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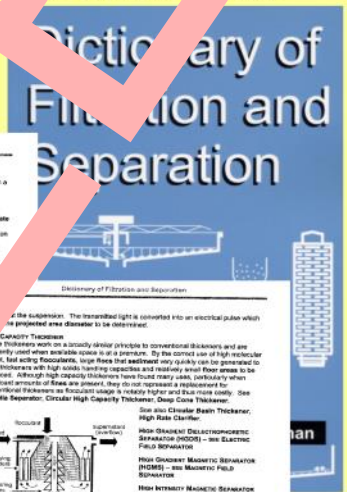
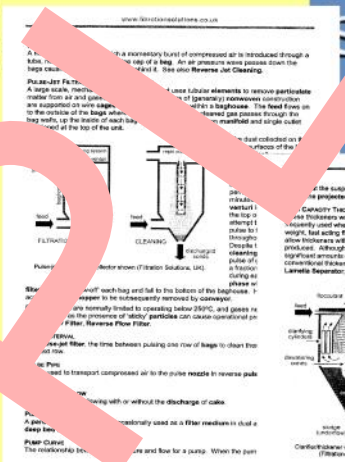
The Dictionary of Filtration and Separation

Steve Tarleton and Richard Wa man

Over 1500 definitions of terms for solid/liquid separation, air/gas/dust separations, filter a, contamin control etc – m Abatement and Abrasion to Zone Settling and Zwitterion – plus a list of abbreviations onyms – provided in thi ck reference dictionary (vi + 303 pages). Clear, bold type entries give a direct lead into the d d u equipment, a efine precisely the meanings of terminology.

The book is an authoritative and up to date text which is cross-referenced and illustrated by over 400 diagrams and photographs. It is a source of reference for all practitioners of filtration and separation, and a valuable educational and training resource. It is indispensible for plant engineers, technicians, operators, and all who work with filtration and separation technology as buyers, users, and suppliers of equipment. It is also useful to managers in production and service industries, graduate students and researchers, and standards and health and safety inspectors.





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The authors are international experts in filtration technologies who been Ch of The Filtration Society. Their work has been recognised by awards from several p ssional Insti ons. Richard Wakeman is a Fellow of the Royal Academ eering and an inter nal consultant specialising in particle/fluid separation processes. Steve ical engine onorary Secretary of the Filtration Society and a Senior Lecturer at Lo ough

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Front Cover. Images courtesy of Broadbent (centrifuge) and Pall (membrane unit).

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APRIL 2015

DEAL FOR SEPARATIONS MEDIA BUSINESS

3M (www.3m.com), the multinational conglomerate best known for its adhesives brands including Sellotape, has entered into a definitive agreement with Polypore International to acquire the latter's Separations Media business for $1bn. Polypore's Separations Media business makes microporous membranes and modules for filtration in the life sciences, industrial and specialty segments with annual sales of $210m. In a separate transaction, Japanese chemical company, Asahi Kasei, has announced it is to acquire Polypore's Energy Storage business. Both transactions are subject to regulatory approvals and are conditioned on 3M's transaction with Polypore closing immediately prior to the closing of Asahi Kasei's transaction with Polypore.

Filtration is a priority technology platform for 3M. Customers increasingly require higher performance 'ultra' filtration that membrane technology delivers, particularly in life sciences and biopharmaceutical segments. The addition of Polypore's Separations Media business will add new technology capabilities to complement 3M's existing filtration business in life sciences, industrial, water treatment, electronics and foodservice. "Polypore's Separations Media business is an outstanding business that will expand our opportunities in many large and attractive segments," said Inge G. Thulin, 3M Chairman, President and Chief Executive Officer. "The acquisition of this ultrafiltration membrane technology will enhance 3M's core filtration platform and help generate new growth opportunities across the company."

3M's Purification business, part of 3M's Industrial Business Group, is a leader in residential water, commercial food service, industrial and life science filtration. Adding Polypore's Separations Media business will build on 3M's fundamental strengths in technology, manufacturing, global capabilities, and brand. "The combination of 3M and Polypore's Separations Media business will help us to meet customers' emerging needs for high value filtration solutions," said Michael F. Roman, Executive Vice President, 3M Industrial Business Group. "Together, we will be able to offer a broader array of products to both Polypore's and 3M's customers, which will accelerate the global growth of our membrane business."

On a GAAP reported basis, 3M estimates the acquisition to be $0.03 dilutive to earnings in the first 12 months following completion of the transaction. Excluding purchase accounting adjustments and anticipated one-time expenses related to the transaction and integration, 3M estimates the acquisition to be $0.04 accretive to earnings over the same period.

3M will finance the transaction with cash, the majority of which will come from outside the U.S. The transaction will be structured to deliver to 3M a full step-up in the tax basis of the acquired assets. Taking into account 3M's estimate of the present value of this tax step-up, the effective purchase price multiple is approximately 12 times annual adjusted EBITDA for the

CHINESE GASIFICATION PROJECT

International leader in high performance filtration products, Porvair Filtration Group has won a major new Chinese contract for the filtration of syngas produced from coal gasification (www.porvairfiltration.com). Porvair Filtration Group has been offering advancements in gas filtration to the industry for more than 20 years, and the signing of an agreement with a Chinese state oil company represents another significant success for its UK manufacturing divisions. The coal-to-substitute natural gas (SNG) gasification project will see Porvair supply char filtration equipment to the CNOOC Oil & Petrochemicals Co.

The plant will be built at its Huizhou Refinery in Guangdong Province, China, with deliveries expected to support commissioning in 2016. Porvair will provide critical filtration of the syngas downstream of the gasifier and heat exchanger to remove the erosive and abrasive char that would otherwise damage downstream equipment and processes. Its gasification innovations across the industry enable the production of synthetic natural gas with products encompassing a range of high temperature filter elements and pulse jet blowdown systems.

The contract win follows recent successful orders for similar technology to Posco in South Korea, and Reliance Industries in India. These projects have helped Porvair grow its export sales to Asia and improve its reputation and sales channels in the region. Andy Bevis, Gasification Business Manager, said "The new contract with CNOOC is a significant win that reflects our track record of leading edge technology and successful project delivery in gasification filtration. It will utilise similar technology to that which we supplied to POSCO, Reliance and SG Solutions and will be similar in scale to the POSCO installation. We are now confident that we can reproduce that success for CNOOC."

CREATING ENERGY FROM WASTEWATER

Saxlund is to install sludge cake loading silos for Southern Water and help the UK's Southern Water turn sewage sludge into energy via anaerobic digestion (AD). BioEnergy and bulk materials handling specialist Saxlund International, part of the Opcon energy and environmental group, has secured contracts from Barhale Trant Utilities to design and supply sludge cake truck loading silos for Southern Water wastewater treatment works (WWTW) at Budds Farm in Havant and Millbrook near Southampton, UK.

The projects include the construction of raised storage silos, each with a capacity of 240 m^3 and specially designed to allow dewatered sludge to be directly loaded into trucks below for transportation off site, as part of Southern Water's thermal hydrolysis and AD programme. The flat bottomed silos will incorporate Saxlund's sliding frame technology, which aims to ensure consistent discharge of material, as well as screw conveyors and integrated control systems. Installation for both sites is due to commence in April with commissioning completed during June.

"There is a growing trend for water companies to develop advanced digestion schemes to improve processing efficiency and turn sludge into energy and our systems are specifically designed for storing and discharging non free-flowing, difficult to handle material like this. They've been tried and tested in hundreds of installations across the UK and Europe. We understand the processes and risks and are confident we have one of the best solutions on the market," says Matt Drew, Managing Director, Saxlund International.

Saxlund completed a series of water industry projects for Anglian Water in 2014 and is currently building a 454 m^3 sludge cake process feed silo for KMI Plus on behalf of United Utilities. This will supply an on-site thermal hydrolysis system at Leigh Wastewater Treatment Works, UK. The company's products handle difficult bulk solids including sewage sludge and alternative fuels and it sees growth across its core operating markets including water, cement, Energy from Waste and Combustion solutions such as CHP.

LAUNCH OF ENGINE FILTERS IN US AND CANADA

A new range of engine air filters has been launched by Bosch. Designed to prevent contaminants from entering the engine, Bosch says the filter is 98% efficient, helps performance and boosts longevity. Bosch offers 231 engine air filter stock keeping units (SKUs) covering a total of 219 million vehicles. This represents 90% of United States, Asian and European vehicles.

