ENVIRONMENTAL PROTECTION AGENCY

An Ghníomhaireacht um Chaomhnú Comhshaoil

WATER TREATMENT MANUALS

FILTRATION

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CONTENTS

List of Figures

List of Tables

PREFACE

The Environmental Protection Agency was established in 1993 to licence, regulate and control activities for the purposes of environmental protection. In the Environmental Protection Agency Act, 1992, it is stated that "*the Agency may, and shall if so directed by the Minister, specify and publish criteria and procedures, which in the opinion of the Agency are reasonable and desirable for the purposes of environmental protection*". These criteria and procedures in respect of water treatment are being published by the Agency in a number of manuals under the general heading of Water Treatment Manuals.

This manual on Filtration sets out the general principles and practices which should be followed by those involved in the production of drinking water. Next year, the Agency intends to prepare and publish additional manuals on Disinfection, Coagulation, Flocculation, Clarification and Fluoridation. Where criteria and procedures are published by the Agency, a sanitary authority shall, in the performance of its functions, have regard to such criteria and procedures.

This manual includes information on many aspects of the filtration process. The Agency hopes that it will provide practical guidance to those involved in plant operation, use, management, maintenance and supervision. The Agency welcomes any suggestions which users of the manual wish to make. These should be returned to the Environmental Management and Planning Division at the Agency headquarters on the enclosed User Comment Form.

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LIST OF ABBREVIATIONS

EBCT:	Empty Bed Contact Time
ES:	Effective Size
GAC:	Granular Activated Carbon
LOH:	Loss of Head
m/h:	m^3 per m^2 per hour
mm:	millimetres
NTU:	Nephelometric Turbidity Unit
p.s.i.:	pounds per square inch
THMs:	Trihalomethanes
TON:	Threshold Odour Number
TWL:	Top Water Level
UC:	Uniformity Coefficient
UFRV:	Unit Filter Run Volume
VOC:	Volatile Organic Carbon

1. INTRODUCTION

1.1 PROCESS DESCRIPTION

Filtration is the process of passing water through material to remove particulate and other impurities, including floc, from the water being treated. These impurities consist of suspended particles (fine silts and clays), biological matter (bacteria, plankton, spores, cysts or other matter) and floc. The material used in filters for public water supply is normally a bed of sand, coal, or other granular substance. Filtration processes can generally be classified as being either slow or rapid.

Slow sand filters are the original form of filtration. The first one was built in 1804 by John Gibb of Paisley, Scotland to treat water for his bleachery, with the surplus treated water sold to the public.[2] Slow sand filters were first used in London in 1820 to treat water from the River Thames. From about the 1930s water treatment by coagulation and rapid gravity filtration or pressure filtration tended to replace slow sand filtration in new plants and, in some cases, slow sand filters were replaced by rapid gravity filters following introduction of a coagulation stage. The slow sand filtration process has come back into favour in recent years due to its superior ability, compared to rapid gravity filtration, to remove pathogenic micro-organisms such as *Giardia lamblia* and *Cryptosporidium*.

Typical water treatment processes are shown schematically in Figure 1[1,4], with the relative position of filtration illustrated.

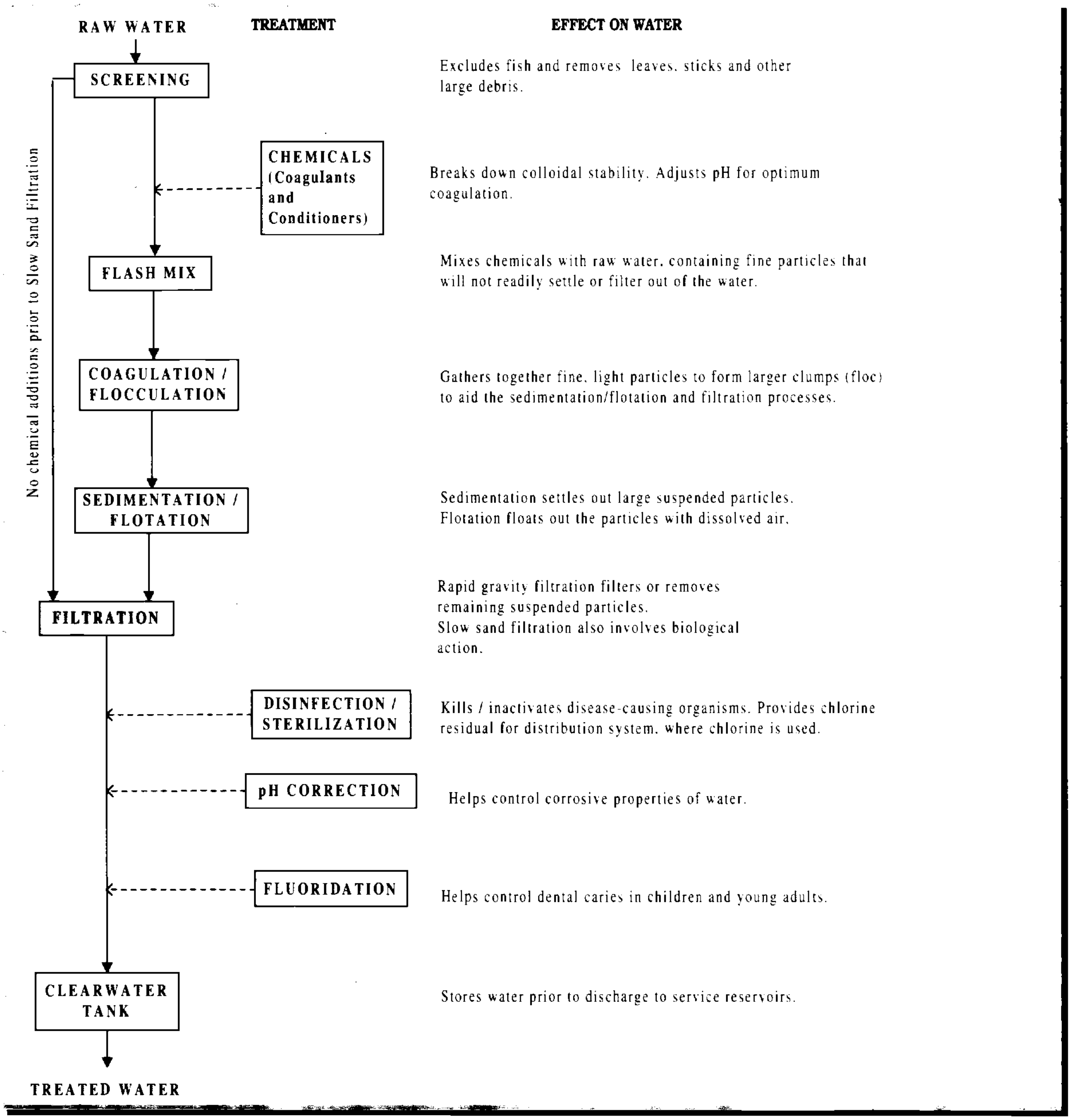

FIGURE 1: TYPICAL WATER TREATMENT PROCESSES

2 FILTRATION MECHANISMS

Filtration is essentially a physical and chemical process and, in the case of slow sand filtration, biological as well. The actual removal mechanisms are interrelated and rather complex, but removal of colour and turbidity is based on the following factors:

- chemical characteristics of the water being treated (particularly source water quality);
- nature of suspension (physical and chemical characteristics of particulates suspended in the water);
- type and degree of pre-treatment (coagulation, flocculation, and clarification); and
- filter type and operation.

A popular misconception is that particles are removed in the filtration process mainly by physical straining. Straining is a term used to describe the removal of particles from a liquid (water) by passing the liquid through a filter or fabric sieve whose pores are smaller than the particles to be removed. While the straining mechanism does play a role in the overall removal process, especially in the removal of large particles, it is important to realize that most of the particles removed during filtration are considerably smaller than the pore spaces in the media. This is particularly true at the beginning of the filtration cycle when the pore spaces are clean (that is, not clogged by particulates removed during filtration).

Thus, a number of interrelated removal mechanisms within the filter media itself are relied upon to achieve high removal efficiencies. These removal mechanisms include the following processes:

- sedimentation on media (sieve effect);
- adsorption;
- absorption;
- biological action; and
- straining.

The relative importance of these removal mechanisms will depend largely on the nature of the water being treated, choice of filtration system, degree of pre-treatment, and filter characteristics.

3 SLOW SAND FILTRATION

3.1 SLOW SAND FILTER MEDIA

Allen Hazen was one of the pioneers in the scientific investigation of slow sand filtration and introduced, as long ago as 1892, the concept of effective size (or diameter).

The *EFFECTIVE SIZE* (ES) is defined as the size of a sieve opening through which 10 percent (by weight) of the particles (sand) will just pass and is given the symbol d_{10}. In a similar way, the size of a sieve opening through which 60 percent (by weight) of the particles (sand) will just pass is given the symbol d_{60}. The *UNIFORMITY COEFFICIENT*, (UC) which is a measure of the grading of the material, is the ratio d_{60}/d_{10}.

It is normal to employ ungraded sand as excavated from natural deposits in slow sand filters. The sand should have a uniformity coefficient of less than 3, but there is little advantage in having a U.C. of less than 1.5 if additional cost is thereby incurred. Pit-run sand may be washed to remove admixed clay , loam or organic matter and this will remove the finest grains thus lowering the U.C. and raising the average particle diameter.

Ideally the effective size should be just small enough to ensure a good quality outflow and prevent penetration of clogging matter to such depth that it cannot be removed by surface scraping. This is usually in the range 0.15 - 0.35 mm and is determined by experiment. Both finer and coarser materials have been found to work satisfactorily in practice, and the final selection will usually depend on the available materials. It is possible to combine two or more types of stock sand to bring the effective size of the mixture closer to the ideal, as shown in Figure 2[2]. The broken line in the Figure indicates the filtering material obtained by mixing 3 parts of sand A with one part of sand B to give an effective diameter of about 0.25 mm.

Desirable characteristics for all filter media are as follows:

- good hydraulic characteristics (permeable);
- does not react with substances in the water (inert and easy to clean);
- hard and durable;
- free of impurities; and
- insoluble in water.

Gravel is used to support the filter sand and should have similar characteristics.

3.2 FILTER LAYOUT AND OPERATION

The filter media is usually contained in concrete filter tanks which are all the same size, but the size will vary widely from works to works. In general, the minimum number of filters is three to allow for one filter to be out of service and yet have sufficient capacity available to meet the average demand. A typical section of a slow sand filter and prefiltration control chamber is shown in Figure 3.

Water, admitted to a slow sand filter, properly "conditioned", flows downward through the media. In the slow sand filtration process, particles are removed primarily by straining, adsorption, and microbiological action. The major part of the particulate material is removed at or in the top layer of sand, which becomes covered with a thin slimy layer, called the "schmutzdecke", built up by micro-organisms as the filter 'ripens'.

Slow sand filtration does not materially reduce the *true colour* of a water. True colour is the colour attributable to light-absorbing organic molecules which are dissolved in the water as distinct from that attributable to light-scattering colloidal particles such as clay. True colour [5,13] is measured following the removal of such colloidal matter by passing a sample of water through a membrane filter of aperture approximately 0.5 µm. With a standard of 20 mg/l platinum/cobalt for colour as the maximum allowable concentration in Ireland, slow sand filtration is unlikely to be suitable for raw water with colour in excess of about 25 mg/l platinum/cobalt, unless colour is oxidised in the filtrate by ozonisation.

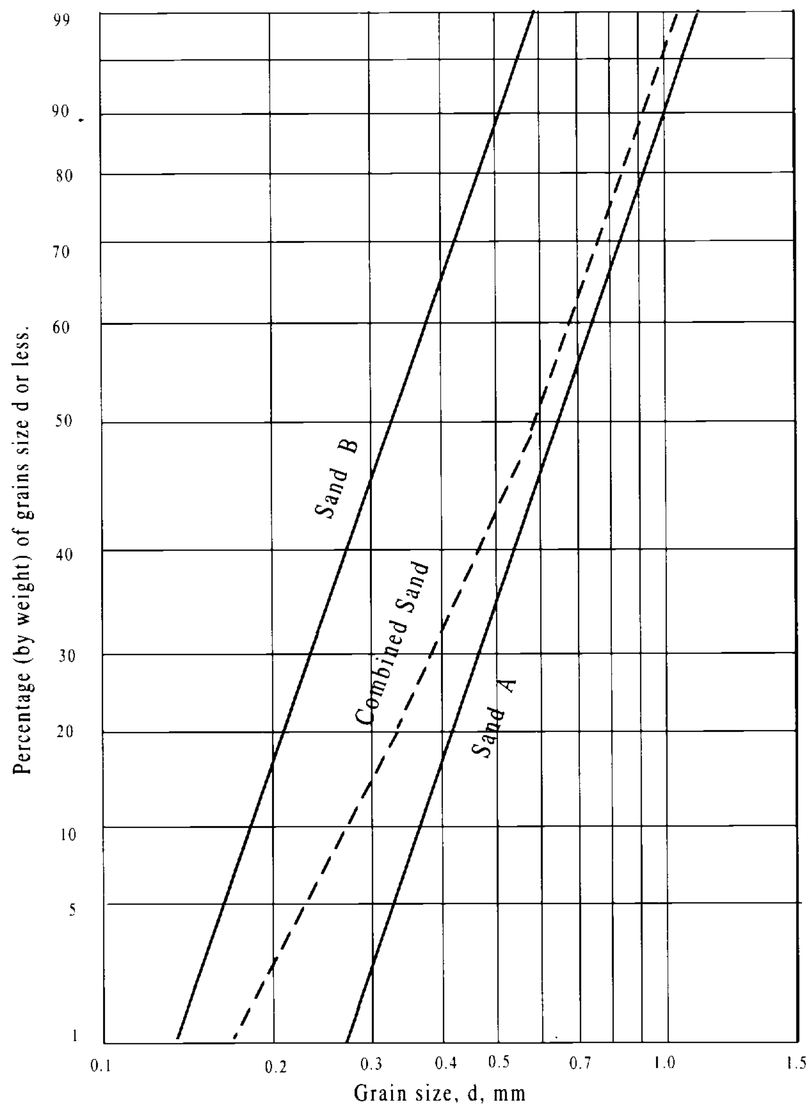

FIGURE 2:COMBINATION OF TWO TYPES OF STOCK SAND

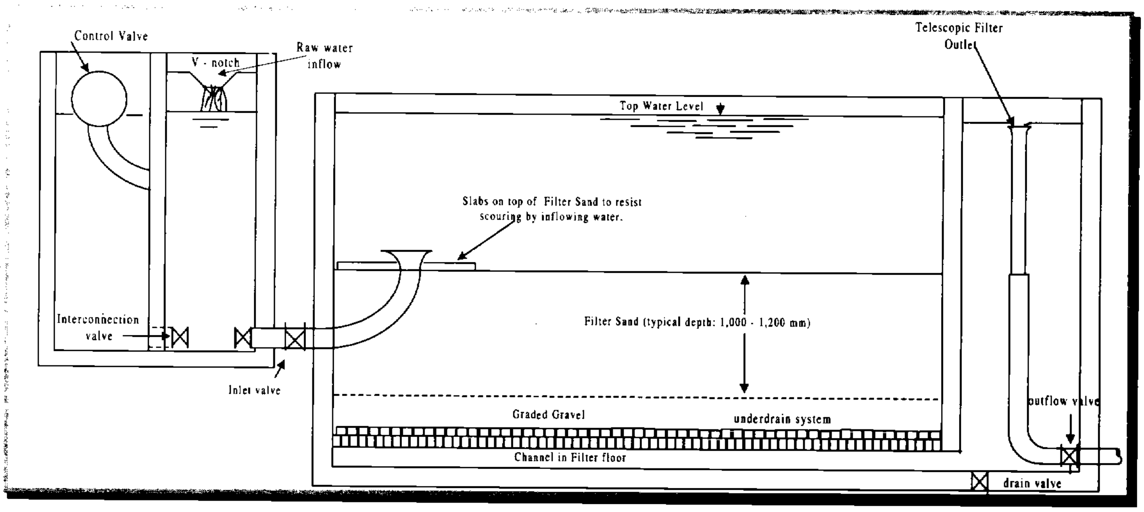

FIGURE 3: SLOW SAND FILTER AND PREFILTRATION CONTROL CHAMBER

Filtration rates are extremely low, typically 0.1 to 0.2 m per hour, depending on whether lowland or upland water is being filtered and the treatment regime applied. The higher filtration rates apply to upland waters, with which the classic schmutzdecke does not form, or to lowland waters which are pretreated by microstraining or roughing filters, as in the case of the Belfast supply from Castor Bay, Lough Neagh, where the water is first treated by rapid gravity filtration. Chemicals such as chlorine are not added before slow sand filtration as this would inhibit microbiological activity.

