total surface area cm^2	2200	3300	3900	3300	2400	1700
Surface area cm^2/kWt	55	70	70	60	50	55

2.5.2. By-pass and combined oil filters

The analysis of researches [35] related to the fine filtration of engine oil in internal combustion engines demonstrated the high efficiency of the use of additional by-pass oil filters, a diagram of the by-pass filter arrangement shown in figure 2.10. The by-pass oil filter is not used as often. This type of the oil filter is found in older engines, or used in combination with the full-flow oil filter in some modern engines. The by-pass filter processes on average 10-20 percent of the engine oil going through the engine. The filtering media used in such filter is very efficient and is designed to remove the smallest particles of contaminants and the engine oil that has been filtered through the by-pass filter typically gets returned to an oil sump. By-pass oil filters are used as part of the auxiliary filtration system that enhances engine filtration beyond the capabilities of full-flow oil filters, this system works in parallel with the standard oil filtration system to remove solid, chemical and other contaminants from the engine oil, as by-pass filters remove particles of contaminants down to 2-5 microns.

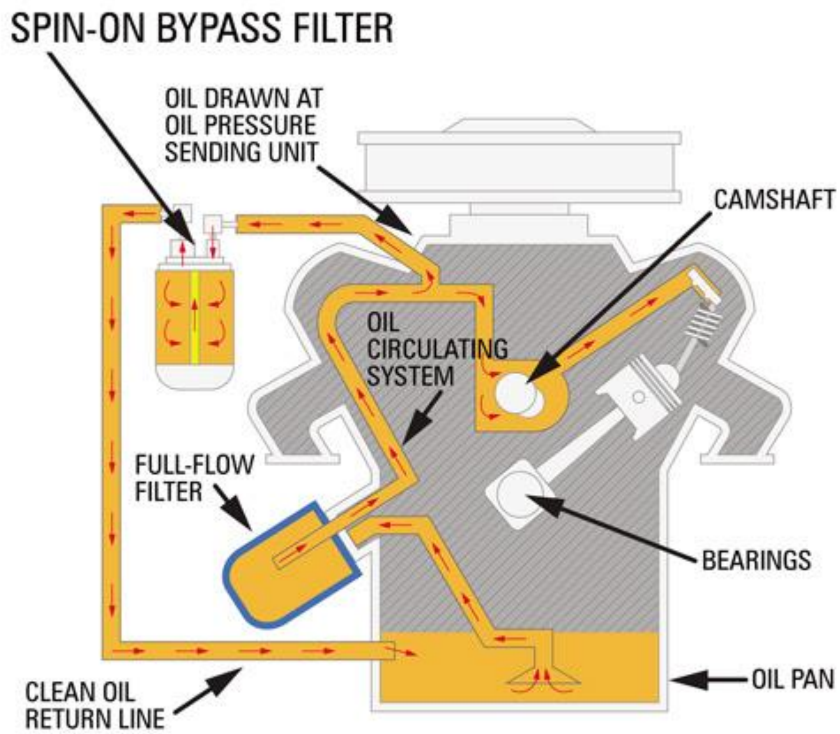


Figure 2.10 Diagram of by-pass filter arrangement

The application of the principle of the combined oil filtration is not new, it has been used over the last 60 years, as the combination of filters of two stage filtration, placed in one case (Cummins, Fleetguard and FRAM filters) [36] [37].

Three prospective areas have been identified as potential for further development of combined oil filtration systems. The first assumes an installation of the by-pass centrifuge in addition to the full-flow oil filter of fine filtration with nominal filtering capacity about 50 microns. The second assumes an additional installation in addition to the full-flow oil filter of the by-pass filter with filtering capacity of 2-5 microns, providing spilling of the filtered oil in an oil sump. This type of filters is produced by Fleetguard and Cummins companies. The main feature of the combined cleaning systems of Cummins and Detroit Diesel engines is the use of volume adsorptive by-pass filters with capacity of 10-12 ltr. The third assumes the combination of two filter elements in one case, e.g. a Fleetguard oil filter consisting of the combination filter element, which has the full-flow paper filter and the paper by-pass filter (figure 2.11).

Figure 2.11 Fleetguard by-pass oil filter consisting of the combination filter element

Figure 2.12 VOLVO by-pass oil filter (depth-absorption type)

The advantage of this type of filters consists in speed of their installation and the possibility of the installation as a replacement of conventional full-flow oil filters.

At present such an installation of additional filters with the high screening capacity in engines is required in order to increase a lifespan of the engine oil and preserve its operational properties, which in turn allows to achieve reduction of operational consumption of the engine oil and costs related to operation of engines.

Leading manufacturers of diesel engines have highest requirements for oil filtration, for example, a Cummins company requires an installation of full-flow oil filters of fine cleaning in all diesel engines and an installation of auxiliary by-pass filters is required for all diesel engines with turbo-supercharging and for diesel engines without pressurization [38].

A Refilco company produces 2 standard series of by-pass filters with a vaporizing chamber, designed for installation in diesel vehicles with volume of an oil sump 7,6-12.8 ltr. [39]. Terms of change of filter elements of filters of the R8, R14, R24 and R60 types, under normal operational conditions required to be carried out every 12-15 thousand miles. According to relevant data presented by these companies, filter elements of the PAC type, in which a 100% of the cotton filter media is used has capacity to hold 99,4% of particles with size of more than 3 microns. A Refilco oil filter consisting of a combination filter element and its hydraulic characteristic shown in figure 2.13.

A Triple-R company produces 3 standard sizes of by-pass oil filters in addition to regular cleaners [40] and use of additional filters allows increase length of oil changes to 60-100 thousand km. A filtering element is made from a cellulose filter media of the uniform density which is twisted in the form of a roll and possesses a high absorbing capacity. A lower part of a filtering element is squeezed by a cardboard ring through a 2-stage filtering system, in which a top layer adsorbs larger particles, and a bottom layer – particles with size of up to 0,2 micron.

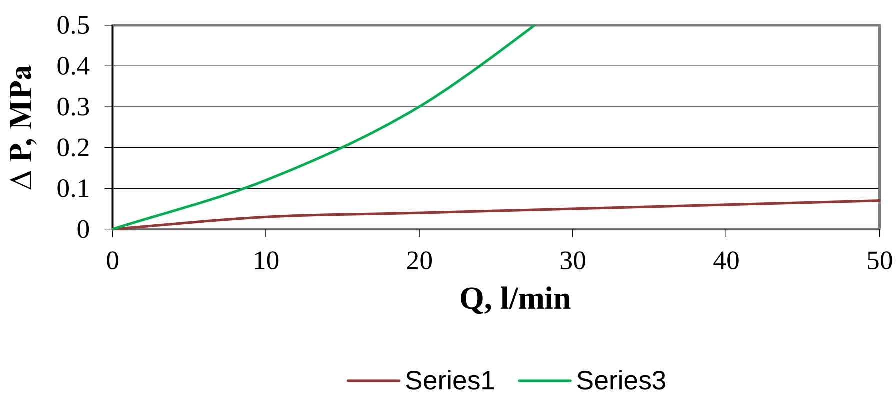


Figure 2.13 Refilco oil filter consisting of a combination filter element and its hydraulic characteristic, series 1- by-pass element, series 3- full-flow element

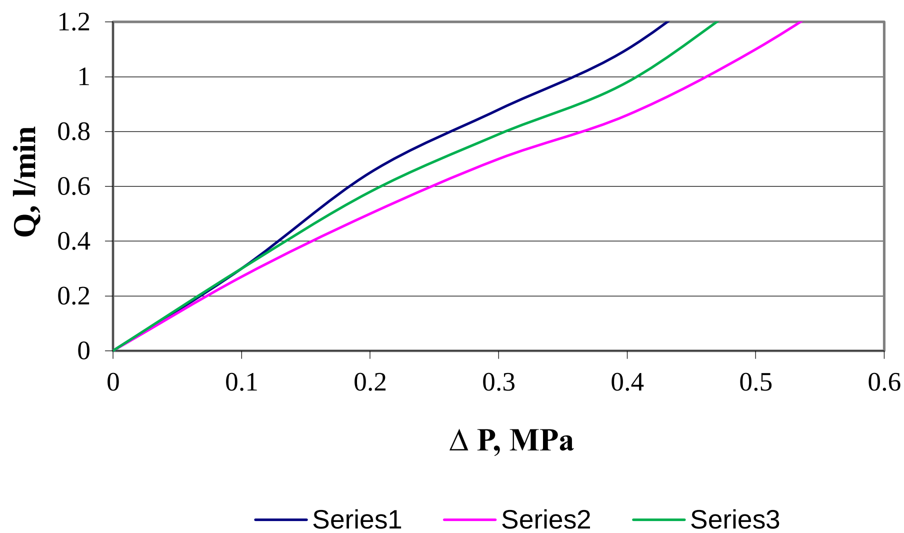


Figure 2.14 Thermo King EMI 3000 oil filter and its hydraulic characteristic, series 1 - 50°C, series 2 - 60°C, series 3 - 70°C

Depending on quantity of the engine oil in the oil sump of the engine, 3 types of TR oil filters (table 2.2) are used.

Table 2.2

Types and applicability of Triple-R filters

Type of filter	Type of engine	Capacity of oil sump ltr
A - 30	small capacity diesel	6
B - 50	diesel	16
C - 100	diesel	25

A Sogefi company, a leading manufacturer of oil filters has developed a range of oil by-pass oil filters [41].

In figure 2.15-2.18 presented by-pass oil filters from table 2.8. The key design features of by-pass oil filters given in table 2.3.

Table 2.3

Design parameters of by-pass filters

Manufacturer of filter	Filter dimensions DxH mm	Element dimensions DxH mm	Filter weight kg	Element weight kg
Megatrol	130x390	110x350	4,86	1,05
Fleetguard	115x350	85x280	3,20	0,53
Triple-R	200x220	170x115	5,54	0,72
MS	130x300	115x250	1,97	0,49

An IPU company produces 3 standard sizes of by-pass filters with a vaporizing chamber [42]. Types of filters 2-10, 11-25 and 26-50 are designed for use in the engines with the volume of the oil 2-50 ltr.

In all countries with significant automotive sectors and developed automotive industries there are ISO standards for oil filters and filtering elements, which regulate their main technical parameters. Besides, some ISO standards provide recommendations related to the typical size of the by-pass filter, e.g. volume of its filter element.

For instance DIN 71455 standard enables to determine a necessary volume of the filtering element of the by-pass filter, based on capacity of the engine. Speed of intake of contamination impurity for diesel engines is recommended at 0,25-1,8 mg/km of kW.

A Cummins company has produced and recommended to use the following technical standards: 10509 for full-flow oil filters and 10547 for by-pass oil filters. This company recommends the users of filters to determine necessary interval for changes of engine oil through the projected schedule method [43] and has developed specific graphs showing dependency of interval between change of the oil and availability of the by-pass filter. The laboratory and field tests were carried out by a Cummins company [44] on V8-185/470 and V504 engines in order to determine the influence of oil filtration systems on the wear of the engine moving parts, established that the application of their "750" type by-pass filter (capacity 10,6 ltr) in addition to an installed full-flow paper filter with the surface area of 1,1 sq.m., and the subtlety of particles elimination around 40 microns, resulted in a considerable decrease of the wear of the engine moving parts.

Figure 2.15 Megatrol by-pass oil filter

Figure 2.16 Fleetguard by-pass oil filter

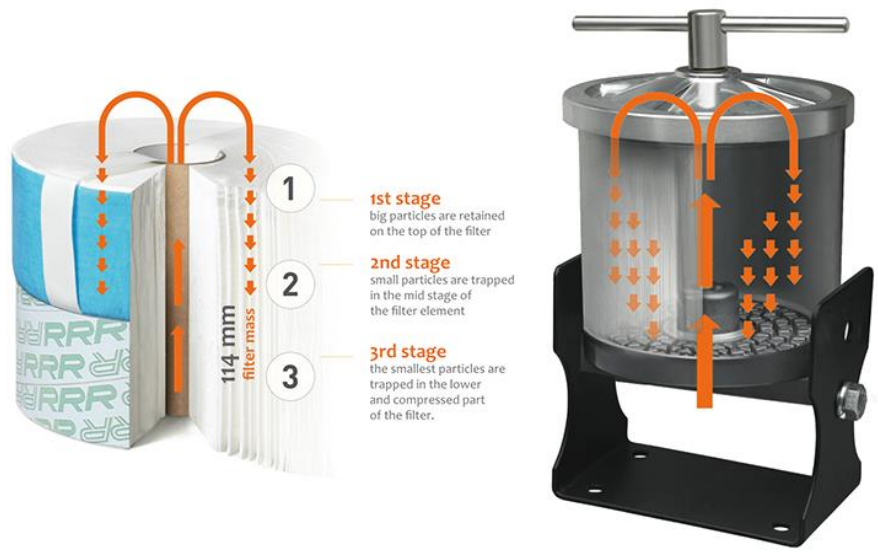


Figure 2.17 Triple - R by-pass oil filter

Figure 2.18 Micronscientific B32 by-pass oil filter

The assessment of degree of the wear was based on a loss of the weight of piston rings and inserts of bearings. For comparison of results of the wear tests was taken for 100% achieved through the oil filtration system, using the full-flow filter with retaining capacity 60 microns and without the by-pass filter included. The wear of the first and second piston rings using the full-flow filter with retaining capacity 40 microns, decreased by 45% and 75% respectively. The combined oil filtration system which included the full-flow filter (60 microns) and the by-pass filter of "volume type" reduced wear of the first and second rings by 13% and 21% respectively. Wear of the oil scraper rings decreased by 44% using the full-flow filter and by 27% using the combined oil filtration system.

A Tecnocar company developed a range of combined filters consisting of the full-flow element, made from paper and the by-pass element made from cotton [45].

This company carried out field tests of vehicles using road trucks with 191 kW diesel engines and with capacity of 13,8 ltr showed that the use of combined filters, in comparison with full-flow filters used for oil filtration, reduced wear of inserts of bearings, namely:

- top connecting rod bearings - by 30%;
- bottom connecting rod - by 45%;
- top radical - by 50%;
- bottom radical - by 40%.

It should be noted that in combined filters, full-flow elements were made from paper with increased throughput capacity with larger pore size than in conventional full-flow filters. It is considered that sufficient consumption of oil through the full-flow filter equals to 3-5% of oil consumption volume [46]. In order to determine the capacity of full-flow filters (without by-pass oil filtration) it is recommended to proceed with the following ratios: 1 cm^3 of engine capacity requires 0,5-1,0 cm^2 of filtering surface and another method is based on: 1 l/min of oil consumption requires 100-150 of cm^2 of filtering surface [47].

According to research [48] an extensive experiment of operation of by-pass oil filters with the vaporizing chamber is described, these filters were installed in engines of school buses. It was shown that along with a considerable decrease in consumption of the engine oil by engines e.g. 481 ltr instead of 538 ltr in engines with conventional cleaning system achieved during 12 months and a decrease in the wear of the engine rotating parts, there was an increase in service life of rubber seals through their reduced contact with acids and fuel, present in the engine oil. The cleaner removes from the engine oil contamination impurity over 1 micron in size.

The primary function of the engine oil is to lubricate moving parts [49]. The oil forms a hydrodynamic film between metal surfaces, preventing metal to metal contacts and reducing friction. When the engine oil is not sufficient to prevent metal-to-metal contact, the following occurs:

- Heat is generated through friction;
- Local welding occurs;
- Metal transfer results in scuffing or seizing.

The engine oil also acts as a cleaning agent in the engine by flushing contaminants from critical components, Sludge, varnish, andoxidation buildup on the pistons, rings, valve stems, and seals will lead to severe engine damage. As a rule the engine oil is formulated with the optimal additives and will hold these contaminants in suspension up to the point when they are removed by the oil filtration system or during the course of an oil replacement. Another function of the engine oil is to provide a protective barrier, isolating non-like metals to prevent corrosion. Corrosion in turn works like a slow acting wear mechanism [50].

One of the main parameters of the engine oil is its viscosity, which is a measure of the resistance to flow offered when one layer of oil molecules move relative to an adjacent layer. The resistance comes from the friction generated by the oil molecules as they move past each other. This shearing action occurs constantly in the oil films lubricating all moving parts of an engine. Most of the wear an engine occurs at initial startup in some applications before the engine oil time to fully circulate.

The engine performance is greatly effected by oil viscosity and its impact is described below:

- The selection of oil of correct vioscosity

In was shown [51] that a decrease in the amount of contamination impurity in the air and the engine oil as a result of the use of extra fine filtration, reduces losses on the friction and wear of engines. Obtained results of conducted tests using a 6 cylinder engine demonstrated an improvement in fuel consumption by up to 5%.

2.6. Conclusions

1. Contamination of the engine oil occurs in the engine continuously and depends on following factors: quality of oil, type of fuel, design of the engine, modes of the engine operation. A reliable operation of the engine and the long service life of the engine oil cannot be provided without the application of effective oil filtration systems.

2. The development of effective engine oil filtration systems is based on the knowledge and the application of bases of theory of calculation of filtration systems, the analysis of features of design of the full-flow, by-pass and combined filters and determination of optimum filtering materials.

3. One of the main indicators of overall performance of oil filtration systems is the reliability of protection of bearings of the engine from the contamination impurity.

4. In combined oil filtration systems various filtering materials and variants of designs of full-flow and by-pass oil filters are used.

5. Combined oil filtration systems in comparison with full-flow oil filtration systems, provide a considerable decrease of the contamination impurity in the engine oil, an increase in the oil service life, an increase in the length of operation of filtering elements of full-flow filters and reduce formation of carbon deposits on surface of parts of piston group.

Chapter 3 – Experimental Techniques

3. Methods of researches of oil filtration systems and their improvement

In order to determine efficiency and overall performance of the oil filtration system operational tests are carried out, as these provide the most reliable data. However these tests are not cost effective and time consuming and therefore common methods of researches are based on laboratory engine bench and engine tests.

3.1 Laboratory and bench tests

Filtering properties of porous materials depend on the size, quantity, shape of pores, and pores distribution. There are several methods of experimental assessment of pores. In some methods various physical regularities are used for indirect assessment of the size of pores. Other methods for assessment of the size of pores are based on measurement of the size and quantity of particles passed by a porous partition.

3.1.1 Methods of indirect determination of the sizes of pores

Vesiculate method.

This method is based on determination of minimum pressure of the air passed through a sample required to observe air bubbles on its surface. This pressure corresponds to opening of maximum pore. When using petrol fuel in tests diameter of the maximum time is determined by equation

(3.1) $$d = \frac{86200}{p}$$

where: d - diameter of maximum pore, micron;

p - unit of air pressure, Pa.

Dependence of subtlety of filtration on unit of air pressure and diameter of maximum pore is presented by empirical equations:

(3.2) $б_н = 266000\ P^{-1,34}$; $б_н = 0,044\ d^{1,45}$;

(3.3) $б_а = 164000\ P^{-1,24}$; $б_а = 0,125\ d^{1,24}$;

where: $б_н$ - nominal subtlety of filtration, micron;

$б_а$ - absolute subtlety of filtration, micron.

Method of mercury porosimetry.

This method is based on applying pressure to a sample immersed in mercury, the mercury is forced into pores and cavities and therefore the sizes of these pores and cavities can be determined. Mercury porosimetry can determine a broader pore size distribution more quickly and accurately than other methods [52]. Taking the form of pore cylindrical and using equation

$$d = \frac{4\delta \cos\psi}{p} \cdot 10^{-6} \qquad (3.4)$$

where: d - diameter of pore, micron;

δ - superficial tension of liquid, н/м^2;

ψ - wetting corner;

which enables to count distribution of conditional pore of a sample by the sizes. Besides this method provides data on the sizes of the deadlock pores of material.

Method of direct measurement of pores.

This method is based on use of SEM images of the porous mass and is used for the assessment of porosity of mineral materials [53]. Due to the fact that some filtering materials have a complex fibrous structure, use of this method leads to considerable errors.

Hydraulic resistance of fluids method.

This method is based on experimental determination of coefficient of specific hydraulic resistance of sample of porous material using equation

(3.5) $$R = \frac{981 \cdot t}{\nu \cdot \ln \frac{H_1}{H_2}}$$

where: ν - kinematic viscosity stokes;

t - time of expiration of liquid from mark H_1 to H_2, sec.

Based on R the average subtlety of elimination is calculated

(3.6) δ_0 = 35,1928 - 15,6739 lg R 10^{-4}, micron

3.1.2 Methods of assessment of filtering materials using artificial contaminants

Method of fractional coefficients of elimination.

When using this method a curve of fractional coefficients of elimination is drawn, determining concentration of particles of contaminant in set dimensional ranges, before and after the filter, which in turn precisely describes filtering properties of porous partition [54].

Multi-pass method.

This method is based on experimentally established dependence of coefficient of filtration β_x on size of particles of contaminant X, which is determined as correlation of the number of particles more set size X in certain volume of liquid before the filter to the number of the same particles in the same volume after the filter [55].

Tests are carried out using the closed circuit with the continuous delivery of the contaminants. This method requires special instruments with high resolution for calculations of the large number of particles.

3.2. Engine and bench tests of oil filtration systems

Provided laboratory results are obtained previously by the author on completion of the laboratory and bench tests of various oil filters and further tests are required to estimate an increase of length of service life of the oil, a decrease in the wear of bearings, the general level of contamination of rotating parts and service life of filter elements.

3.2.1. Analysis of methods of engine and bench tests

Required engine bench tests were carried out in collaboration with the author in accordance with a set programme and following modes given in table 3.1.

Table 3.1

Tests procedure

Operating mode	Rotation frequency, min.$^{-1}$	Capacity, bhp	Time, min.
1. Idling	1000	0	10
2. Full load	3000	maximum	180
3. Idling	1000	0	10

Based on results of conducted tests to determine the optimal condition of operation of the oil and the engine oil filtration system it was concluded that data collected in during the work carried out for this thesis is correct, which is confirmed by results of tests on the Cummins engine. In table 3.2 shown results of engine bench tests of Cummins ICB e-4 diesel engine carried out in repeated cycles, using Premium Blue SAE 15W-40 engine oil.

Table 3.2

Physical and chemical indicators of the oil

Operating time oil, hrs.	Kinematic viscosity mm^2/s at 1000C	Alkaline number of KOH/g mg	Mass fraction mechanical impurity, %	
			NRB	Unburnable
0,2	10,49	5,59	0,42	0,19
100	11,19	4,36	0,83	0,31
200	11,69	3,83	1,30	0,39

In table 3.3 shown quantities of deposits of contamination impurity, found in the oil of Cummins ICB e-4 engine.

Table 3.3

Quantity of deposits of contamination impurity in centrifuges

Engine	Cummins ICB e-4		
Engine test	1	2	3
Quantity of deposits in centrifuge, g	198	169	305

It is noticeable that during 200 hours of the engine operation there is an insignificant decrease in the alkalinity of the oil down to 3,9-4,3 mg KOH/g and an increase in content of oil mechanical impurity to 1,4-1,5%.

3.3 Conclusions

1. Determined laboratory and bench tests methods of researches of filtering materials and oil filtration systems.

2. Method of engine and bench tests of oil filtration systems was tested. Used in researches low-temperature ("cold") and high-temperature ("hot") stages of tests provided engine assessment of oil filtration systems.

Chapter 4 – Filtering Material Properties

4. Research of filtering materials

4.1. Research of filtering materials of full-flow oil filters

Efficiency of oil filters is determined by filtering properties of used filtering materials which provide superficial or volume (depth) filtration. According to [56] superficial filters include the following types of filter medium: mesh, slotted hole, cardboard, paper, nonwoven fabric and based thin-walled filter partition design. Furthermore volume filters based on the use of fibrous and metal canvases of various types and therefore these filters are differentiated by the principle of action which depends on their application and other factors such as necessary thickness of filtering material and size of retained particles.

In figure 4.1 shown images of various filtering materials used in full-flow oil filters. They include the following types: micro-glass, cellulose, synthetic, synthetic micro-glass, polyester and metal mesh.

The analysis of overall performance of mesh and slotted hole filters were carried out in various researches [57] and published data was used for this research which pursued detailed analysis of the potential and efficiency of the application in full-flow oil filters, polymer filtering elements and for comparison purposes paper filter media.

4.1.1. Research of polymer filter elements.

The present research relates to the polymer filter for filtration of engine oil and polymer filter elements, these elements are of depth type, produced in form of cylinders consisting of porous mass. Polymer elements made using mixture of polyvinyl chloride (PVC), polyethylene terephthalate (PET) and compatibilising agents which facilitates blending of PET and PVC. The porosity of filter elements defined as correlation of total volume of pores of a sample to its total volume,

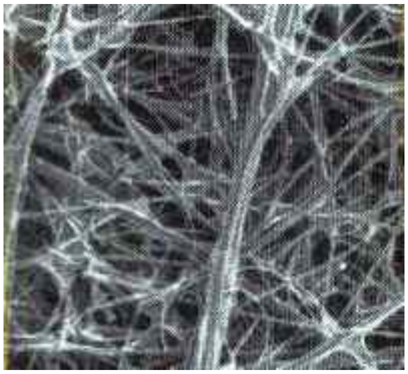
comprised 0,9 that exceeded the level of paper filtering materials shown in table 4.1.
.

Table 4.1

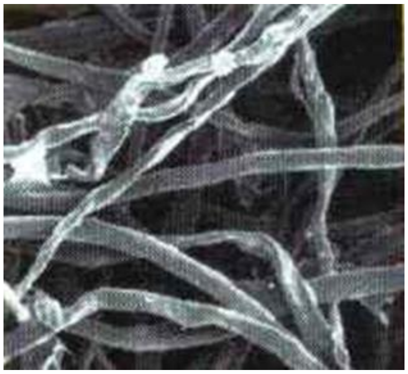
Porosity of filtering materials

Filtering material	Thickness, mm	Porosity
DC 0.9	9,96	0,9
PFM - 1	0,87	0,82
PFM - 2	0,35	0,75

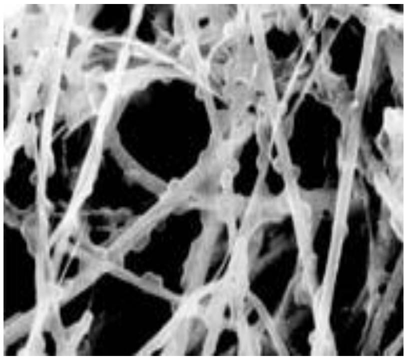
In figure 4.9 and 4.10 given following characteristics of polymer filter elements: dependence of change of oil consumption and reliability of protection of bearings. Polymer filters DC 0.9 shown in figure 4.3, were produced with following dimensions: Ø-80mm and H-100mm, these are identical to the original "Fram" oil filter, shown in figure 4.2. Polymer elements have a slightly increased initial resistance compared to paper elements and sufficient service life due to their increased surface area (x5).