The product is the latest addition to the firm's Workshop Filters range which includes air, oil, fuel and cabin air filters supplied in the United States and Canada. "Proper filtration plays a vital role in the proper functioning and longevity of many key vehicle systems," said John King, Director, Product Management, Filtration and Energy Products at Bosch.

HYGIENIC DECANTER TECHNOLOGY

Intelligently equipped for processing milk and whey, the GEA dairysmart permits a flexible production with easy operation on account of the integrated input/output (IO) control (www.gea-foodsolutions.com).

In the dairy industry, there are many possibilities to use the new decanter family GEA Westfalia Separator **eco**force. The new dairy decanter, belonging to this series, is economically and efficiently used in various applications, such as production of the basic material of processed cheese, raw material for curd cheese bars or bakers cheese. In addition, the processing of cheese fines as well as lactose and casein production are assisted by the design of the decanter which has been optimized for the production of sensitive food products. Based on strict hygienic guidelines, such as EHEDG or 3-A, the new dairy decanter can be offered with different levels of hygiene standards. Thus, the dairy industry can choose from sanitary, economically sustainable and effective centrifuges for a large range of processing capacities.

Proven and tested components intelligently combined on a single skid – this is how the new dairy**smart** from GEA presents itself, which has been designed for small to medium-sized dairies as well as cheese dairies. The dairy**smart** consists of the **eco**cream skimming separator for milk and whey in combination with an intelligent production kit for smart, flexible product processing as well as the connecting interface – the new **IO** control system from GEA. On account of the experience and competence bundled on a skid, the customer can safely produce and offer a wide range of products without having to invest in an extensive set of machinery. From automatic tank standardization as well as milk and whey skimming to the standardization of cream, all tasks can be handled quickly, reproducibly and thus safely with the skid.

With the CSI 500, GEA presents a bacteria removing separator for capacities of up to 60,000 l/h, equipped with the efficient, space and energy saving integrated direct drive. Bacteria, somatic cells and non-dairy components can contaminate milk products considerably, and thus can have a serious influence on further processing and product safety. A reliable bacteria removal from milk and whey is all the more important for this reason. The application scope covers everything from single-stage and double-stage bacteria removal from drinking milk and special bacteria removal from cheese making milk to the treatment of whey concentrate.

Optionally, the bacteria removing separators can be equipped with the **pro**plus module. With **pro**plus it is possible to considerably extend the ejection interval during the production. The result is a significant increase in the protein yield from the raw milk used. Moreover, wastewater, maintenance and wear costs are reduced.

Greek Yoghurt Made the Greek Way

The basis for the success of Greek yoghurt on an industrial scale is the special quality of the product and the similarity of the procedure to the original production method. The conventional method is to allow about 3 litres of coagulated milk to drip whey off through a cloth bag in order to get about 1 litre of yoghurt in the end. Nowadays, using the same ratio of 3 to 1, GEA centrifuges are run at about 5000 rpm to continuously separate whey from the coagulated mass in order to obtain the requested high protein Greek yoghurt – with a quality and taste which in its full-bodied creaminess in no way is inferior.

The results are achieved by a number of advantages of the GEA centrifuges. Not only do they ensure constant throughput and product characteristics with respect to product structure during the process, for example, but they also permit direct filling immediately after concentration. In addition, the centrifuges can be integrated in the existing process equipment easily, and compared to alternative processes they offer long service life and thus a high availability of the production.

GEA centrifuges, which are already being used successfully for the production of Greek yoghurt, stand out for their high flexibility as, depending on the process, they can be used also for the production of Thermo Quark and cream cheese.

CHANGE OF NAME

GLV Inc. has changed its name to Ovivo Inc. The name change follows completion of the sale of the Pulp & Paper Division and reflects the company's focus on water treatment products and solutions.

Ovivo Inc's shares are traded on the Toronto Stock Exchange under the ticker symbols OVI.A and OVI.B.

MEMBRANES HANDLE DIFFICULT OIL/ WATER & SLUDGE/WATER SEPARATIONS

One of China's largest steel manufacturers is relying on Pall technology for critical process separations. Pall Membralox® ceramic UF membranes are being employed for oil/water separations and Pall Schumasiv™ ceramic MF membrane filter elements are being used for bioreactor sludge/water separations (www.pall.com). The plant has a capacity of several million tons/year.

In steel production 'rolling' is a metal-forming process in which metal stock is passed through one or more pairs of rollers to reduce thickness and provide uniformity. An oil/water emulsion is used as a lubricant and for heat control in this process. Subsequently, Membralox® ceramic membranes are used to help concentrate the emulsion, enabling the oil to be reclaimed and the water to be sent to the membrane bioreactor to reduce the amount of organic compounds in the water. A concentrated sludge/water mixture is a by-product of the ensuing bioreaction. Schumasiv™ ceramic membranes are used to separate the sludge and water, enabling the sludge to be safely disposed of and allowing the water to be reclaimed for re-use.

"Fluid cleanliness is critical to the operation and reliability of the systems used in steel production," said Mitch Summerfield, President, Pall Process Systems. "Pall technology is enabling this plant to deliver the consistent, high quality product which its customers demand."

Pall's Membralox® membranes and Schumasiv™ filter elements are designed for a wide range of industrial processes. The ceramic membranes are less prone to fouling and offer greater reliability in handling process upsets than the traditional settling tank and polishing filtration which the MF system replaced.

In addition, they provide high quality filtrate, such that the plant no longer needs to install a traditional large post-aerobic clarifier. The reduced footprint resulted in significant savings for the plant. The Pall system also eliminated the need for additional downstream polishing equipment, further reducing capital and operation costs. Finally, Pall's systems feature innovative modular designs, which will make future plant expansion simpler and less expensive.

NEW LUBE FILTER WITH NANONET® MEDIA TECHNOLOGY

Cummins Filtration (www.cumminsfiltration.com), a leader in diesel engine filtration technology, have announced the release of the Fleetguard LF14000NN lube filter for Cummins ISX15 diesel engines.

The new filter is the company's first lube filter with NanoNet® media, a patented polymeric nanotechnology-based synthetic media originally developed for Fleetguard fuel filter applications. Cummins Filtration technology developments, found first in the LF14000NN, bring a new level of lube filter performance to the heavy duty diesel engine market.

"Many of the characteristics that make NanoNet® media so successful in fuel filter applications translate well to lube filters," said Brad Long, Senior Engineering Technical Advisor, Cummins Filtration. "By pairing NanoNet® with our proven StrataPore® synthetic media, we can offer a lube filter that's suited to meet the needs of today's advanced engine platforms and lubricants as well as those coming in the near future."

Introduced by Cummins Filtration in 2012, NanoNet® filtration media removes and retains 98.7% of all particles as small as 4 microns (12 times smaller than the smallest particle visible to the human eye). The 100% synthetic, multi-layer polymer design is thinner than a typical small coin yet comprises a robust structure, allowing for maximum contaminant holding capacity over the course of the filter's service life. In the case of the LF14000NN lube filter, the NanoNet® and StrataPore® media structures are claimed to work together for best-in-class particle removal, capacity, and cold flow ability to give uncompromising protection and filter life for today's ISX engines.

"Our NanoNet® media structure enables much higher cold flow ability (than competitors) while retaining its high efficiency characteristics in filtering lube oil," Long said. "High cold flow ability means less restriction and faster oil lubrication during cold start-up, and lubricating and protecting the vital engine components. Filter efficiency, capacity and cold flow ability are all improved."

"NanoNet® media provides the absolute best in filtration performance in applications where uptime, performance, and cost effective operations are imperative," said Jeremy Harden, Lube Global Product Manager, Cummins Filtration. "The LF14000NN with NanoNet® is one more example of how Cummins unites quality and innovation in diesel engine filtration."

NEW TYPE OF MEMBRANE PERMITS CHEAPER AND MORE EFFICIENT WATER PURIFICATION

New selective membranes in the form of thin hollow straws can improve water purification. This conclusion emerges from research by Joris de Grooth from UT's MESA+ research institute. The membranes that De Grooth jointly developed make it possible to purify water in a single process step, while preliminary treatment is always required in existing water treatment plants. The most important benefits of the new membranes are that they can make the provision of drinking water easier, and therefore cheaper, whilst at the same time improving the removal of micropollutants such as pharmaceutical residues.