The entire top layer of the filter, including the schmutzdecke, must be physically removed when the filter becomes clogged, or else the filter cleaned in-situ. No works with in-situ mechanical cleaning exists in Ireland as far as is known. Disadvantages to slow sand filtration are the large land area required and the manpower, or investment in plant, required for cleaning the filters.

3.3 SLOW SAND FILTER CONTROL

Slow sand filters are normally supplied through an inlet chamber housing a control valve and a measuring weir (see Figure 3). A single inlet chamber usually feeds a group of filters or even an entire small works and controls the level of water in the filters. The head on the filters in smaller works is normally controlled by an adjustable bellmouth in the outlet chamber of each filter, sometimes fitted with a scale to enable the flow over the lip to be gauged. When a filter has been cleaned and put into service, the headloss through it is only a few cm and the bellmouth is set near the top of its travel. The headloss increases as the filter ages and the bellmouth is lowered to maintain the desired flow through the filter. When the bellmouth has reached the bottom of its travel,the filter has reached the end of its run and needs to be cleaned again. The adjustable outlet bellmouth ensures that negative pressures cannot occur within the bed. Alternative forms of adjustable outlets to that described above are available. Control of the filtration rate on larger works may be achieved automatically by measuring the outflow from each filter using a flow rate controller and using this signal to raise and lower the bellmouth or other device.

3.4 SLOW SAND FILTER CLEANING AND RESANDING

3.4.1 WORKER SAFETY AND HYGIENE PRACTICE

During filter cleaning or resanding operations all workers should wear rubber boots, which are disinfected in a tray of bleaching solution before entering the filters. The highest standards of personal hygiene should be observed by all workers and no worker with symptoms that might be attributable to waterborne or parasitic disease should be permitted to come into direct or indirect contact with the filter medium.

3.4.2 RECOMMENDED PROCEDURE FOR CLEANING A SLOW SAND FILTER

1. Draining the filter and preparing it for cleaning

When a filter has reached the end of its run and arrangements for its cleaning have been made, the raw water inlet valve is closed, to initiate the cleaning operation, thus allowing the filter to continue to discharge at a reducing rate to the clear water tank for as long as possible (usually overnight).

The outflow valve is then closed (e.g. next morning) and the remaining water above the sand is run to waste.

The water within the bed is then lowered about 100mm below the surface of the bed by opening the drain valve.

2. Cleaning the filter

Cleaning should start as soon as the schmutzdecke is dry enough to handle. If the filter is left too long, it is likely to attract scavenging birds that will not only pollute the filter surface but disturb the sand to a greater depth than will be removed by scraping. If, as is normal, mechanised methods are not available, workers using squarebladed shovels should strip off the schmutzdecke and the surface sand adhering to it and stack it in ridges or heaps for removal.

Great care should be taken to minimise disturbance of the upper layers of filter media so that the biomass is protected. For this reason, dumpers or other machines used for removal should be designed to operate with low pressure tyres and barrows or handcarts should always be run on protective planks.

Cleaning is a simple matter when the schmutzdecke consists largely of filamentous algae forming an interwoven mat. The knack of curling back this mat in reasonably large sections is quickly acquired, provided that the operation is timed so that the material is neither waterlogged nor so dried out that it is brittle. Cleaning will be less easy if the schmutzdecke consists largely of non-filamentous algae and greater care will be necessary to control the depth of scraping, which should be between 15 and 30 mm.

After removal of the scrapings the bed should be smoothed to a level surface. The quicker the filter-bed is cleaned the less will be the disturbance to the biomass and consequently the shorter the period of re-ripening. The micro-organisms immediately below the surface will quickly recover, provided they have not been completely dried out, and will adjust to their position relative to the new bed level. A day or two should be sufficient for re-ripening in this event.

Before refilling the filter, the walls below normal top water level should be swabbed down to discourage the growth of slimes and algae.

3. Refilling the filter

The filter is refilled by closing the drain valve, reopening the outflow valve and allowing the filtered water to backflow through the underdrain system until there is sufficient depth on the sand surface to prevent disturbance of the bed by inflowing raw water. When the filter is sufficiently charged the outflow valve is closed. The raw water inlet valve is then gradually opened and the filter is filled to normal operating level.

The bellmouth of the telescopic outlet is raised to near its maximum and the filter outflow is run to waste at a gradually increasing rate, (or if there is a suitable pump, recycled to the works inlet), for a day or two until the filter is re-ripened and analysis shows that the outflow satisfies the required quality standards.

4. Disposal of scrapings

The material removed from the filter, depending on the size and available equipment at the works, may be washed for reuse or disposed of on land by burial or used in agriculture. The workforce who scrape the filters or wash the sand should be instructed in necessary hygiene practice.

3.4.3 RECOMMENDED PROCEDURE FOR RESANDING A SLOW SAND FILTER

Each cleaning of the filter removes between 10 and 15 mm of filter sand, so that after twenty or thirty scrapings the thickness of the sand bed will have been reduced to its minimum design thickness, usually about 300 mm and resanding is then necessary. The following procedure is recommended for re-sanding a slow sand filter. The filter can either be re-sanded by the 'trenching' method which makes use of the residual sand, or by refilling with new sand. Generally, re-ripening of the filter is quicker if the trenching method is employed.

1. Preparation

The bed is cleaned, as described in section 3.4.2 above, and the water level lowered to the bottom of the sand layer.

2a. Resanding - the 'trenching' method

Most of the residual sand is removed from a strip of the filter along one wall thus forming a trench, taking care not to disturb the underlying gravel layer by leaving 100 to 150 mm of residual sand above it. The sand is placed adjacent to the filter for later re-use.

Fresh sand (either new or washed sand from filter cleaning) is placed in the trench to a thickness which, with the residual sand, equals the depth of sand in the filter prior to re-sanding (see Figure 4) or as determined in consultation with the designer.

Residual sand from the adjacent strip is "thrown over" on top of the freshly placed sand in the first strip, fresh sand is placed in the second trench just formed and sand from the next adjoining strip is "thrown over" as shown in Figure 4.

This process is continued until the entire filter has been resanded and the residual sand from the first strip is placed on top of the last strip filled. In this way, the residual sand forms the upper layer of the re-sanded filter and the new sand the lower layer.

The filter-bed may have a layer of crushed shells incorporated near the bottom, to correct the pH, where the raw water is naturally aggressive. The residue of the shell layer must normally be removed and replaced during re-sanding operations. Occasionally, a layer of activated carbon about 100mm deep is placed near the bottom of the filter-bed to absorb traces of taste and odour-producing substances that have passed through the filters. This layer should be removed and replaced during the resanding operations, as the carbon will have become saturated with the impurities and/or inactivated.

2b. Resanding - clean sand method

An alternative to the trenching method described above is to remove all the old sand from the bed down to the support gravel and refill with clean sand.

3. Refilling the filter

The bed should be smoothed to a level surface and refilled with filtered water through the underdrainage system. The raw water inlet is then opened as described in section 3.4.2.

4. Re-ripening the filter

The ripening of a filter with clean sand will take longer than the time for re-ripening a filter resanded using the trenching method. Care must be taken to ensure that a satisfactory quality outflow is being produced before the filter is put back into service.

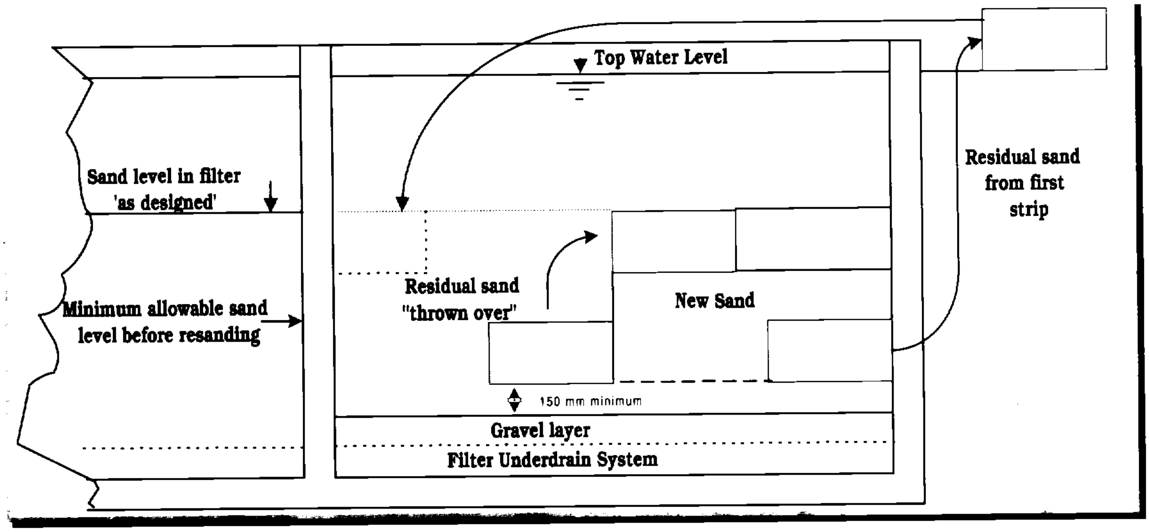

FIGURE 4: REASANDING A SLOW SAND FILTER USING THE TRENCHING METHOD

4 RAPID GRAVITY AND PRESSURE FILTRATION

Filtration preceded by coagulation, flocculation and clarification is commonly referred to as conventional filtration. In the direct filtration process, although coagulation and flocculation may be used, the clarification step is omitted. Typical treatment processes for these two filtration methods are shown in Figure 5. The conventional filtration (treatment) process is used in most municipal treatment plants. This process includes "complete" pretreatment (coagulation, flocculation, and clarification/flotation). This system provides flexibility and reliability in plant operation, especially when source water quality is variable or the water is high in colour and suspended solids.

Direct filtration is an alternative to conventional filtration, particularly when source waters are low in turbidity, colour, plankton, and coliform organisms. Direct filtration can be defined as a treatment system in which filtration is not preceded by clarification or flotation.

4.1 RAPID GRAVITY FILTRATION

In all gravity filtration systems the water level or pressure (head) above the media forces the water through the filter media as shown in Figure 6. The rate at which water passes through the granular filter media (the filtration rate) may vary widely, depending on the purpose for which the water is required. However, for public water supply in Ireland, 5 m/hour may be regarded as the standard rate and most authorities limit the maximum filtration rate to between 5 and 7.5 m/hour. Rates in excess of this may be used where special technology is employed. The rate of water flow through the filter is referred to as the hydraulic loading or the filtration rate. The filtration rate depends on the raw water quality and the type of filter media. Various filter media configurations used are illustrated in Figure 7.

They are:

- single media (sand);
- dual media (sand and anthracite); and
- multi or mixed media (sand, anthracite, garnet).

Activated carbon (in granular form) can also be used in association with these configurations for the removal of tastes, odours, and organic substances.

In rapid gravity filtration the particulate impurities are removed in or on the media, thus causing the filter to clog after a period. Clogged filters are cleaned by backwashing. Gravity filtration is the most widely used form of water treatment in this country.

4.2 PRESSURE FILTRATION

A pressure filter is similar to a gravity sand filter except that the filter is completely enclosed in a pressure vessel such as a steel tank, and is operated under pressure, as shown in Figure 8. Pressure filters have been used in public water supplies, and have limited applicability, for instance, in the removal of iron and manganese from groundwaters. Their use in Irish practice is mainly confined to the treatment of water for industrial purposes, but they have been installed by a number of local authorities.

Pressure filters have been found to offer lower installation and operation costs in small filtration plants. However, they are generally somewhat less reliable than gravity filters. Maximum filtration rates for pressure filters are in the 5 to 7.5 m/hr range.