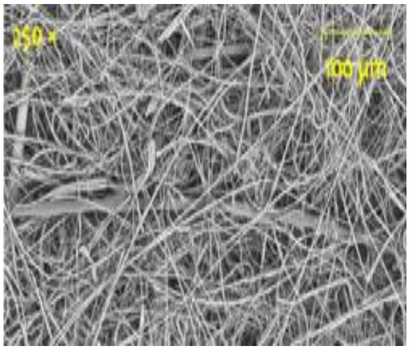
1- Micro-glass filter media



2 - Cellulose filter media



3 - Synthetic filter media



4 - Synthetic micro-glass media

5 - Polyester filter media

6 - Metal mesh filter media

Figure 4.1 Images of various filtering materials used in full-flow oil filters

Figure 4.2 Fram paper oil filter

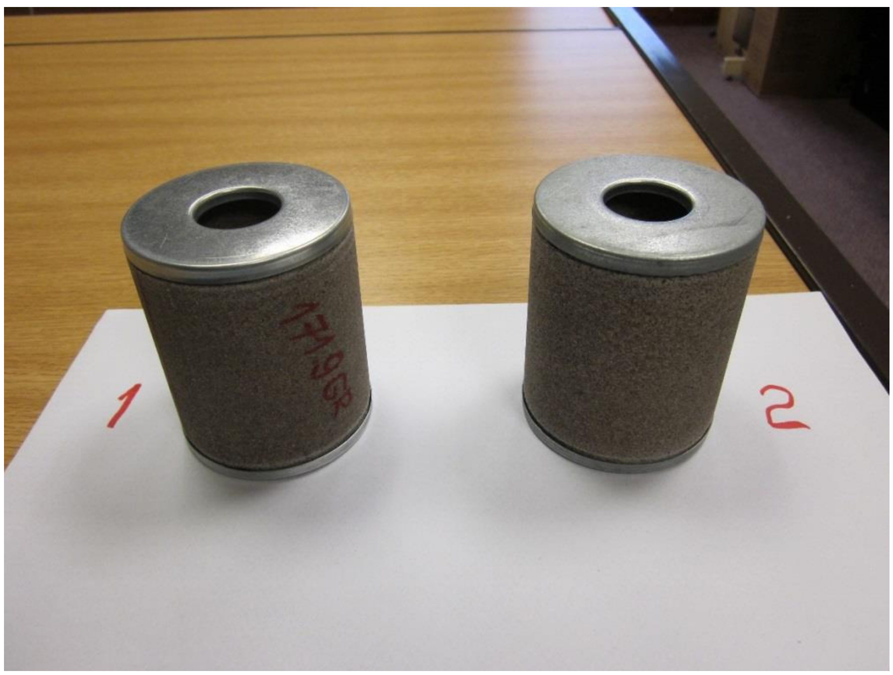


Figure 4.3 Polymer oil filters DC 0.9

4.1.2 Research of paper filter elements.

The research of efficiency of paper filter elements was carried out in collaboration with the author with use of the laboratory test rig, replicating operation of the full-flow filter in an engine and using a Volkswagen 1.2 TSI petrol engine with the following filtering elements: PFM (paper filter media - 30 micron) No. 1, given as series 1, and DC 0.9 (polymer filter media - 26 micron) No. 2 given as series 2. During the tests the following parameters of filters performance have been analysed: hydraulic characteristics, subtlety and completeness of elimination, characteristic of contamination and reliability of protection of bearings of the engine from contamination impurity with each sample. In figure 4.4 - 4.9 and table 4.2 given the results of conducted tests.

Table 4.2

Sample No.	Elimination subtlety, micron	Completeness of elimination, %	Operating time before reaching 0,1 MPa, min.
No. 1	30	70	180
No. 2	45	44	300
No. 3	35	75	340

Results of tests showed that the DC 0.9 polymer filter has a longer life span before reaching its maximum contamination. The character of an inclination of the curve No. 2 (figure 4.7) is determined by dependence of change of share of oil consumption through a polymer curtain. Sample No. 1 PFM has high density, which leads to fast contamination of a paper filter media of the element.

One of the main indicators of overall performance of the full-flow filter is the reliability of protection of bearings of the engine against contamination impurity. Curves of the reliability of protection of bearings given in figure 4.9, these were calculated and based on redistribution of the oil stream in the combined filter and operation of the relief valve of the filter.

The following references are used in Figure 4.4 - 4.9, series 1 - PFM (paper filter media - 42 micron) 1st filter, series 2 - PFM (paper filter media - 30 micron) 2nd filter and series 3 - DC 0.9 (polymer filter media - 26 micron) filter.

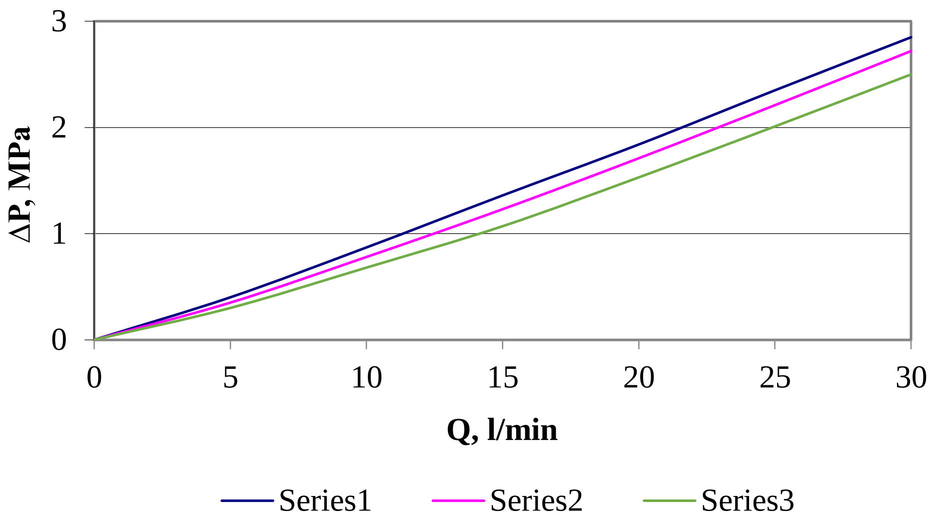


Figure 4.4 Hydraulic characteristics of PFM 1-2 series 1-2, DC 0.9 series 3

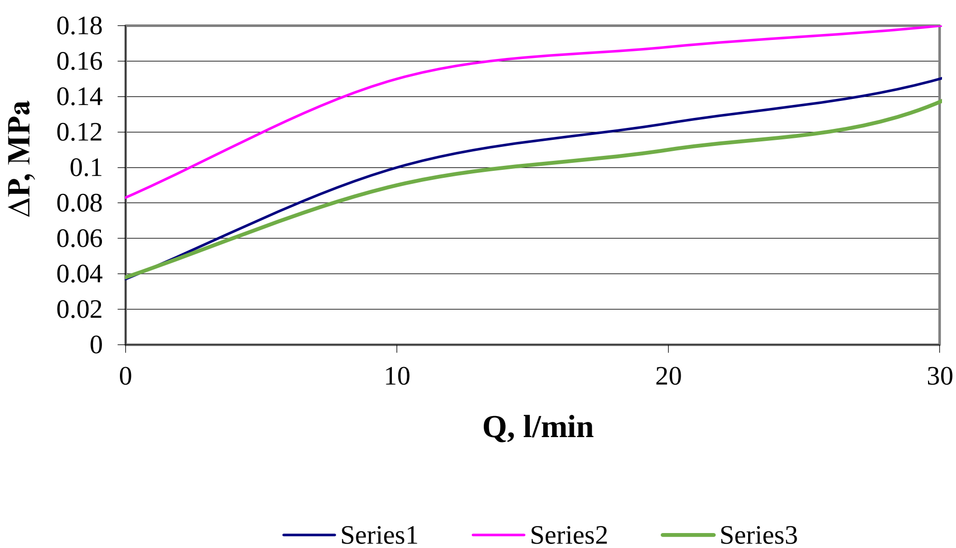


Figure 4.5 Hydraulic characteristics of relief valves of PFM 1-2 series 1-2, DC 0.9 series 3

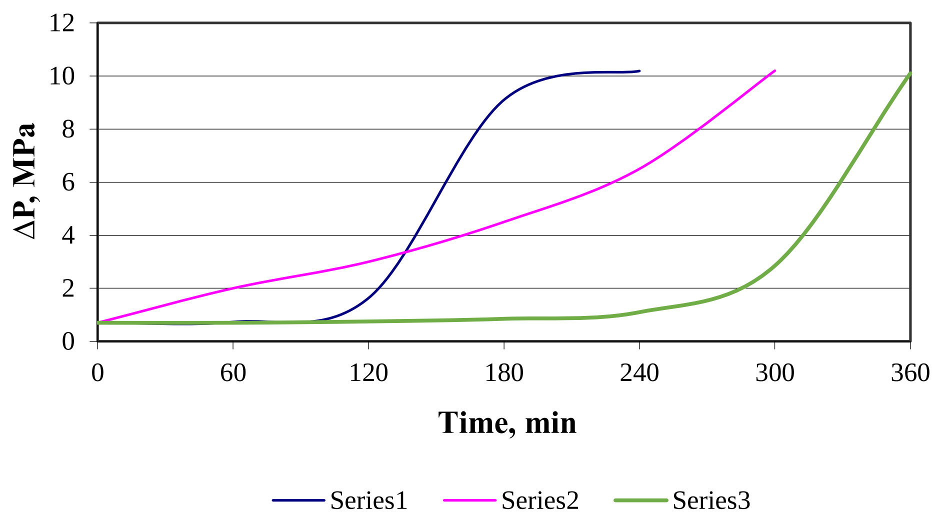


Figure 4.6 Characteristics of contamination of PFM 1-2 series 1-2, DC 0.9 series 3

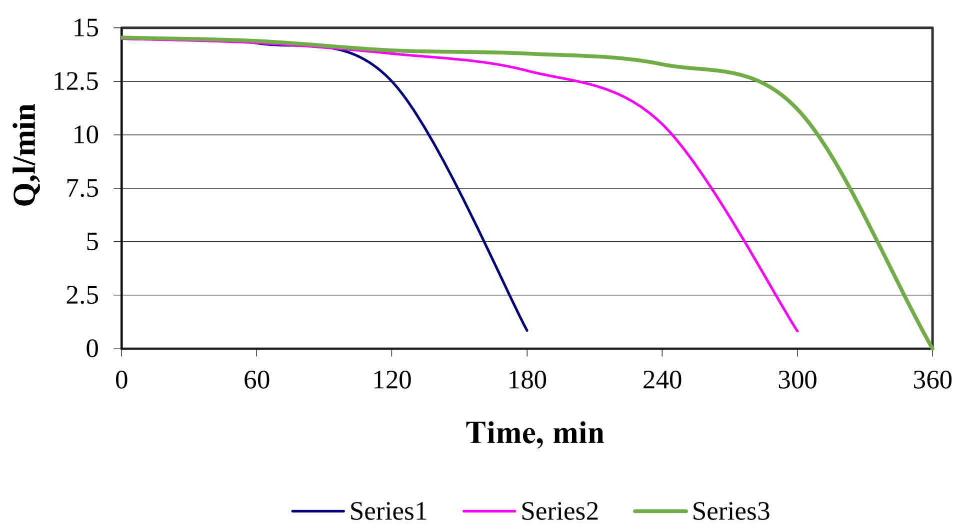


Figure 4.7 Change of oil consumption through the filtering partitions of PFM 1-2 series 1-2, DC 0.9 series 3

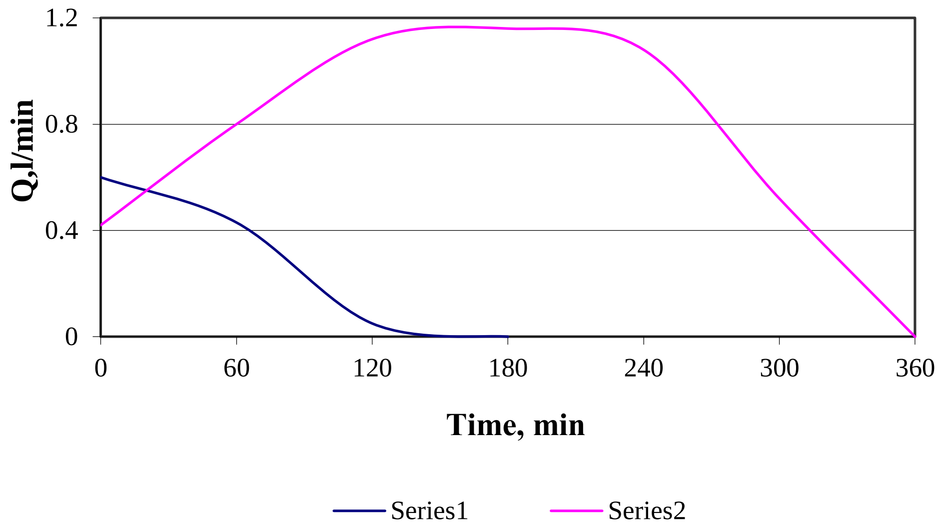


Figure 4.8 Dependence of change of oil consumption through the filtering partitions with opened relief valve of PFM series 1, DC 0.9 series 2

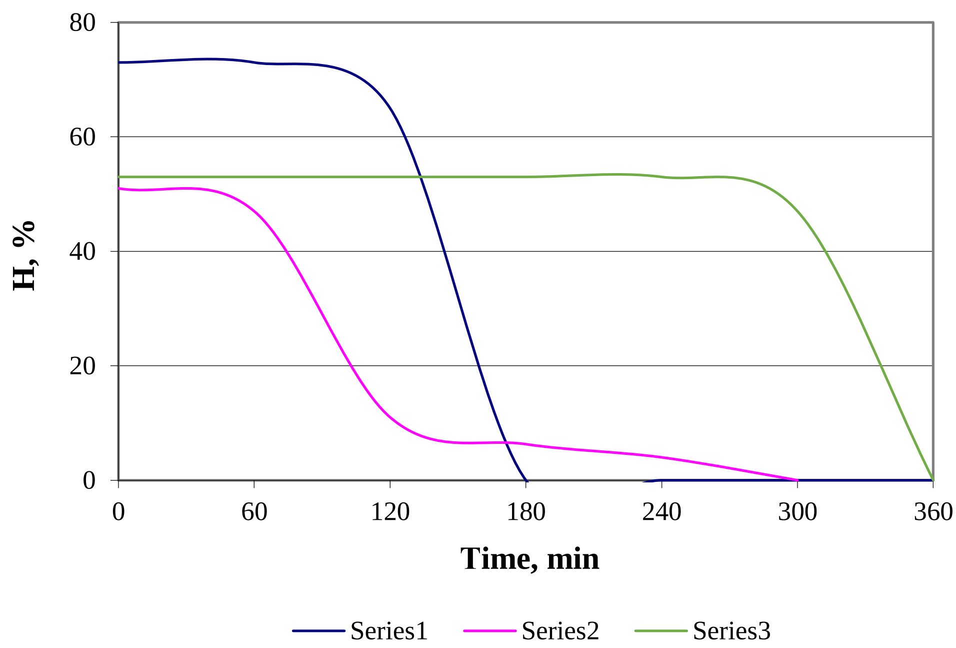


Figure 4.9 Reliability of protection of bearings provided by PFM 1-2 series 1-2, DC 0.9 series 3

4.2. Conclusions

1. Carried out research of volume polymer filter elements for full-flow oil filters, demonstrated that these elements have the satisfactory subtlety of elimination (from 20 to 26 microns), required porosity (0,9) and sufficient contaminant holding capacity, these elements have an increased initial hydraulic resistance which is still within filters technical specification.

2. Carried out research established advantages of the application of the polymer filtering media in full-flow oil filters for diesel and petrol engines. The polymer filtering media used in the DC 0.9 oil filter has the nominal subtlety of elimination of 20-26 microns.

3. The application of polymer filtering media instead of PFM (paper filtering media) allows to increase the service life of polymer filtering elements by 3 times, at the same time there is no adverse impact on reliability of the engine operation and provide considerable economic effect through an extended lifespan of filtering elements resulting in a decrease in the number of used oil filters. It should be noted that engine oil possesses necessary stock of quality.

Chapter 5 – Theory

5. Calculation and analytical researches of oil filtration systems

5.1 Schemes of cleaning systems

In diesel engines the following cleaning systems are used:

- combined oil filtration system with the full-flow paper filter (FFF) and the by-pass centrifuge (BPC), or the by-pass filter - BPF;

- combined oil filtration system with the by-pass centrifuge (BPC);

- combined oil filtration system with the by-pass centrifuge (BPC), included in lubrication system of the engine before the full-flow filter;

- oil filtration system with the full-flow paper filter (FFF).

Tests were conducted on an engine test bench with the Cummins ISB e-4 diesel engine using three cleaning systems:

FFF + BPC included in the filtration system before FFF;

FFF + BPF with inclusion in the filtration system after FFF;

FFF.

5.2 Researches of the efficiency of oil filtration and reliability of protection of bearings of the engine against contamination impurity

The efficiency of oil filtration is determined by two following factors [56]:

- coefficient of elimination φ of the cleaner which characterizes the completeness of the oil filtration from the contamination impurity for one pass of engine oil through the cleaner. For particles of contamination of one size the coefficient of elimination is called fractional;

- coefficient of elimination on oil consumption through the cleaner in a unit of time Q, expressed as $Q \cdot \varphi$ which characterizes intensity of filtration of contamination impurity from the engine oil over a specific period of time.

The coefficient of elimination is presented as:

(5.1) $$\varphi = (X_1 - X_2)/X_1 \ ,$$

where X_1 and X_2 - the content of contamination impurity before and after the cleaner.

The total coefficient of elimination of the combined cleaning system (FFF + BPC fed by oil to FFF) is determined as:

(5.2) $$\varphi_\Sigma = \varphi_{bpc} \cdot m_{bpc} + \varphi_{fff} \cdot m_{fff};$$

For the cleaning system of FFF + BPF with inclusion after FFF:

(5.3) $$\varphi_\Sigma = \varphi_{fff} \cdot m_{fff} + \varphi_{bpf} \cdot m_{bpf}(1 - \varphi_{fff});$$

For the cleaning system consisting of one FFF:

(5.4) $$\varphi_\Sigma = \varphi_{fff};$$

Total intensity of cleaning by combined system is determined by equation $Q_\Sigma \cdot \varphi_\Sigma$

where Q_Σ - total volume of oil consumption in a unit of time, moving from the pump to the engine:

$\varphi_{fff}, \varphi_{bpc}, \varphi_{bpf}$ - coefficients of elimination by the full-flow filter, the by-pass centrifuge and the by-pass filter:

$m_{fff}, m_{bpc}, m_{bpf}$ - shares of oil consumption through the full-flow filter, the by-pass centrifuge and the by-pass filter from quantity of the oil, moving from the pump to the engine.

Calculation of coefficient of elimination of the centrifuge was carried out by equation:

$$\varphi = \frac{R_p^2}{R_p^2 - r_0^2}\left(1 - e^{-\frac{1}{9}\frac{\omega^2 \Omega \delta^2 (\rho_1 - \rho_2)}{Q\mu}}\right) \tag{5.5}$$

where R_p - radius of internal surface of the rotor;

r_0 - internal radius of layer of liquid in the rotor;

ω - angular speed of rotation of the rotor;

Ω - the working volume of the rotor ($\Omega = \Pi h\left(R_p^2 - r_0^2\right)$);

h - average height of the rotor);

δ - size (diameter) of particles of contamination;

$\rho_1 u \rho_2$ - density of particle and oil ($\rho_1 - \rho_2 = \Delta$);

Q - quantity of oil consumption through the centrifuge over a specific period of time;

μ - dynamic viscosity of oil.

Carrying out calculations allows to determine the probability of passage of particles of contamination to bearings λ_{nm} and the reliability of their protection from particles $N_{рт}$ by following ways (1,2):

For the cleaning system consisting of one FFF polymer filter DC 0.9:

(5.6)
$$\lambda_{nm} = 1 - \frac{\varphi_{nn\phi}}{(1-\varphi_{nn\phi}) \cdot m_{nm} + \varphi_{nn\phi}};$$

(5.7)
$$N_{nm} = \lambda_{nm} - 1$$

where m_{fc} - share of oil consumption of bearings from stream of the oil moving from the pump to the diesel engine.

For the standard cleaning system: BPC (before FFF) + FFF.

(5.8)
$$\lambda_{nm} = 1 - \frac{\varphi_{bpc} \cdot m_{bpc} + \varphi_{fff} \cdot m_{fff}}{(1-\varphi_{fff}) \cdot m_{fc} + \varphi_{bpc} \cdot m_{bpc} + \varphi_{fff} \cdot m_{fff}};$$

For the experimental cleaning system of FFF +BPF (with inclusion in the lubrication system after FFF):

(5.9)
$$\lambda_{nm} = 1 - \frac{\varphi_{fff} + \varphi_{bpf} \cdot m_{bpf}(1-\varphi_{fff})}{(1-\varphi_{fff}) \cdot m_{nm} + \varphi_{fff} + \varphi_{bpf} \cdot m_{bpf}(1-\varphi_{fff})};$$

Calculations of efficiency of oil filtration by three cleaning systems were carried out for the following power setting using “Premium Blue” SAE 15W-40 oil:

1) $n_{eng.}$ = 2200min-1, $T_м$ = 95^{0}C, dynamic viscosity of the oil μ =10 cP, Q_Σ = 287 l/min, Q_{bpc} = 20 l/min, Q_{fff} = 267 l/min, Q_{bpf} = 4 l/min, Q_{nm} = 0,8 Q_{fff} , $Q_{пкв}$ = 0,1 Q_{fff} , where – oil consumption through bearings of cranked shaft: n_{bpc} = 6300 min^{-1}.

2) $n_{eng.}$ = 1200 min^{-1}, $T_м$ = 95^{0}C, μ = 10 cP, Q_Σ = 170 l/min, Q_{bpc} = 13 l/min, Q_{fff} = 157 l/min, Q_{bpf} = 2,3 l/min, n_{bpc} = 4000 min^{-1}.

3) $n_{eng.}$ = 1200 min^{-1}, $T_м$ = 60^0C, μ = 31,2 cP, Q_Σ = 173 l/min, Q_{bpc}= 16 l/min, Q_{bpf} = 2,3 l/min, Q_{fff} =157 l/min, n_{bpc} = 4000 min^{-1}.

Coefficients of elimination of the centrifuge were determined in the following modes, given in tab. 5.1.

.

Table 5.1

Number of operating mode	$N_{en.}$, мin^{-1}	$T_м$, r^0C	μ , cP	N_{bpc}, мin^{-1}	P_{bpc}, kg/cm^2	Q_{bpc}, l/min
1	2200	95	11	6200	8,2	19
2	1200	95	11	3900	3,4	12
3	1200	80	14	3900	4,1	12
4	1200	60	32,2	3900	5,9	15
5	1200	30	250	2300	10,2	19

Note. n_{eng}. $N_{bpc.}$ - speed of rotation of cranked shaft of the engine and rotor centrifuge; $T_м$, μ - temperature and dynamic viscosity of engine oil, P_{bpc} and Q_{bpc}- oil pressure before the centrifuge and engine oil consumption through the centrifuge.

In figure 5.1 given fractional coefficients of elimination of the by-pass centrifuge in operating modes, according to data in table 5.1 for the full-flow paper filter and by-pass filters 1 and 2.

Numbers of curves 1, 2, 3, 4, 5 correspond to numbers of operating modes of the centrifuge given in table 5.1. Continuous lines of organic particles with density of ρ_1= 1,1 g/cm^3, dotted 1’, 2’, 3’, 4’, 5’ - for quartz particles (ρ_1= 2,5 g/cm^3) and a stroke - dotted 1", 2", 3", 4", 5" - for iron particles (ρ_1= 7,9 g/cm^3).

Fractional coefficients of elimination given in figure 5 by the full-flow filter under numbers 6 and by-pass filters 1 and 2 under numbers of curves 7 and 8.

It is visible that fractional coefficients of elimination of particles provided by the centrifuge significantly depend on the sizes and density of particles of contamination speed and temperature setting of the engine operation, pressure and viscosity of the engine oil and its consumption through the rotor. Fractional coefficients of elimination by porous filters from insoluble in oil particles of contamination do not depend on viscosity, temperature and the oil consumption. The coefficient of elimination of centrifuges and filters is affected by the quantity of retained contaminants at the same time the coefficient of elimination of centrifuges tend to decrease and the coefficient of elimination of filters and by-pass filters increases. However the oil consumption of filters considerably decreases as a result of intensity of the oil filtration in the engine provided by filters and significantly more than by centrifuges.

For the centrifuges the limit of its clearing ability (centrifugation) can be determined and characterized by the critical size of particles, below this limit sedimentation of particles in the rotor does not occur.

(5.10) $$\delta_{кр} = 2{,}7\sqrt[4]{\frac{R_г T}{N_A \Delta\omega^2 R_p}};$$

where R_g - universal gas constant;

T - absolute temperature of the oil, K;

N_A - Avogadro's number (N_A=6,022x10^{23} mol^{-1});

Δ - difference of density of the particle and the oil.

In figure 5.2 – 5.5 given data related to the intensity of oil filtration by three oil filtration systems. It is visible that the essential difference in intensity of the oil filtration by three systems takes place from particles of small sizes up to 5 microns. Thus the oil filtration of organic particles is significantly better when the by-pass filter is included in the combined system, and from quartz and iron particles – with the inclusion of the by-pass centrifuge in the filtration system.

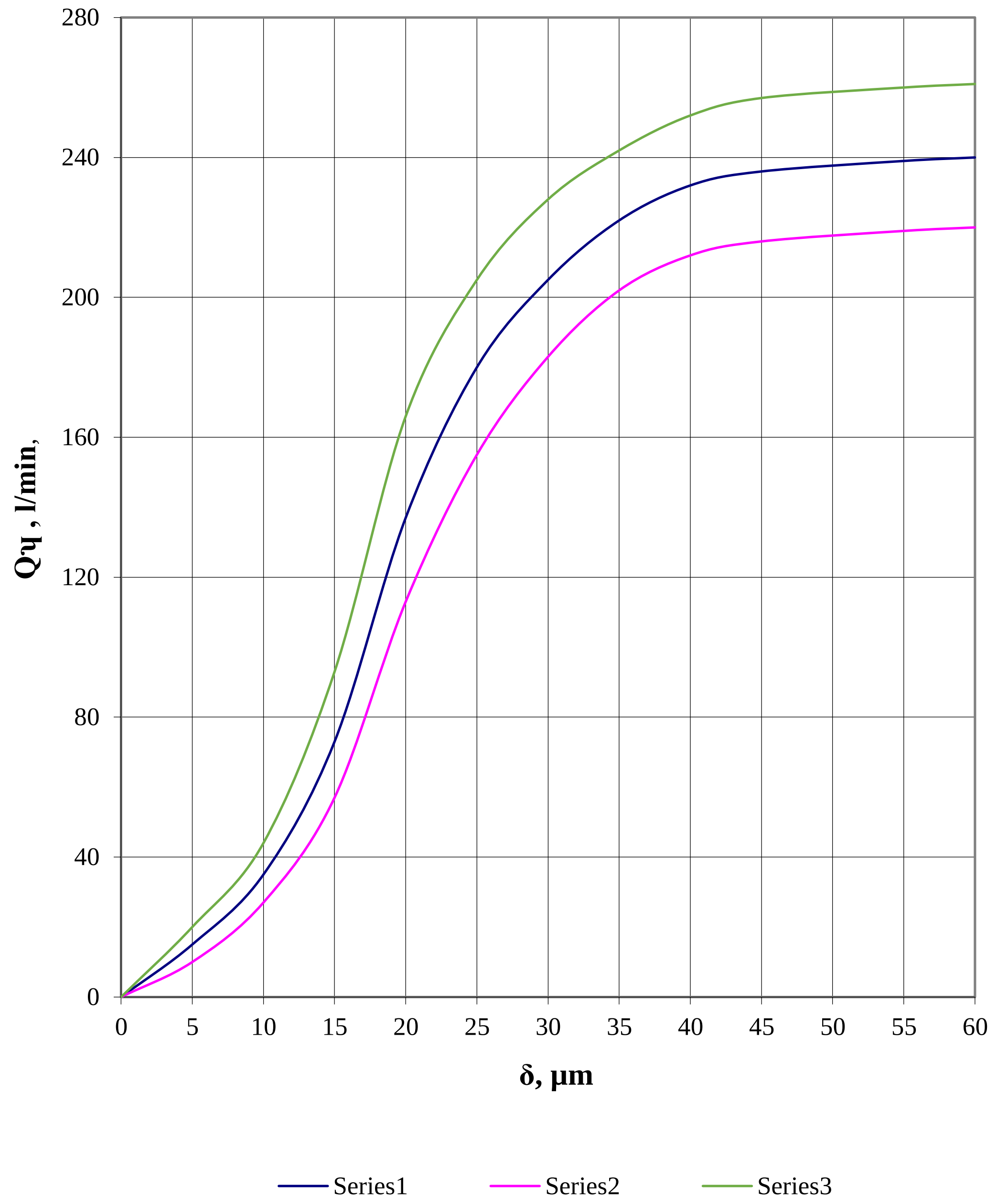


Figure 5.2 Dependence of intensity of oil filtration Q φ on size of impurity particles δ, RPM = 2200, T = 95^0 C, PFM 1-2 series 1-2, DC 0.9 series 3