Surface water in The Netherlands contains increasing amounts of medicines, pesticides and hormones (including from the contraceptive pill). With existing water treatment techniques it is consequently becoming more and more difficult to produce clean drinking water. After all, they were not developed to remove these contaminants from the water.

A new type of membrane, partly developed at the University of Twente, can help. This selective membrane is applied to thin porous straws (also referred to as fibres) with holes of about 5 nm in diameter. Multiple thin layers of polymer coating (of about 2 nm thick) are applied over the holes by means of a relatively simple chemical process.

A major advantage of the method is that the thin layer can be introduced from water, and chemical solvents are therefore not necessary. In addition, the creation of the polymer layers can be controlled very accurately. Depending on the desired application, the number of layers, the density and the charge of the layers can be chosen.

The new membranes have a number of important advantages. For example, they make it possible to purify water in a single process step, while a pretreatment step is normally always required in order to filter 'larger substances' from the water. This makes water treatment cheaper and facilitates the use of smaller-scale water treatment plants, so that clean drinking water becomes possible in remote areas of, for example, developing countries. Furthermore, compared to existing hollow fibre membranes, with the new membranes it is easier to remove micro-pollutants such as medicine residues, hormones and pesticides from water.

For larger scale water purification, more than 10,000 straws of about one metre in length are placed in a module. Anywhere between a few dozen to hundreds of these modules can be installed in a water treatment plant. The company Pentair in Enschede, which was closely involved in the research, is taking over the further product development of the membrane.

NEW FLOW OPTIMIZATION METHODS LAUNCHED

New methods for flow related optimization of mesh textures were unveiled at the Filtech exhibition. GKD (www.gkd.de) demonstrated how a stainless steel woven wire mesh filter media can achieve a 25% higher flow rate, without any changes to the size of the mesh openings. The company says users will benefit from significant savings in terms of space requirements and energy consumption. At the exhibition a range of products were showcased that all feature the enhanced property including cartridges for ballast water filtration, policing filters for low pressure exhaust gas recirculation in the latest and next generation petrol and diesel engines, and NeverLeak filter leaves (rescreenable plate filter elements for precoat filtration applications).

PORTABLE WATER FILTRATION TANK

The Science, Technology and Innovation Ministry is hoping to bring portable water filtration tanks to provide clean water for flood victims. Minister Datuk Dr Ewon Ebin said a portable water filtration tank had been created and researched by University Teknologi Malaysia. The project was funded by the ministry in 1998. "A 100% local technology device, it utilises membranes and ultraviolet technology to filter dirty water and provide clean water to drink," he said during an award ceremony held by CyberSecurity Malaysia.

Ewon said the water tank could easily be moved around on a lorry and had the capability to provide clean drinking water for up to 3,000 people. "You just park it next to a river and it will filter the water. This tank can be used for underground water sources or even during the drought season. We are proposing to the government to purchase 30 of these tanks to deploy in flood-hit areas; each costs RM400,000. They can then be kept there and maintained for use during future emergencies." Apart from that, the ministry is also proposing for CyberSecurity Malaysia to help flood victims retrace and backup any lost data.

RO TECHNOLOGY BOOSTS QUALITY AND CUTS COSTS FOR BREWERIES

Reverse osmosis technology is helping to improve the quality and flavour of beer. A water purification system, Elite Plus, developed by UK-based Purite (www.purite.com), uses the technology which also helps cuts costs and ensures consistent machine operating time. The units incorporate semi-permeable membranes through which pressurised feed water is passed to remove up to 98% of inorganic ions and 99% of dissolved organic contaminants.

The Elite Plus range can provide permeate outputs from 750-10,000 l/h. The system is especially useful for lagers and ales with more delicate flavours, where purified water has far less impact on taste. An in-built automatic alarm system constantly monitors quality of the purified water and users are alerted if it dips. The Elite Plus also enables breweries to reduce the number of consumable items normally used in the water purification process, resulting in lower operating costs.

NEW WASTEWATER PURCHASE

Hydro International plc (www.hydro-int.com) has purchased the operating assets and brand of Settled Solids Management Inc. (SSM) based in Florida, USA. SSM provides services to remove sand and grit from wastewater treatment plants based around a patented Vertical Grit Separator system. The SSM business will operate as part of Hydro International's Americas Wastewater division which is headquartered in Hillsboro, Oregon. UK headquartered Hydro International develops solutions for stormwater and wastewater management. The company has operations in the UK, Ireland and the USA.

Michael Jennings, Chief Executive of Hydro International, said "As we continue to drive growth efforts, particularly with our services strategy, this deal represents an important step forward to broaden the scope of what we can offer to better serve our customer base, always building around our core technology."

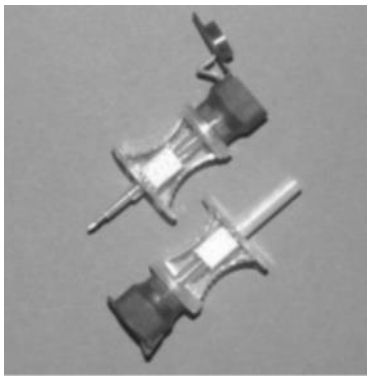
CCECO FILTRATION ACQUIRED

Y2K Fluid Power (www.y2kfluidpower.com) recently announced its purchase of CCECO Filtration of Kent, Washington. A manufacturer of depth media bypass filtration products for the construction, energy, manufacturing and broad industrial markets, CCECO Filtration offers low flow/high retention (LFHR) filtration technology to remove fine contaminants (less than 1 micron) from lubricating oils. "The acquisition of CCECO increases our depth within the filtration industry, enabling us to offer new, diverse capabilities in a large number of industry segments," said Rick Lindemann, President of Y2K Fluid Power. "Through our existing distribution network and partnerships, Y2K will be able to expand the CCECO product line to an even broader geographic reach."

The acquisition allows a combination of the technologies of Y2K and CCECO to help customers achieve increased levels of equipment reliability, productivity and fluid cleanliness. The transition of CCECO to Y2K Fluid Power will also result in enhanced customer support as well as an increased filtration portfolio. A division of Dakota Fluid Power Inc. and based in, South Dakota, Y2K Fluid Power is an original equipment manufacturer that markets filtration products to help improve equipment reliability and extend lubricant life.

SIMULTANEOUS FILTRATION AND STERILE VENTING IN ONE COMPACT DEVICE

When a needle or spike is inserted into a vial, hazardous aerosols can be released that are both harmful to operators and can cross contaminate other products in the aseptic area or isolator cabinet. The new Rowespike Filter will protect operators and avoid cross contamination and is an ideal choice for reconstituting cytotoxics (www.helapet.co.uk). The Rowespike incorporates a 5 micron liquid filter and a 0.1 micron PTFE air filter to simultaneously filter a solution and sterile vent whilst simply drawing the solution into a syringe. Convenient and easy to use, your syringe attaches directly to the top of the device with a luer lock offering security whilst handling cytotoxics.



SILICON CARBIDE (SiC) MEMBRANES FOR THE REMOVAL OF HEAVY METALS FROM POWER PLANT WASTEWATER

LiqTech International (LiqTech, www.liqtech.com) has won a $130,000 SiC membrane order from a European customer. This is a follow-on order from a customer that first installed a system in 2014. The installation is for a German power plant for the removal of heavy metals from a flue gas cleaning process. This new order will be installed at another German power plant.

Mr Sune Mathiesen, LiqTech CEO, remarked, "We are very pleased to receive an additional order from this customer. The system reduces the environmental impact from coal and biomass fired power plants and was developed by the customer with technical support from LiqTech. The second order is further verification that our membrane technology is an excellent solution for this very difficult problem."

"We have dedicated significant marketing resources, both on-shore and off-shore, developing solutions for the removal of heavy metals using our SiC membrane technology, and we are now seeing the first re-orders. This is very encouraging and we will continue to devote the necessary resources to establish new commercial relationships for these applications. The removal of heavy metals is one of our chosen focus applications and we believe that it has a significant worldwide market potential. Awareness to this very serious environmental problem is growing with an increasing likelihood of legislation to address this worldwide problem."