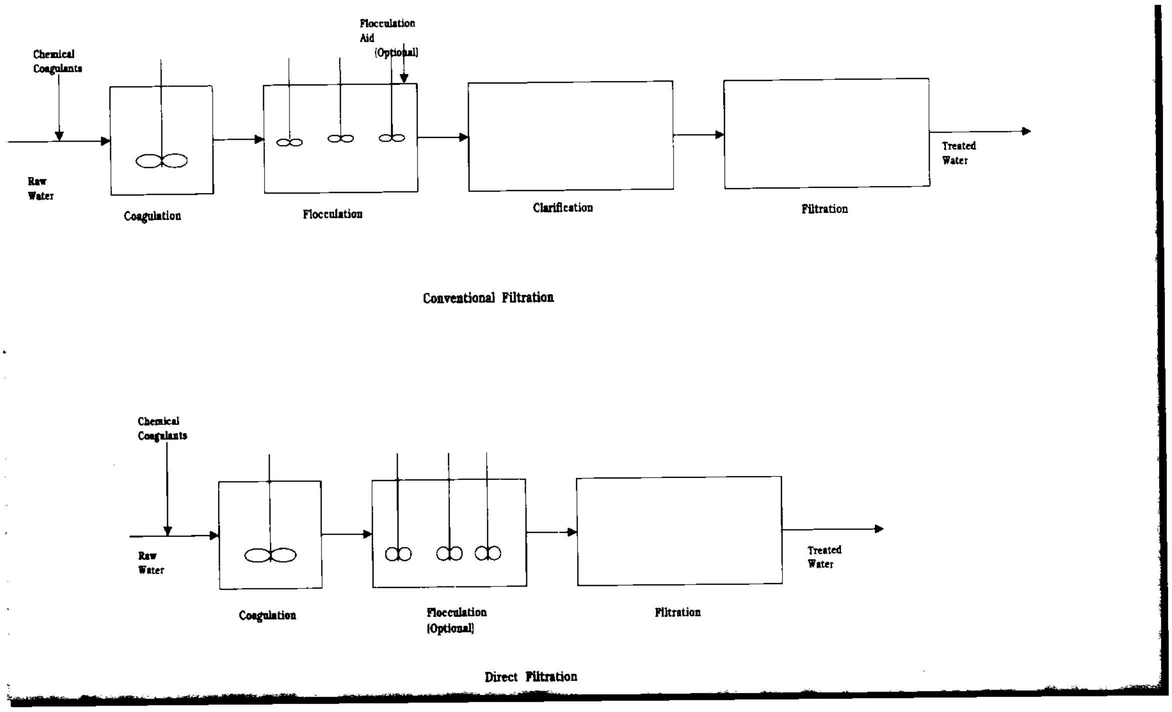

FIGURE 5: CONVENTIONAL AND DIRECT FILTRATION

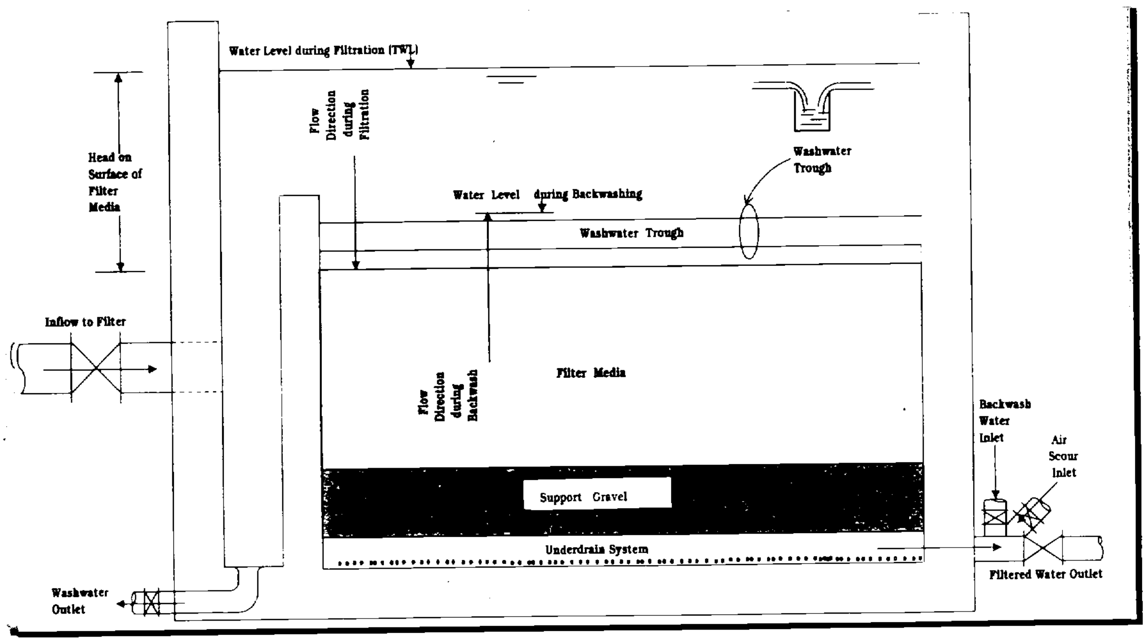

FIGURE 6: RAPID GRAVITY FILTER

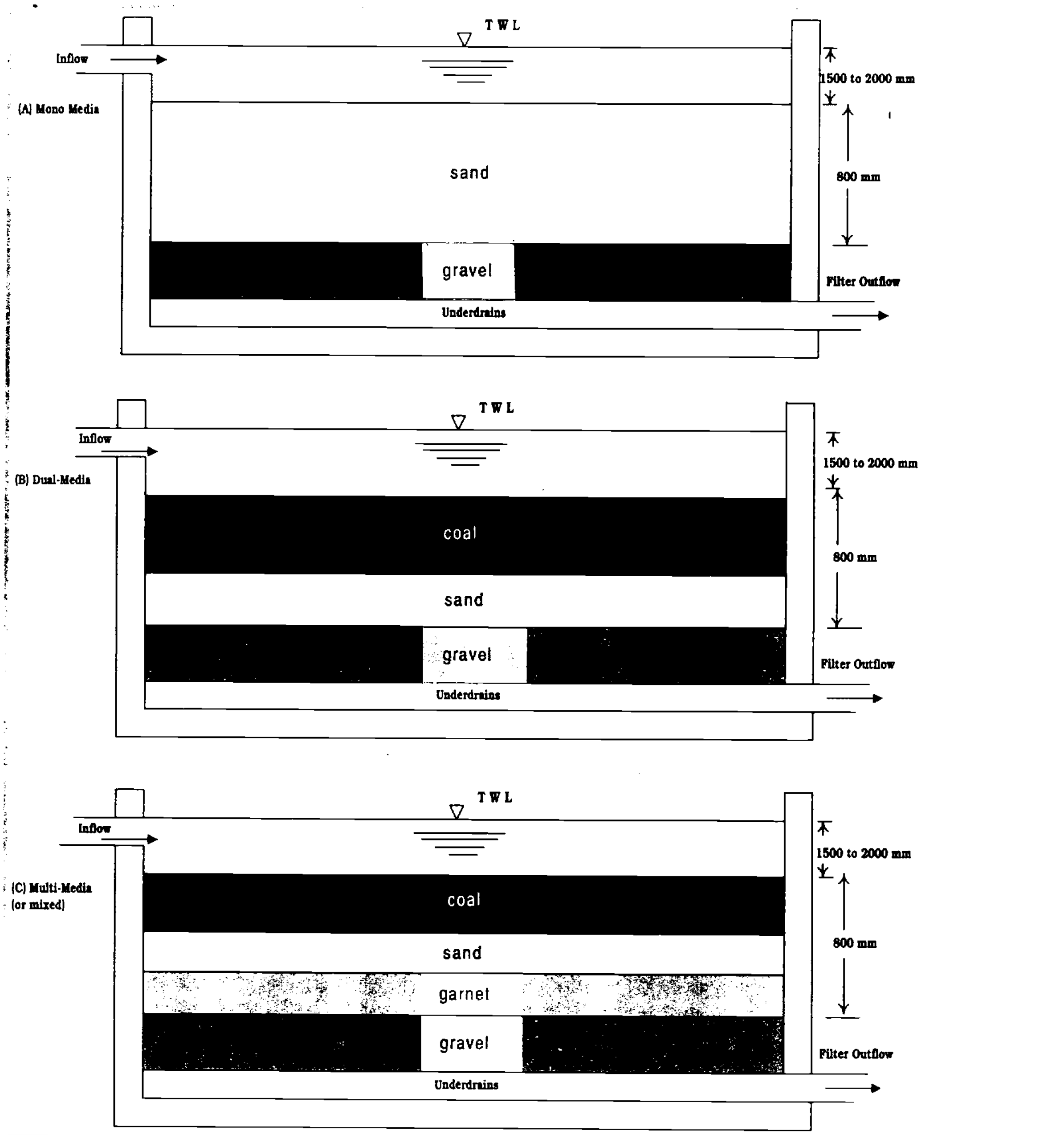

FIGURE 7: GRAVITY FILTER MEDIA CONFIGURATIONS

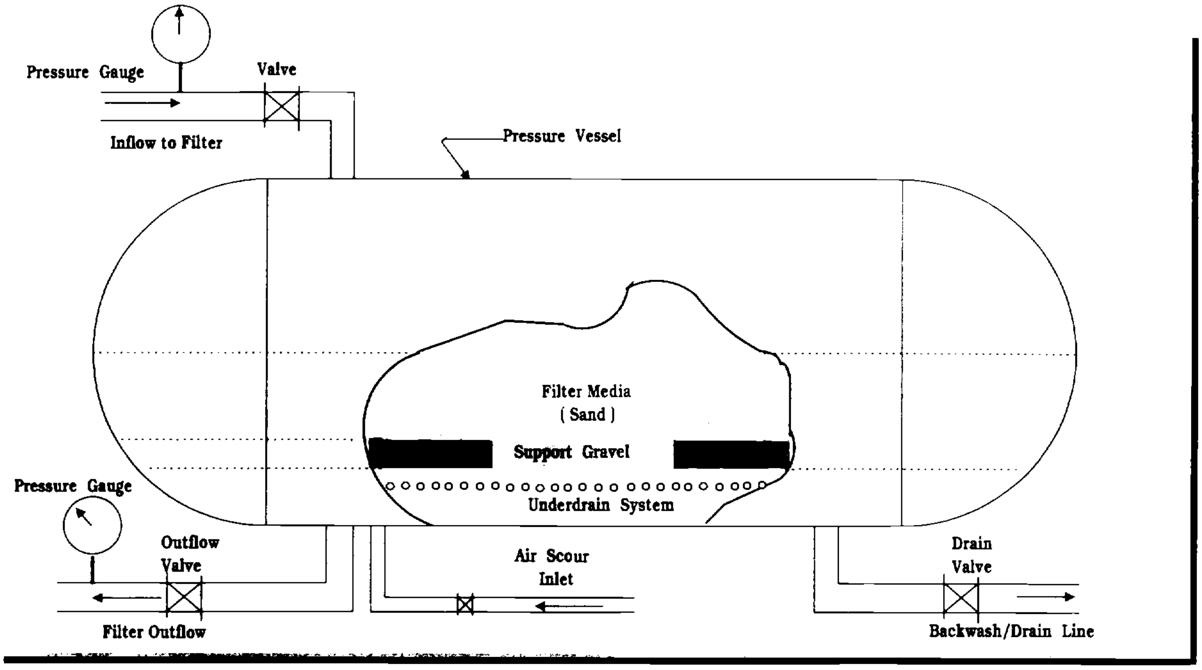

FIGURE 8: PRESSURE FILTER

5. PROCESS CONSIDERATIONS

5.1 RAPID GRAVITY FILTER MEDIA

The most common filtering material in rapid gravity (and pressure) filters is sand[3]. The dual media filter is a refinement of the rapid gravity monosand filter, in which an upper layer of anthracite or similar material above the sand provides increased void space to store impurities removed from the incoming water. The mixed media filter is a further refinement, in which a layer of garnet or similar dense material is placed below the sand. Other inert materials may also be used including activated carbon. Gravel is commonly used to support the filter media. Desirable characteristics for all filter media are as follows :

- good hydraulic characteristics (permeable);
- does not react with substances in the water (inert and easy to clean);
- hard and durable;
- free of impurities; and
- insoluble in water.

Gravel is used to support the filter sand and should also have the above characteristics.

It has been the custom to designate sand for rapid gravity filters in terms of its effective size and uniformity coefficient. Other materials for rapid gravity filters are referenced by means of the suppliers code reference (e.g. No 2 Anthracite)[5]. A U.K. standard for the specification, approval and testing of materials for rapid gravity filtration has recently been published by the British Effluent and Water Association[6]. The standard is intended to cover all granular materials used in rapid gravity filtration, in terms of the parameters necessary for the successful operation of the filtration system including backwash. Effective size and uniformity coefficient are omitted and a new parameter, *hydraulic size*, is defined. This parameter can be used in calculating the fluidization threshold, the point in backwashing where the hydraulic (pressure) loss through the filter sand equals the dead (submerged) weight of the material. Other important parameters in this calculation are the density of the material and its voidage, or porosity as it is more commonly known. The porosity is dependant on the shape of the grains. Rounded grains tend to have a lower porosity and can be washed at a lower backwash rate; however, as a filtering material it has less space within it to hold the flocs and solids removed from the water and also produces a higher headloss. Given the correct backwash rate in the first place, material with higher porosity has much to commend it. Anthracite, which is a crushed material, is a good example of a high porosity medium which has been in use for many years.

Two factors are very important in making judgements about media selection :

- the time required for turbidity to break through the filter bed; and
- the time required for the filter to reach limiting head loss.

With a properly selected media, these times are about the same.

If the limiting head loss is frequently a problem and turbidity breakthrough rarely occurs, then a larger media size may be considered. If turbidity breakthrough is frequently a problem and limiting head loss is rarely encountered, then a smaller media size may be considered.

If both head loss and turbidity breakthrough are a problem, while the filter is operating within its rated capacity, a deeper filter bed with a larger sand size may be required. The optimum depth needed to obtain a given quality and length of run varies with the size of the sand. However, increasing the media depth is not always possible without modification of the filter. Adequate clearance must be allowed between the top of the media and the weir cill of the washwater channel. Otherwise, filter media will be carried over into the washwater channel during backwash, when the bed expands.

The relationship between turbidity breakthrough and limiting head loss is also strongly affected by the efficiency of chemical pre-treatment. Poor chemical pre-treatment can often result in early turbidity breakthrough, rapid head loss buildup or binding of the filter sand.

It must also be remembered that backwashing is possibly a more critical part of the filtration process than the forward filtration phase. If the backwash rate is slightly too high, filter material can be lost rapidly. If it is slightly too low, the cleaning efficiency will fall abruptly, the filter will cease to be cleaned properly and its performance will quickly deteriorate. The backwash sequence must be selected taking account of the material used and the temperature of the backwash water. Existing backwash procedures will require adjustment if a new filtering material has a different size, density or voids ratio.

Selection of an appropriate media for rapid gravity filtration depends on the source water quality, filter design and anticipated filtration rate. Generally the more uniform the media the slower the head loss buildup. Media with uniformity coefficients of less than 1.5 are readily available. Media with uniformity coefficients of less than 1.3 are only available at a high cost. Typical filter media characteristics are given in Table 1.

Table 1: Typical Media Filter Characteristics

Material	Size Range (mm)	Specific Gravity
Conventional Sand	0.5-0.6	2.6
Coarse Sand	0.7-3.0	2.6
Anthracite/Coal	1.0-3.0	1.5-1.8
Gravel	1.0-50	2.6

5.2 OPERATIONAL CRITERIA

5.2.1 FILTER LAYOUT

In rapid gravity filtration, the filter media is usually contained in a number of concrete filter tanks (or cells) which are all the same size. Steel or aluminium tanks are sometimes used. However, the size will vary widely from plant to plant. In general, the minimum number of filters is three. This allows for one filter to be taken out of service leaving sufficient filter capacity available to meet the demand. Typical filter sections are shown in Figure 7.

5.2.2 FILTER PRODUCTION AND FILTRATION RATE

For public water supply in this country, the standard filtration rate for rapid gravity filters is usually 5 m/hour and most authorities limit the maximum filtration rate to between 5 and 7.5 m/hour. The minimum number of filters should be three for the smallest works as noted above, but the number and size should be kept reasonable in relation to the total works throughput with the size based on a 20 hour working day. In larger water treatment plants, filter capacities range up to about 25,000 m^3/day for the largest filter units. Filtration plants operated at rates in excess of those quoted above generally require additional supervision.

5.2.3 FILTRATION EFFICIENCY

Rapid gravity filtration efficiency is roughly measured by overall plant reduction in turbidity, although it should be noted that up to 90% of the reduction may take place in the pretreatment stages. Overall reductions of over 99.5 percent can be achieved under optimum conditions, while a poorly operated filter and inadequate pre-treatment (coagulation, flocculation, and clarification) can result in turbidity removals of less than 50 per cent. The best way to assure high filtration efficiency is to select an outflow turbidity target and stay below the target value [such as 0.5 NTU (Nephelometric Turbidity Units)].

Solids removal efficiency depends largely on: the quality of the water being treated; the effectiveness of the pre-treatment processes in conditioning the suspended particles for removal by clarification and filtration; and, filter operation.

Filter unit design and filter media type and depth also play a role in determining solids removal efficiency, but are less important than water quality and pre-treatment considerations. Rapid gravity sand filters usually produce a filtered water turbidity comparable to that of a dual-media filter if the applied water quality is similar. However, the operational differences between sand and dual-media filters are significant.

Because of their smaller media grain size, typically 0.8 to 1.0 mm, sand filters tend to clog with suspended matter and floc more quickly than dual-media filters. This means that more frequent backwashing will be required to keep the sand filter operating efficiently. Sand filters have fine, light grains on the top which retain all floc and particulates at or near the surface of the filter. Dual-media filters have lighter, larger diameter grains in the top layer of the media which retain the larger particles; the smaller particles are usually retained deeper in the filter. The larger grain size of the anthracite layer (up to 1.5 mm) in the top portion of a dual-media filter permits greater depth penetration of solids into the anthracite layer and larger solids storage volume in the filter. The sand layer below the anthracite is used as a protective barrier against breakthrough. These characteristics generally produce filter runs which are longer than those achieved by sand filters. Taps at various depths in the filter may be used to observe the depth of solids penetration.

Multi-media filters (sand, activated carbon and anthracite) are also used to extend filter run times, and these filters generally perform in a manner similar to sand filters, except that the filter media is enclosed in a pressure vessel. With the filter media fully enclosed, it is impossible to assess the media condition by simple visual observation. In addition, excessive pressure in the vessel will force solids as well as water through the filter media. Obviously, this will result in the deterioration of filtered water quality. Pressure should therefore be maintained within the range provided for by the designer.

Particular care should be taken when a filter is being backwashed to ensure that the remaining filters are not overloaded. Backwashing, together with routine and emergency maintenance, should be completed without overloading the remaining filters.

5.3 FILTER OPERATION

5.3.1 RAPID GRAVITY FILTRATION

In the filtration mode of operation, water containing suspended solids is applied to the surface of the filter media. Depending on the amount of suspended solids in the water being treated and the filtration rate, the filter will exhibit head loss and "clog" after a given time period (varies from several hours to several days).

Clogging may be defined as a buildup of head loss (pressure drop) across the filter media until it reaches some predetermined design limit. Total design head loss in gravity filters generally ranges from about 1.8 to 3.0 m depending on the depth of the water over the media. Clogging of the filter leads to *breakthrough,* a condition in which solids are no longer removed by the already over-loaded filter. The solids pass into the filtered water where they appear as increased turbidity.

A filter is usually operated until just before clogging or breakthrough occurs, or a specified time period has passed, generally 24 to 40 hours and is related to the efficiency of the clarification process. In order to save money, energy and water by maximizing production before backwashing, filters are sometimes run until clogging or breakthrough occurs. This is a poor practice and should be discouraged. When breakthrough occurs, there will be an increase in filtered water turbidity and hence a decrease in water quality with the risk that pathogenic organisms may pass through the filter.

5.3.2 BACKWASHING

After a filter clogs (reaches maximum head loss), or break-through occurs, or a specified time period has passed, the filtration process is stopped and the filter is taken out of service for cleaning or backwashing. Detailed procedures for backwashing tend to be particular to each plant and specific instructions are provided by plant contractors.

Backwashing is the process of reversing the flow of water through the filter media to remove the entrapped solids. Backwashing may comprise the application of water alone, air and water seperately and sequentially, or air and water simultaneously. The latter procedure is generally acknowledged to be the most efficient, but filters must, in general, be designed for an air/water backwash as changing existing filters to use this system is fraught with difficulty. With all three types of wash, the process conditions are related to the (minimum) fluidization threshold as a reference point, even with combined air and water washes. This threshold is the point where the hydraulic (pressure) loss through the filter bed equals the dead (submerged) weight of the material. The maximum backwash water flow rate should not exceed 20 m/hr, as higher flow rates will result in excessive media loss. During the backwash cycle the bed should be expanded by a minimum of 10% and a maximum of 20% to ensure adequate cleaning.

As mentioned previously, backwashing is possibly a more critical part of the filtration process than the forward filtration phase. If the backwash rate is slightly too high, material can be rapidly lost. If it is slightly too low, the cleaning efficiency will fall abruptly, the filter will cease to be cleaned properly and its performance will quickly deteriorate. The backwash sequence and duration must be selected taking account of the filtering materials in use and the temperature of the backwash water. It may be necessary in some cases to adjust the backwash rates seasonally in order to maintain optimum conditions without losing media.