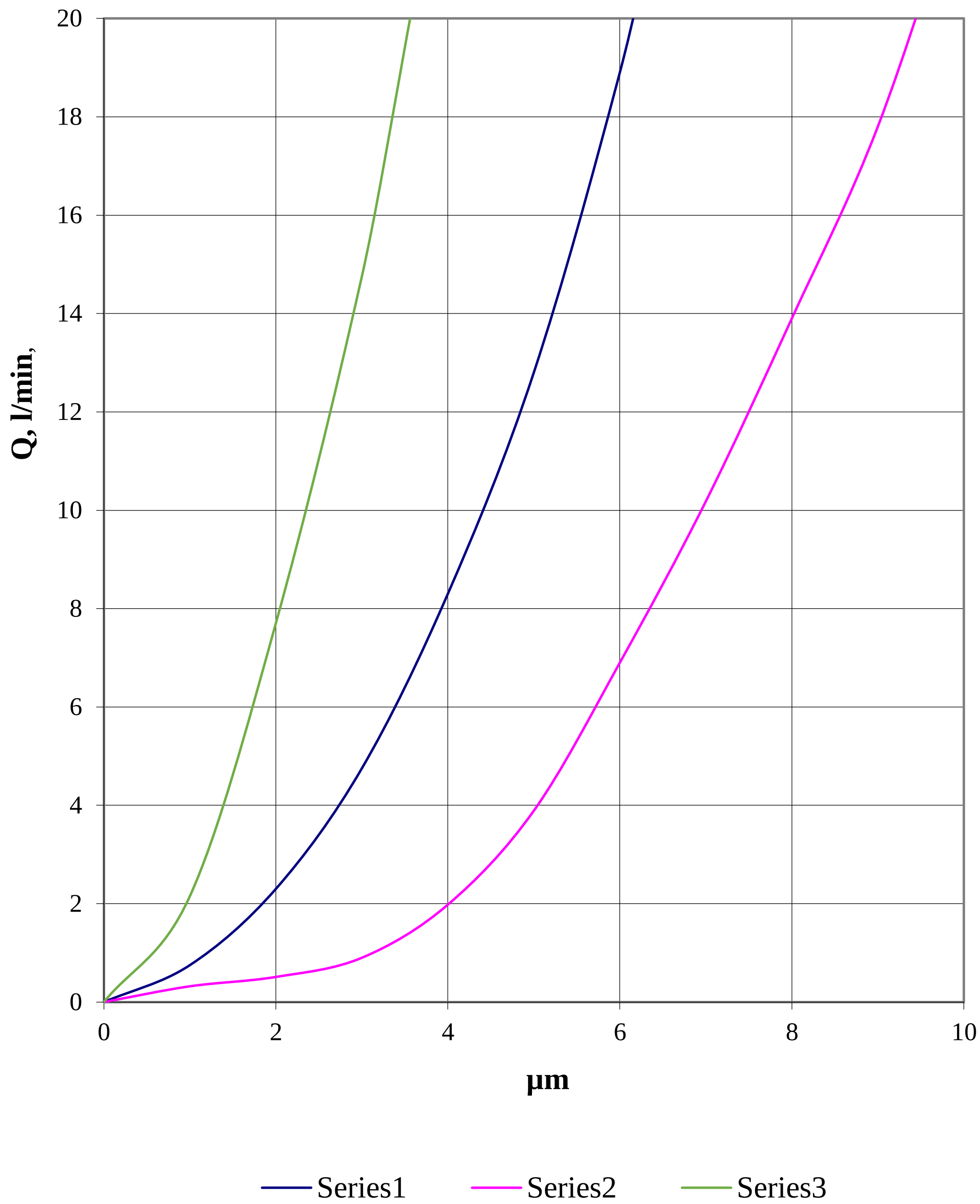


Figure 5.3 Dependence of intensity of oil filtration Q φ on size of impurity particles δ, RPM = 2200, T = 95^0 C, PFM 1-2 series 1-2, DC 0.9 series 3

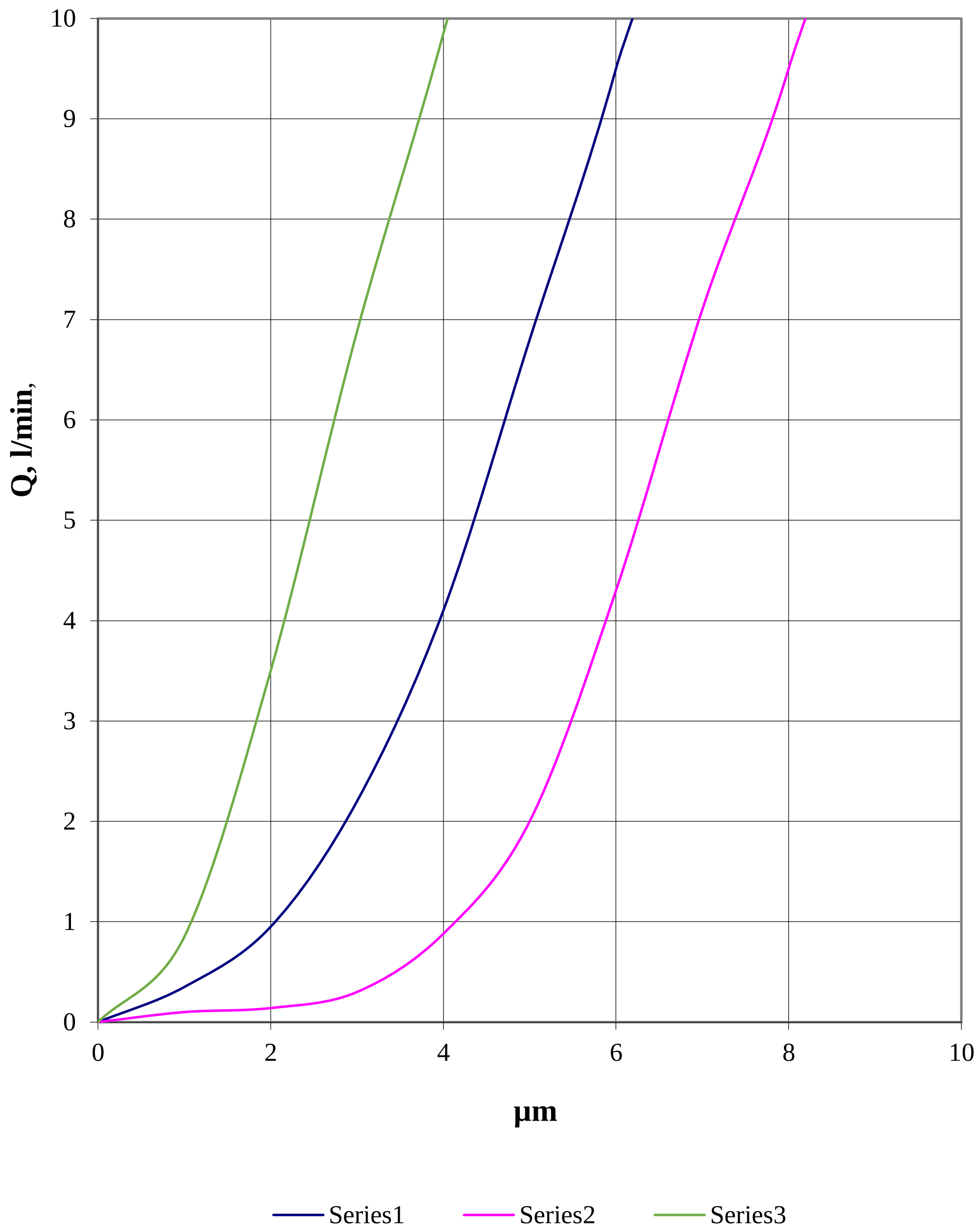


Figure 5.4 Dependence of intensity of oil filtration Q φ on size of impurity particles δ, RPM = 1200, T = 95^0 C, PFM 1-2 series 1-2, DC 0.9 series 3

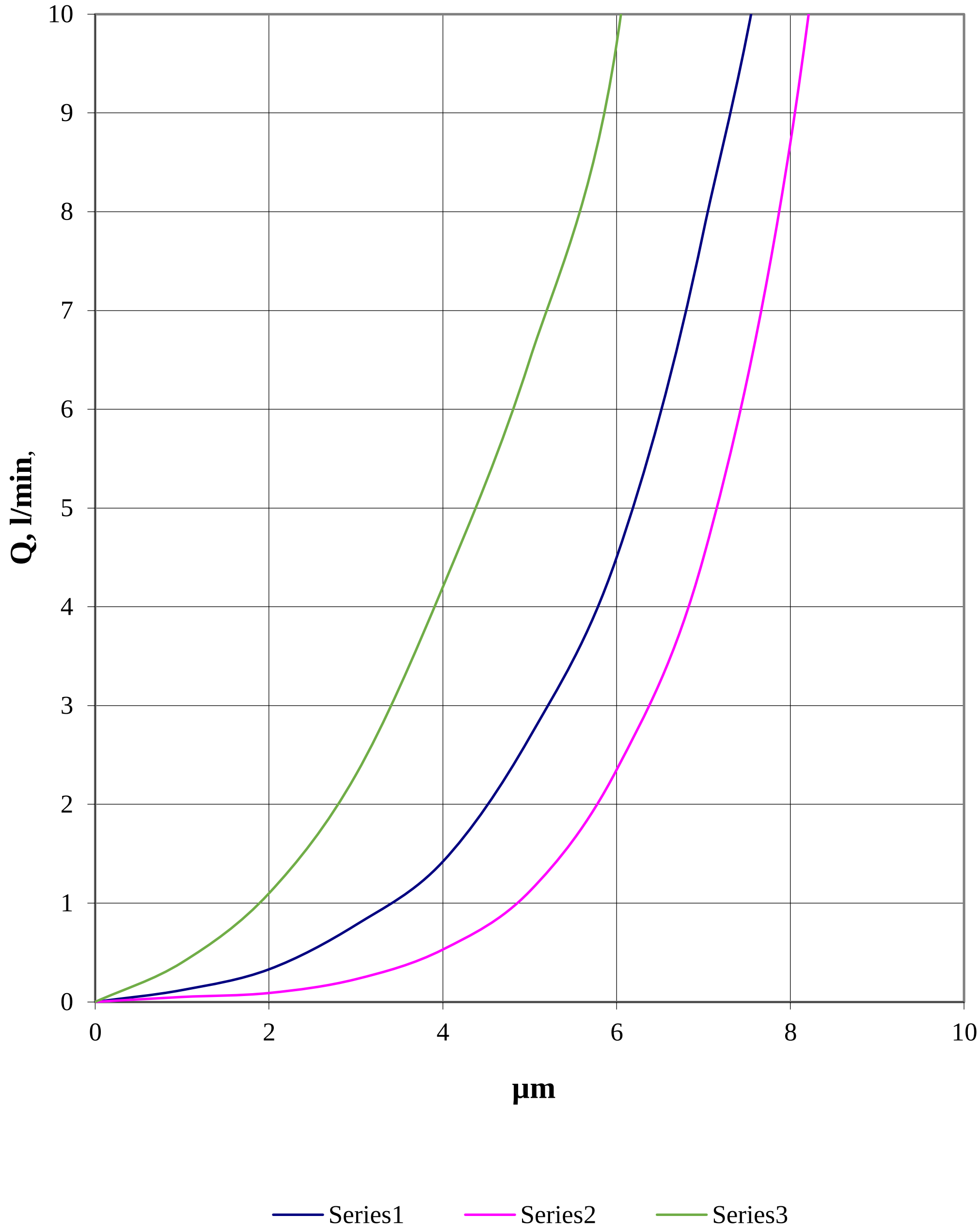


Figure 5.5 Dependences of intensity of oil filtration Q φ on size of impurity particles δ, RPM = 1200, T = 60^0 C, PFM 1-2 series 1-2, DC 0.9 series 3

With a decrease in the engine speed power setting and a reduction of the oil temperature in the oil sump, the intensity of the oil filtration $Q \cdot \varphi$ when using BPC significantly decreases than when using BPF which is connected with pressure and viscosity of the oil that in turn effects more operation of the centrifuge, than the filter.

Considering that essential mass of particles of natural contamination of oil has the average sizes 1-3 microns and in the most part is organic, general oil filtration of essential mass of particles when using BPF is better than when using BPC and as a result of that permissible concentration of contamination impurity in the oil and level of its ageing when using BPF is less. However the high intensity of the oil filtration of BPC from inorganic particles, especially large particles 3-9 microns in size, should have a positive impact on reduction of the wear of moving parts of the engine.

It is confirmed by less probability "λ_{cb}" of presence of such inorganic particles in bearings, in particular in bearings of cranked shaft, and considerably improved reliability of protection of “N_{cf}” of bearings against such particles when using BPC, than BPF and especially, than only FFF (figure 5.6 - 5.9). Therefore by using BPC the probability of presence of particles in bearings and reliability of their protection significantly depends on speed and temperature (oil) modes of the engine operation.

5.3 Conclusions

1. The efficiency of the oil filtration using the following three filtration systems: full-flow (paper filter media) and combined (paper and polymer filter media), including the full-flow paper oil filter and the by-pass centrifuge in combination with the by-pass oil filter tested at various speed and temperature power setting is investigated and defined.

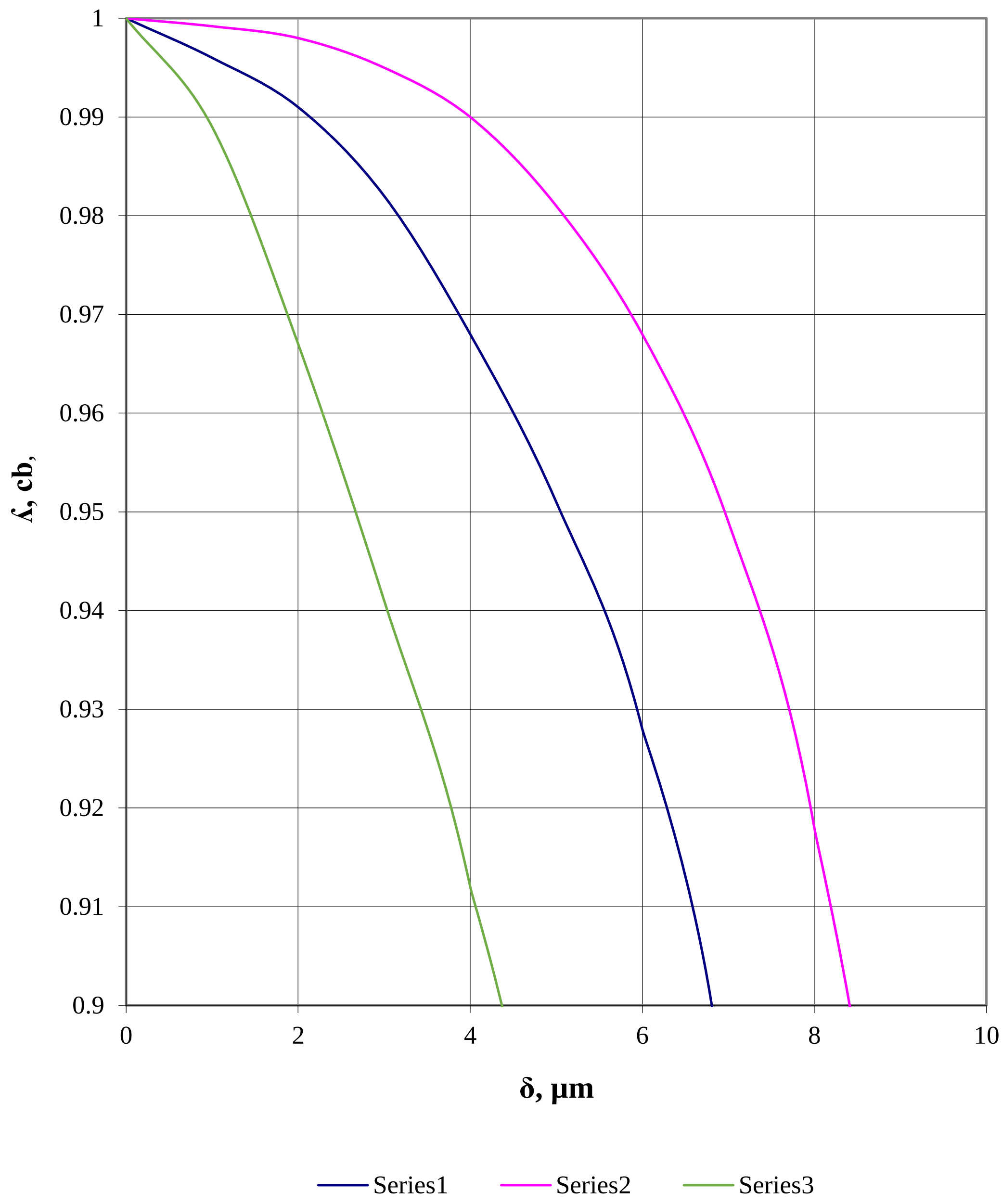


Figure 5.6 Dependence of probability of penetration of impurity particles in bearings of cranked shaft λ bearing and reliability of their protection N bearing from size of particles δ with various oil purification systems RPM = 2200, T = 95^{0}C, PFM 1-2 series 1-2, DC 0.9 series 3

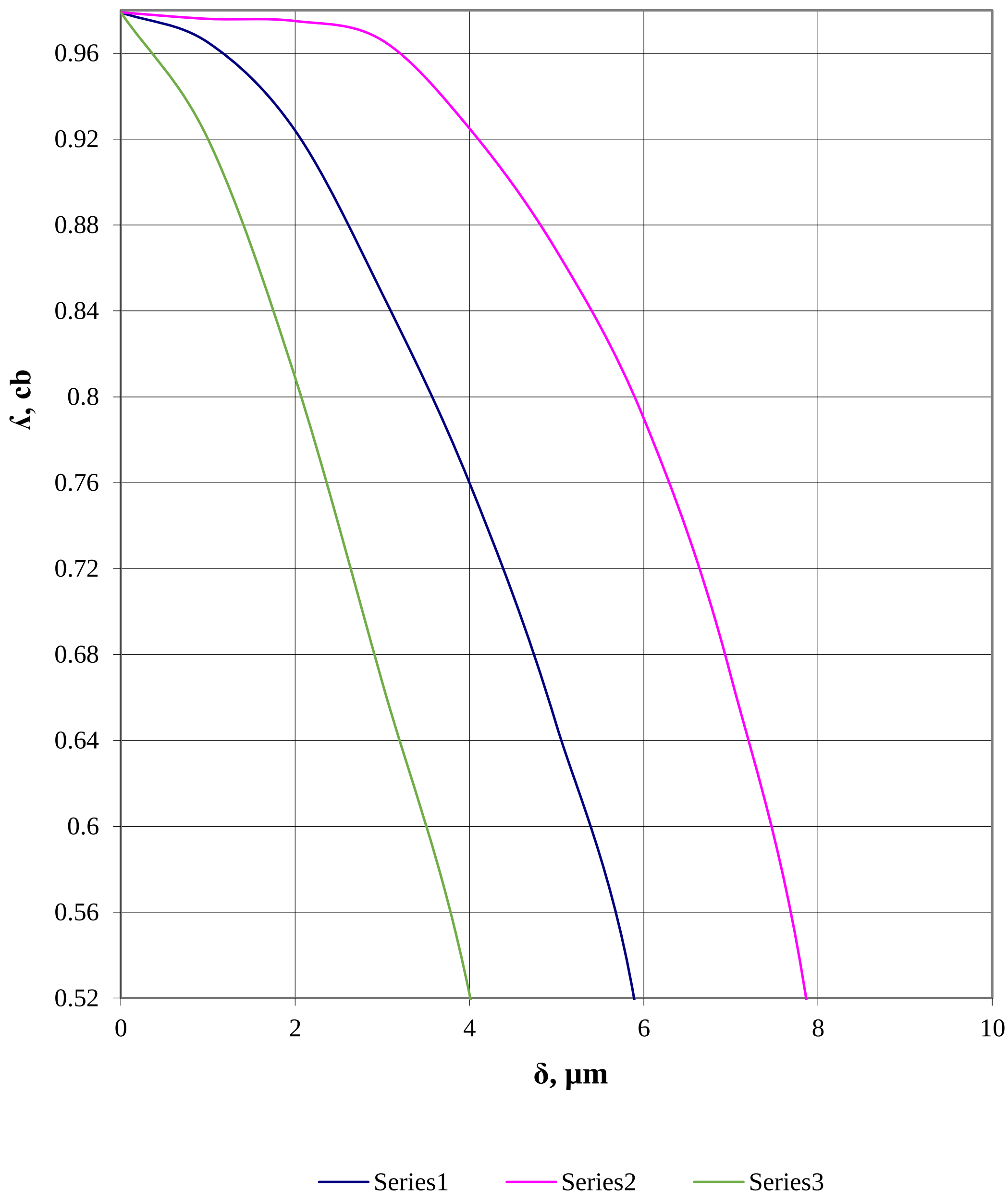


Figure 5.7 Dependence of probability of penetration of impurity particles in bearings of cranked shaft λ bearings and reliability of their protection N bearings from size of particles δ with various oil filtration systems RPM = 2200, T = 60^{0}C, PFM 1-2 series 1-2, DC 0.9 series 3

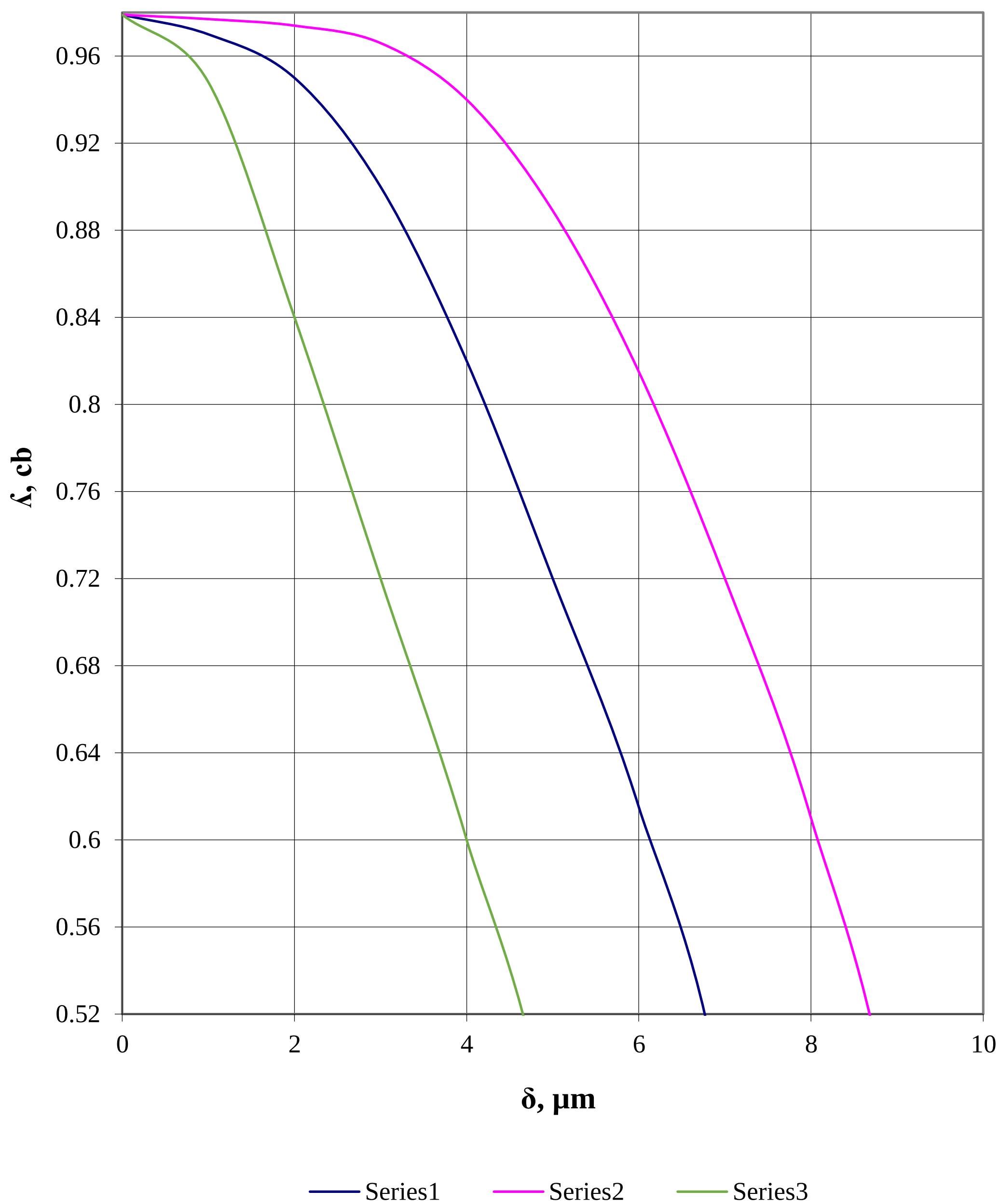


Figure 5.8 Dependence of probability of penetration of impurity particles in bearings of cranked shaft λ bearings and reliability of protection N bearings from size of particles δ with various oil filtration systems RPM = 1200, T = 95^{0}C, PFM 1-2 series 1-2, DC 0.9 series 3

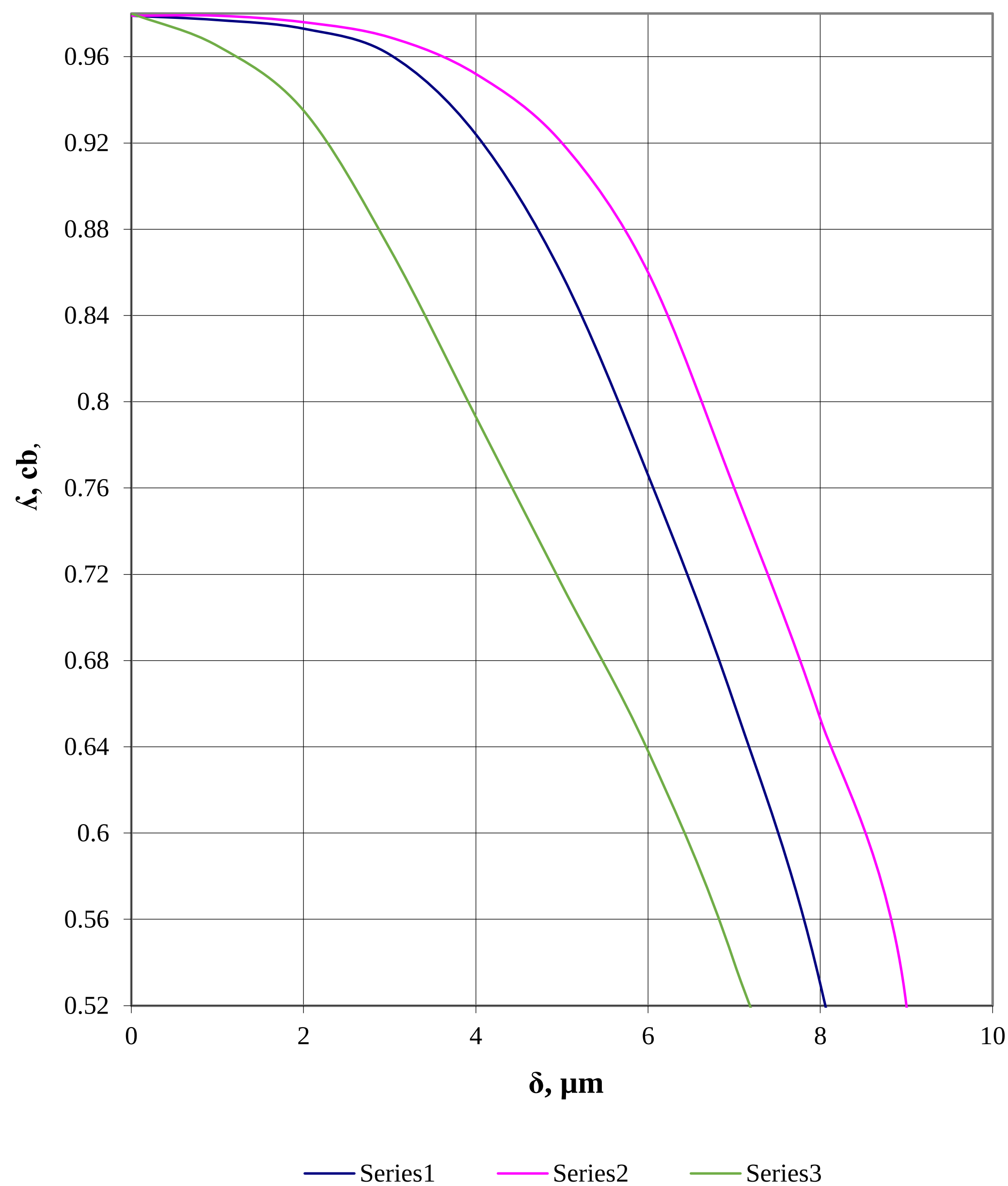


Figure 5.9 Dependence of probability of penetration of impurity particles in bearings of cranked shaft λ bearings and reliability of protection N bearings from size of particles δ with various oil filtration systems RPM = 1200, T = 60^0C, PFM 1-2 series 1-2, DC 0.9 series 3

2. Fractional coefficients of elimination of impurity particles have an impact on impurity of the by-pass filter and the centrifuge, which in case with oil filters do not depend on viscosity and oil consumption, are defined. At the same time the coefficient of elimination of the centrifuge, gradually decreases, and the coefficient of elimination of by-pass filters, in the process of contamination increases, however there is a decrease in the intensity of filtration through a decrease in oil consumption through the filter.