"We offer a practical solution to this environmental problem and we look forward to generating significant future orders," Mr Mathiesen concluded.

.... and SiC Membranes for Enhanced Oil Recovery and Marine Technologies

LiqTech has also secured a US$2.4 million purchase order for a water treatment system based on the company's SiC membranes as part of an enhanced oil recovery (EOR) project. This is LiqTech's largest ever order and is expected to be delivered in the second quarter of 2015. The order was received from LiqTech's preferred partner Nakasawa Mining and Energy Ltd.

LiqTech CEO Sune Mathiesen said "We believe this purchase order marks a commercial breakthrough for our products within the oil & gas industry – one of our strategic industries in which we have been proving the benefits of our unique technology for the last four years."

"LiqTech is currently working with a large number of oil companies, operators and system integrators, predominantly in Europe and the Americas, on membrane projects in phases from initial evaluation to commissioning. Based on customer feedback, we believe that certain additional purchase orders are possible in 2015 for completed oil validation projects, despite low oil prices, given the value proposition our solution provides. We will continue to pursue these orders in addition to opportunities outside of the oil industry," added Mathiesen.

LiqTech has also received a US$350,000 SiC membrane system order from Yara Marine Technologies for delivery later this year. The two companies have agreed to enter a supply agreement for future installations of LiqTech SiC membrane systems for the Yara Marine Technologies exhaust gas cleaning systems.

MOBILE UNIT SUPPLIES FRESH WATER TO CHARITY

Charity workers and local residents in an area of Columbia have been given access to clean drinking water thanks to a mobile desalination system. AMPAC USA designed and supplied the Sea Water Desalination Watermaker to the Red Cross Society in Uribia La Guajira. The system can convert 100,000 gallons of seawater to drinking water on a daily basis.

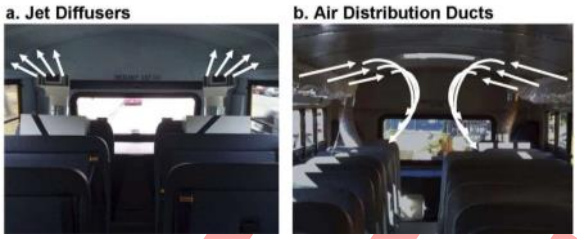
"When we got the order from the Red Cross Society, the task was to be completed in a very short time and in a very compact mobile trailer. It just took a few days to build the system and the results have been satisfactory," said Ampac USA CEO Sammy A. Farag. "The seawater desalination process includes pretreatment, seawater desalination, reverse osmosis, post treatment and on-demand delivery to point of use."

The Mobile Watermaker features an energy recovery booster device that saves about 70% of total power consumption by transferring the pressure from the reject water back to the feed. It also has a microprocessor controller that monitors and controls the system and communicates with pre-treatment equipment and distribution tanks as required. It can also be operated remotely over the internet.

ON-BOARD SCHOOL BUS FILTRATION SYSTEM REDUCES POLLUTANTS

An on-board air filtration system developed specifically for school buses in collaboration with IQAir North America (http://iqserver01.iqair.com) reduces exposure to vehicular pollutants by up to 88%, according to a study by researchers at the UCLA Fielding School of Public Health. The high efficiency cabin air, or HECA, system could help protect the 25 million American children who commute on school buses nearly every day. "Children are more susceptible to air pollution than adults because they breathe more quickly and their immune and cardiovascular systems are still developing", said Dr Yifang Zhu, the study's senior author.

The study found that pollution reduction was even greater under freeway driving conditions, which was surprising because freeways have particularly high pollutant concentrations due to traffic congestion and increased emissions. The air inside buses with the HECA system was as clean as air near the beach in Santa Monica, California. The study tested six school buses without children on board while the buses were still, and while they were driving on freeways and major arterial roadways in Los Angeles. Researchers tested the air both inside and outside of the buses for vehicle emitted particulate matter, including black carbon and fine and ultrafine particles, down to a few nanometres in size.



A previous study, funded by the California Air Resources Board more than a decade ago, was the first to find serious air quality problems inside diesel powered school buses and led to efforts to retrofit school buses with exterior pollution reducing devices. While promising for minimizing emissions from bus tailpipes, these don't always provide cleaner air inside buses.

A previous study by Zhu and her team found that commercially available household air purifiers can reduce pollutant levels inside school buses by about 50%. However, they are not designed to work in moving vehicles. As part of the new study, researchers developed a prototype on-board HECA filtration system for buses and installed two in the rear of each of the six buses tested. Air was drawn in through diffusers on the sides of each unit and fed through the HECA filter. The filtered air was then delivered at a constant rate through air ducts.

ENTRY LEVEL BIOREACTOR LAUNCHED

A compact bioreactor designed as an entry level model for fermentation and cell culture as well as for educational purposes has been launched by Sartorius Stedim Biotech (www.sartorius.co.uk). The BIOSTAT A has a control tower featuring an array of measurement and control functions such as easy-load peristaltic pumps, an aeration module and accessible probe ports and supply connections.

Sartorius says the new aeration system provides automatic control of all gas lines with continuous gas flows removing the need for manual adjustment of rotameters. For cell culture applications, aeration with four gases (air, O_2, CO_2 and N_2) is possible for controlling pH and dissolved oxygen (DO). The microbial version allows aeration with two gases (air and O_2). The new bioreactor is equipped with digital pH and DO probes designed to help users gauge when a probe can be used for the next cultivation process. The user interface can be operated with a tablet or smartphone allowing remote monitoring of the system.

LOCAL SOLUTION FOR DISTILLERY

A relaunched whisky distillery is self-sufficient in water after putting its borehole back into operation. The Annandale Distillery in Scotland, UK, has re-opened after closing in 1919 and a key requirement was the high quality water used for producing the single malt.

Veolia Water Technologies was called in to demonstrate how water from the borehole could be treated economically, avoiding the cost of installing a mains supply and ensuring a consistent source quality (www.veoliawatertechnologies.co.uk). After filtration and softening, the borehole is treated by a Sirion Maxi reverse osmosis plant. Some of the product water is used directly for spirit reduction whilst the remainder is conditioned by the addition of a specially formulated Hydrex chemical for boiler feed. To reduce waste, Veolia installed a RecoBLUE recovery unit to recover approximately 50% of the wastewater from the Sirion Maxi.

TWO-STEP FILTRATION TO CLEAN UP 3D PRINTING PROCESS

Now that 3D printing is becoming a more established technology rather than a shiny new unknown, certain realities are beginning to take centre stage. Some are looking more at the design aspect, with intellectual property often at the forefront of increasing legal debate. On the hardware side of the 3D printing there are concerns about the actual process of additive manufacturing, including the effects that the process has on the surrounding environment.

Enclosed 3D printers are more popular for home projects, as no one wants to breathe in dangerous fumes or unpleasant odours. These concerns are exacerbated even further in homes with small children, elderly family members, or even omnipresent pets, all of whom are especially susceptible to airborne discomforts. There are a few enclosures for open model 3D printers, including the BuzzBox, which was successfully funded on Kickstarter in January. The technology (along with that of 3D printers themselves) is still coming along and so far isn't ubiquitous. With the latest in 3D printer enclosures, one which doesn't just contain the contaminants but also filters the air and thereby enhances print quality.

James Nordstrom has told 3DPrint.com about his patent pending 3DPrintClean recirculating filtration system. "My company, 3DPrintClean is developing a 3D Printer enclosure that filters ultrafine particles, making it safe to print in homes and offices," Nordstrom said. "In addition, the enclosure improves print quality by reducing warping, curling and cracking."

The 3DPrintClean system relies on two 120 mm centrifugal blowers to lead the way in two steps of filtration. The air in the system is pulled up through the blowers from inside the enclosure space, and passed through an activated carbon filter. A HEPA filter then takes the lead in the second step, filtering in a repeated scrubbing process to remove what 3DPrintClean refers to as 'ultrafine particles', ensuring the reduction of contaminants before recirculating the cleaned air back into the 3D printing work area.