Filtered water is almost invariably used for backwashing and is usually supplied by a backwash pump. An elevated storage tank may also be used to store water to backwash filters. The backwashing process will use about two to four percent of the filter output, the lower percentages being associated with combined air/water washing.

It is very important to observe the surface of the filter during the whole backwash operation. Any non-uniform surface turbulence during air scour may indicate a problem with the air distribution arrangements or the occurrence of "mudballs" in the media. Mudballs occur when backwashing of a filter is inadequate. The surface 'crust', formed by the filtered solids and sand at the top of the filter bed becomes cemented into a compact crust. This cracks and pieces sink into the expanded sand bed during backwashing, without being broken up. These pieces of crust gradually increase in size during the subsequent operation of the filter. If mudballing is suspected the mudball evaluation procedure detailed in Appendix C should be used. The simplest method of improvement of a filter affected by mud-balling is to agitate the expanded bed with a "drag" or long-tined rake.

The used washwater should be settled and the settled washwater either discharged to waste or recycled through the treatment process. Recycling of washwater (without balancing) directly to the head of the works has been found to cause operational difficulties with chemical dosing equipment and control of chemical dosing plant and hence it is not recommended.

The settled solids should be treated with the sludge from the clarification stage. It should be noted that recycling of washwater can result in a concentration of viruses, cysts and other undesirable particles, as well as polyelectrolyes, on the filters which, in turn, increases the potential of breakthrough into the water supply. Under normal operating conditions where the raw water is uncontaminated this should not pose a problem. However, it is important that plants develop contingency plans which avoid the recycling of washwater when a pollution incident is known to have contaminated the raw water supply. Under normal conditions, the settled washwater should be recycled, if possible, to the balancing tank or reservoir supplying the works, or mixed with the raw water, ahead of the flashmixer.

Any polyelectrolytes used in the solids handling phases should be suitable for use in potable water, if supernatant / other liquors are to be recycled.

5.4 FILTER CONTROL SYSTEMS

The filter control system regulates the flow rate through the filter by maintaining an adequate head above the media surface. This head (*submergence*) forces water through a gravity filter. The flow through a filter must be as stable as possible and any changes in flow rate, whenever operating conditions at the plant change, should be controlled in order for the filter to yield the optimum outflow quality. The best control system therefore is one with simple, safe and reliable controllers that controls filtration without hunting, and includes sensors that monitor the largest possible water surface areas so that changes in set-point values are representative.

Without an effective filter control system, sudden flow increases or surges could dislodge solids trapped on the filter media. If these solids were discharged, they would seriously degrade water quality. An adequate depth of water above the media surface is essential to ensure that the inflow does not disturb (scour) the media. In this way, the energy of the inflow is absorbed before it reaches the media, thus preventing scouring.

An essential element in the control system for rapid gravity filtration is a slow start controller, which restricts the output from a filter for a period after backwashing while the filter is 'ripening'. In new works, slow start controls are generally incorporated in the plant design, while in older or smaller works hydraulic/mechanical controls are used. The latter depend on the flow of water into a tank, through a submerged orifice with increasing depth of submergence, to open the outlet valve from the filter.

Rapid gravity filter control systems can be classified into three types :

constant rate, with a controller;

constant rate, variable head type; and

declining rate (or variable flow rate).

The *constant rate* type with a *controller*, may be operated either on the *Constant Level* system or with *Flow Measurement.* With *Constant Level* control the inflow to the plant is distributed equally between the filters, each receiving a flow equal to the incoming flow rate divided by the number of operating filters. Each filter is equipped with a controller which detects the upstream level, which it keeps constant by adjusting the outflow controller. Because the upstream level is kept constant, the outflow is equal to the inflow and clogging is compensated for until it reaches a limit, which depends on the available head. When a filter is shut down for backwashing or maintenance, the inflow is automatically distributed over the filters that are still in service with the exception of filters using a surface flush of settled water. Equal distribution of inflow is achieved simply and reliably by static devices (orifice plates, weirs, etc). Use of this control system also eliminates the discrepancies between total filtered flow and incoming flow that can occur with control systems based on flow rate measurements.

In the *Constant Rate* control with *Flow Measurement* system each filter outlet has a flowmeter linked to a controller which compares the metered flow from the filter to the flow rate set point and adjusts the outflow valve until they coincide. This system has no means of maintaining a specific water level above the filter media, so an additional central controller is needed. Normally the inflow rate to the filters is measured and the central controller adjusts the individual set-point rate of the filters accordingly. If the inflow rate increases, the level upstream of the filters rises and the central controller adjusts the set-point rate for the filters until the upstream level stabilizes and plant inflow and outflow are in balance. The central controller may alternatively adjust the individual set-point rate of the filters by reference to the water level in the clearwater tank. Another central controller detects the water level in the inflow channel and adjusts the inflow control valve to provide the filters with a flow to correspond with their set-point rate. The change in water level in the filters can be as much as 300 mm with this system.

Constant rate, variable head filters operate with a filtered water outlet control structure (weir) to control the minimum water level just above that of the media in the filters. The total inflow to the plant is distributed equally between all the operating filters. When the filter is clean the media is just covered by water and at maximum clogging the water reaches the level in the inflow channel.

The *self-backwash* (or Streicher design) system, is a variation of the constant rate, variable head filter. The inflow to the plant is distributed equally between all the operating filters, by a weir arrangement. The water surface level in each filter varies according to head loss, but the flow rate remains constant for each filter. This system reduces the amount of mechanical equipment required for operation and backwashing, such as washwater pumps, and also requires an outflow control structure and a deeper filter. These filters have a use where neither electricity nor compressed air is available and the water to be treated has low to moderate levels of suspended solids.

In *declining-rate* filters, flow rate varies with head loss. Each filter operates at the same, but variable, water surface level. This system is relatively simple, but again requires an outflow control structure (weir) to provide adequate media submergence.

6 ACTIVATED CARBON FILTERS[7]

The primary purpose of filtration is to remove suspended particles and floc from the water being treated. Another dimension is added to the filtration process by the use of activated carbon (granular form) as a filter media. The high adsorptive capacity of activated carbon enables it to remove taste and odour-causing compounds, as well as other trace organics from the water. However, not all organic compounds are removed with the same degree of efficiency.

While activated carbon filtration is very effective in removing taste and odour-causing compounds, the construction, carbon handling equipment and operating costs are generally quite high. Activated carbon can be added to existing filters provided there is sufficient depth available or can be incorporated as a separate process. Provision should be made for regeneration or reactivation of "spent" carbon (carbon which has lost its adsorptive capacity) either on or off-site.

The effectiveness of activated carbon in removing taste and odour producing organic compounds is well known. The chlorination of water containing certain natural organic substances, such as humic or fulvic acids or substances derived from algae may give rise to the production of trihalomethanes (THMs) or haloforms. The concern regarding these substances is reflected in the Drinking Water Regulations[8]which state that "Haloform concentrations must be kept as low as possible". The use of granulated activated carbon (GAC) filters to remove the organic substances that are the `precursors' of THMs is becoming more widespread.

GAC filters employed for organics removal are similar to sand filters of the rapid gravity or pressure type with generally similar design, filtration rates and backwashing arrangements, with the flow rate adjusted to suit the lower density of GAC. The GAC is placed in the filter over the support gravel. Media depth is a function of the empty bed contact time (EBCT). GAC characteristics will vary according to the material from which it is made whether wood, coconut shell or peat.

EBCT is normally in the range 5 to 30 minutes and will vary for different micropollutants. For pesticides removal an EBCT of 15 to 30 minutes is used while 10 minutes is considered adequate for THMs and VOCs (volatile organic compounds).

Although GAC removes most micropollutants efficiently, its adsorption capacity towards some is low, so that frequent regeneration becomes necessary, with consequent costs. Breakthrough will not normally occur for 2 to 3 years, when using an EBCT of about 10 minutes, if only taste and odour removal is required. Most pesticides may show breakthrough in 6 to 24 months using an EBCT of 10 to 30 minutes; THMs in 6 to 12 months and VOCs in 3 to 9 months.

7 INTERACTION WITH OTHER TREATMENT PROCESSES

7.1 PREFILTRATION TREATMENT

The treatment of water prior to filtration has profound effects on the quality of the filtered water. The interdependence of filtration with pretreatment processes is particularly illustrated in the fourth column of Tables 2 and 3 where very many of the "Possible Operator Actions" listed refer to changes in pretreatment processes. As much as 90% of the removal of colour and turbidity is effected in the pre-filtration stages of treatment. In this regard, the rapid gravity or pressure filtration process is the final step in the solids removal process which usually includes the pretreatment processes of coagulation, flocculation, and clarification. The degree of pretreatment applied prior to filtration depends on the quality of the raw water, type of filtration (pressure or gravity filter) and the size of the treatment facility. Most large municipal treatment plants include complete pretreatment facilities and gravity filtration.

Floc particles which are carried over from clarification into the filter inflow must be small enough to penetrate the upper filter media (depth filtration). Floc which is too large will cause the top portion of the filter to clog rapidly, thus leading to short filter runs. In addition, large floc (particularly alum floc) is often weak and easily broken up by water turbulence. This can cause degradation of outflow water quality. Ideally, floc removal is accomplished by contact with the media grains throughout the upper part of the filter media. After the initial coating or conditioning of the media surfaces with floc at the beginning of the filtration cycle, subsequent applications of floc will build up on the material previously deposited on the media surface. This process is often referred to as the "ripening" period. Higher filter outflow turbidities may occur during the first few minutes at the beginning of the filter run until "ripening" is completed.

Attempts are sometimes made to increase the throughput of filters by adding polyelectrolyte dosing to the pretreatment process. While this may be effective in the short term, it should be noted that because separate air and water backwash does not remove polyelectrolyte residues, the filter sand may be turned into a gelatinous mud if a combined wash is not available. The timing of polyelectrolyte addition is critical. A delay period, usually site-specific, after the addition of the primary coagulant is required for its effective working. Typical doses of approved cationic polymers range upwards from 0.05 but the dose used must not average more than 0.25 mg/l and the absolute maximum dose permitted is 0.5 mg/l. The procedures and precautions to be adopted in the use of these chemicals are detailed in a companion manual on Coagulation, Flocculation and Clarification which is currently being prepared by the Agency.

On occasion attempts are made to increase plant throughput by increasing polyelectrolyte dosage above the recommended level. This practice should be avoided. In all cases the lengths of chemical lines and ducted services should be minimised.

7.2 IN-LINE FILTRATION

In in-line filtration the coagulant is added immediately before the water enters the filter. This pretreatment method is commonly used in pressure filter installations. Chemicals are added directly to the filter inlet pipe and are mixed by the flowing water.

This process is not as efficient in forming floc as conventional or direct filtration when source water quality has variable turbidity and bacterial levels. Problems may develop with alum carry through or the formation of floc in the water after filtration.

TABLE 2: SUMMARY OF ROUTINE FILTRATION PROCESS ACTIONS

Actions	Location	Frequency	Possible Operator Actions
Monitor Process Performance and Evaluate Water Quality Conditions			
Measure Turbidity	Outflow/Inflow	Inflow at least once per day Outflow every 2 hours	• Increase sampling frequency when water quality is variable. Perform jar tests if required
Measure Colour	Inflow/Outflow	At least once every 2 hours	• Make necessary process changes a) Adjust coagulant/ coagulant aid dosage b) Adjust flash mixer/flocculator mixing intensity c) Change filtration rate d) Backwash filter
Determine Head Loss	Filter	At least twice per day	
Measure Metal ion residuals	Outflow	Daily	• Verify responses to process changes at appropriate times
Operate Filters and Backwash			
Put filter into service	Filter	Depends on process conditions	• See operating procedures in Section 11.5
Change filtration rate			
Remove filter from service			
Backwash filter			
Change backwash rate			
Check Filter Media Condition			
Media Depth evaluation	Filter	At least monthly	• Replace lost filter media
Media cleanliness			• Change backwash procedure
Cracks or shrinkage			• Send sample of media for testing
Make Visual Observations of Backwash Operation			
Check for media boils	Filter	At least once per day or whenever backwashing occurs when less frequent	• Change backwash rate
Observe media expansion			• Change backwash cycle time
Check for media carryover into washwater channel			• Adjust wash rate, air scour or cycle time
Observe clarity of washwater			• Inspect filter media for disturbance
Check Filtration Process and Backwash Equipment Condition			
Noise/Vibration/Leakage Overheating	Various	Once per day	• Correct minor problems • Notify maintenance/supervisory personnel of major problems
Accuracy of flows	Inflow/outflow Air scour Backwash	Daily Monthly Monthly	• Recalibrate meters or gauges
Inspect Facilities			
Check physical facilities	Various	Once per day Daily	• Report abnormal conditions to maintenance/supervisory personnel
Check for algae buildup on filter walls and channels			• Remove debris from filter media surface • Perform routine cleaning/maintenance

TABLE 3: FILTRATION PROCESS TROUBLESHOOTING

Trigger	Possible Operator Actions	Possible Process Changes
	Source Water Quality Changes	
Changes in: • Turbidity • Colour • pH • Temperature • Alkalinity • Chlorine demand	• Perform necessary analysis to determine extent of problem • Assess overall process performance. • Perform jar tests if indicated • Make appropriate process changes (see right-hand column, 'Possible Process Changes') • Increase frequency of process monitoring • Verify response to process changes at appropriate time (be sure to allow sufficient time for change to take effect) • Add lime or caustic soda if alkalinity is low	• Adjust coagulant dosage • Adjust flash mixer/flocculator mixing intensity • Change frequency of sludge removal (increase or decrease) • Change filtration rate (add or delete filters) • Adjust backwash cycle (rate, duration)
	Clarification Process Quality Changes	
Changes in: • Turbidity or floc carryover • Metal ion residual carryover	• Assess overall process performance • Perform jar tests if indicated • Check that selected chemical doses are being applied • Make appropriate process changes • Verify response to process changes at appropriate time	Same suggestions as for source water quality changes
	Filtration Process Changes/Problems	
Changes resulting in: • Head loss increase • Short filter runs • Media surface sealing • Mudballs • Filter media cracks, shrinkage • Filter will not clean • Media boils • Media loss • Excessive head loss	• Assess overall process performance • Perform jar tests if indicated • Make appropriate process changes • Verify response to process changes at appropriate time • Manually remove mudballs • Replenish lost media • Clear underdrain openings of media, corrosion or chemical deposits when filter is out of active service • Check head loss indicator for correct operation	• Adjust coagulant dosage • Adjust flash mixer/flocculator mixing intensity • Change frequency of sludge removal • Decrease filtration rate • Adjust backwash cycle (rate, duration)
	Filter Outflow Quality Changes	
Changes resulting in: • Turbidity breakthrough • Colour • pH • Chlorine demand	• Assess overall process performance • Perform jar tests if indicated • Verify process performance: (a) Coagulation-flocculation process (b) Clarification process (c) Filtration process • Make appropriate process changes. • Verify response to process changes at appropriate time	• Adjust coagulant dosage • Adjust flash mixer/flocculator mixing intensity • Change frequency of sludge removal. • Decrease filtration rate (add more filters) • Change chlorine dosage

8 PROCESS MONITORING AND CONTROL

The quality of treated water for human consumption must, after disinfection, meet legally defined standards as set out in the European Communities (Quality of Water Intended for Human Consumption) Regulations, 1988[8]. Parameters to be monitored under the regulations are divided into five groups - organoleptic, physico-chemical, undesirable in excessive amounts, toxic and microbiological.

It has been found in practice that control of turbidity is, except in rare instances, perfectly adequate for monitoring process performance. In a very short period, the correlation between filter inflow turbidity or colour, filter performance (head loss buildup rate and filter run time) and filter outflow turbidity or colour becomes apparent so that any departure from the norm can be detected by the use of a turbidity rod and almost by eye. It is of course necessary to confirm the visual observation by instrument readings for record purposes. Where metals from the primary coagulant have been detected in the final water, at significant levels in relation to the standards (e.g. aluminium), the level of dissolved metals in the filter outflow should be monitored at intervals, particularly if any change in the chemical dosing regime has occurred. In some plants it may be possible to establish a relationship between turbidity (or colour) and metal ion residuals and this may be used to reduce the frequency of metal ion analysis.

The recycling of washwaters has been found to cause process control problems, where the recycle rate is variable and forms a significant proportion of the plant inflow. The optimum means of handling washwaters from a process control viewpoint is to recycle the supernatent water to a balancing tank or reservoir supplying the works to even out the effects, both in terms of quality and quantity, on the works inflow. Where this is not possible, it should be fed to the inflow, at as uniform a rate as possible, upstream of the flash mixer.