3. The essential difference in the intensity of oil filtration with three filtration systems, takes place for particles of small sizes up to 5 microns, at the same time oil filtration of organic particles of contamination is significantly improved with an addition of the by-pass filter to the combined system, and from inorganic particles with an addition of the by-pass centrifuge.

Chapter 6 – Discussion

6. Research and development of combined oil filtration systems

The carried-out review and analysis of technical literature related to combined oil filtration systems with replaceable by-pass filters and analysis of samples of filters showed that 5 main variants of designs of filter elements found broad application (figure 1.28).

When choosing initial polymer materials for filtering elements, relevant requirements for filter elements related to resistance, subtleties of elimination, mechanical durability, oil, acid and water resistance, availability and cost of polymers were considered.

Taking into account the specified requirements the following types of polymers were chosen: polyvinylchloride (PVC) and polyethylene terephthalate (PET), a mixture of both polymers was used to produce filtering materials.

Physical and chemical properties of filtering materials given in table 6.1.

Table 6.1

Physical and chemical properties of filtering materials

Name of indicators	Cellulose	PVC/PET
Density, g/cm3	1,50	1,70
Destruction temperature, ^0C	180	200
Flash temperature, ^0C	250	-
Ignition temperature, ^0C	450	-
Durability, gs/tex	15-17	30
Moisture absorption at 20^0C and 70% of humidity, %	10	100

For the definition of an optimum polymer composition samples of filtering materials were made of the following polymers:

- PVC - 10%;

- PET - 80%.

The % choice of a polymer composition is based on results of preliminary experiments and previously conducted in collaboration with the author researches on filtering and contaminant retaining capacities and optimum values of mechanical durability of polymer filtering materials and filter elements. It was found that a polymer composition has a desirable feature to retain 100% of water in its porous mass and its moisture absorption greater than paper filter medium by 90%.

Polymer filtering materials were prepared by the author at the laboratory of the University of Sheffield in accordance with an appropriate technical specification related to a polymer composition and a chemical formulation, design of polymer filtering elements and the process of making filter elements.

Characteristics of filtering materials presented in table 6.2 based on selected compositions of two polymers.

Table 6.2

Characteristics of filtering materials

Material of filtering elements	ΔP mmHg	T mm	M kg	Note
PFM paper	8±1	0,8±0,2	0,10±0,02	Cellulose fibers 12-15 micron thick;
PVC and PET	10±0,1	10±0,1	0,5±0,03	PVC and PET granules 70-500 microns

where ΔP - resistance to air stream/specific speed of 0,2 l/min of cm^2;
T - thickness of material, mm, M – weight of 1 m^2 of material.

For comparison purposes the PFM (paper filter media) was used in laboratory tests.

As shown in table 6.3 the use of a polymer filter media causes an increase in resistance of materials whereas thickness and mass of filtering materials with PVC and PET types of polymers and granules diameters remain almost identical. This results from the fact that in the small thickness of polymer material (10±0,1) mm having porous mass structure, the specified indicators depend on diameters of granules.

Preparation of polymer filtering material and filter elements is provided as described below:

The apparatus comprises a chute into which a mixture comprising a plastics material is fed. The electrically powered screw conveyor moves the mixture into a mould via a receiver which acts as a funnel to direct the mixture to the mould. Once the mixture in a mould has been compressed, the indexing pin is withdrawn to permit rotation of the turntable platter, moving an empty mould into the mixture-receiving position and moving the mould containing the filter element precursor body into an unloading position. The operation of the apparatus is controlled by control panel. Once the mixture has been delivered to the mould via the receiver, the mixture is compressed. The electrically-operated piston engages with the tamping member and urges the tamping head into compressive contact with the material in the mould. A mixture comprising a plastics material is formed by mixing 10% by weight of granules of polyvinyl chloride (PVC), 80% by weight of granules of polyethylene terephthalate (PET), 8-9% by weight of a compatibilising agent and 0,02-2% by weight of a liquid. The compatibilising compound facilitates the blending together of PVC and PET. The produced filter element is suitable for laboratory and bench tests.

6.1. Laboratory and bench tests of by-pass filters

To carry out bench tests the standard filter housing was used, which enabled to test filtering elements with the following dimensions: Ø 80 and 100 mm high.

Tests of filters were carried out using the Premium Blue SAE 15W-40 oil at temperature of 90^0C. During tests of filters the following characteristics were defined: hydraulic subtlety of elimination and the contaminant capacity of a filtering element.

The lifespan of filter elements before reaching its end was determined by recorded reduction of oil consumption through the filter elements by 60%, through contamination by quartz dust with the specific surface of 10500 cm^2/g.

Tests of filters were carried out with application of mathematical methods of planning of experiment according to the plan of DFE 2^{4-1} (fractional factorial experiment at two levels) for obtaining incomplete square model taking into account interaction. In tests the following model was used:

$$У = в_0 + в_1X_1 + в_2X_2 + в_3X_3 + в_4X_4 + в_{12}X_{12} + в_{13}X_{13} + в_{14}X_{14} + в_{23}X_{23} + в_{24}X_{24} + в_{34}X_{34};$$

considering mutual influence of factors.

Researched factors and levels of their variation given in table 6.3

Table 6.3

Researched factors and levels of filter elements variation

No.	Factors	Code value	Variation levels		
			-1	0	+1
1	Structure of filtering element (diameter of granules + composition content of CC, %)	X_1	0	10	20
2	Density of filtering element (mass), g	X_2	250 (500)	275 (550)	300 (600)
3	Agglomeration temperature, ^0C	X_3	140	160	180
4	Time of agglomeration, min	X_4	50	70	90

Plan of carrying out DFE 2^{4-1}

No. experim.	Factors				Criterion functions			
	Structure	Weight F.E.	Agglomeration t^0	Set time	$У_1$	$У_2$	$У_3$	$У_4$
	X_1 % CC	X_2 gram.	X_3 ^0C	X_4 min				
1	+	+	+	+				
2	+	+	-	-				
3	+	-	+	-				
4	+	-	-	+				
5	-	+	+	-				
6	-	+	-	+				
7	-	-	+	+				
8	-	-	-	-				
9	0	0	0	0				
10	0	0	0	0				
11	0	0	0	0				

Criterion functions of bench tests:

$У_1$ - the hydraulic characteristic of filter;

$У_2$ - subtlety and completeness of elimination of filtering element;

$У_3$ - contaminant capacity of filtering element;

$У_1$ - water resistance.

Results of conducted by the author experiments are analysed and on their basis the dependences of influence of the structure of filtering elements, their weight, temperature and time of agglomeration for criterion functions are investigated.

The most significant interest presents the analysis of dependences **$У_1$ = f (X_1,X_2)** and **$У_2$ = f (X_1,X_2)**, determining the hydraulic resistance and the contaminant capacity of filtering elements.

Dependence **$У_1$ = f (X_1,X_2)** presented as:

$$У_1 = 0{,}396 + 0{,}139\ X_1 - 0{,}031\ X_2 + 0{,}026\ X_{12};$$

factors **X_3** and **X_4** have zero values.

Dependence **$У_2$ = f (X_1,X_2)** presented as:

$$У_2 = 144{,}75 - 59{,}5\ X_1 + 11{,}0\ X_2 - 4{,}25\ X_{12};$$

factors **X_3** and **X_3** have zero values.

In the obtained equation of value of factors, which are presented in the coded form. Transition to the equation of function response surface in natural values of researched factors is carried out by substitution of values:

$$X = \frac{X_i - X_{io}}{\sigma_i}$$

where X_i - value of “i" factor;

X_{io} - value of “i” factor at zero level;

σ_i - interval of variation of “i” factor;

In figure 6.1 given image of function response surface.

$У_1$ = f (X_1,X_2) (shaded plane ABCD) in the coded values of coordinates of **X_1** and **X_2**. In figure 6.2 is given image of function surface.

$У_2$ = f (X_1,X_2) (plane ABCD). It is visible that use in filtering elements of polymer granules (CC) considerably increases the hydraulic resistance of elements.

In figure 6.3 given image of function response surface **$У_3$ = f (X_3,X_4)**, defining operating time of the filter before contamination, depending on time and temperature of agglomeration of filtering elements. It is noticeable that these factors do not influence filter operating time before contamination.

Porosity of filtering elements (m) was determined as a correlation of total volume of pores of sample (V_n) to its total volume (V_0):

$$m = \frac{V_n}{V_0} \quad \text{or} \quad m = 1 - \frac{\rho_0}{\rho_t}$$

where ρ_0 - density of sample;

ρ_t - density of firm part of sample.

The porosity of filtering elements No: 1 determined thus (containing 20% of CC) and No. 2 (not containing CC), comprised 86 and 88% respectively and matches the level of paper filtering materials.

Thus there is some decrease in oil consumption with its subsequent stabilization. For the filter element from (PVC + PET) (10x80%) there is a decrease in oil consumption by 15% as a result of polymer material ability to absorb water, for the filter element from viscose (100%) by 5%.

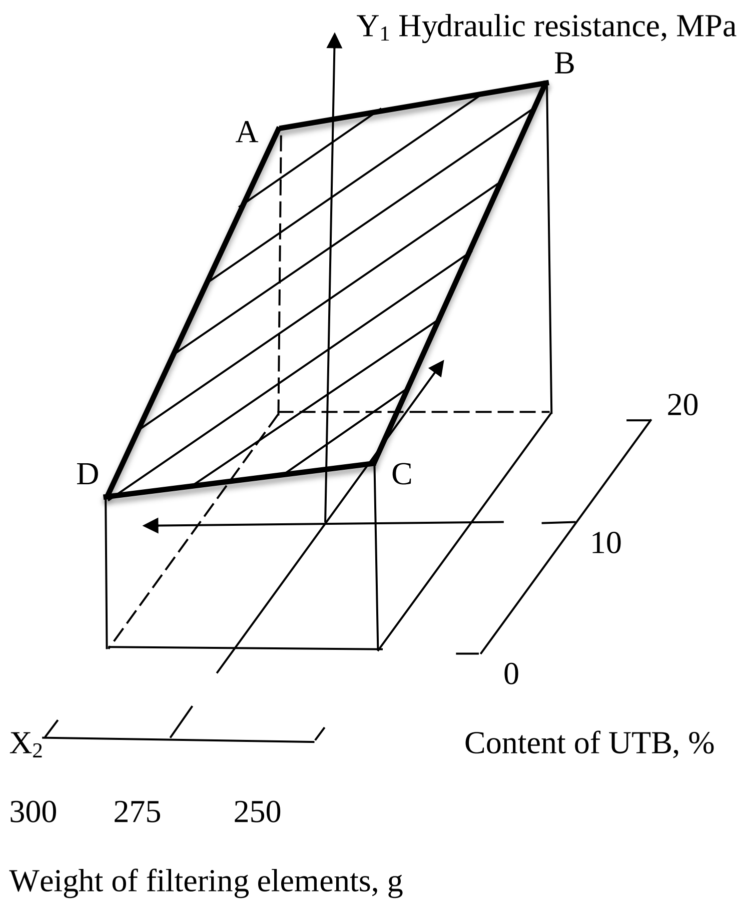


Figure 6.1 Surface of response (ADCD) function $Y_1=f(X_1,X_2)$ depending on content of UTV and weight of filtering elements, factors X_3, X_4 have zero values

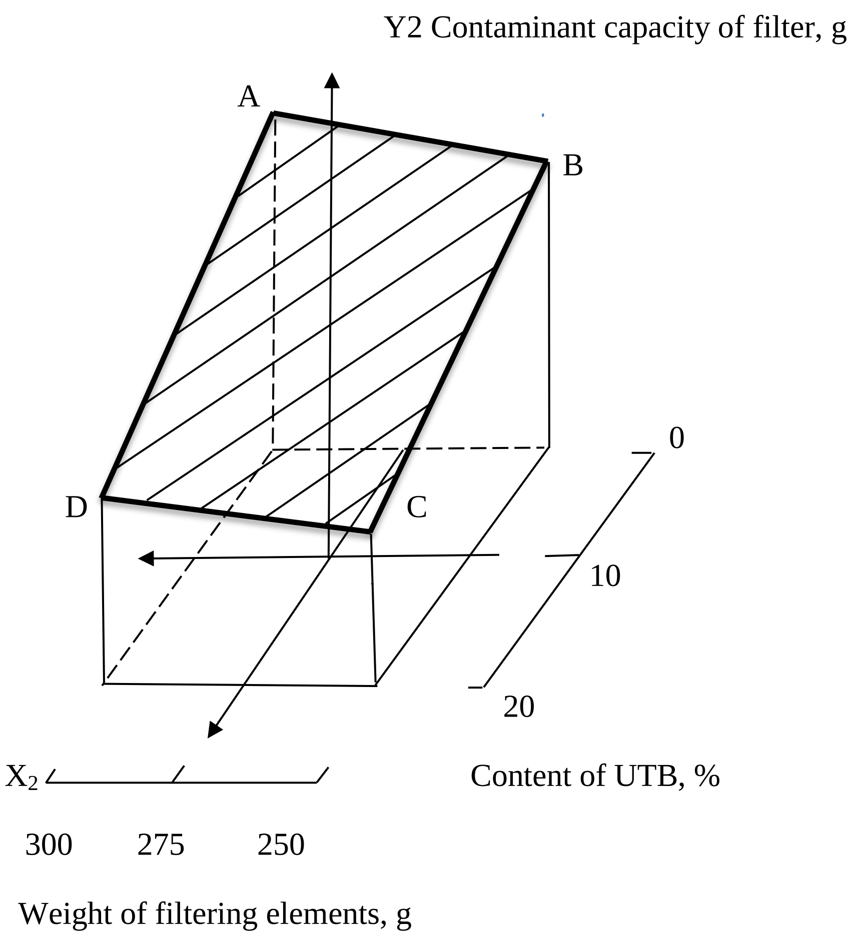


Figure 6.2 Surface of response (ADCD) function $Y_2=f(X_1,X_2)$ depending on content of UTV and weight of filtering elements, factors X_3, X_4 have zero values

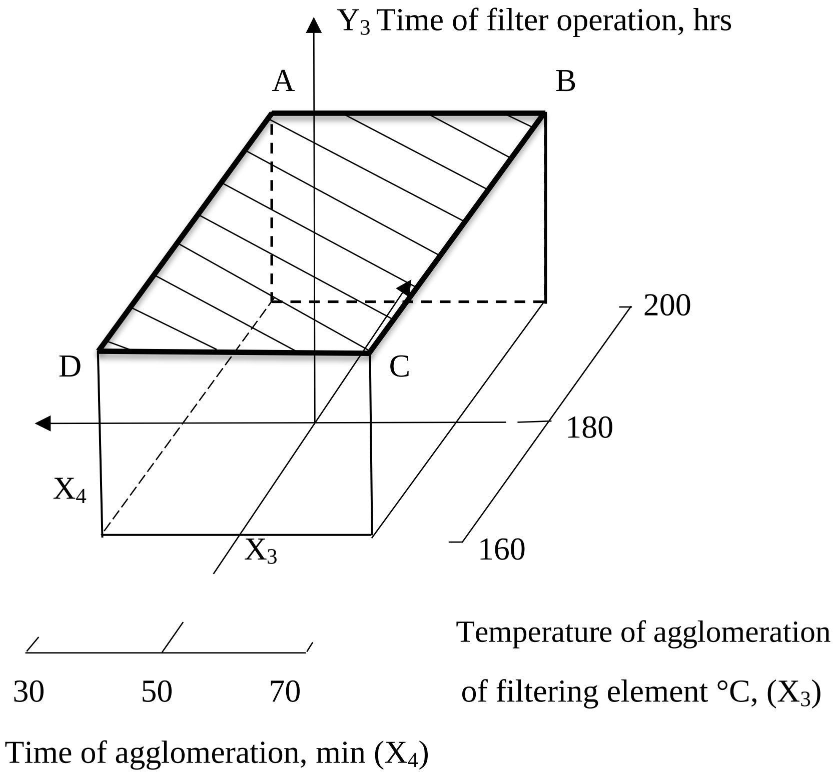


Figure 6.3 Surface of response (ADCD) function $Y_3=f(X_3,X_4)$ depending on temperature of smelting and length of smelting of filtering element, factors X_1, X_2 have zero values

Tests of filtering elements for the thermal stability were carried out as per following procedure: filtering elements were placed in the container with the oil before their full immersion. Then the container consistently cooled in the fridge and later heated up in the oven and cooled down at the room temperature in the following cycle:

- keeping at temperature – 50^{0}C - 65;

- keeping at temperature + 140^{0}C - 65;

- keeping at temperature + 30^{0}C - 125.

On completion of laboratory tests the visual assessment of filter elements and determination of their hydraulic characteristics was carried out. There was not a significant change in oil consumption through filtering elements before and after tests, which did not exceed more than 5%.

6.2 Engine bench tests of combined oil filtration systems

Tests were carried out in collaboration with the author on the engine bench using the Cummins ISB e-4 diesel engine connected to hydraulic brake (dynamometer) Schenk D 700-IE. This engine installation included connection of the air flow to the suction of turbocharger and exhaust gas output (turbine of the filling aggregate) into the discharge manifold of exhaust gases, fuel supply and cooling air supply to the engine. Other installed equipment included: flow meter of crankcase gases; device for sampling of the exhaust gases for the analysis of their smoke, manometers for measurement of pressure drop across oil filters, a flow meter for measurement of oil consumption via the by-pass filter, a device for supplying of part of the exhaust gases in the crankcase with measurement of its temperature and quantity. For all tests of the engine Cummins ISB e-4, standard diesel fuel was used with specification EN 590:2004.

The image of the engine bench with an installed Cummins engine shown in Figure 6.4.

Technical specification of the engine Cummins ISB e-4 used for laboratory tests of combined oil filtration systems is described below:

Basic data of the engine Cummins ISB e-4

Diesel engine:	Cummins ISB e-4, water cooling
Bore:	107.6 mm
Stroke:	123.7 mm
Cylinder number, arrangement:	4 - stroke
Displacement volume	4,499 1
Compression ratio ε:	17.5
Rated power of engine:	130Kw/2300 rpm
Torque of engine max. $M_{t\text{-}ISO}$:	680 Nm/1500 rpm
Injection set:	Common Rail, Bosch B 445 224 151
Injectors:	Bosch 23 30 957
Pressure opening:	40 - 180 MPa
Intercooler:	Cummins No: 345 228 241
Turbocharger:	Holset – type HE 22 1M/H050112120

6.2.1 Engine tests of Cummins ICB e-4 diesel engine

Tests were carried out in cycles in following modes shown in table 6.4.

Table 6.4

Stage of tests	Rotation frequency, $min.^{-1}$	Loading, kg. m	Temperature of water/oil, ^0C	Length of operation, min.	Consumption of crankcase gases, l/min
"cold"	1200	15	26/30	140	105-110
"hot"	2200	60	90/110	260	115-120

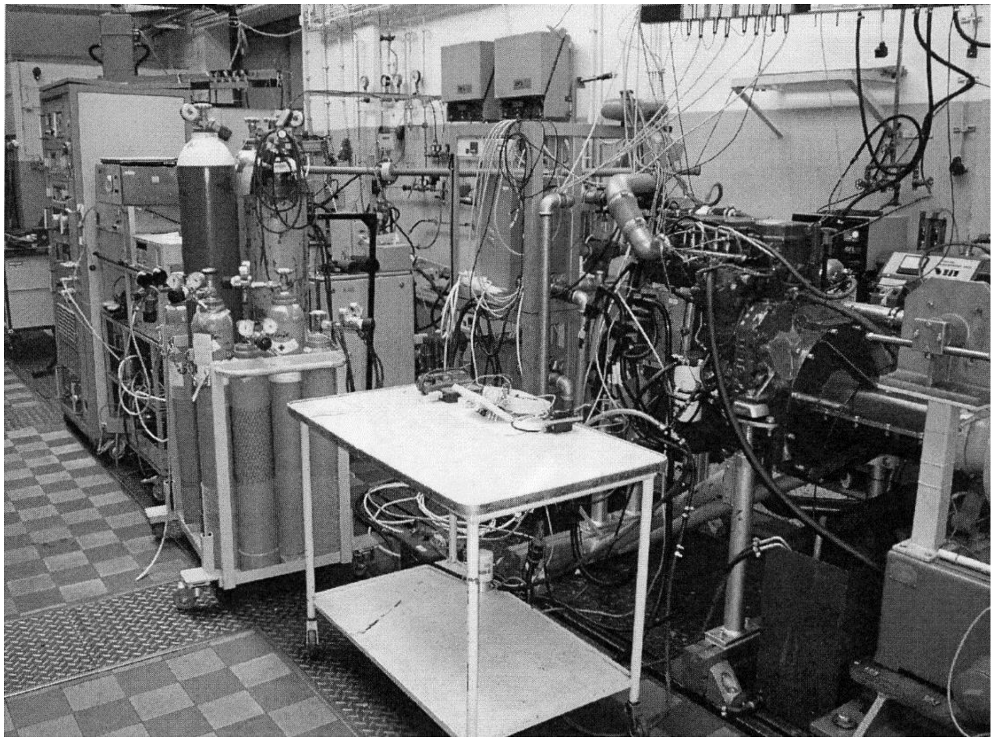


Figure 6.4 Engine test bench Cummins ISB e-4

6.2.1.1 Physical and chemical properties of engine oil

During the tests of oil filters samples of the oil were taken from the crankcase of the Cummins ICB e-4 diesel engine for laboratory analysis of oil samples, carried out in accordance with ASTM standards.

Samples of the oil were taken by a technician every 20 hours at equal intervals: 20hrs, 40hrs, 60hrs, 80hrs, 100hrs, 120hrs and on completion of tests of three fuel filtration systems tested, 2 paper and 1 polymer oil filters were removed by a technician for further laboratory analysis of oil filters and also analysis of retained by filter media (paper and polymer) contaminants.

On completion of the bench engine tests a technician also removed moving parts from the engine for the laboratory analysis in relation to wear tests of parts.

In figure 6.5-6.9 shown results of the analysis of tested oil samples.

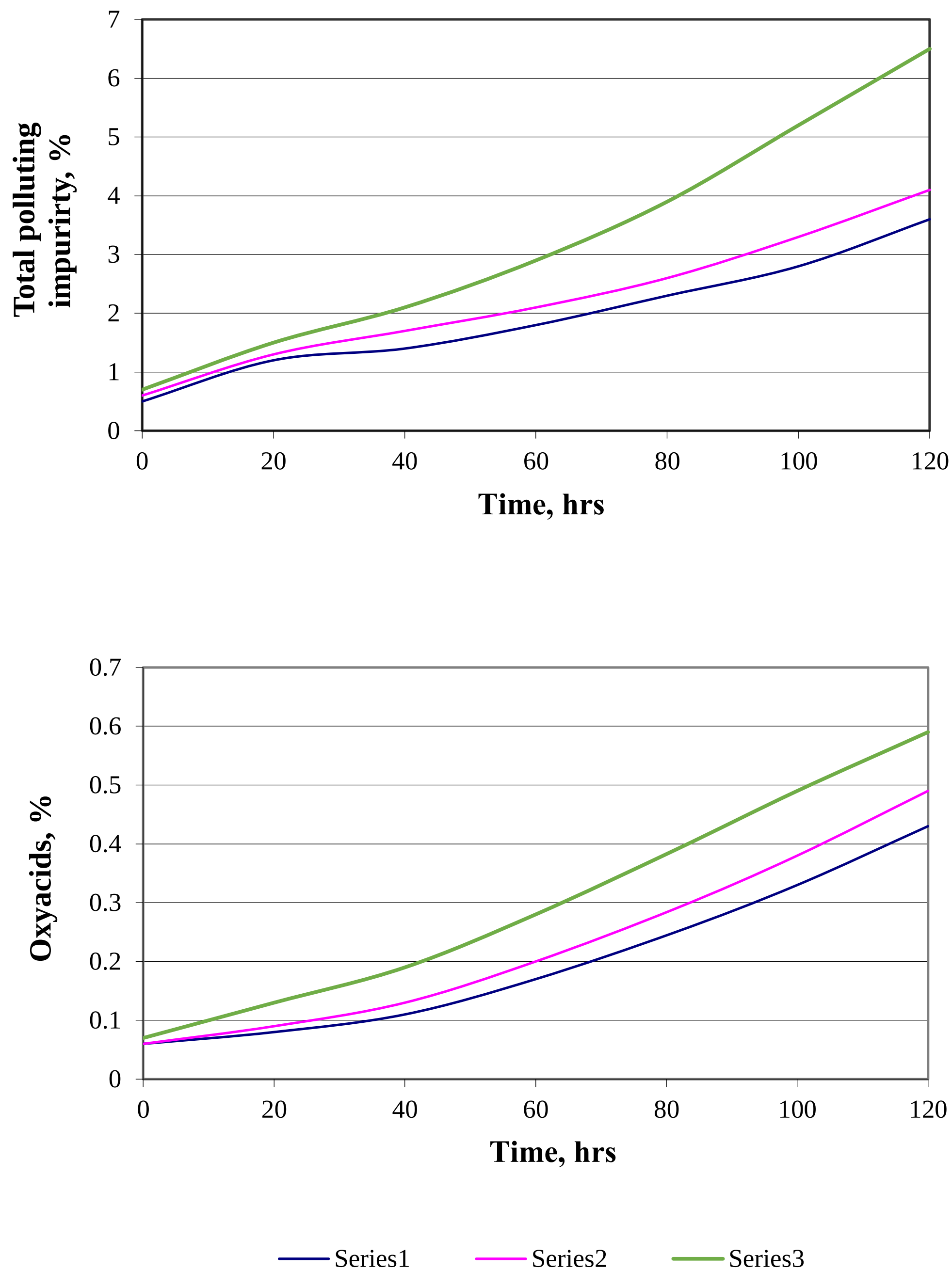


Figure 6.5 Physical and chemical properties of the oil, PFM 1-2 series 1-2, DC 0.9 series 3