PRODUCT DEVELOPMENTS AND CASE STUDIES

NEW HYDROCYCLONES LAUNCHED IN EUROPE

Weir Minerals has launched two new versions of its heavy duty CAVEX hydrocyclones in the European market. The new CVXU polyurethane hydrocyclone and CVXT ceramic tile-lined hydrocyclone are designed to withstand severe abrasion. They feature a laminar spiral inlet geometry that allows slurry to follow a natural path without encountering sharp edges. Weir says this reduces turbulence inside the cyclone which helps to maximise separation efficiency, hydraulic capacity and extend wear life.

"Cavex hydrocyclones are highly regarded for their proven hydraulic efficiency and durability in harsh environments and the range of lining materials available make them ideal for highly erosive and corrosive applications," said Tony G. Locke, Managing Director of Weir Minerals Europe. "We are committed to ensuring that our products perform with optimum efficiency and offer a lifetime cost of ownership that is low."

NEW GREEN WASTEWATER PLANT SYSTEM

A new energy saving filtration system for wastewater treatment plants has been launched. The PURON MBR ultrafiltration membrane bioreactor series from Koch Membrane Systems has been designed to minimize downtime and increase flux in a cost efficient manner.

It features reinforced polyvinylidene fluoride hollow fibres that are fixed only at the bottom, virtually eliminating the build-up of hair and fibrous materials that typically clog the upper ends of other modules. Solids and particulates, including bacteria, remain on the outside, while permeate is drawn through the membrane to the inside of the fibres. The modules feature an aeration nozzle in the centre of the fibre bundle which facilitates scouring of the entire length of the fibres, thereby minimizing power consumption.

DESIGN AND INSTALLATION OF WATER TREATMENT PLANT IN RWANDA

Rwanda's Water and Sanitation Corp Ltd (WASAC) has selected Culligan International to design and install a water treatment plant to provide drinking water for Kigali. Culligan will design the system to initially produce 25,000 m^3/d with the ability to expand capacity to 39,000 m^3/d once performance results are proven. The company will provide all design and engineering works, equipment supply, civil works and installations.

The treatment system is made up of raw water intake from the river including screening, a raw water intake pump station, sedimentation tank, aeration tank, raw water pump station, Culligan Omni Filtration (OFSY) Systems, disinfection and a 1000 m^3 treated water reservoir. The plant is expected to be completed by July 2015.

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NEW CATALYTIC FILTER BAG TECHNOLOGY

Haldor Topsoe A/S (www.topsoe.com), a leader in catalysis, and FLSmidth A/S (www.flsmidth.com), a leading supplier of equipment and services to the global cement and minerals industries, have signed a co-operation agreement that marks the beginning of a joined global effort to commercialize a newly developed and unique catalytic filter bag technology .

The product will carry the brand name EnviroTex™ catalytic filter bags and is capable of removing dust, volatile organic compounds and nitrogen oxides in one integrated and cost-effective process. A long list of industries including cement, power, biomass, waste incineration as well as glass and metal production are the target customers and the global commercial potential is huge.

Over the past four years the two parties have been working closely together on developing the EnviroTex™ technology. As part of this effort the product has been thoroughly tested and proven efficient for several industrial applications.

A Strong Fit of Competences

"Developing this product has been a combination of the very best that Topsoe and FLSmidth have to offer from an R&D perspective. By combining FLSmidth's expertise in filtration in industrial processes with Topsoe's leadership in catalysis, we have created a unique product that will allow customers to meet increasingly stringent environmental legislation at a fraction of the operating cost that even the best available technologies offer today," says Bjerne S. Clausen, CEO at Haldor Topsoe.

The key differentiating factor about the patent pending catalytic filter bags lies in the fact that EnviroTex™ consists of three layers of filter fabric. Each layer contains a tailored catalyst optimised for the removal of specific kinds of compounds from the off-gas that passes through it.

"The three layer structure is unique. Not only because it provides us with the flexibility to tailor different catalytic combinations for different industries. It also makes it possible to handle the removal of several critical compounds in one integrated process. This can significantly reduce the cost of off-gas cleaning because today's standard is to use separate stand-alone systems to address the removal of specific compounds. Such a combination translates into complexity and higher customer operating cost", says Bjerne S. Clausen.

Leveraging Existing Strengths

Fabric filters are used across a variety of different industries today of which cement and minerals represent a large market segment. In many applications they are used as a final purification step to remove particulate matter from the flue gas. FLSmidth has been a leader for many years in this field with extensive experience and in-house knowledge on how to design, manufacture and operate fabric filters for a broad range of industries, and possess detailed process integration know-how.

"The beauty of this collaboration is that we can fully leverage each other's strengths and market presence and efficiently target a global market opportunity. EnviroTex™ catalytic filter bags allow customers to upgrade their environmental equipment to fulfil tightened legislation at low cost and with minimum influence on existing production equipment," says Thomas Schulz, CEO at FLSmidth and continues: "Initially we believe the US market will benefit from the product, because cement producers here are faced with immediate challenge in order to meet new regulatory requirements that have been issued by the US Environmental Protection Agency and will take effect 1 September 2015. In the longer term China may hold an even greater market potential as stricter emission legislation is also being imposed there. Therefore, EnviroTex™ adds to both companies' product lines being one of many solutions to the need for emissions reduction and improved energy efficiency."

As part of the agreement between FLSmidth and Topsoe, the new product will be manufactured at FLSmidth's bag production facilities in Georgia, USA. The high quality filter bags will then be catalyzed and assembled at Topsoe's catalyst production site in Houston, Texas. In fact Topsoe's production site will be expanded with an entirely new production line dedicated to the production of EnviroTex™ catalytic filter bags. The goal is to complete construction of this facility by the end of 2015.

180 FILTRATION PLANTS UNSAFE: MILLIONS OF CITIZENS DRINKING UNHYGIENIC WATER IN RAWALPINDI

Customs Today report that millions of citizens of Rawalpindi are drinking unsafe water as about 180 filtration plants in the city are providing unhygienic water to the consumers. A large number of people fill water from these filtration plants that contain particles of iron which develops arsenic. These arsenics cause many diseases of the stomach, kidneys and heart.

According to sources, the Water and Sanitary Authority (WASA) was not taken into confidence while building these plants. The citizens of Rawalpindi demanded that WASA, a provincial government and health department, take notice of the matter. They urged that samples of water from tube wells and water filtration plants located in Rawalpindi district should also be tested so that people could drink safe and healthy water.

FULL OWNERSHIP OF MICRODYN-NADIR ACQUIRED

Mann+Hummel (www.mann-hummel.com) has increased its stake in German membrane and module manufacturer Microdyn-Nadir from 50 to 100%. This follows Mann+Hummel's acquisition of 50% of Microdyn-Nadir's shares in May 2014. The goal is to establish Mann+Hummel as a major player in the water filtration business. The two companies have minimal product overlap and operate in different geographical markets. Wiesbaden based Microdyn-Nadir focuses on the production and distribution of flat sheet membranes and is a global supplier of membranes and modules for micro-, ultra- and nano- filtration, while Mann+Hummel is a global supplier of filtration solutions to the automobile and manufacturing industries.

Mann+Hummel entered the water filtration market in 2010 with the acquisition of Singapore based Ultra-Flo, in an effort to grow its business outside the automotive sector. Since August 2014 Microdyn-Nadir has been responsible for Mann+Hummel's water business. Mann+Hummel's membrane activities are marketed under Microdyn-Nadir's company brand.

Under full Mann+Hummel ownership, Microdyn-Nadir will continue to focus on membranes and modules. Mann+Hummel's ultrafiltration membranes and modules will be marketed and distributed under the AQUADYN product brand, which is a registered trademark of Microdyn-Nadir in Europe.

In addition to its own production sites in Wiesbaden and in Xiamen, China, Microdyn-Nadir now has another manufacturing base in Singapore and has sales offices in Raleigh, North Carolina, USA and in Jundiaí, Brazil.

FOOD INDUSTRY MAGNET LAUNCHED

The latest version of a magnet filter that has been specially developed for the food industry has been unveiled. The updated EHEDG filter from Goudsmit Magnetic Systems (www.goudsmit-magnetics.nl) is made up of Neoflux magnets that the company says will provide an efficient separation of minute iron particles from 5 microns, weak magnetic particles and even iron dust. Launched at the Anuga Trade Fair in Nuremberg, it generates a magnetic field of up to 10,700 Gauss on the bars and removes particles from both liquid and powder products. The system complies with the HACCP/EHEDG standard, the highest in the field of food safety.