9 OPERATING PROCEDURES ASSOCIATED WITH NORMAL PROCESS CONDITIONS

9.1 INDICATORS OF NORMAL OPERATING CONDITIONS

Filtration is the final step in the solids removal process. From a water quality standpoint, filter outflow turbidity will give a good indication of overall process performance. However, the operator must also monitor the performance of each of the preceding treatment processes (coagulation, flocculation, and clarification /flotation), in which up to 90% of the solids removal occurs as well as filter outflow water quality, in order to anticipate water quality or process performance changes which might necessitate changes in the treatment process such as adjustment of the chemical dosage.

Filter inflow turbidity levels can be checked on a periodic basis by securing a grab sample either at the filter or from the laboratory sample tap (if such facilities are provided). Filter outflow turbidity may be monitored and recorded on a continuous basis by an on-line turbidimeter. If the turbidimeter is provided with an alarm feature, virtually instantaneous response to process failures can be achieved. As noted previously the level of dissolved metals in the filter outflow should be monitored if metals from the primary coagulant have been detected in the final water at more than trace levels. In larger works, an on-line detector for dissolved aluminium is desirable for the purpose of demonstrating that the residual is kept at all times within the standard set in the Regulations. It is essential to have the services of an instrument technician available on demand, where on-line monitors are installed.

For smaller works a turbidity rod, made by fixing two bright platinum wires, one 1mm diameter and the other 1.5mm diameter, at right angles to the bottom of a rod marked in centimetres, is a useful practical guide to turbidity. The depth of immersion at which one wire disappears while the other remains visible when viewed from above is related to turbidity[3] as shown in Table 4.

Other indicators that can be monitored to determine if the filter is performing normally include head loss build up and filter outflow colour.

TABLE 4: READING A TURBIDITY ROD

DEPTH OF IMMERSION (cm)	TURBIDITY (mg/l SiO Scale)	NOTES
2 10	1000 100	Filter clogs quickly
15	65	Filters operate with difficulty
30 45	30 18	Special care in operation required
80	10	Maximum desirable limit

A written set of process guidelines should be developed to assist in evaluating normal process conditions and in recognizing abnormal conditions. These guidelines should be developed based on water quality, design considerations, water quality standards and, most importantly, experience in operation of the plant.

9.2 PROCESS ACTIONS

In the normal operation of the filtration process, a variety of functions are performed with emphasis on maintaining a high quality filtered water. For all practical purposes, the quality of the filter outflow constitutes the final product quality that will be distributed to consumers (subject to disinfection).

The recommendations of the plant designer and supplier in regard to process actions should be followed in all cases. Typical functions to be performed in the normal operation of the filtration process include the following:

- monitor process performance;
- evaluate water quality conditions (colour and turbidity) and make appropriate process changes;
- check and adjust process equipment (check outputs of chemical dosing plants);
- backwash filters;
- evaluate filter media condition (media loss, mudballs, cracking); and
- visually inspect facilities.

Monitoring process performance is an ongoing activity. It is essential that seasonal water quality variations and the necessary chemical dose rate adjustments are planned and actions taken to ensure that the finished water quality is maintained.

Measurement of head loss buildup (Figure 9) in the filter media will give a good indication of how well the prefiltration solids removal process is performing. The total design head loss from the filter inflow to the outflow in a gravity filter is usually less than 3 metres at maximum. The actual head loss from a point above the filter media to a reference point in the outflow can be monitored as "loss-in-head". For example, suppose that a gravity filter is designed for a total potential head loss of 2.5m. If at the beginning of the filtration cycle the actual measured head loss due to clean media and other hydraulic losses is 0.5m; this would permit an additional head loss of 2.0m due to solids accumulation in the filter. In this example, a working limit might be established at an additional 1.8m of head loss (total of 2.3m for backwashing purposes).

The rate of head loss buildup is also an important indicator of process performance. Sudden increases in head loss might be an indication of surface sealing of the filter media (lack of depth penetration). Early detection of this condition may permit the making of appropriate process changes such as adjustment of the chemical feed rate or the filtration rate.

Monitoring of filter outflow turbidity on a continuous basis with an on-line turbidimeter will provide continuous feedback on the performance of the filtration process. In most instances it is desirable to cut off (terminate) filter operation at a predetermined outflow turbidity level. Preset the filter cutoff control at a point where experience and tests show breakthrough will soon occur (Figure 10). Results of metal ion residual determinations should be checked for correlation with turbidity breakthrough. Residual metal ion determinations should be carried out on a daily basis if an accurate correlation is not established.

In the normal operation of the filter process, it is best to calculate when the filtration cycle will be completed on the basis of the following guidelines:

- head loss;
- outflow turbidity level; and
- elapsed run time.

A predetermined value is established for each guideline as a cutoff point for filter operation. When any one of these levels is reached, the filter is removed from service and backwashed.

Filter performance from season to season, filter bed to filter bed and from plant to plant may be compared by reference to the filter run length in hours. The reason for this is that as the filter run gets shorter, the amount of water used in backwash becomes increasingly important when compared to the amount of water produced during the filter run. Percent backwash water statistics should be collected.

Although of some use, filter run length is not a satisfactory basis for comparing filter runs without considering the filtration rate as well. For example, at a filtration rate of 7.5 m/hour , a 27 hour filter run is quite adequate, whereas, at a filtration rate of 4 m/hour a 27 hour filter run is not satisfactory.

The best way to compare filter runs is by using the Unit Filter Run Volume (UFRV) technique. The UFRV is the volume of water produced by the filter during the course of the filter run divided by the surface area of the filter. This is usually expressed in m^3 per m^2. UFRVs of 200 m^3 per m^2 or greater are satisfactory, and UFRVs greater than 300 m^3 per m^2 are desirable. In the examples in the paragraph above the UFRV for the filter operating at 7.5 m/hour would be 202.5 m^3/m^2, and for the filter operating at 4 m/hour would be 108 m^3/m^2.

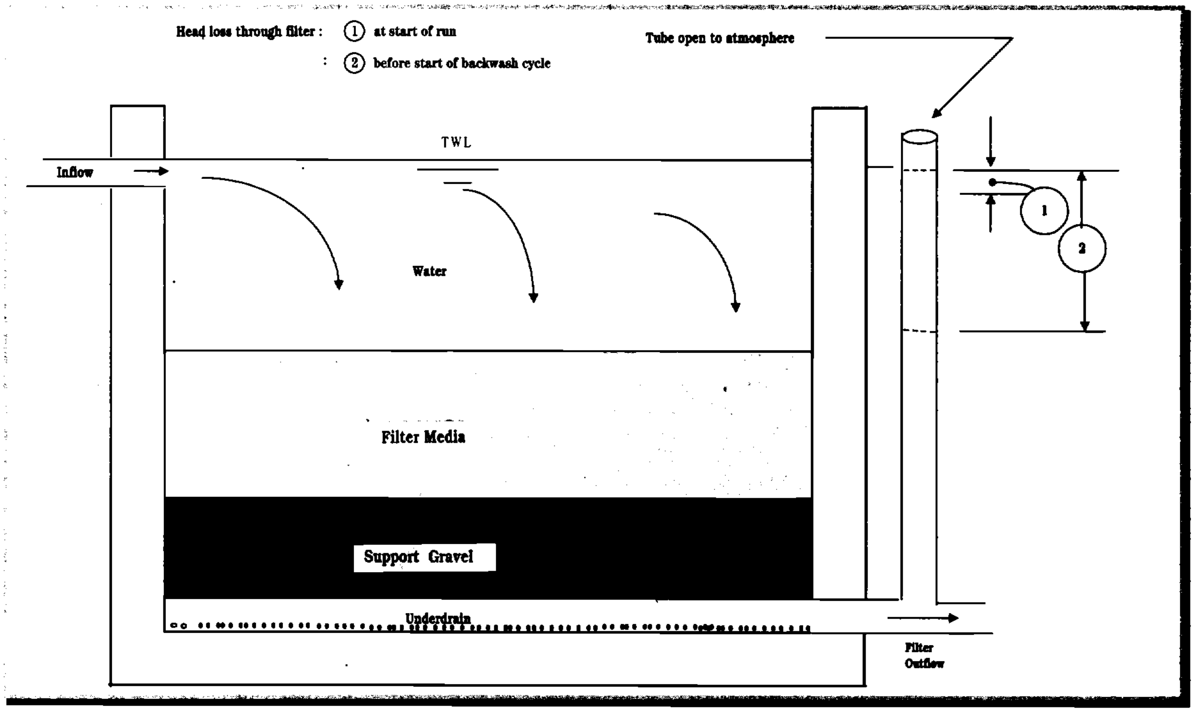

FIGURE 9: MEASUREMENT OF HEADLOSS

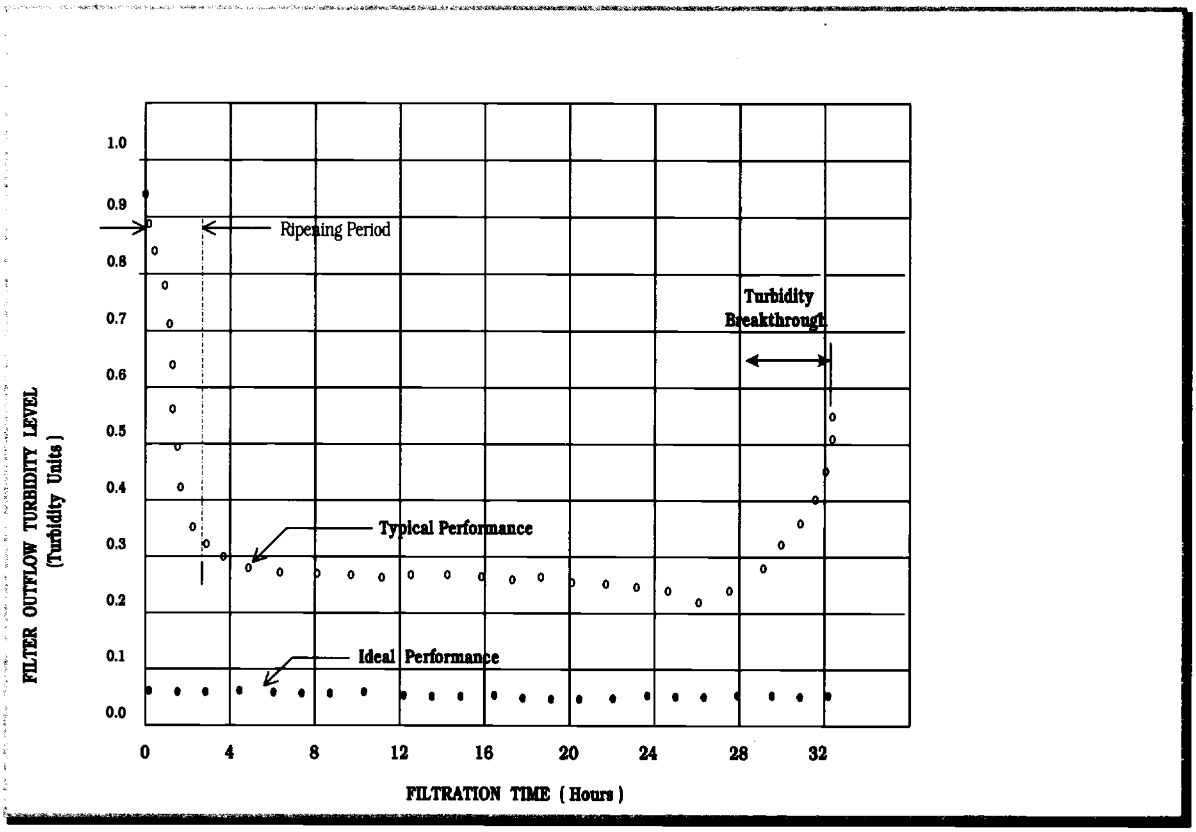

FIGURE 10: TYPICAL OUTFLOW TURBIDITY DATA

Water quality indicators used to assess process performance include turbidity and colour (Figure 11). Based on an assessment of overall process performance, changes in the coagulation-flocculation process or in the clarification process may be required.

At least once a year :

examine the filter media and evaluate its overall condition;

measure the filter media depth for an indication of media loss during the backwashing process; if noticeable send media sample for analysis and/or adjust backwash rates; and

measure mudball accumulation in the filter media, as detailed in Appendix C, to evaluate the effectiveness of the overall backwashing operation.

In daily operations:

observe the backwash process to qualitatively assess process performance. Watch for media boils (uneven flow distribution) during backwashing, media carryover into the washwater channel, and clarity of the washwater near the end of the backwash cycle;

upon completion of the backwash cycle, observe the condition of the media surface and check for filter sidewall or media surface cracks; and

inspect physical facilities and equipment as part of good housekeeping and maintenance practice. Correct or report abnormal equipment conditions to the appropriate supervisor or maintenance personnel.

9.3 PROCESS CALCULATIONS

In the routine operation of the filtration process, a variety of process calculations have to be performed, related to filter operation (flow rate, filtration rate), backwashing (backwash rate, surface wash rate), water production, and percent of water production used to backwash filters. Typical calculations are shown in Appendix D.

9.3.1 FILTRATION RATE

Filtration rates are measured in m^3/m^2 /hour or per day, abbreviated to m/hr or m/day. For public water supply in this country, the standard filtration rate for rapid gravity filters is usually 5 m/hr and most authorities limit the maximum filtration rate to between 5 and 7.5 m/hr. Problems can develop if design filtration rates are exceeded.

9.4 RECORDKEEPING AND QUALITY CONTROL

Accurate records of the following items should be maintained:

process water quality (turbidity, pH, temperature, conductivity and colour);

process operation (filters in service, filtration rates, loss of head, length of filter runs, frequency of backwash, backwash rates and UFRV);

process water production (water processed, amount of backwash water used, and chemicals used);

percent of water production used to backwash filters;

process equipment performance (types of equipment in operation, equipment adjustments, maintenance procedures performed, and equipment calibration); and

media condition (e.g. congealing of sand grains which may be caused by carry-over of polyelectrolyte).

Entries in logs should be neat and legible, should reflect the date and time of an event, and should be initialled by the operator making the entry.

An example of a typical daily operating record for water treatment plant filters is presented in Appendix A. Irrespective of the size of plant or number of filters, a similar record sheet should be kept.

9.5 FILTER MONITORING INSTRUMENTATION

To evaluate filtration process efficiency, familiarity with the measurement of turbidity, colour, pH, temperature and conductivity is essential. Turbidity may be quickly estimated using the turbidity rod described in section 9.1 and more exactly, for record purposes using a turbidimeter. In addition, on-line or continuous water quality monitors, such as turbidimeters, soluble aluminium and pH monitors will give early warning of process failure and will aid in making a rapid assessment of process performance.

Familiarity with methods used to measure filter media loss and to determine the presence of mudballs in the filter media will also be needed.

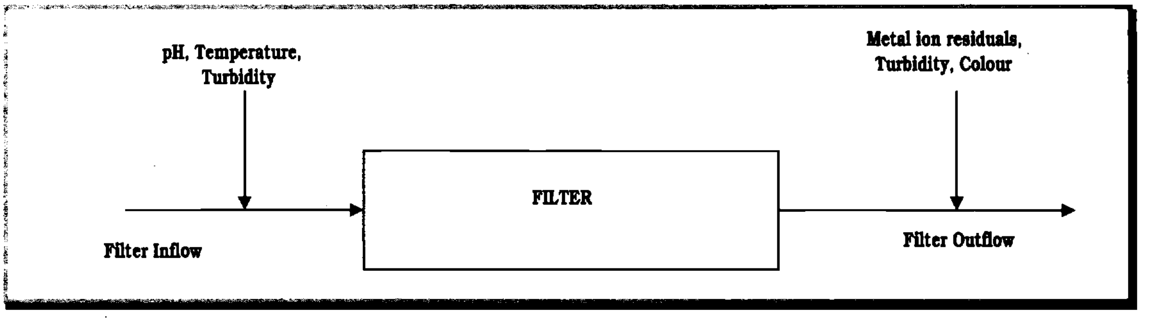

FIGURE 11: FILTRATION PROCESS MONITORING - PARAMETERS AND LOCATIONS

10 OPERATING PROCEDURES ASSOCIATED WITH ABNORMAL PROCESS CONDITIONS

10.1 INDICATORS OF ABNORMAL CONDITIONS

Abrupt changes in water quality indicators such as turbidity, pH, alkalinity, threshold odour number (TON), temperature, chlorine demand (source water), chlorine residual (in-process), or colour are signals that the performance of the filtration process, as well as pretreatment processes (coagulation, flocculation, and clarification/flotation) should be immediately reviewed.

During a normal filter run, watch for both rapid changes in turbidity and head loss buildup in the filter. Significant changes in either of these parameters may indicate an upset or failure in the filtration process or pretreatment processes.