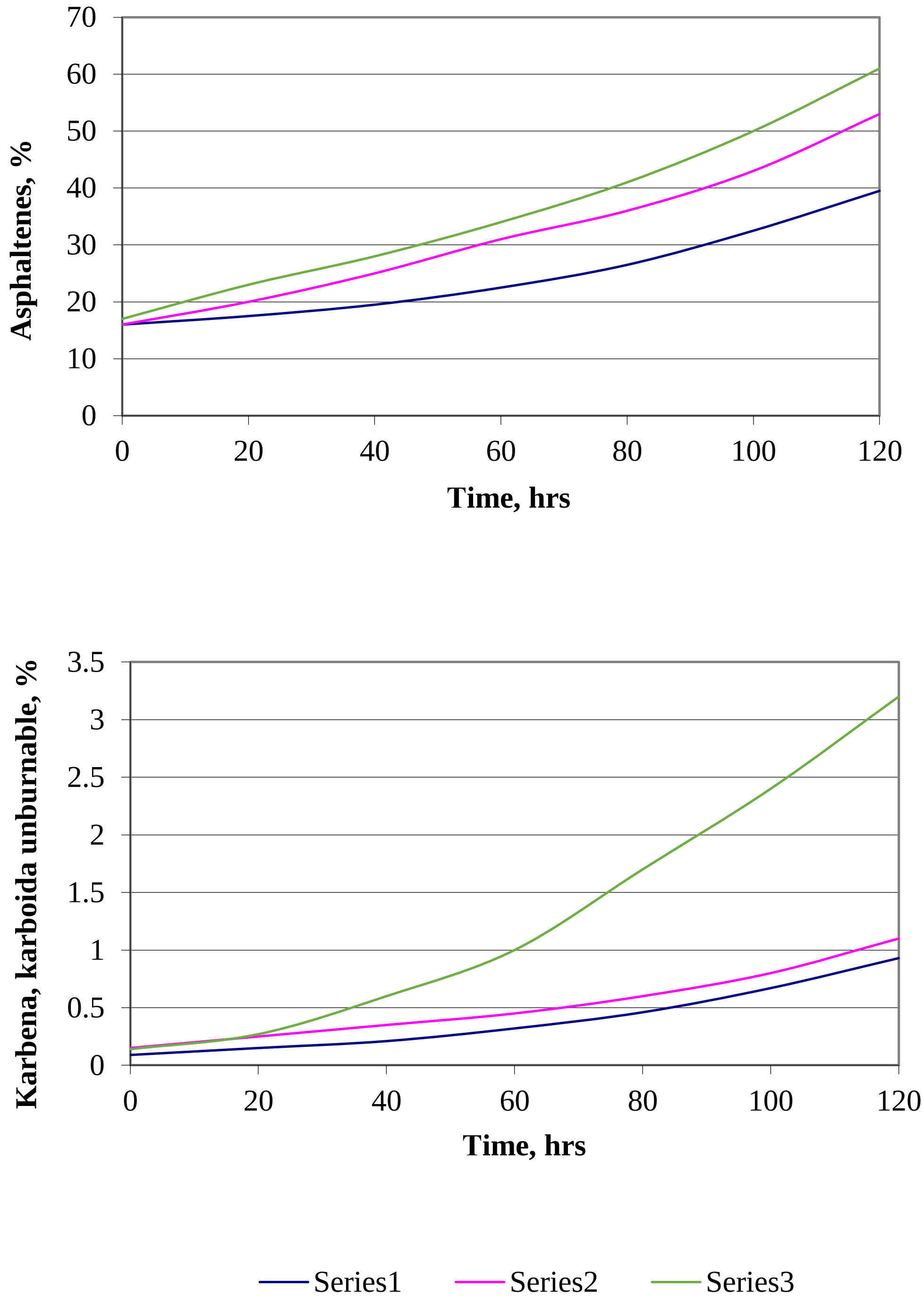


Figure 6.6 Physical and chemical properties of the oil, PFM 1-2 series 1-2, DC 0.9 series 3

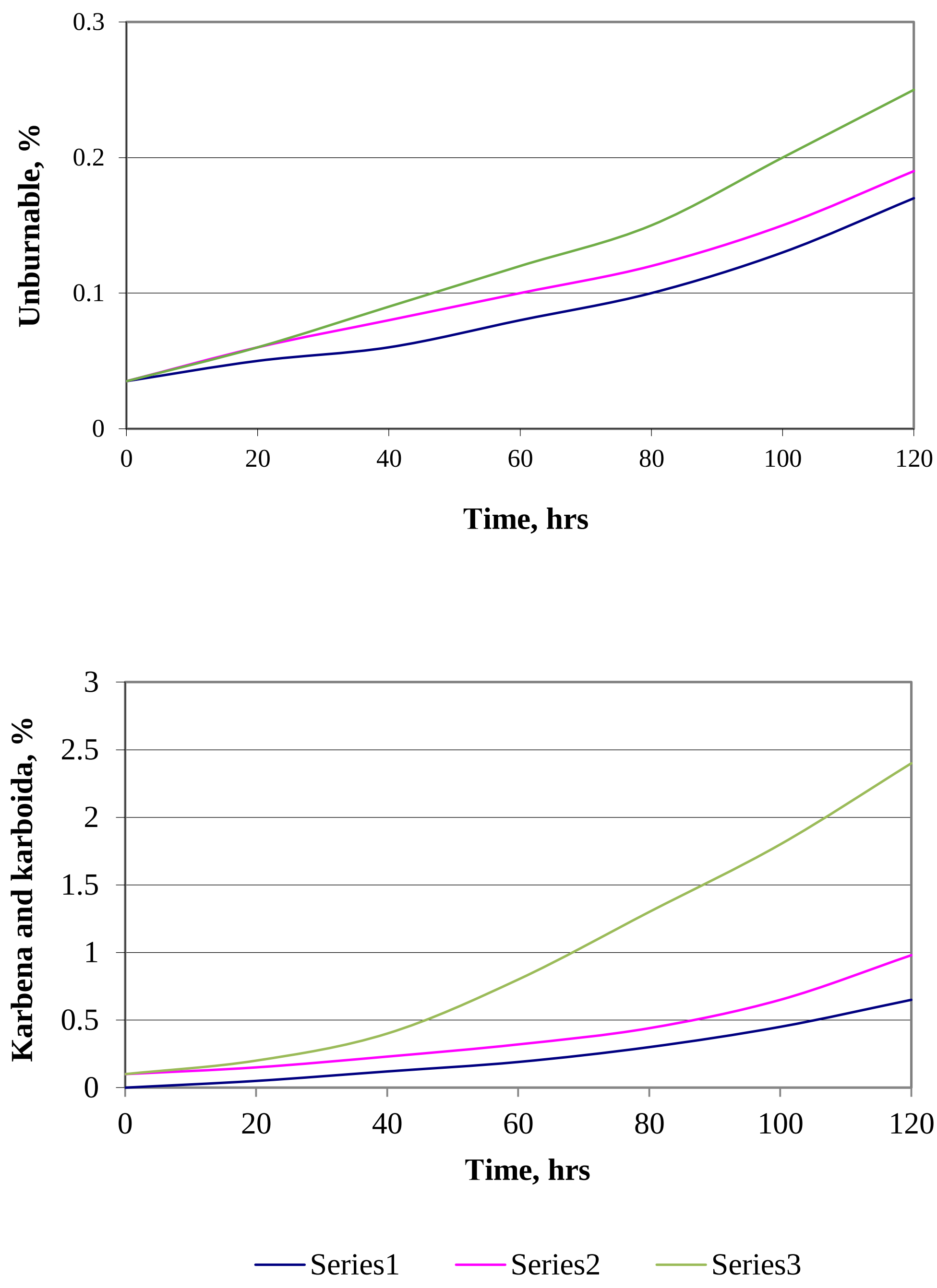
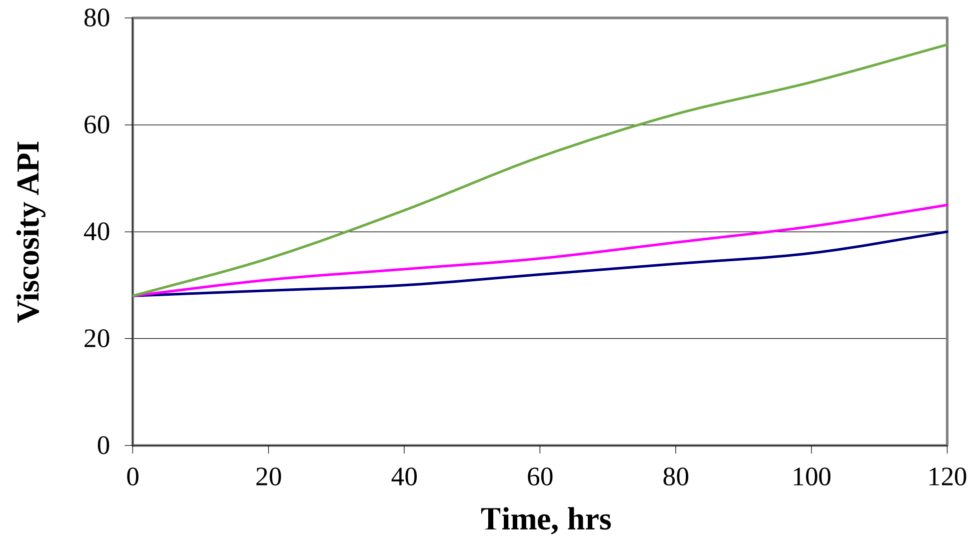


Figure 6.7 Physical and chemical properties of the oil, PFM 1-2 series 1-2, DC 0.9 series 3



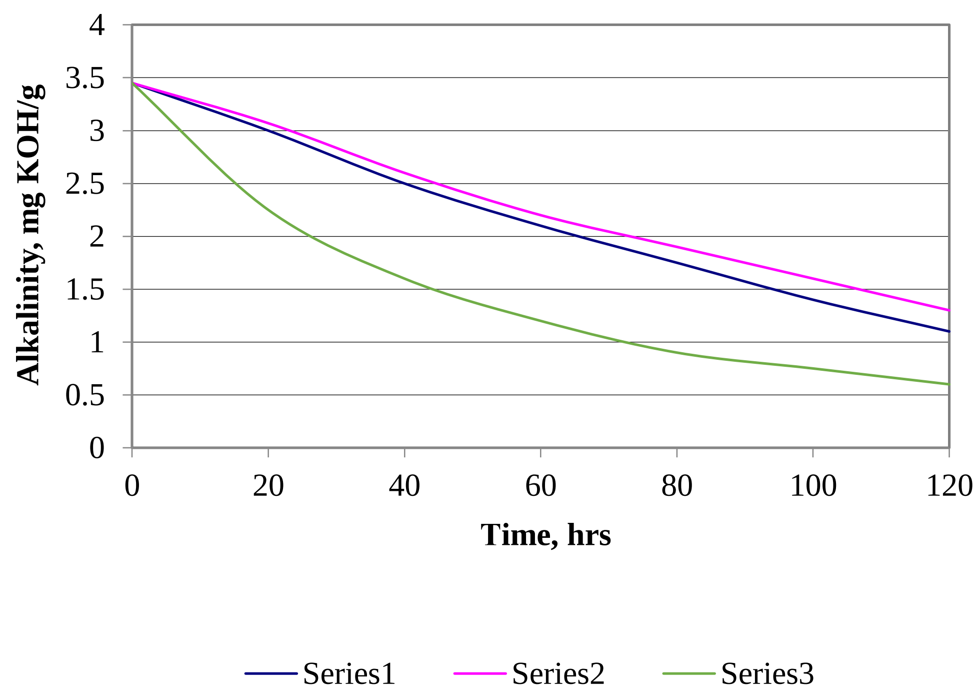


Figure 6.8 Physical and chemical properties of the oil, PFM 1-2 series 1-2, DC 0.9 series 3

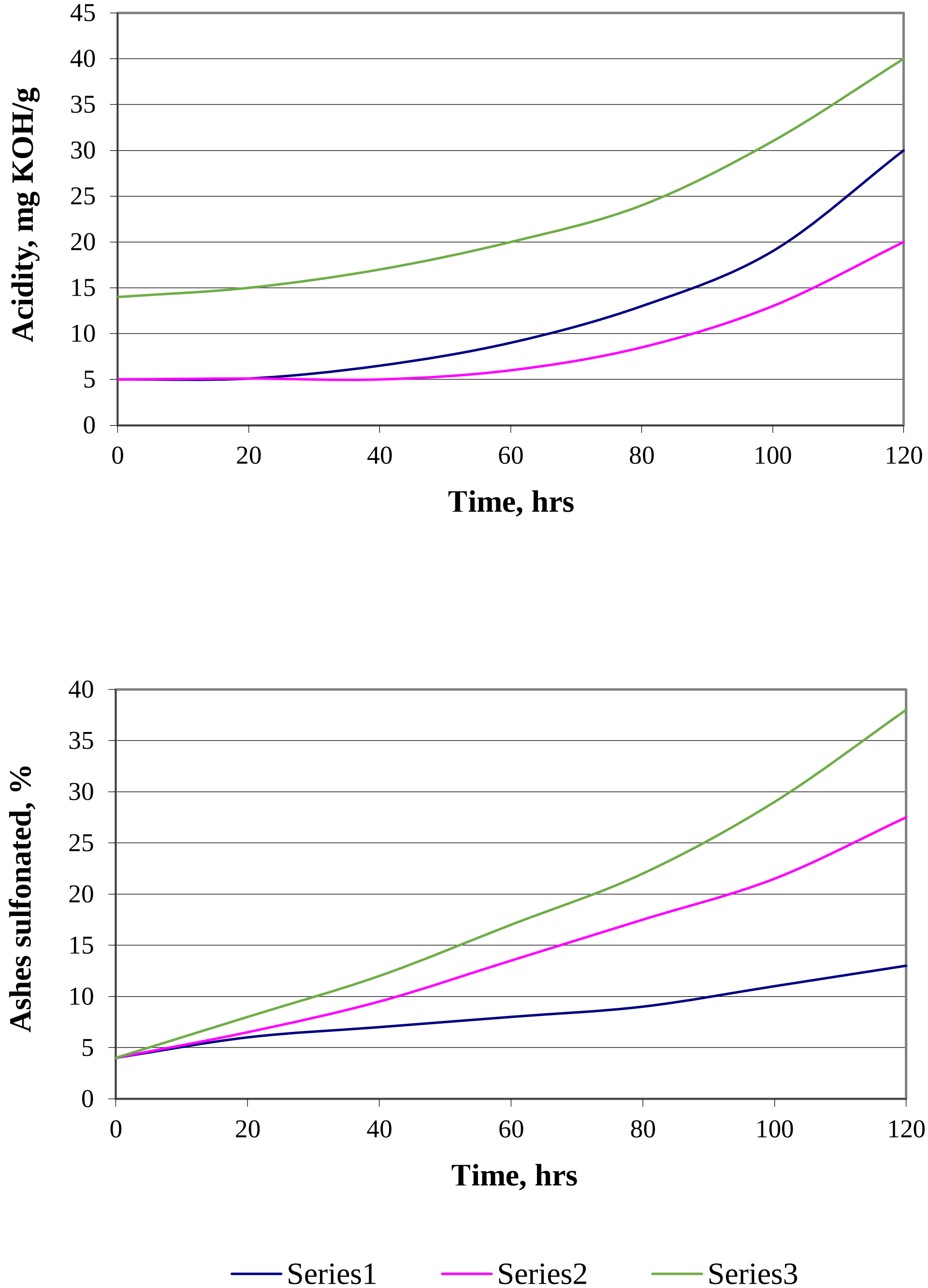


Figure 6.9 Physical and chemical properties of the oil, PFM 1-2 series 1-2, DC 0.9 series 3

The use in the engine of the additional centrifuge along with the full-flow filter reduced the content of total contamination impurity and maximum concentration of total contamination impurity in the Premium Blue SAE 15W-40 oil of the Cummins ICB e-4 diesel engine equipped with the additional by-pass filter and the centrifuge did not exceed 4,5% (figure 6.5). Tests with the use of the only full-flow filter in the engine showed content of total contamination impurity reached 5,5%, significantly more than provided by the combined system. An increase in concentration of contamination impurity in the oil with regular and polymer systems with by-pass filters incurred evenly.

The content of oxyacids in the oil is significant when using only FFF and reaches 0,7%. When using FFF+CF reached 0,4%, and using FFF+BPF reached 0,55%.

The content of asphaltenes when using only FFF reached 3,5%, when using FFF+CF reached 3,3%, and FFF+BFF reached 2,8%.

The content of carbenes, carboides and incombustibles when using only FFF reaches 3,8%, when using FFF+CF reached 1,3%, and FFF+PBPF reached 0,9%.

The content of unburnables in the oil when using only FFF reached 0,5%, when using FFF+CF, and FFF+BPF is almost identical and reached 0,3%.

The content of carbenes and carboides, which structure is determined by the content of soot, when using only FFF reached 4,5%, when using FFF+CF reached 0,9%.

The viscosity of the oil with an increase in the length of tests considerably increased with FFF after 80 hours of tests reached 11,5 API. With increased length of tests incurred an intensive increase in the viscosity of the oil. When using FFF+CF and FFF+BPF for 120 hours of tests, the viscosity of the oil increased to 10,6 API and 10,5 API respectively.

The alkalinity of the oil during tests decreased and on completion of tests when using only FFF reached 0,5 mg KOH/g, and when using FFF+CF and FFF+BPF 1,3-

1,4 mg KOH/g. respectively. The acidity of the oil with an increase in the length of tests continuously increased and when using only FFF reached after 120 hours 2,5 mg KOH/g, when using FFF+CF and FFF+BPF - 2,1 and 1,5 mg KOH/g. respectively. The content of sulphatic ashes when using only FFF reached 0,9% when using FFF+CF and FFF+BPF - 0,68 and 0,77% respectively.

6.2.1.2 Quantity of deposits retained by filters and their component structure

In table 6.5 shown the quantity of deposits retained by filters of tested oil filtration systems on completion of tests. It is visible that the largest quantity of deposits is held by the centrifuge (CF) and the by-pass filter (BPF), while the dry phase of total contamination impurity in CF comprised about 50%, in BPF 25%, in the full-flow filter (FFF) 20%.

Table 6.5

Quantity of deposits retained by filters and centrifuges during tests of the engine with various cleaning systems

Parameters	1 stage		2 stage		3 stage
	Regular system		Polymer system (FFF+BPF)		Cleaning system with FFF only
	FFF	CF+BPF	FFF	BPF	FFF
1. Quantity of retained deposits G, g	0,156	0,296	0,171	0,512	0,131
X_0, % (dry phase)	19,4	54,4	17,9	27,3	22,8
2. Component structure of deposits, g					
total content of insoluble impurity	0,031	0,162	0,032	0,142	0,058
oxyacids	0,0034	0,071	0,0036	0,0092	0,0043
asphaltenes	0,0029	0.0049	0,0031	0,0031	0,0051
carbenes, carboides and unburnables	0,250	0,150	0,025	0,103	0,049

6.2.1.3 Efficiency of operation of oil filters

For the assessment of efficiency of operation of oil filters and filtration systems were defined:

- balance of contamination impurity found in the oil and retained by filters, both total contamination impurity and their components;
- coefficient of oil filtration by filters and cleaning systems from total contamination impurity and their components;
- service life of filter elements of full-flow filters and service life of the oil;
- impurity of piston group (various deposits);
- wear of moving parts of the engine.

The balance of total contamination impurity and their components found in the oil and retained by filters during tests shown in table 6.6-6.11 and the coefficient value of coefficient of oil filtration of various filters and systems shown in table 6.12.

The quantity of contamination impurity (total and their components entered engine oil and retained by filters) is determined by the equation:

$$\mathbf{g_1 = g_{м} + g_{уг} + g_{п} + g_{3\Sigma}}$$

The coefficient of oil filtration provided by the filter during tests is determined as:

$$K_i = \frac{g_{3i}}{g_1}$$

where g_{3i} - quantity of retained contamination impurity by an i - cleaner during tests. The coefficient of the oil filtration system of filters is expressed as following:

$$K_\Sigma = \frac{g_{3\Sigma}}{g_1}$$

where $g_{3\Sigma}$ - quantity of the contamination impurity retained by filters during tests.

Table 6.6

Balance of total contamination impurity in engines using various oil filtration systems

No.	Designation and parameter unit of measure	1 stage		2 stage		3 stage
		Regular system		Polymer system (BPF instead of CF-BPF)		Cleaning system without BPF and CF-BPF
		FFF	CF-BPF	FFF	BPF	FFF
1	X_0, %	2,61		2,61		2,61
2	$X_к$, %	4,6		4,3		5,3
3	X_{cp}, %	5,3		3,21		3,9
4	$G_м$, kg	20		20		20
5	$g_м$, kg	0,439		0,377		0,586
6	G_{yg}, kg	13,14		16,27		12,33
7	g_{yg}, kg	0,103		0,12		0,16
8	G_p, kg	1,49		1,49		1,31
9	G_p, kg	0,011		0,098		0,107
10	G_f, dry kg	0,64	-	0,644	0,407	0,644
11	G_f, mixed in oil	1,33	-	1,362	1,766	1,354
12	G_{f3}, after tests	1,496	-	1,549	2,279	1,583
13	G_3, (contaminated)	0,156	0,296	0,171	0,512	0,256
14	X_3, %	20,3	54,4	17.9	27,4	22.9
15	g_3, kg	0,031	0,161	0,03	0,14	0,06
16	$g_3 \Sigma$, kg	0,193		0,071		0,058
17	g_1, kg	0,751		0,669		0,834
18	g_1, g/hour	5,95		5,31		7,58
19	K_i, %	4,25	21,4	4,58	21,1	7,02
20	$K \Sigma$, %	25,75		25,5		7,02

Parameters given in tables:

X_0 and $X_к$ - concentration of contamination impurity in engine oil before and after tests;

$G_м$, G_{yg}, $G_п$ - the weight of the oil being in crankcase, burned and taken during tests;

g_{yg} - quantity of the contamination impurity found in engine oil during tests;

g_{yg} - quantity of contamination impurity in burned-down engine oil;

g_p - quantity of contamination impurity in samples of engine oil;

X_{cp} - average concentration of contamination impurity in engine oil during tests;

X_3 - concentration of dry phase of contamination impurity;

G_3 - quantity of products of contamination retained by filters and centrifuges during tests;

g_3, g_{3_Σ} - quantity of contamination impurity (dry phase) retained by each cleaner; all cleaners together;

g_1 - total quantity of contamination impurity entered engine oil of the engine during tests:

$$\mathbf{g_1=g_м+g_{уг}+g_п+g_3}$$

Table 6.7

Balance of oxyacids in Cummins ISB e-4 engine with various oil filtration systems

No	Designation and parameter unit of measure	1 stage		2 stage		3 stage
		Regular system		Polymer system (BPF instead of CF-BPF)		Cleaning system without BPF and CF-BPF
		FFF	CF-BPF	FFF	BPF	FFF
1	X_0, %	0,11		0,11		0,11
2	$X_к$, %	0,32		0,51		0,53
3	X_{cp}, %	0,21		0,27		0,43
4	$G_м$, kg	20,9		20,9		20,9
5	$g_м$, kg	0,041		0,083		0,091
6	G_{yg}, kg	13,14		16,27		12,33
7	g_{yg}, kg	0,028		0,045		0,053
8	G_p, kg	1,49		1,49		1,31
9	G_p, kg	0,002		0,003		0,05
10	G_f, dry kg	0,64	-	0,694	0,407	0,644
11	G_f, mixed in oil	1,33	-	1,378	1,766	1,354
12	G_{f3}, after tests	1,49	-	1,551	2,281	1,583
13	G_3, (contaminated)	0,156	0,296	0,171	0,512	0,256
14	X_3, %	2,23	2,42	2,12	1,79	1,71
15	g_3, kg	0,0034	0,0071	0,0035	0,0092	0,0043
16	$g_3 \Sigma$, kg	0,0106		0,0126		0,0043
17	g_1, kg	0,0848		0,1468		0,1565
18	g_1, g/hour	0,673		1,165		1,423
19	K_i, %	4,11	8,44	2,44	6,18	2,82
20	$K \Sigma$, %	12,5		8,63		2,82

Table 6.8

Balance of asphaltenes in Cummins ISB e-4 engine with various oil filtration systems

No.	Designation and parameter unit of measure	1 stage		2 stage		3 stage
		Regular system		Polymer system (BPF instead of CF-BPF)		Cleaning system without BPF and CF-BPF
		FFF	CF-BPF	FFF	BPF	FFF
1	X_0, %	2,25		2,21		2,2
2	$X_к$, %	2,98		2,91		3,1
3	$X_{ср}$, %	2,5		2,4		2,6
4	$G_м$, kg	0,213		20		20
5	$g_м$, kg	0,154		0,146		0,188
6	G_{yg}, kg	13,14		16,27		12,33
7	g_{yg}, kg	0,323		0,406		0,332
8	G_p, kg	1,51		1,51		1,31
9	G_p, kg	0,038		0,037		0,035
10	G_f, dry kg	0,64	-	0,644	0,407	0,644
11	G_f, mixed in oil	1,33	-	1,362	1,766	1,354
12	G_{f3}, after tests	1,54	-	1,549	2,281	1,583
13	G_3, (contaminated)	0,156	0,298	0,171	0,512	0,256
14	X_3, %	2,17	1,75	1,51	5,37	1,79
15	g_3, kg	0,002	0,004	0,002	0,002	0,004
16	$g_3 \Sigma$, kg	0,007		0,005		0,004
17	g_1, kg	0,544		0,596		0,562
18	g_1, g/hour	4,32		4,73		5,12
19	K_i, %	0,061	0,953	0,435	4,68	0,81
20	$K \Sigma$, %	1,03		5,12		0,81

Table 6.9

Balance of deposit from carbenes and carboides in Cummins ISB e-4 engine with various oil filtration systems

No.	Designation and parameter unit of measure	1 stage		2 stage		3 stage
		Regular system		Polymer system (BPF instead of CF-BPF)		Cleaning system without BPF and CF-BPF
		FFF	CF-BPF	FFF	BPF	FFF
1	X_0, %	0,24		0,14		0,24
2	$X_к$, %	1,02		0,81		2,3
3	$X_{ср}$, %	0,3		0,2		1,12
4	$G_м$, kg	20		20		20
5	$g_м$, kg	0,157		0,1364		0,451
6	G_{yg}, kg	13,14		16,27		12,33
7	g_{yg}, kg	0,052		0,039		0,135
8	G_p, kg	1,49		1,49		1,31
9	G_p, kg	0,005		0,004		0,014
10	G_f, dry kg	0,64	-	0,644	0,407	0,644
11	G_f, mixed in oil	1,33	-	1,362	1,766	1,354
12	G_{f3}, after tests	1,49	-	1,551	2,281	1,583
13	G_3, (contaminated)	0,156	0,298	0,171	0,512	0,256
14	X_3, %	13,12	33,28	11,7	18,04	17,1
15	g_3, kg	0,02	0,098	0,0202	0,092	0,0436
16	$g_3 \Sigma$, kg	0,1194		0,1128		0,0436
17	g_1, kg	0,335		0,293		0,645
18	g_1, g/hour	2,6		2,2		5,8
19	K_i, %	6,92	29,43	6,92	31,51	6,76
20	$K \Sigma$, %	35,56		38,42		6,76

Table 6.10

Balance of deposit from carbenes, carboides and unburnables in Cummins ISB e-4 engine with various oil filtration systems

No:	Designation and parameter unit of measure	1 stage		2 stage		3 stage
		Regular system		Polymer system (BPF instead of CF-BPF)		Cleaning system without BPF and CF-BPF
		FFF	CF-BPF	FFF	BPF	FFF
1	X_0, %	0,29		0,21		0,32
2	$X_к$, %	1,1		1,2		2,5
3	$X_{ср}$, %	0,48		0,39		1,3
4	$G_м$, kg	20		20		20
5	$g_м$, kg	0,188		0,167		0,482
6	G_{yg}, kg	13,14		16,27		12,33
7	g_{yg}, kg	0,065		0,064		0,147
8	G_p, kg	1,49		1,49		1,31
9	G_p, kg	0,007		0,005		0,015
10	G_f, dry kg	0,64	-	0,694	0,407	0,644
11	G_f, mixed in oil	1,35	-	1,378	1,766	1,354
12	G_{f3}, after tests	1,49	-	1,549	2,281	1,583
13	G_3, (contaminated)	0,156	0,298	0,171	0,512	0,256
14	X_3, %	15,95	50,37	14,3	20,32	19,47
15	g_3, kg	0,0252	0,1495	0,024	0,103	0,051
16	$g_3 \Sigma$, kg	0,1746		0,1289		0,051
17	g_1, kg	0,437		0,367		0,696
18	g_1, g/hour	3,46		2,91		6,33
19	K_i, %	5,72	34,15	6,73	28,33	7,18
20	$K \Sigma$, %	39,88		35,07		7,18

Table 6.11

Balance of unburnables in Cummins ISB E-4 engine with various oil filtration systems

No:	Designation and parameter unit of measure	1 stage		2 stage		3 stage
		Regular system		Polymer system (BPF instead of CF-BPF)		Cleaning system without BPF and CF-BPF
		FFF	CF-BPF	FFF	BPF	FFF
1	X_0, %	0,11		0,11		0,09
2	$X_к$, %	0,19		0,19		0,02
3	$X_{ср}$, %	0,12		0,12		0,14
4	$G_м$, kg	20		20		20
5	$g_м$, kg	0,022		0,022		0,045
6	G_{yg}, kg	13,14		16,27		12,33
7	g_{yg}, kg	0,016		0,022		0,018
8	G_p, kg	1,49		1,49		1,31
9	G_p, kg	0,0018		0,0018		0,003
10	G_f, dry kg	0,64	-	0,644	0,407	0,644
11	G_f, mixed in oil	1,33	-	1,362	1,766	1,354
12	G_{f3}, after tests	1,54	-	1,551	2,279	1,583
13	G_3, (contaminated)	0,156	0,298	0,171	0,512	0,256
14	X_3, %	2,84	17,08	2,59	2,27	2,49
15	g_3, kg	0,0044	0,052	0,0044	0,0116	0,0063
16	$g_3\Sigma$, kg	0,0552		0,0161		0,0063
17	g_1, kg	0,094		0,059		0,072
18	g_1, g/hour	0,68		0,43		0,69
19	K_i, %	4,73	53,46	7,49	19,4	8,71
20	$K\Sigma$, %	58,22		27,02		8,76

From the obtained tests data it is evident that largest quantity of the total contamination impurity and their components is retained by combined cleaning systems (FFF+CF and FFF+BPF). Thus, the coefficient of oil filtration from the total contamination impurity during tests of the FFF+BPF system comprised 26%, and the FFF+BPF system comprised 25%, the system consisting of one full-flow filter, has the coefficient of filtration 7%. Regarding other components of contamination impurity, approximately the same parameters were recorded, except for unburnables retained by combined filtration systems and therefore the coefficient of filtration from unburnables, which have considerably higher density (1;2) than other components, when using the centrifuge (CF) is twice more, than when using the by-pass filter (BPF) as a result of selective capacity of centrifuges related not only to the sizes, but also density of contamination particles.