The filter can be used in tubes or piping in the food sector and removes iron particles from products that are transported under pressure and sticky produce such as chocolate, pastes and fruit juice. The magnet filter is available in seven standard dimensions up to 200 mm and has a flange connection according to DIN 11864.

SLUDGE POWERED WASTEWATER TREATMENT PLANT TO GET UPGRADE

Suez Environnement subsidiary Degrémont (www.degremont.com) has won a four year contract worth a total of €84 million to operate and maintain two wastewater treatment plants at Gabal El Asfar in Cairo.

This contract was won in a consortium with three Egyptian companies: DHCU, ARCOM and ICAT. Degrémont will be in charge of operating the facilities and their rehabilitation, to ensure that the water discharged into the environment is of the highest quality, to protect the canal water near the plant and in the Nile Delta. Located in Cairo, Gabal El Asfar is the biggest wastewater treatment facility on the east bank of the Nile. It has a processing capacity of more than 1,400,000 m^3/day, including a cogeneration plant fuelled by anaerobic sludge digestion that produces up to 65% of the power needed to run the facility.

To date, 70% of Greater Cairo's potable water is produced by facilities built by Degrémont (Fostat, Mostorod, Amerya, Ghiza, etc). In 2007, Suez Environnement won the Gabal El Asfar Optimisation contract (300,000 m^3/day), and in 2008 the contract to expand the Alexandria East plant (800,000 m^3/day). In 2014, the Group also entered into a contract to operate and maintain the Gabal El Asfar 2A wastewater treatment plant.

UK MANUFACTURER TO ENSURE HIGH GRADE POLYMER PRODUCTION

Petlon Polymers Ltd (http://petlonpolymers.co.uk) are investing in its polymer compound production lines by upgrading their metal detection and separation equipment with the EZ-Tec 9100 all metal separator, developed and manufactured by UK-based manufacturer Eriez Magnetics Europe Ltd (http://en-gb.eriez.com). The EZ-Tec 9100 all metal separators from Eriez are being installed at critical stages of the process to ensure metal free end product quality at an affordable price.

A leading manufacturer of engineering polymer products, Petlon offers a range of prime, recovered (R-Prime) and recycled materials as well as material recovery solutions for waste products from manufacturing operations in the range of engineering polymers as well as in PET (polyethylene terephthalate). The plastic waste material is collected, shredded, granulated and then used as a base feedstock in the manufacture of high end quality engineering compounds.

Designed and manufactured in South Wales, UK, the EZ-Tec 9100 is a vital part of the process, removing ferrous and nonferrous metals in order to protect expensive machinery and ensuring all finished products are free from any metal fragments. The result is a high quality finished product. Explaining the reason for their choice, Gavin Rees, Managing Director and James Moverley, Maintenance Electrician at Petlon Polymers commented: "We're delighted to be working with a UK manufacturer. It provides us with a responsive support at a lower cost and allows us to develop a solution that matches our requirement exactly. Due to the potential of metal components in the raw material, protection of equipment is vital and the EZTec 9100 enables this at a competitive price. Working together with Eriez has enabled us to develop an upgraded metal separator with a specially designed reject flap which has a longer life and significantly reduces overall repair costs, and down time."

The EZ-Tec 9100 is a high sensitivity, all metal balanced, coil technology metal separator, equipped with a quick acting pneumatic reject mechanism. The model installed on Petlon's production lines detects and removes any ferrous, nonferrous and stainless steel particles greater than a 0.5 mm sphere. Petlon are upgrading the equipment at different stage in the production flow, where it is used for improved pre-screening as well as ensuring the high quality of the final products. Easily retro-fitted, this compact metal separator is designed for installation in free fall or gravity applications and can be used as a standalone unit or installed in line with the process flow.

"We have been working with the Petlon Polymer engineering team for the last 18 months in order to find a highly reliable, efficient and cost effective solution" comments Paul Hale, Eriez Sales Manager – metal detection. "Thanks to years of experience in dealing with similar issues, and our range of material handling equipment, Eriez could work out a sustainable solution combining magnetic separation, metal detection and vibratory feeders."

ANTISTATIC FINISH IN ACCORDANCE WITH ATEX

Freudenberg Filtration Technologies offer air filters for use in potentially explosive atmospheres that are suitable for positioning within hazardous areas, according to the ATEX directive 94/9/EG, and prevent the risk of electrostatic charges that can be created by gas or dust. Those available with antistatic finish are Maxi-Pleat cassette filters, P-15 Series filter mats, T60 Compact pocket filters and HEPA filters in classes F9 and H13.

ATEX is derived from the French term **AT**mosphere **EX**plosibles. The European Union Directive currently includes two guidelines in the area of explosion protection:

1. Directive 94/9/EG, also known as ATEX 95, covering protective measures in potentially explosive hazardous environments applies to electrical and non-electrical equipment intended for use in hazardous areas (ambient atmosphere with gases, vapours or dust). This directive specifies that equipment and protective systems used in hazardous areas must be electrostatically conductive. Air filters used in these danger zones must also be designed to be antistatic.
2. Directive 1999/92/EG, also known as ATEX 137, requires employers to protect employees in potentially explosive hazardous environments.

NEW SEPARATOR LINES FOR ALGAE

The most distinctive features of the algae**prime** series are automatic discharge and cleaning; no manual intervention anymore so processes stay closed, clean and safe. On top, GEA offers different bowl types to meet every need. The algae**pro** series on the other hand can be customized right down to the smallest detail. For example, the separators can be equipped with the direct drive system for minimum space requirements, low noise emissions, top energy efficiency and low-wear operation.

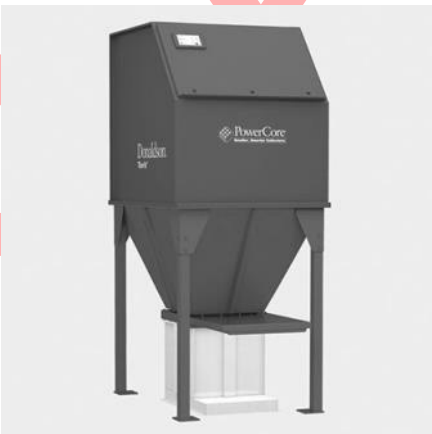
The prime series with its capacity range from 100 to 23,000 l/h is ideal for research and development, but also for start-up companies. It offers high flexibility for processing all kinds of algae with all possible recipes, features easy and simple operation, high capacities and separation efficiency along with maximum scale-up safety. The algae**pro** series on the other hand is the best solution for processing algae on full industrial scale, offering cutting-edge separation technology for capacity ranges of 20,000 to 80,000 l/h. The separator can be customized right down to the smallest detail to optimally fit process and demands.

Highlights are the new 2-in1 ejection system for a fast and easy change of algae types as well as the inte-

grated**direct**drive which can be chosen for maximum energy efficiency. Moreover, this most modern drive system from GEA Westfalia Separator needs 30 percent less space, has a lower noise level and fewer parts than a flat belt drive. Profitability and cost management were the clear focus when designing the new algae**pro** separators. Both lines come in food grade design with stainless steel for all product contacting parts and FDA approved gaskets. Special bowl material for salt water algae is also available.

POWERCORE® DUST COLLECTORS FOR USE IN EXPLOSIVE ATMOSPHERES

PowerCore® technology developed by Donaldson is claimed to provide highly efficient dust filtration, a simplified filter changeout and fast maintenance (www2.donaldson.com). The dust collectors are up to 70% smaller than conventional dust collectors with filter bags and filter pack changes taking only about one fifth of the time in a direct comparison. At the same time, significantly higher filtration efficiency is possible. Independent laboratory tests confirm that PowerCore® filter packs reduce emissions by up to 78 % when compared to standard polyester bags.



These advantages can now also be applied by users of dust collectors that are installed in potentially explosive areas. Donaldson has expanded the PowerCore® range to cover the airflow rate from 1,000 to 30,000 m^3/h for use in potentially explosive areas of zones 21 and 22, as well as zones 1 and 2 for gas according to the ATEX Directive.