Other indicators of abnormal conditions are as follows:

- mudballs in filter media;
- media cracking or shrinkage;
- media boils during backwash;
- excessive media loss or visible disturbance;
- short filter runs;
- filters that will not come clean during backwash;
- algae on walls and media; and
- congealing of sand grains (indicates polyelectrolyte carryover).

10.2 PROCESS ACTIONS

A summary of routine filtration process actions is presented in Table 2. Significant changes in source water turbidity levels, either increases or decreases, require immediate verification of the effectiveness of the filtration process in removing suspended solids and floc. A quick determination of filtration removal efficiency can be made by comparing filter inflow and outflow turbidity levels with those of recent record.

In the event that filter turbidity removal efficiency is decreasing, look first at the performance of the coagulation and flocculation processes to determine if the coagulant dosage is correct for current conditions. This may require the performance of jar tests in the laboratory to properly assess treatment conditions.

Increases in source water turbidity and resultant increases in coagulant feed rates may impose a greater load on the filters if the majority of suspended solids and floc are not removed in the clarification tanks. This condition may require a decrease in filtration rates (put additional filters into service) or more frequent backwashing of filters.

Changes in source water quality such as alkalinity and pH may also affect filtration performance through decreased coagulation-flocculation process performance. This is particularly evident when source water quality changes result from precipitation and runoff, or algal blooms in a source water reservoir. It would appear to be American practice to use filter aid chemicals, such as nonionic polymers, to improve filter performance in such cases. Current Irish practice would avoid the use of polymers, or other filter aid chemicals, in such circumstances and would concentrate on the adjustment of the prefiltration treatment processes.

The need for addition of polyelectrolytes during periods when water temperatures are above 12° C should be examined. Above this temperature, coagulants work more effectively and at some plants it may be possible to reduce or omit polyelectrolytes during the period from April to early October, if the raw water quality is of a reasonable standard. The upflow rates adopted in the clarification stage should not exceed 1.0 m/hr, unless specialised technologies are employed, if problems with filtration and floc carryover are to be avoided. Coagulant and polyelectrolyte dose rate adjustments should only be carried out by or under the control of a competent person and the effects of all adjustments should be monitored.

Increases in filter outflow turbidity may also result from floc carryover from the clarification/flotation process. The optimum floc size developed in the flocculation process ranges from about 0.1 to 3.0 mm. In conventional filtration, the optimum floc size is closer to 3.0 mm for settling purposes. However, in the direct filtration process (no clarification stage) the optimum floc size is closer to 0.1 mm to permit depth penetration of the filter media. When flotation is not used and larger floc is not removed in clarification (too light), it will be carried over into the filters, rapidly clogging the media surface. Hydraulic forces in the filter will shear weak flocs, further contributing to turbidity breakthrough. Re-evaluation of coagulation-flocculation and clarification performance may be required if floc carryover into the filters reduces filtration efficiency. The size of floc can be estimated by observation, as it is seldom necessary to make an accurate measurement of floc size.

If backwash problems such as media boils, media loss, or failure of the filter to come clean during the backwash process are encountered, corrective actions should be taken immediately. Generally, these problems can be solved by adjusting air scour and backwash flow rates, surface wash flow rate or duration, or adjusting the sequence and/or duration of the backwash cycle. In filters with nozzle-type underdrains, boils are often the result of nozzle failure. In this situation the filter should be taken out of service and the nozzles replaced. Possible corrective actions are summarized in Table 3 which gives a summary of filtration process problems, how to identify the causes of problems, and also how to correct the problems.

Problems within the filter itself, such as mudball formation or filter cracks and shrinkage, result from ineffective or improper filter backwashing. Correction of these conditions will require evaluation and modification of the backwash procedures.

If filters are not thoroughly washed, material filtered from the water is retained on the surface of the filter. This material is sufficiently adhesive to form minute balls. In time these balls of material come together in clumps to form mudballs. Usually as time goes on, filter media becomes mixed in to give it additional weight. When the mass becomes great enough, it causes the mudballs to sink into the filter bed. These mudballs, if allowed to remain, will clog areas in the filter. Generally, regular and controlled backwashing will prevent mudball formation.

10.3 AIR BINDING

Shortened filter runs can occur because of air bound filters. This is caused by the release of dissolved air in saturated water due to a decrease in pressure or air trapped in the filter media on completion of the backwash cycle. Air is released from the water when passing through the filter bed by differences in pressure produced by friction through the media. Subsequently the released air is entrapped in the filter media. Air binding will occur more frequently when large head losses are allowed to develop in the filter. Whenever a filter is operated to a head loss which exceeds the head of water on the media, air will be released. Air bound filters are objectionable because the air prevents water from passing through the filter and causes shortened filter runs. When an air bound filter is backwashed, the released air can damage the filter media. When air is released during backwashing, the media becomes suspended in the washwater and is carried out of the filter. Significant media loss can occur, particularly when lighter media such as activated carbon is used.

10.4 EXCESSIVE HEAD LOSS

Short filter runs may result from increased solids loading, excessively high filtration rates, excessive mudball formation in the filter media, or clogging of the filter underdrain system. Possible corrective actions are summarized in Table 3.

If excessive head loss persists in a filter after backwashing, a representative sample of the filter media should be sent for analysis, to include the determination of:

hydraulic size of media;

organic content;

particle size distribution;

uniformity co-efficient;

grain shape factor;

grain sphericity; and

- grain porosity.

The degradation of the filter media over time can be determined by calculating the 'resistance to filtration' and the 'efficiency of filtration'. If the nature of the filter media does not account for the headloss, the filter underdrain system and the head loss measurement equipment should be checked for malfunctioning. High head losses can be caused by reduction in the size and number of underdrain openings. The underdrain openings can be reduced in size or clogged by media, corrosion or chemical deposits. Pipework should also be checked for blockages; deposits, for example, have been asociated with the use of magnetic flowmeters and soda ash.

11 STARTUP AND SHUTDOWN PROCEDURES

11.1 CONDITIONS REQUIRING IMPLEMENTATION OF STARTUP AND SHUTDOWN PROCEDURES

Startup and shutdown of filtration is a routine procedure in most water treatment plants, unlike the coagulation, flocculation and clarification processes. This is true even if the treatment plant is operated on a continuous basis, since it is common practice for a filter to be brought into service or taken off line for backwashing. A clean filter may be put into service when a dirty filter is removed for backwashing, when it is necessary to increase filtration rates, or when plant production needs to be increased as a result of increased demand for water. However, most plants keep all filters on line except for backwashing and in service except for maintenance. Filters are routinely taken off line for backwashing when the media becomes clogged with particulates, turbidity breakthrough occurs, or demands for water are reduced.

11.2 IMPLEMENTATION OF STARTUP/SHUTDOWN PROCEDURES

Typical actions performed in the startup and shutdown of the gravity filtration process are outlined below. These procedures also generally apply to pressure filters.

Figures 12 and 13 illustrate sectional views of typical gravity filters. The figures show the valve position and flow patterns in the filtration and backwash mode of filter operation.

11.3 FILTER CHECKING PROCEDURES

The following actions should be taken to check the operational status of a filter:

- check that filter flow control equipment is operational;
- check that filter media and washwater channels are clear of all debris such as leaves, twigs and tools;
- ensure all access covers and walkway gratings are in place;
- ensure process monitoring equipment such as head loss and turbidity systems are operational; and
- check source of backwash water to ensure there is sufficient volume available. This could be an elevated reservoir, washwater storage tank or other source.

11.4 BACKWASH PROCEDURES

Filters should be washed prior to placing them in service. There is a variety of different backwash arrangements for filtration plants and these will vary with individual plant designs. Usually filter washing is divided into three distinct operations

Operation	Details
Air Scouring	consisting of low pressure / high volume compressed air ONLY applied up through the filter bed.
Washing (low rate)	consisting of a low rate of low pressure washwater ONLY applied up through the filter bed, with wash water drained to waste.
Washing (high rate)	consisting of a high rate of low pressure washwater ONLY applied up through the filter bed, with washwater drained to waste.

as follows:

A further combination may be the inclusion of an air scour and low rate wash together for a period of time. This may supercede the necessity for a low rate wash.

Generally wash cycles are automatically controlled, with pre-set wash rates and adjustable time durations. The duration of each part of the wash cycle can therefore be adjusted in order to ensure efficient filter washing.

If filters are to be washed automatically, check that the length of cycle times set for air scour, backwash and surface wash cycles are "correct". "Correct" times vary from plant to plant and with time of year. These settings should be based on physical observations of actual time required to clean the filter.

If filters are usually washed automatically, it is good practice to occasionally use a manual wash procedure to ensure efficient cleaning of the media during the wash cycle. This is carried out as follows.

Each filter to be washed is drained down to the level required to commence washing. This is achieved by closure of the filter inlet, whilst maintaining the filter outlet flow. This allows the filter to drain down evenly, without any undue stress to, or compaction of, the filter bed prior to washing.

When the water level has drained down to the required level, a few centimetres above the media, the backwash cycle is started. The surface of the media should show an even spread of bursting air bubbles coming through. Any unevenness in the distribution should be regarded as an indication of potential difficulty, its cause investigated as far as possible and the observation logged.

If sufficient time has been allowed for cleaning of the filter media the backwash water coming up through the media becomes clear. This generally takes from three to eight minutes. If flooding of washwater channels or carryover of filter media is a problem, the backwash rate must be reduced. This may be accomplished by adjusting the back wash control valve, thereby throttling the amount of washwater used.

In many water treatment plants backwash water is allowed to settle in a tank, and then the supernatant (clear, top portion of water) is pumped back, if possible to the reservoir or balancing tank feeding the works, to be recycled through the plant. Usually it is best to gradually add the backwash water to the headworks of the treatment plant (ahead of the flash mixer). This is because a sudden return requires changes in chemical dosages due to the additional flow and increased turbidity.

Procedures for backwashing a filter under manual control are provided overleaf: (Refer to Figures 12 and 13).

11.5 FILTER STARTUP PROCEDURES

The initial few hours after a filter is placed in service is a time when turbidity breakthrough can pose a problem. For this reason, filters should be eased into service to avoid hydraulic shock loads. After washing, filters should be brought back on line gradually. With automatic equipment this is generally done by a gradual opening of the filter's outflow valve (usually an actuated butterfly valve). Manual operations require a gradual increase of the amount of water treated by the filter, usually achieved by an automatic slow start control device. Many plants have provisions to waste some of the initial filtered water (by opening V-6). This provision can be very helpful if turbidity breakthrough occurs. Turbidity analyses of filtered water should be carried out and process adjustments made as necessary.

11.6 FILTER SHUTDOWN PROCEDURES

Remove the filter from service by:

- closing inflow valve (V-1);
- allowing filter to drain to correct backwashing level; and
- closing outflow valve (V-5).

Backwash the filter, as described in preceding section. If the filter is to be out of service for a prolonged period, drain water from filter to avoid algae growth. Note status of the filter in operating record. Backwash again before placing filter 'on-line', as noted previously.

TABLE 5: PROCEDURE FOR BACKWASHING A FILTER UNDER MANUAL CONTROL

Step	Action
1	Log length of filter run since last backwash
2	Log filter loss of head (L.O.H.)
3	Close filter inflow valve (V-1)
4	Allow filter to drain to correct backwashing level
5	Close filter outflow valve (V-5)
6	Open drain valve (V-4)
7	Open air scour valve (V-7)
8	Start air blower(s)
9	Run air scour for pre-determined period
10	Open backwash valve (V-3)
11	Start wash water pump(s) at low rate
12	Run low rate wash for pre-determined period
13	Stop air blower(s)
14	Close air scour valve (V-7)
15	Open surface wash valve(V-2) (optional)
16	Increase wash rate to High Rate Wash
17	Run High Rate and surface wash (optional) for pre-determined period
18	When wash water going to drain becomes clear : • Close drain valve (V-4) • Allow filter to refill
19	Once filter is refilled, put into service by : • Stopping wash water pump(s) • Closing backwash valve (V-3) • Closing surface wash valve (V-2) (optional) • Opening filter inlet valve (V-1) • Opening filter outlet valve (V-5)
20	Log duration of each part of wash and water volumes used
21	Log loss of head at commencement of service run

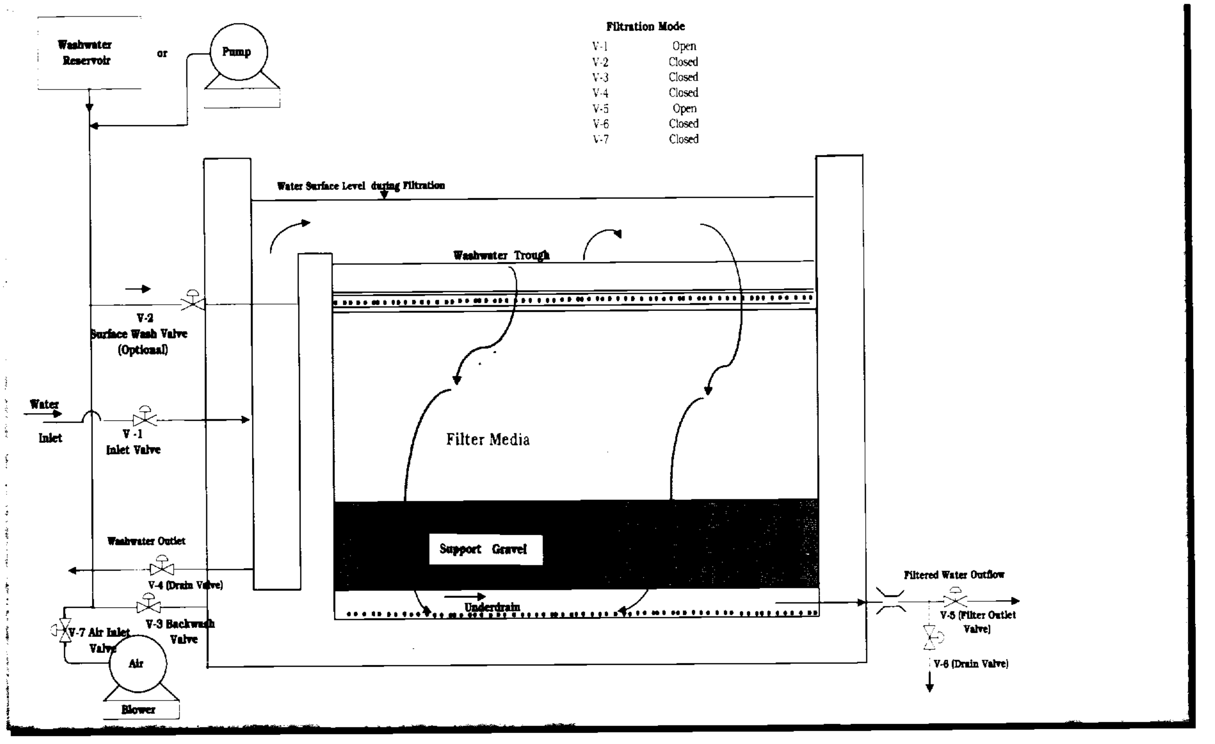

FIGURE 12: FILTRATION MODE OF OPERATION

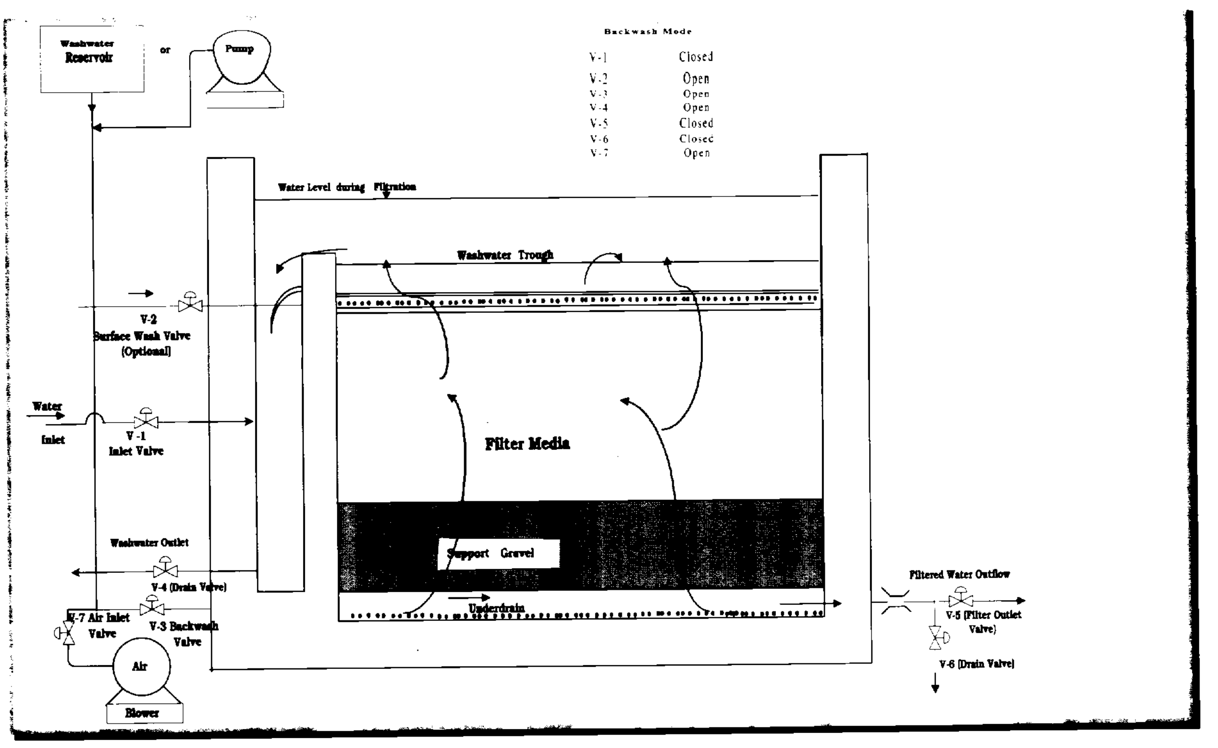

FIGURE 13: BACKWASH MODE OF OPERATION

12 PROCESS AND SUPPORT EQUIPMENT OPERATION AND MAINTENANCE

12.1 TYPES OF EQUIPMENT

To run a filtration process the operating personnel must be competent and familiar with the operation and minor (preventive) maintenance of a variety of mechanical, electrical, and electronic equipment including:

- filter control valves;
- backwash and surface wash pumps;
- air (dryer) compressor and blowers;
- flowmeters and level/pressure gauges;
- water quality monitors such as colorimeters, thermometers, pH and conductivity meters, turbidimeters and dissolved aluminium detector/recorders;
- process monitors (head loss and water level); and
- electrical filter control systems.