In figure 6.10 shown dependence of drop of pressure in the full-flow filter (FFF) on length of tests of the engine when using only one FFF, and when using combined systems (FFF+CF and FFF+BPF). It is noticeable that when using the combined oil filtration system the resource of filter elements is 200% more, than when using only one full-flow filter. Due to technical characteristics of the centrifuge large part of the contamination impurity is kept by the centrifuge (CF) and also the by-pass filter (BPF) and that enables to improve efficiency of operation of the full-flow filter and additionally achieve a reduction of depletion of additives in the oil when using combined systems, resulting in less probability of coagulation of particles.

In table 6.13 given the impurity of pistons of the engine when using various oil filtration systems. It is noticeable that when using combined filtration systems FFF+BPF and FFF+CF the impurity of pistons 1.4 and 1.6 times respectively less than when using only one full-flow filter (FFF).

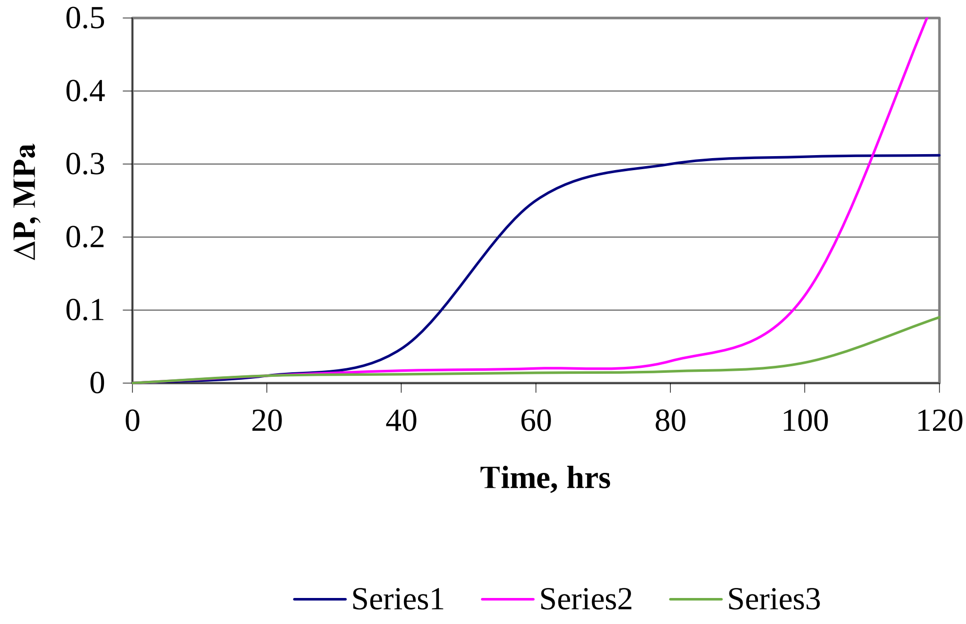


Figure 6.10 Dependence of drop of pressure in the full-flow filter (FFF) on length of tests of the engine, PFM 1-2 series 1-2, DC 0.9 series 3

Table 6.12

Coefficient of oil filtration

Component structure of contamination	Value of coefficient of oil filtration				
	1 stage		2 stage		3 stage
	FFF	BPF	FFF	BPF	FFF
Total contamination impurity	4,25	21,4	4,5	21,1	7,0
	25,65		25,6		
Oxyacids	4,11	8,47	2,44	6,18	2,8
	12,58		8,62		
Asphaltenes	0,061	0,953	0,43	4,68	0,8
	1,014		5,11		
Carbenes, carboides and unburnables	5,72	34,15	6,73	28,33	7,2

Table 6.13

Impurity of pistons of the engine (in points)

Parameter designation	1 stage	2 stage	3 stage
	Regular system	Polymer system BPF and CF-BPF	Regular system without BPF and CF-BPF
	120 hours	120 hours	110 hours
Mobility of rings ΣQ	0,05	0	2,1
Total impurity of flutes ΣQ	1,71	1,91	2,2
Total impurity of crossing points ΣQ	0,07	0,21	0,21
Impurity of skirt of the piston Q	4,46	4,58	4,74
Impurity of internal surface of head Q	0,068	0,21	0,79
Total score of extent of pollution of piston Q	6,3	6,8	9,8

Table 6.14

Wear of rings by weight, g

Stage of tests	Number of ring		
	1	2	3
1 Regular system (FFF-BPF)	0,102	0,0546	0,0633
2 Polymer system (PPF-BPF)	0,102	0,0475	0,0793
3 Regular system without BPF and CF-BPF	0,145	0,0635	0,22

Table 6.15

Wear of inserts of bearings (thickness) micron

Stage of tests	Crankshaft journal		Rod journal	
	top	bottom	top	bottom
1. Regular system (FFF-BPF)	1,69	10,2	2,86	1,72
2. Polymer system (FFF-BPF)	2,69	9,65	3,55	1,87
3. Regular system without BPF and CF-BPF	7,2	14,84	11,1	6,05

Table 6.16

Wear of necks of cranked shaft, micron

Shaft necks	Stage of tests		
	1	2	3
rod journal	within the accuracy of measurement		9,35
crankshaft journal	within the accuracy of measurement		15,8

Table 6.17

Wear of sleeves of cylinders, micron

Depth of belt, mm	Stage of tests		
	1	2	3
24,6	5,03	5,72	18,2
34	1,92	2,02	6,53
44	2,47	2,45	13,12

Based on the analysis of physical and chemical characteristics of tested engine oil, including total contamination impurity and their components, alkalinity, sulphatic ash-content, viscosity, balance of contamination impurity, coefficients of oil filtration during tests, service life of filter elements before reaching their limit of contamination and impurity of pistons, it was concluded that in operation the service life of the oil when using the combined cleaning system (FFF+CF and FFF+BPF) is twice longer, than when using only one full-flow filter (FFF).

In table 6.15-6.18 given data obtained from engine bench tests in relation to the wear of engine parts, data was obtained after 120 hours of tests using various filtration systems. It is visible that when using combined polymer filtration systems FFF+BPF and FFF+CF the wear of engine parts considerably decreased.

6.2.2 Engine tests of VW 1.2 TSI with various oil filtration systems

Comparative engine tests of various oil filtration systems were carried out in collaboration with the author on the VW 1.2 TSI engine using the full-flow paper filter and the combined polymer filter consisting of the by-pass polymer filter element designed in the form of the two layer filter element. Technical specification of the engine VW 1.2 TSI used for laboratory tests of combined oil filtration systems is described below:

Basic data of the engine VW 1.2 TSI

Petrol engine:	VW 1.2 TSI, water cooling
Bore:	71.0 mm
Stroke:	75.6 mm

Cylinder number, arrangement:	4 - straight
Bore/stroke ratio	0.94
Valve gear	single overhead camshaft (SOHC) 2 valves per cyl.
Compression ratio ε:	10:1
Rated power of engine:	77 kW/5000 rpm
Torque of engine max. Mt-ISO:	175 Nm/1500-4100 rpm
Fuel system	direct petrol injection
Injection set:	Common Rail Bosch
Injectors:	Bosch
Aspiration	Turbo
Turbocharger:	with maximum pressure 1.6 bars (23.2 psi)
Capacity	1.2 litre 1197 cc
Engine construction	aluminium alloy block & head sump wet sumped

6.2.2.1 Physical and chemical characteristics of tested engine oil

During the tests of oil filters samples of the oil were taken from the crankcase of the VW 1.2 TSI petrol engine for laboratory analysis of oil samples, carried out in accordance with ASTM standards.

Samples of the oil were taken by a technician every 20 hours at equal intervals: 20hrs, 40hrs, 60hrs, 80hrs, 100hrs, 120hrs and on completion of tests of three fuel filtration systems tested 1 paper and 1 polymer oil filters were removed by a technician for further laboratory analysis of oil filters and also analysis of retained by filter media (paper and polymer) contaminants.

On completion of the bench engine tests a technician also removed moving parts from the engine for the laboratory analysis in relation to the wear tests of parts.

In figure 6.10 shown images of the combined polymer filter with the incorporated polymer by-pass element. Results of the laboratory analysis of tested samples of the oil shown in figure 6.11-6.15 with following references: Series 1 - standard oil filtration system with a paper filter, Series 2 – combiner oil filtration system with a polymer by-pass filter.

The application of the combined polymer filter in the engine reduced the content of total insoluble contamination impurity. The maximum concentration of the contamination impurity in the crankcase of the engine equipped with the combined polymer filter comprised 4,1% after 100 hours of operation of the engine. After 60 hours of operation of the engine with the regular oil filtration system the concentration of the contamination impurity comprised 3,9% and after 80 hours of operation of the engine increased to 4,7%. In figure 6.16 given the dependence of drop of pressure of engine oil of the polymer full-flow filter and consumption of the oil through the polymer by-pass filter on length of operation of the engine.

6.2.2.2. Quantity of deposits retained by filters and analysis of overall performance of oil filtration systems

The component composition of the Premium Blue SAE 15W-40 oil and the contamination impurity retained by polymer full-flow and polymer by-pass filters given in table 6.18.

Table 6.18

Component composition of Premium Blue SAE 15W-40 oil and sludge from filters

Sample name	Operation time hours	Content of components, %						
		oil	oxyacid	asphaltenes	resins	Sludge		
						Total	carbenes, carboides	unburnables
Oil	90	96,5	1,24	1,49	0,12	0,54	0,29	0,24
FFF	90	82,4	1,28	0,67	1,1	14,4	11,2	3,1
BPF	90	71,8	2,12	2,2	-	1,1	18,2	4,3

(1) Inner and outer layer *(2) Arrangement of filtering elements*

Figure 6.11 Images of combined polymer filters with polymer by-pass element

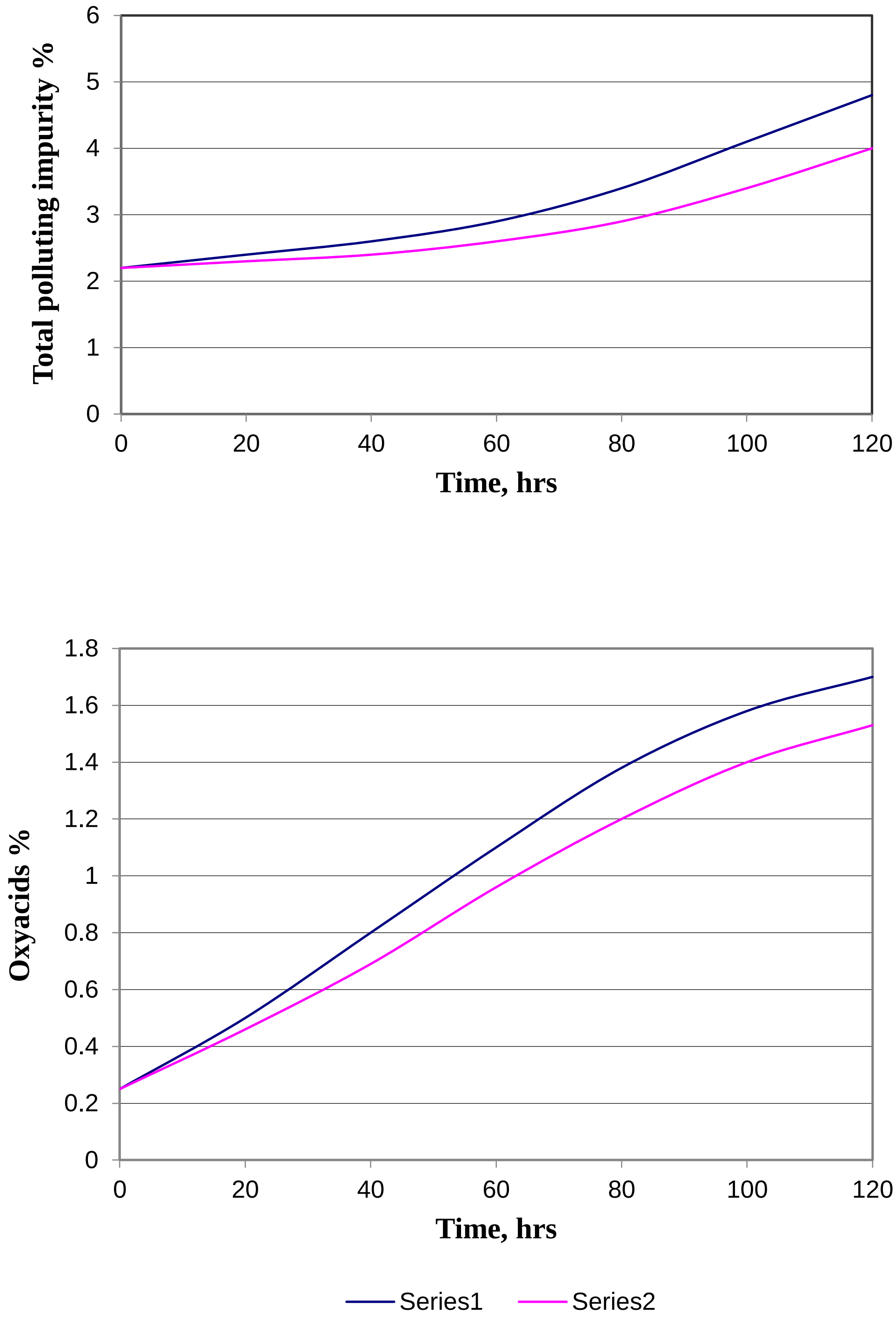


Figure 6.12 Physical and chemical properties of the oil, PFM 1 series 1, DC 0.9 series 2

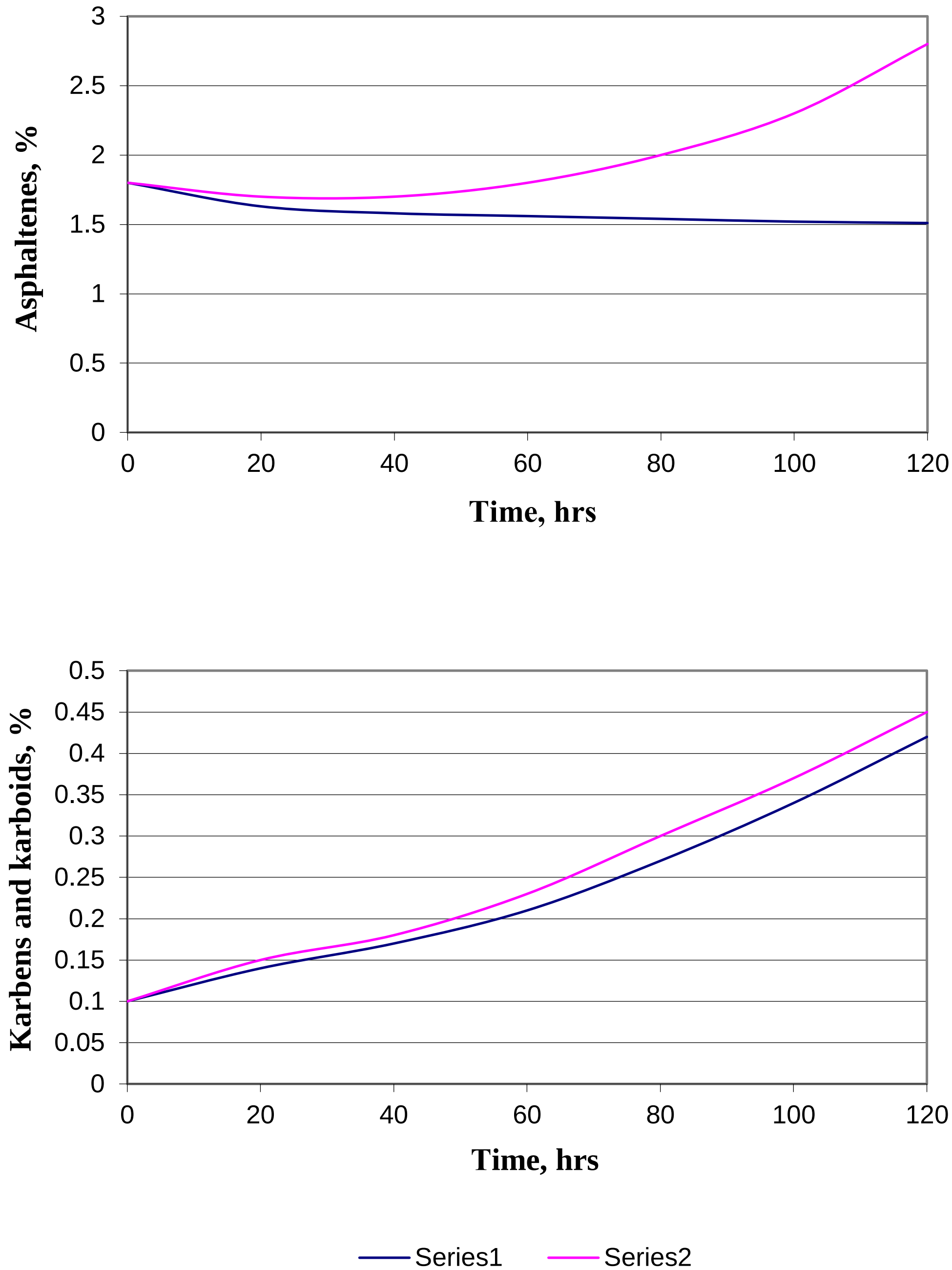
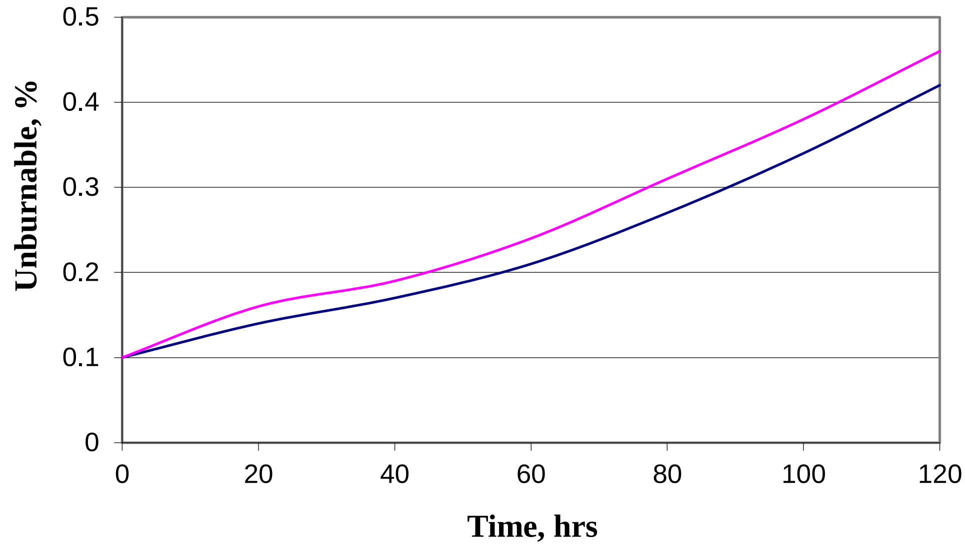


Figure 6.13 Physical and chemical properties of the oil, PFM 1 series 1, DC 0.9 series 2



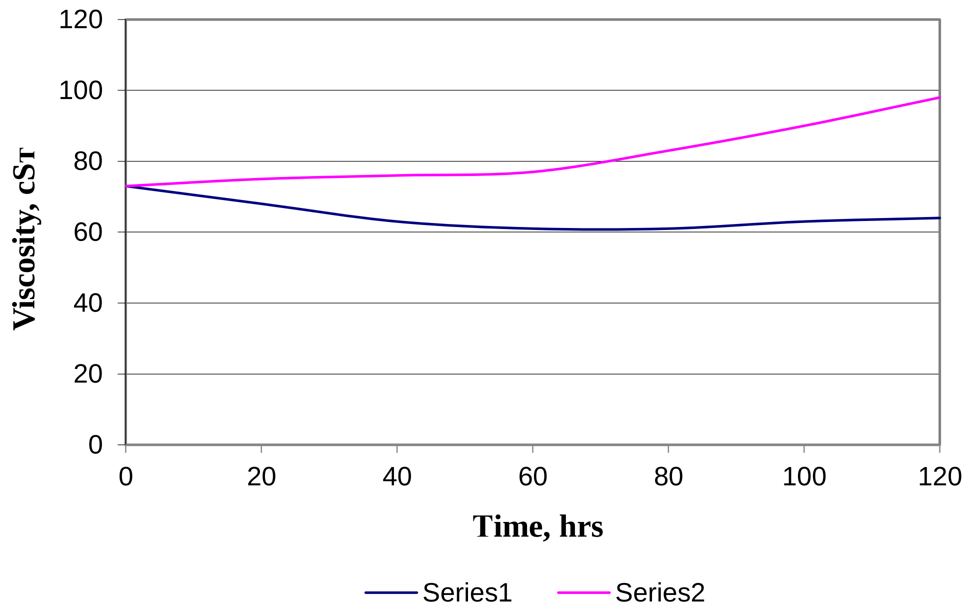


Figure 6.14 Physical and chemical properties of the oil PFM 1 series 1, DC 0.9 series 2

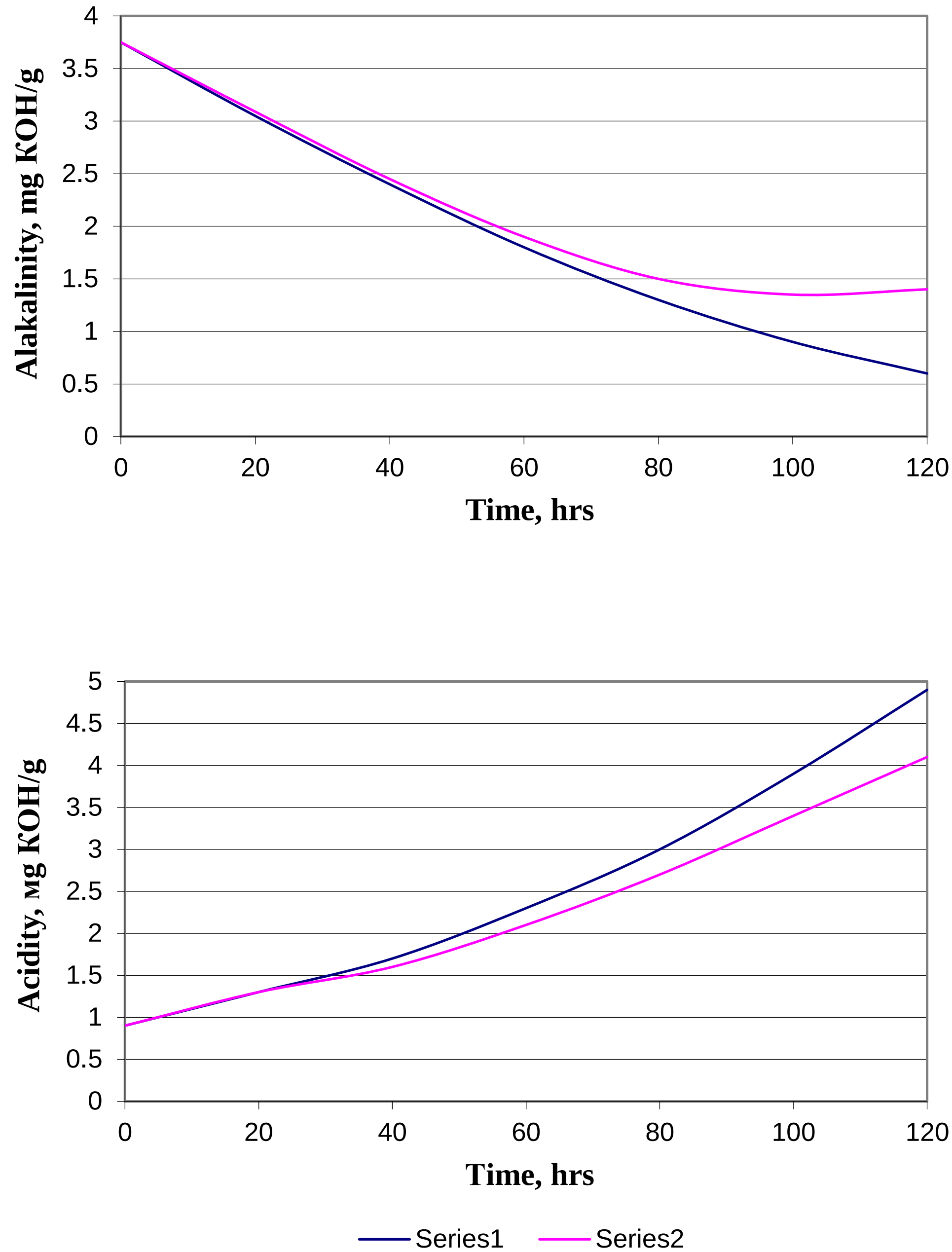


Figure 6.15 Physical and chemical properties of the oil PFM 1 series 1, DC 0.9 series 2

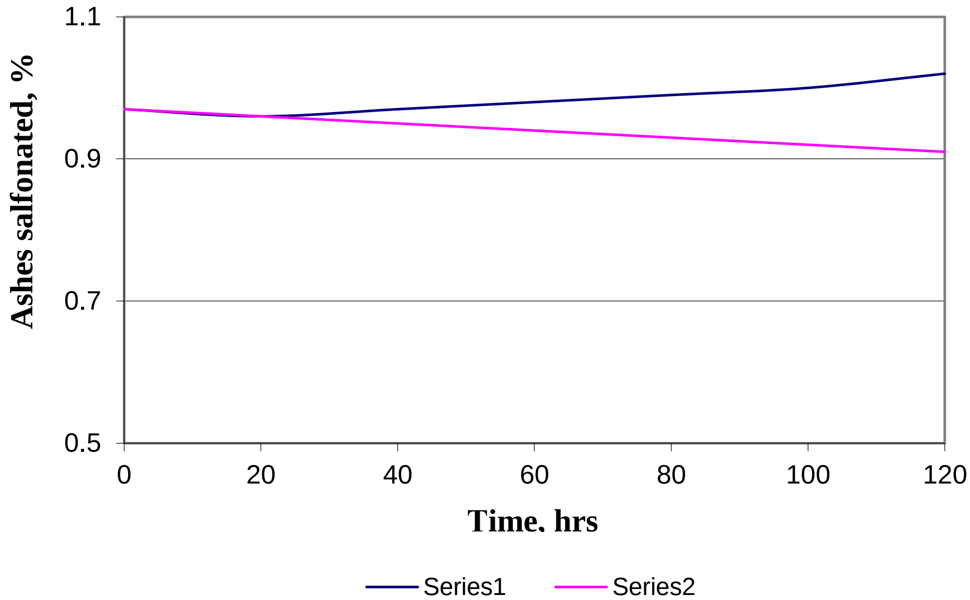


Figure 6.16 Physical and chemical properties of the oil, PFM 1 series 1, DC 0.9 series 2

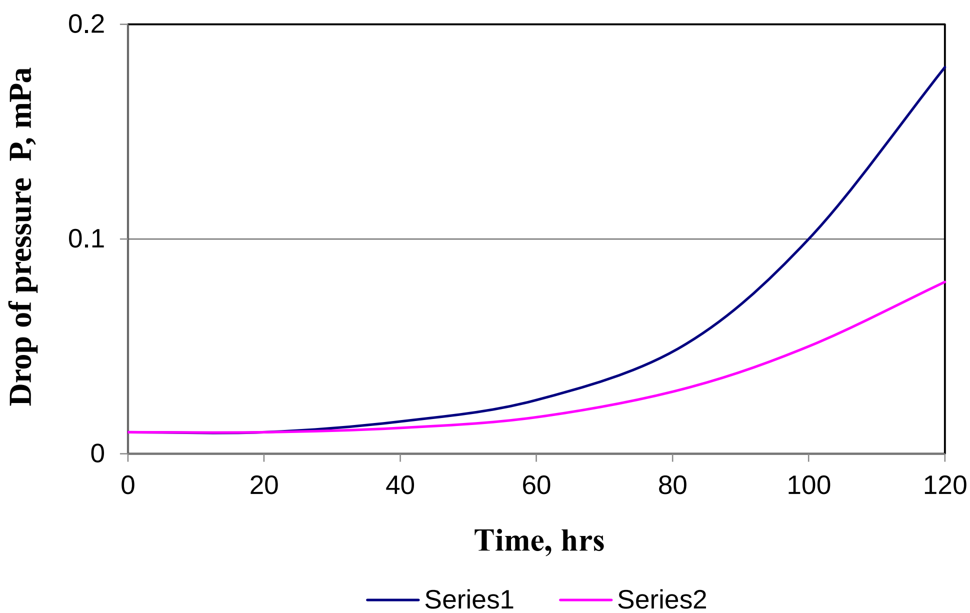


Figure 6.17 Dependence of drop of pressure in full-flow filter on length of tests of VW engine, PFM 1 series 1, DC 0.9 series 2

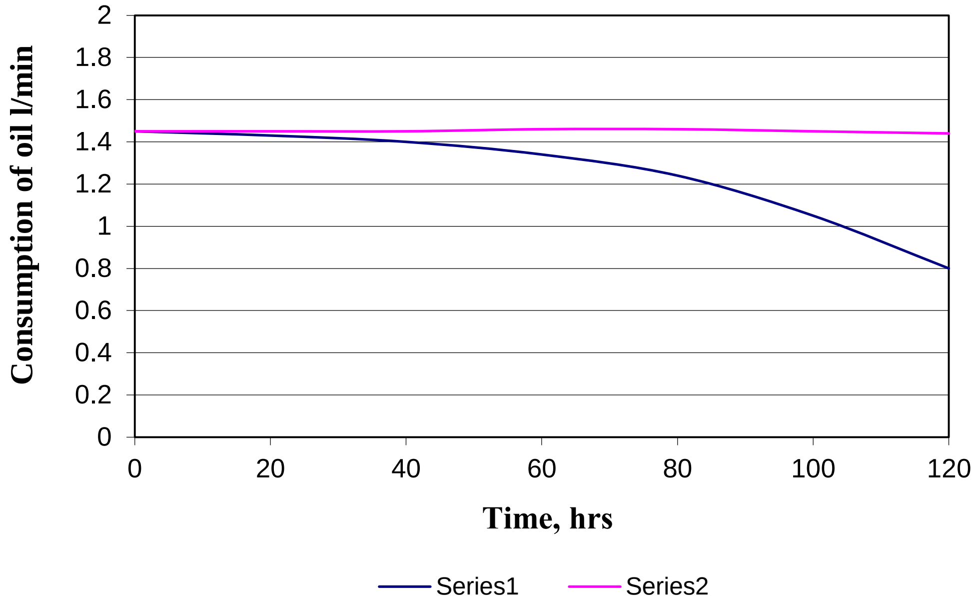


Figure 6.18 Dependence of consumption of oil through by-pass filter on length of tests of VW engine, PFM 1 series 1, DC 0.9 series 3

For the assessment of efficiency of operation of filters and filtration systems the balance of the total contamination impurity found in the oil, retained by the filters, burned and taken with samples of the oil for laboratory tests was determined.