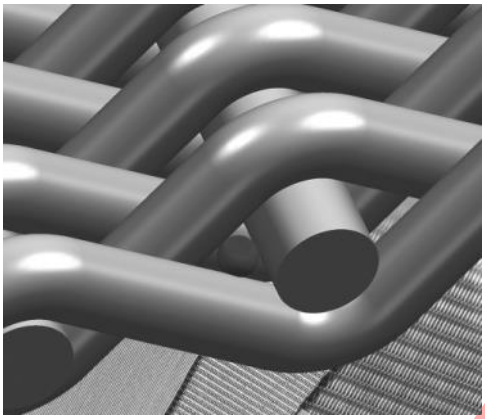
PowerCore® dust collectors are available in explosion prevention designs in accordance with ATEX Directive 92/9/EG. Another option, also available for the entire series, is a reinforced construction of filter housing for the filtration of explosive dust, which can withstand a dust explosion up to certain reduced explosion pressures. Such units can be equipped with several protection devices. The user who handles explosive dusts can select exactly the dust collector that meets the individual requirements with these options.

Also, from an economic point of view, the compact design and modular structure of PowerCore® dust collectors offer particular advantages when used in hazardous zones. Compared to conventional dust collectors with tubular and envelope bag filters, they have a lower crude gas volume with a correspondingly lower energy content. This facilitates the use of compact sized and cost effective ATEX compliant components.

Donaldson is able to advise customers on-site worldwide on the selection of the appropriate dust collector for their particular application. During an ATEX consultation, the user can take the opportunity to have the efficiency of their dust control system examined.

BREAKTHROUGH RESEARCH FOR WOVEN WIRE MESH

Haver & Boecker has upgraded its MINIMESH woven filter cloths and optimised them for certain application properties. The move follows a collaboration between the company and the University of Stuttgart into the specific properties of a woven wire mesh.



Compared to other filter media, woven wire mesh may be precisely described geometrically and defined through the type of weave, wire diameter and mesh count. That means the geometric pore size and permeability can be precisely calculated without the need for exhaustive measuring methods. A characteristic value is determined for the geometric pore and describes the diameter of a round sphere that is just able to pass through the wire mesh. The pressure drop coefficient for air in laminar flow is used for determining permeability.

The mathematical formulae behind this process were experimentally validated by glass bead tests and air flow-through measurements. The result is that Haver & Boecker have been able to develop new filter weave structures for Minimesh with properties it says were once thought impossible to attain.

New filter elements tailored to the requirements of the user can be designed without the need for time consuming and costly trials. Haver & Boecker says that advantages include a precise pore size which is determinable by calculation, precise filter weave for an efficient filtration, higher flow-through properties and higher cut-point and efficiency.

EMISSION CONTROLS SPARK SCRUBBER SYSTEM DEMAND

New emission controls are spelling growth in demand for Alfa Laval's marine SOx scrubber systems. Now in its second generation, the system has generated 70 orders as shipping operators look to comply with the enforcement of Emission Control Areas (ECAs) through exhaust gas cleaning. The orders include two full scale pilot installations and the first deals struck in the US and Asia. "Shortly after its launch at SMM 2014 in Hamburg, we received orders for the second generation system from Atlantic Container Line, Royal Caribbean Cruises and Horizon Lines," said René Diks, Manager Marketing and Sales, Exhaust Gas Cleaning at Alfa Laval.

PureSOx allows for the continued use of heavy fuel oil while meeting emission limits in ECAs. The system's first class approvals have been granted from Lloyd's

Register for the DFDS Petunia and Primula Seaways while the recently opened test and training centre in Denmark is helping with development. "We are continuously developing and enhancing PureSOx. We are currently preparing for the launch of an inline version during the course of 2015," added Mr Diks.

NEW AIR FILTRATION ORDER

Nederman has won an US$8 million order from a major steel producer in the USA to provide air filtration for an electric arc furnace. The customer's existing air filtration equipment is aging and undersized. After working closely with the customer to engineer a solution to fit the existing facility, Nederman will supply a Mikropul long bag pulse jet fabric filter. The order includes ductwork, ID fans (induced draft), controls, material handling, dust unloading system and other accessories.

"We continue to strengthen our position in the USA. This order confirms our ability to fulfil the customers' need of eco-efficient solutions that filter, clean and recycle," said Per Lind, Senior Vice President Nederman Americas Division.

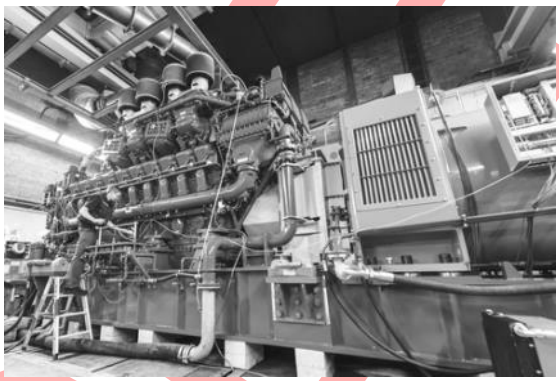
Installation should be completed by the first quarter of 2016.

EXHAUST AFTERTREATMENT FOR LARGE ENGINE TEST STANDS - NEW TERRITORY IN EXHAUST TECHNOLOGY

Rolls-Royce Friedrichshafen, Germany - MTU is introducing new technology for scrubbing exhaust emissions from its engine test stands at Plant 2 in Manzell (www.rrpowersystems.com). Working with external specialists, company experts have developed a concept designed to significantly reduce soot emissions from the test stands. The initial phase is scheduled to enter pilot operation at the start of 2017.

"We are confident that the filtration plant will deliver the results we want, but this is as yet untried technology for us," said Dr Ulrich Dohle, Chairman of the Board at Rolls-Royce Power Systems and CEO at MTU Friedrichshafen. This is the very first plant of its kind to be installed anywhere for the aftertreatment of exhaust from test stands for large engines.

No exhaust limits have yet been set for large engine test stands of this magnitude, but an obvious obligation exists to equip them with state-of-the-art technology. A study commissioned by MTU and conducted by TÜV Südwest concluded that exhaust aftertreatment plants for test stands of this type do not reflect the latest technological developments. A feasibility study carried out by MTU in conjunction with specialist manufacturers and engine experts from the University of Rostock subsequently developed a technical concept that is now to undergo trials with a pilot plant. The trials will involve equipping the four test stands for engines producing higher levels of particulate, with dedusting systems and then routing the scrubbed exhaust gas to a new stack that will also be used for exhaust from the other series-production test stands. An application for approval is currently being processed by the relevant authorities for the Lake Constance Region for two test benches to be modernized.



"Our plans go a lot further than current legal requirements demand," said Dohle. "We are pleased that we have now found a technical solution which seems to be feasible. We cannot be 100% certain of the actual results but we are ready to take a chance and invest the millions of euros needed for the project," he added. The initial phase of construction is due to start in spring 2016 with test operation scheduled for Spring 2017. If the new exhaust aftertreatment technology proves successful, the two other test stands for the engines in question will also be fitted with similar equipment from 2018.

SEAL OF APPROVAL FOR BALLAST WATER MANAGEMENT SYSTEM

GEA Westfalia Separator Group has received class approval for its ballast water management system, BallastMaster ultraV 250.

The benchmark from the Classification Society Det Norske Veritas Germanischer Lloyd (DNV GL) indicates that the chemical-free system solution for ballast water treatment fulfils all D-2 standards of the International Maritime Organization (IMO). It means that the system can be used without restrictions all over the world. With a performance of up to 250 m^3/h and its modular design GEA Westfalia says the system is suitable for retrofitting existing ships. Designed as a two-stage system, it combines mechanical preliminary filtration with disinfection of the ballast water by UV-C and ultrasonic cleaning. GEA Westfalia says the system will operate with bad water quality and a high concentration of organisms and sediment particles with disinfection corresponding to IMO guidelines. The system does not use or generate environmentally harmful chemicals.

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A PERFECT COMBINATION OF PRECISION AND PROFITABILITY

The core requirements that critical key industries have towards grinding processes are excellent work piece geometries and efficient loss rates. Grinding processes have to be customer specific yet reliably reproducible, while at the same time catering to increasingly shorter delivery times and fluctuating lot sizes. The precision grindery Jores GmbH in Bad Sobernheim, Rhineland Palatinate, is proof that through consistent investment in cutting edge technology and production processes high precision and cost efficiency are not mutually exclusive.