Since a wide variety of mechanical, electrical, and electronic equipment is used in the filtration process, the operating personnel should be broadly familiar with the operation and maintenance instructions for each specific equipment item or control system in the plant.

12.2 EQUIPMENT OPERATION

Before starting a piece of mechanical equipment, such as a backwash pump, be sure that the unit has been serviced on schedule and its operational status is positively known.

After startup, always check for excessive noise and vibration, overheating, and leakage (water, lubricants). When in doubt about the performance of a piece of equipment, refer to the manufacturer's instructions.

Much of the equipment used in the filtration process may be automated and only requires limited attention by operating personnel during normal operation. However, periodic calibration and maintenance of this equipment is necessary, and this usually involves special procedures. Detailed operating, repair, and calibration procedures are usually described in the manufacturer's or suppliers literature.

12.3 PREVENTIVE MAINTENANCE PROCEDURES

Preventive maintenance programmes are designed to ensure the continued satisfactory operation of treatment plant facilities by reducing the frequency of breakdown. This is accomplished by performing scheduled or routine maintenance on valves, pumps, and other electrical and mechanical equipment items.

In the normal operation of the filtration process, routine maintenance functions must be performed as part of an overall preventive maintenance programme. Typical functions include:

- keeping electric motors free of dirt, moisture, and pests (spiders, flies, larvae, rodents and birds);
- ensuring good ventilation (air circulation) in equipment work areas;
- checking pumps and motor for leaks, unusual noise, vibrations or overheating;
- maintaining proper lubrication and oil levels;
- checking bearings for overheating and proper lubrication;
- checking for proper valve operation, leakage or jamming;
- checking automatic control systems for proper operation;
- checking air/vacuum relief systems for proper functioning, dirt and moisture;
- checking chemical delivery lines for leakage [chemical delivery lines should be colour

coded, placed in ducts and lengths minimised];

verifying correct operation of filtration and backwash cycles by observation; and

inspecting filter media condition (look for algae and mudballs and examine gravel and media for proper gradation).

Accurate recordkeeping is the most important element of any successful preventive maintenance programme. These records provide operation and maintenance personnel with clues for determining the causes of equipment failures. They frequently can be used to forecast impending failures thus avoiding costly repairs.

12.4 SAFETY CONSIDERATIONS [9,10,11]

The filtration process does not normally involve the use of chemicals. There are however hazards involved for the plant operators, which should be identified in the Safety Statement prepared for each treatment works, as required by the Safety, Health and Welfare at Work Act, 1989 and Regulations made under the Act. Reference should be made to this Safety Statement by all persons involved in the operation and maintenance of the works.

Some of the potential hazards, which might be encountered in different areas and operations in the filtration process are listed in Table 6.

TABLE 6: POTENTIAL HAZARDS IN FILTRATION

Area / Operation	Potential Hazard
Electical Equipment	• earthing of tools • locking out and tagging of switches and panels when servicing equipment • electric shock due to lying water or grounding on pipes
Mechanical Equipment	• removal of guards from rotating equipment • locking out and tagging of switches and panels when servicing pumps, automatic valves and other equipment • slippery surfaces due to lubricant spills • wearing of loose clothing in the vicinity of rotating equipment
Open Water Surfaces	• damage to handrails or failure to close safety chains • slippery surfaces on stairways or ladders due to spillages or use of unsuitable footwear •
Confined Space	• Hazardous atmospheres (toxic or explosive gases, lack of oxygen) • Presence of dust

GLOSSARY

ABSORPTION
The taking in or soaking up of one substance into the body of another by molecular or chemical action.

ACTIVATED CARBON
Adsorptive particles or granules of carbon usually obtained by heating carbon. These particles or granules have a high capacity to selectively remove certain trace and soluble materials from water.

ADSORPTION
The gathering of a gas, liquid, or dissolved substance on the surface or interface zone of another material.

AIR BINDING (LOCKING)
The clogging of a filter, pipe or pump due to the presence of air released from water. Air contained in the filter media is harmful to the filtration process. Air can prevent the passage of water during the filtration process and can cause the loss of filter media during the backwash process.

ALGAE
Algae are primitive organisms which are usually classified as plants. There are hundreds of different types, many of them microscopic, which may become visible by multiplication. When present to excess they cause trouble by blocking filters. Outbreaks vary with the region and the season.

BACKWASHING
The process of reversing the flow of water, either alone or in association with air, back through the filter media to remove the entrapped solids.

BASE METAL
A metal (such as iron) which reacts with dilute hydrochloric acid to form hydrogen.

BREAKTHROUGH
A crack or break in a filter bed allowing the passage of floc or particulate matter through a filter. This will cause an increase in filter outflow turbidity. A breakthrough can occur when a filter is first placed in service, when the outflow valve suddenly opens or closes, and during periods of excessive head loss through the filter.

COLLOIDS
Very small, finely divided solids (particles that do not dissolve) that remain dispersed in a liquid for a long time due to their small size and electrical charge. When most of the particles in water have a negative electrical charge, they tend to repel each other. This repulsion prevents the particles from becoming heavier and settling out.

COLOUR
Many waters have a distinct colour, normally due to the presence of complex organic molecules derived from vegetable matter (such as peat, leaves, branches etc.,), even after all turbidity has been removed. This is expressed in terms of the platinum-cobalt scale (Hazen units). Exceptionally, natural colour may be due to the presence of colloidal iron and/or manganese in a water.

CONVENTIONAL FILTRATION
A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation-flocculation, clarification by sedimentation / flotation and filtration.

CRYPTOSPORIDIUM
The general descriptive term for the parasite *Cryptosporidium Parvum* (*C. Parvum*). C. Parvum is the only species of cryptosporidium knowm to cause disease in man. The environmentally resistant transmittable form of cryptosporidium excreted in the faeces of an infected host is called an Oocyte.

DIRECT FILTRATION
A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation, minimal flocculation, and filtration. The flocculation facilities are occasionally omitted, but the physical-chemical reactions will occur to some extent. The clarification/flotation process stage is omitted.

EFFECTIVE SIZE (ES)
The diameter of the particles in a granular sample (filter media) for which 10 percent of the total grains are smaller and 90 percent larger on a weight basis. Effective size is obtained by passing granular material through sieves with varying dimensions of mesh and weighing the material retained by each sieve.

FLASH MIXER
A chamber in which coagulants are stirred into the raw water with considerable turbulence, induced either hydraulically or mechanically.

FLOC
Floc is the fine cloud of spongey particles that form in water to which a coagulant has been added. The particles are basically hydroxides, commonly of aluminium or iron. They accelerate the settlement of suspended particles by adhering to the particles and neutralizing such negative charges as may be present.

FLOCCULATION
Flocculation is the practice of gently stirring water in which floc has formed to induce the particles to coalesce and grow and thus settle more rapidly.

FLUIDIZATION THRESHOLD
The fluidization threshold is the point during backwashing where the hydraulic pressure loss through the filter bed equals the dead (submerged) weight of the filter material.

FLUIDIZED
A mass of solid particles that is made to flow like liquid by injection of water or gas is said to have been fluidized. In water treatment, a bed of filter media is fluidized by pumping backwash water and/or air through the filter.

GARNET
A group of hard, reddish, glassy, mineral sands made up of silicates of base metals (calcium, magnesium, iron and manganese). Garnet has a higher density than sand.

***GIARDIA INTESTINALIS* (*Giardia lamblia*)**
A protozoan parasite capable of infecting man and causing diarrhoea.

HEAD LOSS
The head, pressure or energy lost by water flowing in a pipe or channel as a result of turbulence caused by the velocity of the flowing water and the roughness of the pipe, channel walls or restrictions caused by fittings. Water flowing in a pipe loses head, pressure or energy as a result of friction losses. The head loss through a filter is due to friction losses caused by material building up on the surface or in the interstices of the filter media.

HYRAULIC SIZE
The hydraulic size of filter material is that grain size which gives the same surface area, and therefore the same hydraulic behaviour, as the mixture of sizes in the filter material.

IN-LINE FILTRATION
The addition of chemical coagulants directly to the filter inlet pipe. The chemicals are mixed by the flowing water. Flocculation and sedimentation facilities are eliminated. This pre-treatment method is commonly used in pressure filter installations.

INTERFACE
The common boundary layer between two substances such as water and a solid (metal); or between two fluids such as water and gas (air); or between a liquid (water) an another liquid (oil).

NTU
Nephelometric Turbidity Unit, numerically equivalent to Jackson Turbidity Unit.

PERMEABILITY
The property of a material or soil that permits considerable movement of water through it when it is saturated.

PORE
A very small open space in a rock or granular material.

POROSITY
The ratio (normally expressed as a percentage) of the volume of the space between grains (voids) to the overall volume of the granular material. This will vary depending on how the material has been handled, whether tipped, backwashed or packed. Alternatively called **voidage**.

SLURRY
A watery mixture or suspension of insoluble (not dissolved) matter; a thin watery mud or any substances resembling it (such as a grit slurry or a lime slurry)

SPECIFIC GRAVITY
(1) Weight of a particle, substance, or chemical solution in relation to the weight of an equal volume of water. Water has a specific gravity of 1.000 at 4^0C (or 39^oF). Particulates in raw water may have a specific gravity of 1.005 to 2.5.

(2) Weight of a particular gas in relation to an equal volume of air at the same temperature and pressure (air has a specific gravity of 1.0). Chlorine for example has a specific gravity of 2.5 as a gas.

SUBMERGENCE
The distance between the water surface and the media surface in a filter.

TURBIDIMETER
An instrument for measuring and comparing the turbidity of liquids by passing light through them and determining how much light is reflected by the particles in the liquid. The normal measuring range is 0 to 100 and is expressed as Nephelometric Turbidity Units (NTUs).

UNIFORMITY COEFFICIENT (U.C.)
The ratio of the diameter of a grain of a size that is barely too large to pass through a sieve that allows 60 percent of the material (by weight) to pass through, to the diameter of a grain of a size that is barely too large to pass through a sieve that allows 10 percent of the material (by weight) to pass through. The resulting ratio is a measure of the degree of uniformity in a granular material.

$$\text{Uniformity Coefficient} = \text{Particle Diameter}_{60\%} / \text{Particle Diameter}_{10\%}$$

VISCOSITY
The property of a substance to offer internal resistance to flow. Specifically, the ratio of the shear stress to the shear strain.

APPENDIX A: TYPICAL FILTERS OPERATING RECORD SHEET

NAMED AUTHORITY

Ballybeg **WATER TREATMENT PLANT**

FILTERS

Sheet No. : 311 Daily Operating Record Date : 7/11/94

Filter No.	Time & Date Start	Stop	Hours Operated Today	Previous	Total	Head Loss Start(m)	Stop (m)	Backwash Minutes	Quantity m³	Notes on condition of filters & problems in operation
1	04/11 08:30	07/11 11:30	11:30	63:30	75:00	0.15	1.85	6	101	Slow start at 12 noon. Full filtration rate resumed 12.30
2	05/11 17:00		24:00	31	55	0.155				
3	03/11 18:00		24:00	54	78	0.165				
4	03/11 14:00	07/11 18:00	18:00	82:00	100:00	0.15	1.8	5	84	Slow start at 18.30. Full filtration rate resumed 19.00
5	05/11 09:15		24:00	38:45	62:45	0.145				
6	04/11 17:20		24:00	30:40	54:40	0.16				

No. of filters washed	2	Average Filtration Rate - m/hr	4.97
Average Run - Hours	87.5	Maximum Filter Rate -m³/hr	720
Total Wash Water - m³	185	Total Water Filtered -m³	17160
Percent of Water Filtered	1.08	No. of Filters Operating	6
Av.Time of Wash - Minutes	5.5	Filters Out per Wash -Mins	30

Shift	Operator
1	AB
2	GC
3	NB

Water Quality Sampling

Location	Turbidity	Colour	Temp (C)	pH	Time
Inflow					
Outflow					
Inflow					
Outflow					
Inflow					
Outflow					

Integrator Readings

Location	Units	Read'g/Time	Difference from Previous

Production Report		Percentage & Remarks
Total Inflow	Cu.m	100%
To Supply		
To Site Storage		
To Filter Backwash		
Other		

NAMED AUTHORITY

WATER TREATMENT PLANT

FILTERS

Sheet No.: .... Daily Operating Record Date: ....

Filter No.	Time & Date Start	Stop	Hours Operated Today	Previous	Total	Head Loss Start(m)	Stop (m)	Backwash Minutes	Quantity m³	Notes on condition of filters & problems in operation
1										
2										
3										
4										
5										
6										

				Shift / Operator
No. of filters washed		Average Filtration Rate - m/hr		
Average Run - Hours		Maximum Filter Rate -m³/hr		
Total Wash Water - m³		Total Water Filtered -m³		
Percent of Water Filtered		No. of Filters Operating		
Av.Time of Wash - Minutes		Filters Out per Wash -Mins		

Water Quality Sampling

Location	Turbidity	Colour	Temp (C)	pH	Time
Inflow					
Outflow					
Inflow					
Outflow					
Inflow					
Outflow					

Integrator Readings

Location	Units	Read'g/Time	Difference from Previous

Production Report		Percentage & Remarks
Total Inflow	Cu.m	100%
To Supply		
To Site Storage		
To Filter Backwash		
Other		

APPENDIX B: CONVERTING TO SI (METRIC) UNITS

CONVERSION TO SI (METRIC) UNITS FROM IMPERIAL (FPS) UNITS[14,15]

The SI (or Metric) base units of most interest for water treatment are those of time, mass and length. The unit of time is the second (symbol 's'), which is the same in both Imperial and SI systems. The unit of mass is the kilogram (symbol 'kg') (1 kg = 2.20462 lbs), which for all practical purposes is the mass of 1 litre of pure water at 20°C. The unit of length is the metre (symbol 'm') (1 m = 39.37008 inches). The other units used in water treatment are derived from these base units. The prefix kilo (k) means 1000 times the unit following - kilogram (kg) is 1000 grams, kilometre (km) is 1000 metres and the prefix mega (M) means 1,000,000 times the unit following but megagram is customarily referred to as a metric tonne. The term megalitre (Ml) is frequently used for 1000 m^3. Conversely, the prefix milli (m) means one thousandth part of the unit following - milligram (mg) is 1 / 1000 of a gram, millimetre (mm) is 1/1000 of a metre, millilitre (ml) is 1/1000 of a litre; the prefix micro (μ - the Greek letter mu) means one millionth part of the unit following - microgram (μg) is 1/1 000 000 of a gram, while the prefix nano (n) means one thousand millionth part of the unit following - nanogram (ng) is 1/1 000 000 000 of a gram.