The balance of the total contamination impurity found in the oil of the engine and retained by filters during tests using various filters and their systems along with values of coefficient of the oil filtration provided by various filters and their systems given in table 3.2.

The quantity of contamination impurity found in the oil is determined by the equation:

$$\mathbf{g_1=g_{м} + g_{yg} + g_p + g_{з}}$$

The coefficient of oil filtration during tests is defined by the filter as following:

$$K_i = \frac{g_{3i}}{g_1}$$

where g_{3i} - quantity of retained contamination impurity given by i - cleaner during tests.

Then coefficient of oil filtration system of filters is defined as following:

$$K_\Sigma = \frac{g_{3\Sigma}}{g_1}$$

where $g_{3\Sigma}$ - quantity of the contamination impurity retained by system of filters during tests.

From data collected in during the work carried out for this thesis, it is evident that the largest quantity of total contamination impurity was retained when using combined oil filtration systems, while coefficient of oil filtration of the full-flow filter comprised 7% when using the regular system and when using the combined oil filtration system comprised 3.5%. However total coefficient of oil filtration when using the combined filtration system comprised 25.% as a result of high coefficient 23% of oil filtration provided by the by-pass filter. The impurity of parts of piston group of the engine is given in table 6.20 when using various oil filtration systems. It is visible that the use of the polymer combined oil filtration system reduced total impurity of engine pistons.

In table 6.21-6.25 data provided in relation to the wear of moving parts of the engine using various oil filtration systems, these systems were used during 120 hours of engine tests. It is evident that the use of the combined polymer oil filtration system instead of the regular paper oil filtration system allows to achieve a significant reduction of the wear of engine moving parts by up to 3 times.

Table 6.19

Balance of total contamination impurity in the engine with various oil filtration systems

Designation and parameter unit of measure	Regular system	Polymer combined system	
	80 hours of test	90 hours of test	
	FFF	FFF	BPF
X_0, %	2,27	2,27	
$X_к$, %	4,59	4,12	
$X_{ср}$, %	3,12	2,89	
$G_м$, kg	9,1	9,1	
$g_м$, kg	0,206	0,161	
G_{yg}, kg	3,47	4,09	
g_{yg}, kg	0,031	0,011	
G_{pr}, kg	0,709	0,61	
G_p, kg	0,004	0,016	
G_f, dry kg	0,324	0,301	0,214
G_f, mixed kg	0,614	0,492	0,283
G_f, after tests, kg	0,712	0,542	0,494
G_3, kg	0,97	0,051	0,212
X_3, %	19,4	17,4	28,14
g_3, kg	0,018	0,0087	0,058
g_3	0,018	0,067	
g_1, kg	0,262	0,258	
g_1, g/hour	3,25	2,87	
K_i, %	7,25	3,3	22,7
K_Σ, %	7,25	26,1	

Table 6.20

Impurity of piston group parts of VW 1.2 TSI engine with various oil filtration systems

Name of the parameter	Oil filtration systems	
	Regular System (FFF) 80 hours of tests	Polymer combined system 90 hours of tests
Degree of mobility of rings	0,92	0,71
Impurity of piston flutes	1,84	1,61
Impurity of piston crossing points	1,03	0,83
Impurity of skirt of piston	0,52	0,32
Impurity of internal surface of head of piston	1,21	0,96
Total impurity of the piston	5,47	4,41

Table 6.21

Average wear of piston rings on radial thickness, micron

Stage of tests	Number of ring		
	1	2	3
1. Regular system used for 100 hrs	28,9	55,7	48,7
2. Combined system with polymer filter used for 100 hrs	18,2	31,4	27,2

Table 6.22

Average wear of piston rings by weight, g

Stage of tests	Number of ring		
	1	2	3
1 standard system	0,12	0,23	0,079
2 combined system	0,045	0,185	0,047

Table 6.23

Average wear of sleeves of cylinders, micron

Depth of belt from top of sleeves, mm	Stage of tests	
	1 standard system	2 combined system
10	20,4	11,7
16	15,2	8,8
23	11,3	9,8
45	9,6	6,1
90	9,3	6,8

Table 6.24

Average wear of cranked shaft necks, micron

Shaft necks	Stage of tests	
	1 standard system	2 combined system
rod journal	3,87	2,2
crankshaft journal	6,4	3,2

Table 6.25

Average wear of cranked shaft inserts (thickness) micron

Stage of tests	Crankshaft journal		Rod journal	
	top	bottom	top	bottom
1 standard system	3,1	27,2	18,1	6,29
2 combined system	2,2	13,4	10,2	3,41

6.4. Conclusions

1. The analysis of designs and filter materials of by-pass filters to determine optimum concentration of polymer composition of the outer and inner filtering elements (PVC and PET 10x80%) was carried out. The nominal subtlety of elimination is within 20-26 microns, porosity 77%, and oil consumption through the filter with the throttle 2,0 mm comprised 2,8 l/min.

2. The contaminant retaining capacity of polymer filter elements of the by-pass filters with dimensions of 80x100 mm (DxH) determined using quartz dust and made of the mixture of 2 polymers (PVC/PET) comprised on average 217, operation time before reaching reduction in oil consumption through the filter by 50% comprised 35 hours. The polymer filter elements have satisfactory water resistance and thermal stability.

3. Engine bench tests of combined oil filtration systems using the diesel engine Cummins ISB e-4 demonstrated that coefficient of total contamination impurity, when using various oil filtration systems, comprised 25%, the filtration system consisting of one full-flow paper filter has coefficient of cleaning 7%.

4. Impurity of pistons of the Cummins ISB e-4 engine when using the combined oil filtration system is 1,5 times less, and the wear of moving parts of the engine is up to 2 times less, than when using only the regular full-flow oil filtration system.

5. Engine bench tests of the combined polymer oil filtration system using the petrol VW 1.2 TSI engine, showed that in comparison with the regular oil filtration system there is a decrease in concentration of total contamination impurity by 50% reduction of impurity of parts of piston group by 30% and decrease in the wear of moving parts of the engine by up to 3 times. The coefficient of oil filtration determined from balance of the contamination impurity increased to 25% in comparison with 7% using the regular filtration system.

6. Technical requirements for the combined polymer oil filtration system were developed, the optimum accuracy of elimination of polymer filtering material for full-flow and by-pass filters, based on the existing level of quality of engine oils and high dispersion of the contamination impurity was determined.

Chapter 7 – Conclusions and Further Work

7.1. Conclusions

Based on the analysis of the existing experience it was established that reliable protection of bearings of internal combustion engines is achieved with the use of effective combined oil filtration systems consisting of full-flow filters with high filtering capacity and the by-pass filters or centrifuges with a significant contaminant capacity and efficiency of operation. It was established that the objective assessment of tested oil filtration systems is achieved as a result of their complex research: in laboratory and engine bench and operational conditions. The key findings of this project are summarized as follows:

1. Using methods of mathematical planning of experiments and analysing existing experience in filtration field, researches of polymer and paper filtering materials were conducted in order to determine most effective filtering media for the application in full-flow and by-pass oil filters. The complex of conducted researches provided sufficient data to support a proposed application of polymer filtering material in full-flow oil filters for internal combustion engines.
2. Extensive laboratory and engine bench tests were carried out by the author and data collected in during the work carried out for this thesis on completion of all tests provided sufficient evidence to demonstrate high efficiency of oil filtration provided by a polymer filter media and compare its performance against a paper filter media. Results of bench tests provided the data for each type of the tested engines - diesel and petrol.
3. A novel polymer filter media for the combined oil filtration systems for diesel and petrol engines was developed by the author. The quantitative assessment of probability of penetration of particles of contamination in bearings of cranked shaft and reliability of their protection with various oil filtration systems and power setting of the engine was carried out. The high efficiency of combined polymer oil filtration systems for diesel and petrol engines which included full-flow filters with the use of elements made from a polymer filter media with a high contaminant retaining capacity and by-pass filters with polymer filtering elements was determined.
4. On completion of the research project the efficiency of full-flow and combined oil filtration systems consisting of full-flow paper filters and by-pass centrifuges or by-pass filters tested in various engine operating conditions was determined. Probabilities of penetration of particles of the

contamination impurity in bearings of the engine and reliability of their protection depending on sizes of contamination particles and schemes of the oil filtration system were calculated. It was established that the essential difference in intensity of oil filtration with various filtration systems takes place for small particles up to 5 microns, however oil filtration of organic particles of contamination is significantly improved with the use of the combined filtration system consisting of the by-pass polymer filters.

5. On completion of the research project the structural change in the balance of components was investigated and the balance of the total contamination impurity was found in analysed samples of the oil of the tested engines and retained by filters during tests using various filters and filtration systems along with values of coefficient of oil filtration provided by various filters and filtration systems
6. The conducted researches demonstrated high efficiency of combined polymer oil filtration systems, which provided a significant decrease in concentration of impurity contamination of the engine oil by up to 3 times and a reduction of impurity of parts of sleeve assembly group of the engine by up to 2 times along with a considerable decrease in the wear of bearings of engines. It was proven that the polymer oil filter DC 0.9 with nominal subtlety of elimination 20-26 microns allows to increase a service life of filter elements by up to 3 times without a decrease in the reliability of operation of the engines.

Based on results of this work 3 UK Patents were granted by the UK Intellectual Property Office in 2012.

7.2. Further work

Based on the knowledge gained from the research conducted in this project, a number of topics related to this area might be interesting to look into in the future.

- It is necessary to look at the effect of increasing/decreasing dimensions of polymer filtering elements of oil filters on oil filtration, because although the current version of full-flow and by-pass polymer filters provides sufficient level of oil filtration and exceeds performance of paper oil filters there is need to investigate further dependence between volume of filter media and length of operation of polymer filters.

- It is also necessary to look at the influence of the polymer filter media on quality of oil filtration resulting in improvement of protection of bearings of the engine. As the oil-polymer medium interaction is a two way-process, it would be valuable to analyse changes in condition of engine oil after longer operational intervals to determine which additives and oil properties are effected and how much longer the oil could be used without losing its ability to provide reliable protection of bearings and other moving parts of the engine.

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Appendix A

Three UK Patents were granted in 2012 by the UK Intellectual Property Office, details as follows: GB2488624 – Formulation of the Filter Element. GB2446584 – Apparatus for manufacturing the Filter. GB2446579 – Design of the Filter Element. Description of the Patent No: GB2446579 is as follows:

Filter elements and filter

The present invention relates to a polymer filter for the filtration of liquids, such as fuel and oil and polymer filter elements for use in such filters.

Conventional filter elements for use in fluid filtration, in particular, filtration of fuel and oil in automotive vehicles are made from paper. Once used, such filters cannot be readily cleaned for re-use, nor can they be readily recycled so the spent filter elements are typically disposed of as waste, for example, on landfill sites.

It has therefore been proposed to make filter elements from plastics materials, such as those described in US5256284 and US5182015. US5695638 discloses the use of a filter element of polyacetal and US6221242 discloses the use of a polyester filter element. US2002/0033365 and US5547481 disclose filter elements made from sintered high density polyethylene.

It is an object of the present invention to provide an improved and/or alternative filter element.

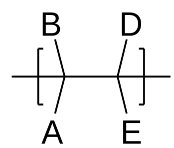
In accordance with a first aspect of the present invention, there is provided a polymer filter element for the removal of contaminants from a fluid, the polymer filter element preferably comprising a polymeric blend comprising from 2% to 30% by wt. of a poly(chloroalkylene).

The polymer filter elements of the first aspect of the present invention have been found to be effective filter for oil, automotive fuel and hydraulic fluid.

The poly(chloroalkylene) may comprise a poly(chloroethylene). The chloroethylene groups may comprise 1, 2, 3 or 4 chlorine atoms, and each chloroethylene group may be the same or different.

The poly(chloroalkylene) may, for example, be provided by polyvinyl chloride, chlorinated polyvinyl chloride, plasticized polyvinyl chloride, unplasticized polyvinyl chloride or related polymer, or a copolymer in which all or substantially all, that is, more than 90% by weight of the copolymer is derivable from chlorohydrocarbon monomer units.

It is preferred that at least 50% by weight (and preferably at least 80% by weight and more preferably at least 90% by weight) of the poly(chloroalkylene) is provided by group X having the general structure (i) below wherein A, B, E and D are H or Cl provided that at least one of A, B, E and D is Cl.

Structure (i) is 

Each repeat group X in the polymeric blend may be mutually the same. For example, the repeat group X may always be a

–CH_2-CHCl- repeat group. Alternatively, the polymeric blend may comprise repeat groups X of mutually different structure. For example, the polymeric blend may comprise two or more of the repeat groups –CH_2-CHCl-, -CH_2-CCl_2-, -CHCl-CHCl-, -CHCl-CCl_2- and –CCl_2-CCl_2-.

The repeat group X content of the polymeric blend may substantially be provided, for example, by polyvinyl chloride (PVC) or chlorinated polyvinyl chloride (CPVC). It has been found that polyvinyl chloride and its related derivatives produce efficient filters. This is of importance in that PVC and derivatives are common waste products that may be recycled. The filter element of the present invention is not limited to one using recycled materials; virgin materials may be used, such as Evipol-SH, -EP and -EH polymers (Ineos Vinyls, Runcorn, UK).

Those skilled in the art will realize that the poly(chloroalkylene) may comprise impurities or defects, such as the presence of unchlorinated branch groups (such as methyl, ethyl and butyl), carbonyl groups and unsaturated carbon-carbon bonds. For example, a polyvinyl chloride, chlorinated polyvinyl chloride, plasticized polyvinyl chloride, unplasticized polyvinyl chloride or related polymer may comprise up to 5% (and preferably up to 1%) by weight of groups having a structure other than a chloroethylene structure (chloroethylene meaning –CH_2-CHCl-, -CH_2-CCl_2-, -CHCl-CHCl-, -CHCl-CCl_2- or –CCl_2-CCl_2-).

It is preferred that the polymeric blend comprises from 2% to 20% by weight of the poly(chloroalkylene), preferably from 2% to 15%, more preferably from 3% to 12%, further more preferably from 4% to 12% and most preferably from 8% to 12% by weight of the poly(chloroalkylene).

It is preferred that the polymeric blend comprises from 60 to 98% (preferably from 70 to 95%, more preferably from 80 to 90% and most preferably from 80 to 85%) by weight of a further thermoplastic. It is preferred that the further thermoplastic comprises one or more of poly acrylonitrile butadiene styrene, acrylic, celluloid, cellulose acetate, a polyester (such as poly ethylene vinyl acetate, a polyacrylate and a terephthalate [e.g. polybutylene terephthalate, polyethylene terephthalate and polycyclohexylene dimethylene terephthalate], polyhydroxyalkanoates), poly ethylene vinyl alcohol, fluoroplastics (for example, polyfluorotetraethylene (PTFE)), polyacetal , polyacrylonitrile, polyamide (such as nylon), polyamide-imide, polyaryletherketone, polybutadiene, polybutylene, , polycarbonate, polyketone, polyethylene, polyetheretherketone, polyetherimide, polyethersulfone, polyethylenechlorinates, polyimide, polylactic acid, polymethylpentene, polyphenylene oxide, polyphenylene sulfide, polyphthalamide, polypropylene, polystyrene and polysulphone.

It is preferred that the further thermoplastic comprises one or more of a polyamide, a polyester (such as a terephthalate) and a polyalkylene. The polyamide may be a nylon, such as nylon 6,6. The polyalkylene may be polypropylene or polyethylene, for example. The polyalkylene terephthalate may be polyethylene terephthalate. The polyalkylene may be a high density or a low density polyalkylene. Examples of high density polyethylenes include HMA 014, HMA 025 and HMA 035 (Exxon

Mobil Corporation). Examples of low density polyethylenes include LL6101, LL6201 and LD100AC (Exxon Mobil Corporation).

The filter element may be a substantially porous structure. It is preferred that the mean pore size is between 10 to 20 microns. It is preferred that at least some of the pores are sufficiently small so as to inhibit passage therethrough of particles having a largest dimension of 5μm. It is preferred that the filter comprises pores having a pore size of about 3μm.

It should be understood that the filter element of the present invention may be an inherently physically stable, shaped body.

The filter elements may also comprise from 2 to 10% by weight of a compatilising agent. The compatibilising agent enables blending of the poly(chloroalkylene) with the further thermoplastic (if present).

It is preferred that the filter element of the first aspect of the present invention is made from granules of a poly(chloroalkylene), such as a poly(chloroethylene). Examples of a poly(chloroalkylene) include polyvinyl chloride, chlorinated polyvinyl chloride, plasticized polyvinyl chloride, unplasticized polyvinyl chloride or related polymer. It is preferred that said granules are heated. It is also preferred that the granules are subject to a raised pressure to aid formation of the filter element. The granules may be subject to raised pressure prior to, simultaneous with or subsequent to heating, It is further preferred that the filter element is made using a mould.

It is especially preferred that the filter element is made by: (i) providing a mixture comprising granules of a poly(chloroalkylene), such as a poly(chloroethylene);

(ii) introducing said mixture into a mould;

(iii) subjecting the mixture to a raised pressure to form a filter element precursor body; and

(iv) heating the filter element precursor body.

It is preferred that the mixture provided in step (i) comprises a further thermoplastic such as those listed above. The mixture may also comprise a liquid. The liquid may be present up to 5% by weight of the weight of the mixture, more preferably up to 2%, and further more preferably from 0.02 to 1%. The liquid has been found to ease removal of the filter element from the mould.

The mixture may also comprise from 2 to 10% by weight of a compatilising agent. The compatibilising agent enables blending of the poly(chloroalkylene) with the further thermoplastic (if present).

In accordance with a second aspect of the present invention there is provided a filter comprising a filter element in accordance with the first aspect of the present invention and a filter housing for accommodating the filter element for use.

In accordance with a third aspect of the present invention, there is provided there is provided a method of making a filter element, said method comprising:

(i)providing a mixture comprising a plastics material;

(ii) introducing said mixture into a mould;

(iii) subjecting the mixture to a raised pressure to form a filter element precursor body; and

(i) heating the filter element precursor body.

The method of the third aspect of the present invention is a preferred method of making the filter element of the first aspect of the present invention.

The mixture may comprise a liquid. The liquid may be present up to 5% by weight of the weight of the mixture, more preferably up to 2%, and further more preferably from 0.02 to 1%. The liquid has been found to ease removal of the filter element from the mould.

It is anticipated that step (iv) may remove some or all of the liquid from the filter element precursor body. For example, some of the fluid may be retained.

It is preferred that the mixture comprises from 2% to 30% by wt. of a poly(chloroalkylene), such as a poly(chloroethylene). The chloroethylene groups may comprise 1, 2, 3 or 4 chlorine atoms, and each chloroethylene group may be the same or different.

The poly(chloroalkylene) may, for example, be polyvinyl chloride, chlorinated polyvinyl chloride, plasticized polyvinyl chloride, unplasticized polyvinyl chloride or related polymer, or a copolymer in which all or substantially all, that is, more than 90% by weight of the copolymer is derivable from chlorohydrocarbon monomer units.

It is preferred that at least 50% by weight (preferably at least 80% by weight and more preferably at least 90% by weight) of the poly(chloroalkylene) is provided by group X having the general structure (i) as shown above in relation to the first aspect of the present invention, wherein A, B, E and D are H or Cl provided that at least one of A, B, E and D is Cl.

Each repeat group X may be mutually the same. For example, the repeat group X may always be a $–CH_2$-CHCl- repeat group. Alternatively, the mixture may comprise repeat groups X of mutually different structure. For example, the mixture may comprise two or more of the repeat groups $–CH_2$-CHCl-, $-CH_2$-CCl_2-, -CHCl-CHCl-, -CHCl-CCl_2- and $–CCl_2$-CCl_2-.

The repeat group X may substantially be provided, for example, by polyvinyl chloride (PVC) or chlorinated polyvinyl chloride (CPVC). It has been found that polyvinyl chloride and its related derivatives produce efficient filters. This is of importance in that PVC and derivatives are common waste products that may be recycled. The filter element of the first aspect of the present invention and the method of the third aspect of the present invention are not limited to the use of recycled materials; virgin materials may be used, such as Evipol-SH, -EP and -EH polymers (Ineos Vinyls, Runcorn, UK).

It is preferred that the mixture comprises from 2% to 20% by weight of poly(chloroalkylene), preferably from 2% to 15%, more preferably from 3% to 12%, further more preferably from 4% to 12% and most preferably from 8% to 12% by weight of polychloroalkylene.

It is therefore preferred that the mixture comprises from 2% to 20% by weight of group X, preferably from 2% to 15%, more preferably from 3% to 12%, further more preferably from 4% to 12% and most preferably from 8% to 12% by weight of group X.

It is preferred that the mixture comprises from 60 to 98% (preferably from 70 to 95%, more preferably from 80 to 90% and most preferably from 80 to 85%) by weight of a further thermoplastic. It is preferred that the further thermoplastic comprises one or more of poly acrylonitrile butadiene styrene, acrylic, celluloid, cellulose acetate, a polyester (such as poly ethylene vinyl acetate, a polyester [e.g. polybutylene terephthalate, polyethylene terephthalate and polycyclohexylene dimethylene terephthalate] and a polyacrylate), poly ethylene vinyl alcohol, fluoroplastics (for example, polyfluorotetraethylene (PTFE)), polyacetal , polyacrylonitrile, polyamide (such as nylon), polyamide-imide, polyaryletherketone, polybutadiene, polybutylene, polycarbonate, polyhydroxyalkanoates, polyketone, polyester, polyethylene, polyetheretherketone, polyetherimide, polyethersulfone, polyethylenechlorinates, polyimide, polylactic acid, polymethylpentene, polyphenylene oxide, polyphenylene sulfide, polyphthalamide, polypropylene, polystyrene and polysulphone. It is preferred that the further thermoplastic comprises one or more of a polyamide, a polyester (such as a terephthalate) and a polyalkylene. The polyamide may be a nylon, such as nylon 6,6. The polyalkylene may be polypropylene or polyethylene, for example. The polyalkylene terephthalate may be polyethylene terephthalate. The polyalkylene may be a high density or a low density polyalkylene. Examples of high density polyethylenes include HMA 014, HMA 025 and HMA 035 (Exxon Mobil Corporation). Examples of low density polyethylenes include LL6101, LL6201 and LD100AC (Exxon Mobil Corporation).

It is preferred that the mixture further comprises from 2 to 10% by weight of a compatilising agent. The compatibilising agent enables blending of the poly(chloroalkylene) with the further thermoplastic (if present).

The plastics material (such as the polyvinyl chloride, chlorinated polyvinyl chloride, plasticized polyvinyl chloride, unplasticized polyvinyl chloride or related polymer or further thermoplastic) may be supplied in step (i) in a granular form. The granules may have a mean largest dimension of from 0.1mm to 1mm and preferably from 0.2 to 0.6mm. It is anticipated that in many circumstances the mixture will comprise granules of different sizes. For example, several granular sizes of PVC may be used to make-up the PVC component of the mixture (if PVC is present).

If a poly(chloroalkylene) such as polyvinyl chloride, chlorinated polyvinyl chloride, plasticized polyvinyl chloride, unplasticized polyvinyl chloride or related polymer is used in the present method, it is preferred that such material is provided in a granular form in step (i). It is preferred that the mean largest dimension of said granules of the poly(chloroalkylene) is from 0.2 to 0.8mm, and preferably from 0.2 to 0.6mm.

If a further thermoplastic is provided, then it is preferred that it is provided in step (i) in granular form. The mean largest dimension of the granules of the further thermoplastic may be from 0.2 to 1mm and preferably from 0.3 to 0.8mm.

Step (iv) may comprise heating the filter element precursor body to a maximum temperature of 120ºC, more preferably to a maximum temperature of from 80ºC to 110ºC. It is preferred that step (iv) is performed at ambient pressure i.e. not under reduced or increased pressure.

In step (iii), the material may be under compression for from 0.2 to 1.0 seconds, more preferably from 0.2 to 0.6 seconds and most preferably from 0.3 to 0.5 seconds. It has been found that the application of pressure over a short timescale is beneficial to the formation of filter elements with suitable pore sizes that enable the filter elements to be used as oil and fuel filters.

The maximum compressive force applied in step (iii) is preferably from 10kN to 1000kN, more preferably from 10kN to 100kN and most preferably from 10kN to 150kN. In certain circumstances, in particular for the production of larger filter elements, a maximum compressive force of from 30kN to 500kN (and more preferably from 30kN to 150kN) may be preferred.