The conversion factors most needed in relation to water treatment are :

1 gallon (g) = 4.54609 litres

1 m^3 (1000 l) = 219.9736 (220) gallons

1 ft^2= 0.0929 m^2

1 m^2 = 10.76392 ft^2

14.7 p.s.i.= 1.013 25 bar = 1 atm

The term "parts per million" (ppm) was formerly widely used in relation to the dosing of chemicals to water. This term implies a relationship of either volume with volume or weight with weight, but since the density of water is almost exactly unity, this term is in effect synonymous with "milligrams per litre" (mg/l) and is widely regarded as being so. However the preferred usage is mg/l, which is an expression of *mass* or *weight* of chemical per unit *volume* of water, rather than ppm.

Clarification tanks are rated in terms of flow per unit area per hour (gallons per ft^2 per hour, in Imperial units) with alternatively an upflow rate in feet per hour. In SI units, flow per unit area per hour is m^3 / m^2 / hour or, cancelling m^2, m / hour, which is frequently expressed as an upflow rate in mm / sec.

A standard rate of slow sand filtration is 50 gallons per square foot per day.

Converting to SI : 50/ (220 ×24×0.0929) = 0.1019 m^3 / m^2 /hour = 0.10 m /hr.

A standard rate of rapid gravity filtration is 100 gallons per square foot per hour.

Converting to SI : 100/ (220 ×0.0929) = 4.8928 m^3 / m^2 /hour = 4.9 m /hr.

5 m /hr = 102.2 gallons per square foot/hr.

APPENDIX C: MUDBALL EVALUATION PROCEDURE[1,4]

FREQUENCY OF MUDBALL EVALUATION

Use this procedure on a monthly basis, if mudballs in the top of the filter material are a problem. An annual check is sufficient if mudballs are not normally a problem.

PROCEDURE FOR EVALUATION

1. Backwash the filter to be sampled and drain the filter to at least 300 mm (12 inches) below the surface of the top media layer (or layer of interest).

2. Push the mudball sampler some 150 mm (6 inches) into the sand near one corner of the filter. Tilt the handle until it is nearly level then lift the sampler full of media and empty its contents into a bucket.

3. Take samples near the other corners and at the centre of the filter and place contents in bucket.

4. Hold a 10 mesh (9.5mm / $^3/_8$″) sieve in a bucket or tub of water so that it is nearly submerged. Take a handful of the material removed from the filter and place it in the sieve. Gently raise and lower the sieve about 12 mm ($^1/_2$″) at a time until the filter sand is separated from the mudballs. Shift the mudballs to one side by tipping the submerged sieve and shaking it gently.

5. Repeat the process until all the material taken from the filter has been washed in the sieve and the mudballs separated. If the volume of mudballs impedes the washing process, move some of them to the measuring cylinder used in the next step.

6. Place 500 ml of water in a 1000 ml graduated cylinder. Use a larger or smaller cylinder depending on the volume of mudballs. When water has ceased to drip from the mudballs on the sieve, transfer them to the graduated cylinder and record the new water level in it. The volume of mudballs in ml is obtained by subtracting 500 from the new water level.

The total volume of material removed from the filter, if the 'mudball sampler' was full each time, would be 3,540 ml. This can be checked by draining and measuring, by displacement, the volume of sand washed from the mudballs. The percentage mudball volume is calculated as :

$$\frac{\text{Mudball Volume (ml)} \times 100}{3{,}540}$$

Mudball Volume (%)	Condition of Filtering Material
0.0 - 0.1	Excellent
0.1 - 0.2	Very good
0.2 - 0.5	Good
0.5 - 1.0	Fair
1.0 - 2.5	Fairly Bad
2.5 - 5.0	Bad
Over 5.0	Very Bad

The condition of the filter material is evaluated by reference to the preceding Table.*

* Mudballs sink more readily in anthracite than sand. Therefore modify the above procedure to collect samples from the bottom 150 mm (6″) of anthracite by temporarily removing the upper layers.

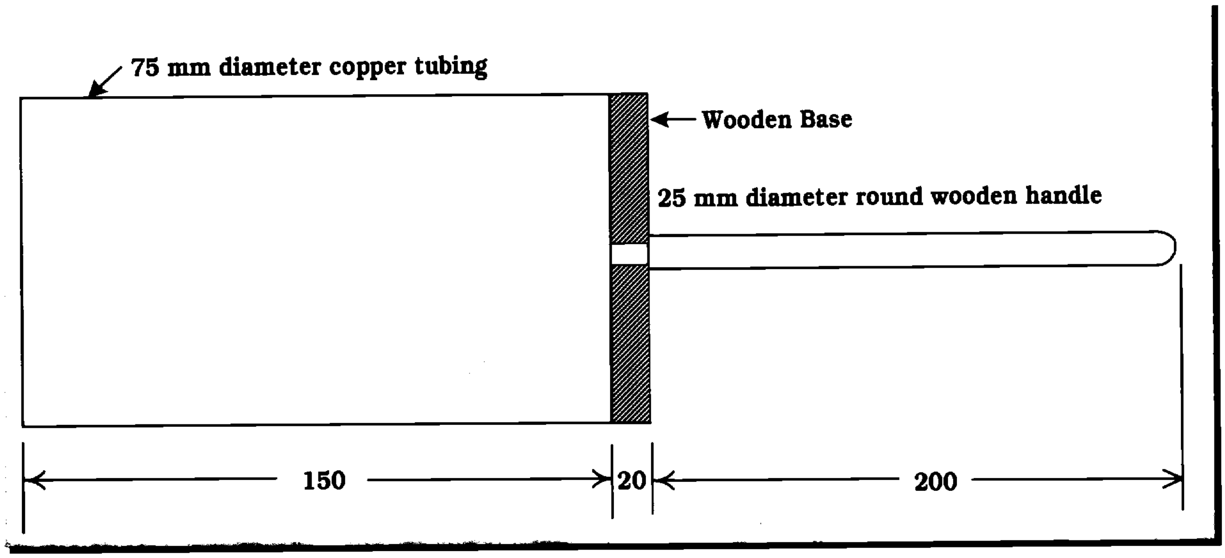

FIGURE 14: MUDBALL SAMPLER

APPENDIX D: HYDRAULIC CALCULATIONS

HYDRAULIC CALCULATIONS [5,6,11,12]

FILTRATION RATE

In order to calculate the filtration rate, the surface area of the filter media (*not* the area within the filter walls) must first be determined. The length of the filter media surface may be measured between filter walls but the width, exclusive of washwater channels, must be measured when the filter is drawn down for backwashing, unless reliable drawings, from which measurements may be taken, are available. The output from the filter for a specific period, say one hour, after it has fully matured, may be read from the flow meter, if one is provided. The filtration rate is found by dividing the output in m^3 by the surface area in m^2.

Example :

Length of filter between walls	= 3.5 m
Width of filter media	= 2.0 m (from wall to washwater channel)
Surface area of filter media	= *7 m^2.*
Output of filter in 1 hour (metered)	= 33.6 m^3
Filtration Rate	= *33.6 m^3 per hr / 7 m^2*
	= *4.8 m / hr.*

The average filtration rate for a filter run may be calculated similarly if the length of run (say 50 hours) and the output (say 1680 m^3) are known. The average filtration rate = 1680 m^3 / 50 hours / 7 m^2 = 4.8 m / hour.

The output of the filter, if a meter is not provided, may be estimated by closing the inlet valve and measuring the drop in the water level in the filter in, say, 5 minutes. The estimated hourly filtration rate would be twelve times the drop in level measured. In the example above the drop in water level in 5 minutes was 400 mm, so the drop in an hour would be 4.8 m, i.e., the filtration rate. The output of the filter is the filter rate by the area of the media :

$4.8 \times 7 = 33.6$ m^3 /hr.

The filtration rate for a bank of filters all of the same size can be calculated by dividing the metered output from the bank by the total filter area (the number of filters multiplied by the individual filter area).

UNIT FILTER RUN VOLUME

The Unit Filter Run Volume (UFRV) can be a valuable indicator of incipient or future problems in a filter, as well as a useful measure of comparison between individual filters. The UFRV for the filter run quoted in the example above [output 1680 m^3 from a filter of area of 7 m^2] is 240 m^3 /m^2.

In a case where the output from an individual filter is not metered, the UFRV can be calculated, by estimating the filter rate a number of times during the course of the run from the measured drop in filter level, and multiplying the average filter rate by the length of run. The filter rate, in the example given above is 4.8 m /hr (or 4.8 m^3/ m^2 /hr). If the length of filter run were 52 hours and 30 minutes the UFRV for the filter would be $4.8 \times 52.5 = 252$ m^3 /m^2.

FILTER BACKWASHING

Backwashing is the reversal of the flow of water through a filter, possibly preceded or accompanied by air scour, to remove accumulated matter removed from the media.

The hydraulics of filter operation have been derived from a dimensional analysis of the factors influencing friction losses, based on initial work by Darcy in France on friction losses in pipes. This work was developed by Weisbach, Kozeny and Carman.

The Kozeny equation describes the pressure gradient, for laminar flow, in a bed of granular material, as :

$$\frac{\Delta p}{h} = \frac{5(1-e)^2}{e^3} S^2 \mu V$$

where
Δp is the pressure difference across a bed of depth h,
e is the porosity of the media,
S is the specific surface per unit volume of grain (= 6/d for spheres diameter d),
μ is the absolute (or dynamic) viscosity of water, and
V is the approach velocity of the water at the bed surface.

During backwashing the particles of filter media are suspended in the flow of water. Fluidization of the filter bed occurs when the drag force or the head loss through the bed equals the submerged weight of the media:

$$\frac{\Delta p}{h} = (\rho_s - \rho_w)(1-e)\rho_w g$$

where
g is the gravitational constant,
ρ_s is the density of the media grains, and
ρ_w is the density of water

$\Delta\, p/h$ cannot exceed the above limit because the porosity '*e*' automatically increases as a result of bed expansion which corrects the head loss. The important parameters in the above equations (and the important characteristics of filtering materials) are the grain size (d) or surface area (S), the density difference (ρ_s - ρ_w) and the porosity 'e'.

Backwash water is normally pumped, by fixed rate pumps, through the filters at the rate chosen by the designer to suit the media being used. The rate is chosen to expand the bed by the required percentage for efficient cleaning without loss of media over the weir walls. Losses of media may occur if air scour pumps are started while high rate backwash is in progress, although interlocks to prevent this are normally provided.

While the density affects the fluidization threshold linearly, the grain size occurs as a square, so that a 10% increase in grain size requires a 20% increase in backwash rate. Sieves, as used in analysis of filtering materials, are spaced at 20% intervals ($\sqrt[4]{2}$) and hence a material which is one sieve size coarser requires a backwash rate 44% higher. A specific grain size must be used in making calculations with these equations, although the media may not be monosize. The parameter needed is the size which gives the same hydraulic behaviour as the mixture of sizes in the media (same surface area per unit volume) and is called the *hydraulic size*. This may be calculated from the results of a sieve analysis of the media. The method and an example are given in the standard published by the British Effluent & Water Association[6].

Calculation of Hydraulic Size:

1.Divide the % retained on each successive sieve by the size of the sieve aperture.
2.Add up the figures thus obtained and divide by 100.
3.Obtain the reciprocal of the above sum.
4.Add 10% to the reciprocal to correct the "retained" size to the centre size between adjacent sieves (see preceding paragraph).

Example

Sieve Size (mm)	Retained on Sieve (%)	Calculation
2.8	0.1	0.04
2.36	0.5	0.21
2.0	10.2	5.1
1.7	22.1	13.0
1.4	42.3	30.25
1.18	22.5	19.1
1.0	1.4	1.4
0.850	0.35	0.35
0.71	0.5	0.7
	100	**70.1**

Divide total calculated by 100 = 0.701
Obtain reciprocal of 0.701 = 1.43
Add 10% = 0.14
Hydraulic Size =*1.57 mm*

Porosity depends on the shape of the grains. A 1% change in porosity (e.g. from 40% to 41%) will produce a 9.5% increase in the backwash fluidization threshold. The temperature of the water affects the required backwash rate as the viscosity (μ) is reduced by half from 1.781 at 0°C to 0.798 at 30°C. This range of water temperatures would be extremely unlikely to be encountered in Ireland, but the temperature effect might combine with a loss of fines from the media, over time, to reduce the effectiveness of the backwashing in cleaning the media thoroughly.

Where flow velocities are above the laminar region, the Carman modification of the Kozeny equation is appropriate:

$$\frac{R^1}{\rho_w V^2} = 5\mathrm{Re}^{-1} + 0.4\,\mathrm{Re}^{-0.1}$$

where

$$\Delta p = \frac{R^1}{\rho_w V^2}\frac{S(1-e)}{e^3}\rho_w V^2 \quad \text{and} \qquad \mathrm{Re} = \frac{V\rho_w}{S(1-e)\mu}$$

where R^1 is the shear stress at the surface of the grains

Re is the particle Reynolds Number

These equations, although presenting problems for manual computation, are readily managed in simple computer programs.

REFERENCES AND READING LIST

1. US EPA (1994) *Water Treatment Plant Operation Volume 1: A Field Study Training Program.* Third Edition.

2. Huisman, L. & Wood, W.E. (1974) *Slow Sand Filtration,* Geneva, World Health Organisation.

3. Smethurst, George. (1990) *Basic Water Treatment.* Second Edition, ThomasTelford Ltd.,London.

4. American Waterworks Association. *Water Quality and Treatment : A Handbook of Community Water Supplies.* Fourth Edition. A.W.W.A., 6666 W. Quincy Ave., Denver,CO 80235.

5. Stevenson, D.G., (1994) The Specification of Filtering Materials for Rapid Gravity Filtration in *Journal of Institution of Water and Environmental Management*, Volume 8, October 1994.

6. British Effluent and Water Association (1993) *Standard for the Specification, Approval and Testing of Granular Filtering Materials.* BEWA:P.18.93

7. Twort, A.C., Law, F. M., Crowley, F. W., and Ratanayaka, D.D., (1994) *Water Supply.* 4th Edition. Edward Arnold, London.

8. *European Communities (Quality of Water Intended for Human Consumption) Regulations 1988.* (S.I. No 84 of 1988) Stationary Office, Dublin.

9. *Safety, Health and Welfare at Work Act,1989* (No. 7 of 1989). Stationery Office,Dublin.

10. *Safety, Health and Welfare at Work (General Application) Regulations,1993* (S.I. No. 44 of 1993) Stationery Office, Dublin.

11. *Code of Practice for the Safety, Health and Welfare at Work (Chemical Agents) Regulations,1994* (S.I. No. 445 of 1994). Stationery Office, Dublin.

12. Peavey, Howard, Rowe, Donald and Tchobanoglous (1986) *Environmental Engineering* Mc Graw - Hill, New York.

13. Engineering School, UCD (1972). *Course Notes - Water Quality Management.* Department of Civil Engineering, University College, Dublin.

14. Flanagan, P.J., (1992) *Parameters of Water Quality - Interpretation and Standards.* Second Edition. Environmental Research Unit, Dublin.

15. Mc Evatt (1973) *Metric Guide 1.* Third Edition. An Foras Forbartha, Dublin.

16. Department of the Environment (1990) *Cryptosporidium in Water Supplies: Report of the Group of Experts.* Chairman: Sir John Badenoch. HMSO, London.

17. Department of the Environment (1994) *Proceedings of Workshop on Cryptosporidium in Water Supplies.* Edited by A. Dawson and A Lloyd. HMSO, London.

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Environmental Protection Agency

ESTABLISHED

The Environmental Protection Agency Act, 1992, was enacted on 23 April, 1992 and under this legislation the Agency was formally established on 26 July, 1993.

RESPONSIBILITIES

The Agency has a wide range of statutory duties and powers under theAct. The main responsibilities of the Agency include the following:

- the licensing and regulation of large/complex industrial and other processes with significant polluting potential, on the basis of integrated pollution control (IPC) and the application of best available technologies for this purpose;
- the monitoring of environmnental quality, including the establishment of databases to which the public will have access, and the publication of periodic reports on the state of the environment;
- advising public authorities in respect of environmental functions and assisting local authorities in the performance of their environmental protection functions;
- the promotion of environmentally sound practices through, for example, the encouragement of the use of environmental audits, the establishment of an eco-labelling scheme, the setting of environmental quality objectives and the issuing of codes of practice on matters affecting the environment;
- the promotion and co-ordination of environmental research; and generally overseeing the performance by local authorities of their statutory environmental protection functions.

STATUS

The Agency is an independent public body. Its sponsor in Government is the Department of the Environment. Independence is assured through the selection procedures for the Director General and Directors and the freedom, as provided in the legislation, to act on its own initiative. The assignment, under the legislation, of direct responsibility for a wide range of functions underpins this independence. Under the legislation, it is a specific offence to attempt to influence the Agency, or anyone acting on its behalf, in an improper manner.

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ADVISORY COMMITTEE

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