The mould determines the shape of the filter element precursor body. One or more of the surfaces of the mould which, in use, comes into contact with the mixture comprising a plastics material may have a low surface energy. A low surface energy may be provided by a substrate that has been coated with a material that provides a low surface energy. Alternatively, a substrate of a material that provides a low surface energy may be used. Materials that provide a low surface energy include polytetrafluoroethylene (PTFE, such as Teflon®). Surfaces with a low surface energy may be formed by coating a substrate with a silane or polytetrafluoroethylene (PTFE, such as Teflon®).

The mould may be shaped so as to form a cylindrical filter element precursor body. The mould may also be provided with one or more end-fitting casting elements to prevent egress of mixture from the mould once the filter element precursor body has been formed in step (iii). This is important if the mould containing the filter element precursor body is physically removed from an apparatus so that the mould-precursor element ensemble can be put into an oven or the like to perform step (iv).

The method may further comprise providing a tamper for compressing the mixture in step (iii). The tamper may comprise a tamping head for contacting the mixture and a means for urging the tamping head into compressive contact with the mixture. The means for urging the tamping head into compressive contact with the mixture may comprise a piston. It is preferred that the piston is electrically driven. This facilitates the tamping head to be brought into contact with, and removed from, the material quickly. Such rapid movement has been found to be beneficial to the formation of filter elements. It has been discovered that certain other pistons (for example, a hydraulic driven piston) do not facilitate the rapid movement of the tamping head. The tamping head may have an annular shape. This is of particular benefit in the manufacture of filter elements for oil or fuel filters.

The method may further comprise providing a return mechanism for urging the tamping head away from the mixture in the mould. Such a return mechanism may comprise a bias means, such as a spring. A helical spring may conveniently be used, for example. When the tamping head is urged into compressive contact with the material the return mechanism acts so as to try to urge the tamping head away from the mixture in the mould. Once the force urging the tamping head into contact with the mixture in the mould is removed, the return mechanism urges the tamping head away from the mixture.

The method may further comprise providing a conveyor for moving said mixture comprising a plastics material towards the mould. The conveyor may comprise a screw conveyor. A screw conveyor has been found to provide an effective mechanism for moving mixtures having the consistency of paste towards the mould.

The method may further comprise providing a receiver for guiding the mixture into the mould. The receiver may be placed adjacent the mould. The receiver may flare outwardly, and, for example, may have a funnel like portion. The receiver may receive the mixture from the conveyor, if present.

The method may comprise providing a plurality of moulds. The method may further comprise providing a transporter for moving the moulds into a position in which material may be delivered into the moulds.

The method of the third aspect of the present invention may be used to make the filter element in accordance with the first aspect of the present invention.

Conventional filter elements are provided with a material having essentially the same permeability to particles. Such filter elements are typically used in filters having an inlet for the introduction of unfiltered fluid and an outlet for the egress of filtered fluid. During normal operation, fluid passes through the filter element, removing particles from the fluid. Under certain circumstances, fluid does not readily pass through the filter element and pressure builds-up on the unfiltered side of the device. This pressure build-up may occur, for example, because the filter element is blocked, the vehicles is operating at high speed or the fluid is more viscous than during normal operation (e.g. at start-up of a vehicle). Such pressure build-up in a filter can be dangerous and so filters are often provided with valves which are operable at a threshold pressure to allow unfiltered fluid to flow from the fluid inlet to the fluid outlet without passing through the filter element. This means that unfiltered fluid is transmitted out of the filter, and this may be damaging to the machinery to which the unfiltered fluid is transmitted.

The present invention provides a filter element that mitigates the problems of conventional filter elements mentioned above.

Falling outside the scope of the present invention there is a filter element for the removal of contaminants from a fluid, the filter element comprising:

(i) a filter inlet for the ingress of unfiltered fluid into a chamber for the receipt of unfiltered fluid;

(ii) a filter outlet for the egress of filtered fluid from a chamber for the receipt of filtered fluid;

(iii) a polymer filter element located in the fluid flow path between the chamber for the receipt of unfiltered fluid and the chamber for the receipt of filtered fluid, the polymer filter element comprising:

(a) a first portion of the polymer filter element having a first permeability 3µm - 30µm to contaminants present in the unfiltered fluid,

(b) a second portion of the polymer filter element having a second permeability 30µm - 40µm to contaminants present in the unfiltered fluid, the second permeability being greater than the first permeability, and

(c) a valve associated with the second portion, the valve being operable so that, below a threshold pressure level in the chamber for the receipt of unfiltered fluid, the valve inhibits transmission of fluid from the chamber for the receipt of unfiltered fluid to the outlet via the second portion of the polymer filter element, and, above a threshold pressure in the chamber for the receipt of unfiltered fluid, the valve permits transmission of fluid from the chamber for the receipt of unfiltered fluid to the outlet via the second portion of the polymer filter element.

The valve may be operable from the first to the second valve state by the application of a force greater than a threshold force.

In the filter element falling outside the scope of the present invention, the filter element comprises two portions of differing permeabilities. The valve is associated with the second portion of the filter element, the second portion of the filter element having a greater permeability than the first portion. During normal operation of the filter element, fluid passes through the first portion of the filter element, thereby filtering the fluid. During normal operation, the valve is closed and so fluid cannot pass through the valve and the second portion of the filter element.

Under certain circumstances, the first portion of the filter element may not operate effectively. For example, if the fluid is cold and viscous, it may not adequately pass through the first portion of the filter element. Likewise, if the first portion of the filter element becomes blocked, fluid may not adequately pass through the first portion of the filter element. This may cause the pressure in a filter, of which the filter element forms a part, to increase. When a certain pressure is reached, the force acting on the valve is greater than a threshold force, and the previously-closed valve is opened to permit fluid flow through the valve and through the second portion of the filter element. This reduces the pressure in the filter, therefore decreasing the chance of the filter exploding. Furthermore, the fluid is also filtered before it reaches the outlet of a filter of which the filter element forms a part.

Falling outside the scope of the present invention, there is a filter for the removal of contaminants from a fluid, the polymer filter comprising:

(i) a filter inlet for the ingress of unfiltered fluid into a chamber for the receipt of unfiltered fluid;

(ii) a filter outlet for the egress of filtered fluid from a chamber for the receipt of filtered fluid;

(iii) a polymer filter element located in the fluid flow path between the chamber for the receipt of unfiltered fluid and the chamber for the receipt of filtered fluid, the polymer filter element comprising:

(a) a first portion of the polymer filter element having a first permeability 3µm - 30µm to contaminants present in the unfiltered fluid,

(b) a second portion of the polymer filter element having a second permeability 30µm - 40µm to contaminants present in the unfiltered fluid, the second permeability being greater than the first permeability, and

(c) a valve associated with the second portion, the valve being operable so that, below a threshold pressure level in the chamber for the receipt of unfiltered fluid, the valve inhibits transmission of fluid from the chamber for the receipt of unfiltered fluid to the outlet via the second portion of the polymer filter element, and, above a threshold pressure in the chamber for the receipt of unfiltered fluid, the valve permits transmission of fluid from the chamber for the receipt of unfiltered fluid to the outlet via the second portion of the polymer filter element.

The valve may conveniently be located on the side of the second portion facing or forming the chamber for the receipt of filtered liquid. Alternatively, the valve may conveniently be located on the side of the second portion facing or forming the chamber for the receipt of unfiltered liquid.

The filter element may be arranged so that, when the valve is open, fluid may pass from the chamber for the receipt of unfiltered fluid, through the second portion of the filter element, before passing through the valve to the chamber for the receipt of filtered fluid.

Alternatively, the filter element may be arranged so that, when valve is open, fluid may pass from the chamber for the receipt of unfiltered fluid, through the valve, before passing through the second portion of the filter element and into the chamber for the receipt of filtered fluid.

For the avoidance of confusion, it is hereby stated that the following statements apply to both elements falling outside the scope of the present invention.

It is preferred that the first portion of the filter element has a first permeability to particles present in an unfiltered fluid and the second portion of the filter element has a second permeability to particles present in an unfiltered fluid, the second permeability being greater than the first permeability. This is often conveniently achieved by the first and second portions of the filter element having a porous structure, the pores of the second portion of the filter element being larger than the pores of the first portion of the filter element.

It is preferred that the filter element is a filter for the filtration of liquids, such as a fuel, oil or hydraulics fluid filter.

The valve may comprise a slit valve. Advantageously, the valve may comprise a valve member which is biased into sealing engagement with a valve seat. The valve member is movable away from the valve seat by a pressure in the chamber for the receipt of unfiltered fluid that is above the threshold level (corresponding to a force above a threshold value in relation to the filter element falling outside the scope of the present invention) so that the sealing engagement is broken, permitting fluid flow from the chamber for the receipt of unfiltered fluid to the outlet via the second portion of the filter element.

The filter element may comprise a substantially tubular structure, such as a hollow cylindrical structure. The first portion may be provided by the substantially tubular structure. The second portion may be provided by a covering or capping structure. The covering or capping structure may be in the form of a disk.

It is preferred that the smallest particles that may be removed from the fluid by the first portion of the filter element are smaller than the smallest particles that may be removed from the fluid by the second portion of the filter element. For example, the smallest particles that may be removed by the first portion of the filter element may have a largest dimension of about 5μm. In this case, it may be desirable for the smallest particles that may be removed by the second portion of the filter element to have a largest dimension of about 15μm.

Reference to the smallest particles that may be removed by a portion of the filter element refers to the filter element in its initial, clean operating state. A dirty or partially blocked filter will obviously inhibit passage therethrough of particles which it may have permitted to pass when in a clean state. The filter element may be provided with a cavity between the second portion of the filter element and the valve. Such a cavity may be formed by a cover placed in sealing engagement with the second portion of the filter element.

The filter element may be inherently physically stable.

The first portion and the second portion of the filter element may be provided by a filter element body. The filter element body may be made from plastics material. The filter element body may, for example, be made from a polyethylene as described in US5547481 or in US2002/0033365.

The filter element may be a filter element in accordance with the first aspect of the present invention. The filter element may be made in accordance with the method of the third aspect of the present invention.

The present invention is now described by way of example only with reference to the following figures of which:

Figure 1 is a schematic side view of an apparatus used to make an embodiment of a polymer filter element according to claim 1;

Figure 2A is a cut-away view of a mould and the tamping portion of the apparatus of Figure 1;

Figure 2B is a side-on view of a part of the apparatus of Figure 1; and

Figure 3 is a schematic cross-section through an embodiment of a polymer filter comprising a polymer filter element according to claim 1.

Figure 1 shows a schematic representation of an apparatus used to make an embodiment of a polymer filter element. The apparatus is denoted generally by reference numeral 1001. The apparatus is now briefly described with reference to Figure 1. The apparatus comprises a chute 1002 into which a mixture comprising a plastics material may be fed. The chute 1002 guides the mixture into a screw conveyor 1003. The electrically powered screw conveyor moves the mixture into a mould 1008a via a receiver 1007 which acts as a funnel to direct the mixture to the mould. Mould 1008a is one of four moulds mounted on a turntable platter 1010 driven by turntable motor 1011, but only two of the moulds (1008a, 1008b) are shown for the purposes of clarity. The turntable platter 1010 is rotated by the turntable motor 1011 to move respective moulds into (and out of) the mixture-receiving position underneath the end of the screw conveyor 1003. Mould 1008a is shown in Figure 1 as being in the mixture-receiving position. An indexing pin 1012 engages with a locking hole (reference numeral 1029 in Figure 2a) in the turntable platter 1010 to prevent unwanted movement of the turntable platter 1010 once a mould is located in the mixture-receiving position. An indexing pin driver 1013 causes the indexing pin to engage with the locking hole.

When in the mixture-receiving position, the mould 1008a is aligned with a tamper 1004 that is used to compress the mixture in the mould 1008a to form a filter element precursor body. Once the mixture in a mould has been compressed, the indexing pin 1012 is withdrawn to permit rotation of the turntable platter 1010, moving an empty mould into the mixture-receiving position and moving the mould containing the filter element precursor body into an unloading position.

The operation of the apparatus is controlled by control panel 1015.

The structure of the moulds 1008a, 1008b and the portion of the apparatus associated with tamping will now be described in more detail with reference to Figures 1 and 2a. Figure 2a shows a cut-away diagram of the tamper 1004, with a mould 1008a in a mixture-receiving position. The mould 1008a comprises a cylindrical outer wall 1031 and a cylindrical inner piece 1009a. At the lower end of the mould 1008a, an annular end-piece 1030 extends between the outer wall 1031 and the inner piece 1009a. The inner piece 1009a, outer wall 1031 and end-piece 1030 form a receptacle for the receipt of the mixture comprising a plastics material. The surfaces of the inner piece 1009a and the outer wall 1031 that come into contact with the mixture have been coated with a low energy material (in this case, polytetrafluoroethylene). This low energy material helps resist adhesion of the mixture and any subsequently-produced filter element to the walls of the mould 1008a. The lowermost part of the inner piece 1009a locates in a cavity 1028 in the turntable platter 1010 provided for accurate and convenient siting of a mould.

Once the mixture has been delivered to the mould 1008a via the receiver 1007, the mixture may be compressed. The tamper 1004 comprises a cylindrical tamping member 1006 which is provided with an annular tamping head 1022. The tamping member 1006 and tamping head 1022 are sized so that they may be received in the gap between the mould inner piece 1009a and the mould outer wall 1031. The electrically-operated piston 1020 engages with the tamping member 1006 and urges the tamping head 1022 into compressive contact with the material in the mould 1008a.

The apparatus is provided with a return mechanism in the form of a helical spring 1025 mounted around a cylindrical insert 1026. When the tamping member 1006 is urged towards the mould 1008a, the lower end of the helical spring 1025 abuts against the upper surface of lip 1027 provided on the mould inner piece 1009a. The upper end of the helical spring 1025 abuts against the tamping member 1006. As the tamping member 1006 is urged further downwards the helical spring 1025 becomes more compressed, increasing the force in the spring 1025. Once the piston 1020 is retracted, the compressed spring 1025 urges the tamping member 1006 away from the mould 1008a. The cylindrical insert 1026 is provided to support the spring 1025.

The tamping member 1006 is provided with two fill-level pins 1023a, 1023b which protrude through fill-level slots 1024a, 1024b respectively provided in cylindrical body 1005. This arrangement may also be seen in Figure 2B. Referring to Figure 2A, during compression, the tamping member 1006 is moved onto the mixture. The displacement of the tamping member 1006 is dictated primarily by the amount of mixture in the mould 1008a. The position of the fill-level pins 1023a, 1023b are indicative of the amount of mixture in the mould 1008a, and (referring to Figure 2B) the position of the fill-level pin 1023a relative to the scale 1032 provided on the body 1005 permits the user to verify that the correct amount of mixture has been loaded into the mould 1008a.

The cylindrical body 1005 is sized so that it may abut against the end of the mould outer wall 1031.

The piston 1020 is associated with a piston cover 1021. The piston cover is cylindrical and sized to that it may abut against cover 1005.

Those skilled in the art will realize that the gaps shown in Figure 2a between different elements of the apparatus have, in many cases, been exaggerated for the purposes of clarity. The true gaps between elements are, in many cases, smaller than those shown.

Those skilled in the art will realize that the moulds 1008a, 1008b are not part of the apparatus in accordance with the present invention.

The operation of the apparatus of Figure 1 will now be described in further detail with reference to Figures 1, 2A and 2B.

An empty mould 1008a is in a mixture-receiving position. The turntable is locked in this position by indexing pin 1012 which is inserted into locking hole 1029.

A mixture comprising a plastics material is formed by mixing 10% by weight of granules of polyvinyl chloride (PVC), 80% by weight of granules of polyethylene terephthalate (PET), 8-9% by weight of a commercially available compatibilising agent and 0.02-2% by weight of a liquid (typically an organic acid). The compatibilising compound facilitates the blending together of PET and PVC. Examples of such compatibilising agents include modified polyolefins (“Elvaloy”, “Fusabond”, “Surlyn” and “Elvanol” agents from DuPont) and styrenic block copolymers (“Styrolux” and “Styroflex” from BASF). Other compatibilising agents of interest are polycaprolactones (such as the TONE P-767 and P-787 polycaprolactones from Dow Chemical Company). Also of particular interest are the block-graft copolymers disclosed as compatibilisers in Polymer, Vol. 37, No. 17, August 1996, page 3871-3877 (Braun et al.). Chlorinated polyethylenes have also been recognized as having compatibilising properties in a PVC/high density polyethylene mixture.

The liquid essentially acts as a lubricant to reduce the likelihood of material sticking to the mould. Examples of liquids which may conveniently be used are organic acids, such as acetic acid.

The liquid content is so small that the mixture has a powdery, granular consistency.

The mixture is delivered via chute 1002 to the screw conveyor 1003. The screw conveyor transfers the mixture to mould 1008a, via a receiver 1007. It is desirable to use the mixture shortly after preparation; leaving the mixture to stand may result in the liquid evaporating. Once the appropriate amount of mixture had been delivered to the mould 1008a, the mixture may be compressed. Piston 1020 contacts tamping member 1006 and urges tamping head 1022 into the gap between the mould inner piece 1009a and the mould outer wall 1031. The tamping head 1022 is urged into compressive contact with the mixture in the mould 1008a, and the mixture is compressed to form a filter element precursor body. The piston is then withdrawn, and the return mechanism provided by the helical spring 1025 ensures that the tamping member is retracted from the mould 1008a.

The maximum force applied during the compression stroke is of the order of 50-100kN. The mixture is under compression for a period of about 0.5 seconds. The piston is electrically actuated. It has been found that a hydraulically-actuated piston may be used but applies a force over a longer timescale, the resulting filter element being less satisfactory than if an electrically-actuated piston is used.

The indexing pin 1012 is then removed from the locking hole 1029 and the turntable rotated so that an empty mould (not shown) is located in the mixture-receiving position and mould 1008a, containing the filter element precursor body, being moved to an unloading position. The mould 1008a is then removed from the turntable platter 1010 and placed in an oven (not shown) so that the filter element precursor body may be heated. The filter element precursor body is heated to 100ºC and kept at 100ºC for 20 minutes. The temperature is then reduced to 60ºC and kept at 60ºC for 30 minutes. The temperature is then reduced to 40ºC and kept at 40ºC for 30 minutes. The temperature is then reduced to 20ºC, and kept at 20ºC for 40 minutes. The filter element may then be removed from the mould; this process includes removing the end-piece 1030 from the filter element. It is expected that the heating process removes substantially all of the liquid from the filter element.

The size of the pores in the filter element may be varied by varying the relative proportions of PVC and PET used. The size of the pores may also be varied by varying the size of the granules of PVC and PET used, the smaller the granules the smaller the pores in the filter element.

Those skilled in the art will realize that the apparatus of Figure 1 is merely exemplary. It may be more efficient to provide a conveyor belt or the like with many moulds which are subsequently filled with paste. The filled moulds may then be moved to a tamping station provided with one or more tampers. Once tamped, the filter element precursors may be moved to a heating station where the filter elements precursors are heated to remove some or all of the fluid (if initially present). Such an apparatus may be substantially automated.

The method described above may be readily adapted in order to change the properties of the filter element. For example, changing the composition of the plastics material can be used to change the properties of the filter element. For example, increasing the mean maximum dimension of the PVC granules used in the mixture gives rise to an increase in pore size. An increase in pore size has been observed when one replaces 0.5mm PVC granules in a mixture with 0.8mm PVC granules.

The method described above with reference to Figures 1, 2A and 2B describes the manufacture of a tubular portion of a polymer filter element. As described below, an embodiment of the polymer filter element may typically comprise a tubular portion (the manufacture of which has been described above) and a disk-shaped cap portion. The disk-shaped cap portion may be made using the same general apparatus and method as described above, but using a different mould. Those skilled in the art would also realize that a different tamper head (having a circular end shape) would also be required. The disk-shaped cap portion may have a different permeability to particles than the cylindrical portion. This may be achieved by the cap portion having a different (typically greater) mean pore size than the cylindrical portion. As explained above, this may typically be achieved by using polymer granules of different size and/or by varying the proportion of PET and PVC.

Figure 3 shows a schematic cross-section through an embodiment of a polymer filter comprising a filter element in accordance with the present invention. The polymer filter (in this case, an oil filter generally denoted by reference numeral 100) comprises a polymer filter element 101 disposed within a housing 102. The space between the filter element 101 and the housing defines a chamber 105 for the receipt of unfiltered fluid. Six inlets (only two of which are labeled using reference numerals 150, 151) are provided to allow unfiltered fluid into the chamber 105. The inlets 150, 151 are provided by holes formed in an annular inlet plate 152. The polymer filter element 101 provides a filtration barrier between the chamber 105 for the receipt of unfiltered fluid and a chamber 106 for the receipt of filtered fluid. Egress of fluid from the chamber 106 is via outlet 200 for the egress of filtered fluid. Polymer filter element 101 is mounted in sealing engagement with an annular plate 170.

A helical spring 120 is provided to urge the polymer filter element 101 into sealing engagement with the annular plate 170 so that unfiltered fluid cannot readily pass to the outlet 200 without passing through the polymer filter element 101.

The polymer filter elements is provided with two portions, first portion 107 and second portion 108. First portion 107 is provided by a cylindrical tube of plastics material made as described above with reference to Figures 1, 2a and 2b. The first portion 107 is porous and the pore size is such that particles having a greatest dimension of less than about 5μm are able to pass through the filter (particles having a greatest dimension of about 5μm or greater are not able to pass through the filter). The second portion 108 is generally disk-shaped. The second portion 108 is porous and the pore size is such that particles having a greatest dimension of less than about 15μm are able to pass through the filter (particles having a greatest dimension of about 15μm or greater are not able to pass through the filter). A valve 110 is provided on the lower face of second portion 108. The valve 110 comprises a valve member 111 urged (under normal operating conditions) into engagement with a valve seat (not shown) [and therefore into a non-transmissive position] by a valve spring 112. A cavity 113 is in the flow path between the second portion 108 of the filter element 101 and the valve 110. The cavity 113 is formed by the placement of a disk-shaped cover 115 against the second portion 108 of the filter element. A sealing member 114 is provided to seal the disk-shaped cover 115 so that fluid may only pass into the chamber 106 for the receipt of filtered fluid via the second portion 108 and the valve 110.

The outlet 200 is provided with a threaded neck 210 for attachment to a corresponding threaded feature on the equipment with which the filter will be used. The filter is also provided with an annular sealing gasket (not shown) which forms a seal when the filter is mounted for use so that unfiltered fluid does not leak from the filter.

The operation of the filter will now be described. Under normal operating conditions (i.e. when the filter is operating normally) the pressure in the chamber 105 for the receipt of unfiltered fluid is below a threshold value. In this case, fluid passes from the chamber 105 for the receipt of unfiltered fluid to the chamber 106 for the receipt of filtered fluid via first portion 107 of filter element 101. Fluid does not pass into the chamber 106 for the receipt of filtered fluid via second portion 108 because valve member 111 is urged into engagement with the valve seat so that fluid may not pass through the valve.

Under certain operating conditions, the pressure in the chamber 105 for the receipt of unfiltered fluid will exceed a threshold value. This may happen, for example, if the first portion 107 of the filter element 101 becomes blocked. In a vehicle engine, pressure may increase when the fluid to be filtered (either oil or fuel) is cold and therefore viscous. High acceleration in a vehicle may also lead to increased pressure in the filter. When the pressure in the chamber 105 is above a threshold pressure, valve member 111 is urged away from the valve seat and fluid may pass through the second portion 108 into the chamber 106 via the valve 110. Even though the filtration provided by second portion 108 is not as good as that provided by first portion 107, the filter element falling outside the scope of the present invention provides better performance than the conventional alternative which is to have a bypass valve that allows unfiltered fluid to be transmitted to an outlet without passing through any filter element.

Once the pressure in chamber 105 falls below the threshold value for keeping the valve 110 open the valve 110 closes and the only way for fluid to pass to the outlet is via the first portion 107 of the filter element 101.

The pore size of the first and second portions of the polymer filter element may be chosen to suit the particular use of the filter. The first portion of the filter element was made from a mixture of 10 wt% polyvinyl chloride, 80wt% polyethylene terephthalate, 8-9% compatibilising agent and 0.02-2% liquid. The second portion of the polymer filter element was made from a similar mixture, using granules of PVC and PET with a larger diameter.

The polymer filter 100 is arranged to be a polymer oil filter. Those skilled in the art will realize that the polymer filter of the present invention may be applied to the removal of contaminants from any fluid.

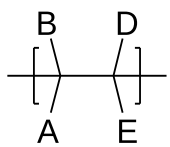
The first and second portions of the polymer filter element 101 are described as being made from a blend of PVC and PET. Other, well-known methods may be used to make polymer filter elements from plastics materials. For example, US5547481 discloses a method for the manufacture of filter elements from polyethylene. US5547481 also discloses how pore size in the filter element may be controlled, for example, by the use of small particles of polytetrafluoroethylene. The teaching of US5547481 may be used to manufacture both the first and second portions of the polymer filter element 101. US2002/0033365 also discloses how filter elements may be made from plastics materials using the so-called “sintering” technique. US2002/0033365 also discloses how the pore size of such a filter depends on the size of the particles or granules that are used to make the filter. The teaching of US2002/0033365 may also be used to manufacture both the first and second portions of the filter element 101.

Those skilled in the art will realize that the filter element of the present invention may be made from materials other than plastics. For example, the first and second portions of the filter element may be made from paper (cellulose), the first and second portions of the filter element having mutually different pore sizes.

Claims

1. A polymer filter element for the removal of contaminants from liquids, such as fuel and oil, the filter element comprising a polymeric blend comprising from 2% to 30% by wt. of a poly(chloroalkylene).

2. A polymer filter element according to claim 15 wherein at least 90% by weight of the poly(chloroalkylene) is provided by group X having the general structure (i) shown below wherein A, B, E and D are H or Cl provided that at least one of A, B, E and D is Cl:

Structure (i) - 

3. A polymer filter element according to claim 16 wherein each repeat group X in the polymeric blend is mutually the same.

4. A polymer filter element according to claim 16 wherein the polymeric blend comprises repeat groups X of mutually different structure.

5. A polymer filter element according to claim 18 wherein the polymeric blend comprises two or more of the repeat groups –CH_2-CHCl-, -CH_2-CCl_2-, -CHCl-CHCl-, -CHCl-CCl_2- and –CCl_2-CCl_2-.

6. A polymer filter element according to any one of claims 15 to 19 wherein the polymeric blend comprises from 2% to 20% by weight of the poly(chloroalkylene).

7. A polymer filter element according to claim 20 wherein the polymeric blend comprises from 8% to 12% by weight of the poly(chloroalkylene).

8. A polymer filter element according to any one of claims 15 to 21 wherein the polymeric blend comprises from 60 to 98% by weight of a further thermoplastic.

9. A polymer filter element according to claim 22 wherein the polymeric blend comprises from 80 to 90% by weight of a further thermoplastic.

10. A polymer filter element according to claim 22 or claim 23 wherein the further thermoplastic comprises one or more of poly acrylonitrile butadiene styrene, acrylic, celluloid, cellulose acetate, a polyester (such as poly ethylene vinyl acetate, a

polyacrylate and a terephthalate [e.g. polybutylene terephthalate, polyethylene terephthalate and polycyclohexylene dimethylene terephthalate], polyhydroxyalkanoates), poly ethylene vinyl alcohol, fluoroplastics (for example, polyfluorotetraethylene (PTFE)), polyacetal , polyacrylonitrile, polyamide (such as nylon), polyamide-imide, polyaryletherketone, polybutadiene, polybutylene, , polycarbonate, polyketone, polyethylene, polyetheretherketone, polyetherimide, polyethersulfone, polyethylenechlorinates, polyimide, polylactic acid, polymethylpentene, polyphenylene oxide, polyphenylene sulfide, polyphthalamide, polypropylene, polystyrene and polysulphone..

11. A polymer filter element according to claim 24 wherein the further thermoplastic comprises one or more of polyamide, a polyester and a polyalkylene.

12. A polymer filter element according to any one of claims 15 to 25 wherein the filter element has a substantially porous structure.

13. A polymer filter element according to claim 26 wherein at least some of the pores are sufficiently small so as to inhibit passage therethrough of particles having a largest dimension of 5μm.