Whether they are dealing with piston and bearing rings or spacer plates with plane parallel functional surfaces, Jores relies on absolutely reliable yet flexible processes to produce such high quality, mass produced, parts while at the same time reducing unit costs. Now, what currently ranks as the world's largest precision grinding machine has been put into operation at the Jores grindery for double sided face grinding in batch process. The Melchiorre ELC 2000 enables the traditional family run company to provide efficient production of high precision work pieces with diameters up to 800 mm. For the processing of the cooling lubricant, Jores has once again opted to deploy the MAXFLOW compact filter system CS 1000-503, made by GKD – GEBR. KUFFERATH AG (GKD). In addition to a filtration fineness of ≤ 5 µm at a filtration rate of over 100 litres per minute, its integrated briquetting facility and the lack of need for filter aids were once more winning arguments for the MAXFLOW concept.

With Tradition Comes Obligation

Jores GmbH, with a company history that goes back to the 14th century, knows that securing its own sustainability means gaining shares of the market and creating appreciable added value for its customers through an unfailing commitment to innovation. Its customers all over Europe include prestigious system suppliers and component suppliers to the automotive sector, manufacturers of roller bearings and machine manufacturers for the printing and wood-processing sectors.

In addition to steel and non-ferrous metals, Jores also processes glass, rubber and ceramics. Jores even grinds material combinations of steel mantle and rubber core – as used, for example for armatures in electric motors – in a single pass. Apart from such special components, medium and large series are the main characteristic of the company's range of services. For example, each year Jores produces about 35 million cams for camshafts, and over 2 million sintered parts for the automotive sector made of sintered steel types D10, D11, D39 and D40. Each week, it produces over 20,000 plastic components with 10 µm tolerance in height that have to be polished and washed at a controlled temperature.

In the precision grinding of sintered parts, for example, the raw parts are transported in a charge carrier from the incoming goods inspection to the workplace, where they are manually placed in batches into squirrel cages and automatically fed into the machine. After grinding, they are manually removed from the cages. Then, interlayered, they are transported on a feed conveyor to the brush de-burring station. In continuous flow, they are run under a planetary head with three brush discs whose rotary motion removes the grinding burrs. After subsequent washing, the required quality is verified by visual inspection before the finished parts are packed and dispatched.

The precision grindery Jores GmbH produces high quality, mass produced, parts and individual special components.

Unattained Dimensions

Regular expansion of the high-tech grinding machinery is indicative of the consistent focus on user benefit at Jores GmbH. Torsten Jores, who runs the company together with his brother, Pascal, is convinced that “In terms of face grinding, no other contract grinder in Europe has production possibilities as wide ranging and flexible as ours.” In addition to surface grinding on 12,000 by 1,200 mm magnetic disks and double sided face grinding machines of up to 400 mm in diameter for throughput treatment, this also includes double-side precision grinding. The comprehensive machine park comprises, among others, machines made by Diskus, Göckel, Melchiorre, Stähli and Peter Wolters.

Now, the company has expanded the park to include a new machine from Melchiorre whose dimensions set standards that have so far never been attained. The ELC 2000, developed for Jores, has grinding disks with a diameter of 2,000 mm on which work pieces can be ground with diameters up to 800 mm in series and up to 1,500 mm as individual parts – work piece formats that few other contract grinders can accommodate. Here, in batch process, axial rings or adjusting

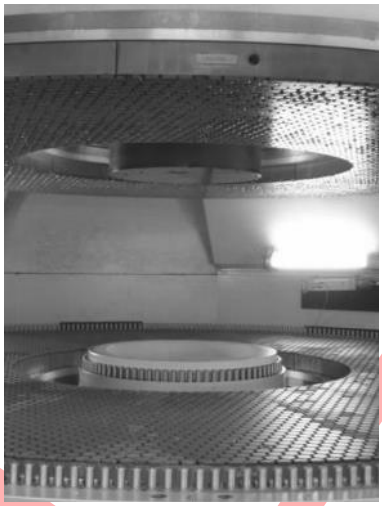
rings for stators and rotors can be produced to meet the highest accuracy values, and with an equally high degree of cost efficiency and process reliability. The integrated feed table reduces setup times, which means that even medium sized work pieces can be processed at particularly low cost. According to Torsten Jores, the impetus for this latest investment came from rising customer expectations regarding the flatness of parts which had previously been ground in a classic continuous flow process, along with accompanying demands for a reduction in unit costs.

What currently ranks as the world's largest precision grinding machine has been put into operation at the Jores grindery for double-sided face grinding in batch process.

"Today, customers often expect not only the highest work piece quality but also compliance with certain trends," says Torsten Jores. "For example, covers for pumps are not supposed to be concave or convex. In a continuous flow procedure, it's very difficult to meet such expectations." But with the new ELC 2000, the medium sized enterprise can now fulfil these demands with precision and cost efficiency thanks to a reliable fine grinding process. The size of the machine makes it possible to process more work pieces at a substantially higher speed than ever before. "We have always been a step ahead of developments," says Torsten Jores, expressing his delight with the performance of the machine. The two grinding disks, each made up of sixteen segments, are ceramic bonded for optimal dimensional stability. While the *ca.* four minute grinding process is running, the satellites on the feed table are manually loaded. In this way, the process of exchanging the squirrel cages takes only 150 s. Without the parallel preparation on the feed table, the machine would have to be loaded and unloaded directly – a procedure that would take just as long as the grinding process itself. The largest satellites can accommodate four 800 mm bearing or roller rings.

Enormous Volume of Cooling Lubricant

To ensure compliance with surface roughness specifications of 2 µm in large series production, not only the precise configuration of the machine but also the efficient processing of the cooling lubricant are of crucial importance. Jores decided to use the MAXFLOW



The Melchiorre ELC 2000 has grinding disks with a diameter of 2 mm.

compact filter system 1000-503 with one filter head, a pressing unit and a lifting station. For years now, the company has been using three of these systems on other grinding machines. The size of the grinding machines and the high throughput rates at Jores produce considerably higher volumes – compared to other grinderies – of cooling lubricant mixed with grinding waste that needs to be processed. In view of the thoroughly positive experience with the previous filter units, Jores decided once again in favour of the MAXFLOW solution.

Made entirely of stainless steel, this patented compact filter system combines filtration and briquetting in a single piece of equipment. The round tank system with a capacity of 1,000 litres has a dirt tank integrated into the clean tank. The dirt tank has a tapered run-off that prevents deposits from accumulating on the tank floor. The easy-to-open filter head contains two filter packets each consisting of two vertically aligned static disc filters screened with YMAX® multi-dimensional blended filter mesh. Following the crossflow principle, the filtrate – a mineral oil based, low viscosity oil con-

The MAXFLOW compact filter looks tiny and frail next to the enormous ELC 2000.

taminated with grinding waste and abraded particles – streams around the disc filters. At the required filtration fineness of ≤ 5 µm, the MAXFLOW compact filter – which looks so tiny and frail next to the enormous ELC 2000 – filters well over 100 litres of oil per minute, without the need for filter aids. The filter cake is detached from the disc filters through automatic backwashing. Per hour, the pressing unit integrated into the MAXFLOW compresses the residues from about 1200 cm^3 of pollutant load into *ca.* 10 kg dry briquettes. The pressing unit for this new system was custom configured by GKD to cater for the higher pollutant load in this particular application and, in contrast to the usual size of briquettes – 80 mm in diameter – it ejects briquettes with a diameter of 130 mm into the collection bin.

The pressing unit integrated into the MAXFLOW compresses the residues into briquettes and ejects them into collection bins.

Many Advantages

Apart from the reliable filtration performance, Torsten Jores also appreciates the fact that the compact filter system runs maintenance free for weeks on end. "Nobody bothers to check the MAXFLOW, it just keeps on running."

Other advantages that convinced Jores to choose this solution again include the significantly easier handling in comparison to other systems, better accessibility and ease of maintenance, something which is also evident in the residue free tank. In addition, the fact that the system does not require filter aids substantially reduces disposal costs. In Torsten Jores' opinion, none of the alternative solutions that were taken into consideration for the filtration of the cooling lubricant came anywhere near the performance level of this package. For him, centrifuges were out of the question because of their high energy consumption and their heat emission.

Other arguments against this solution included the cost intensive maintenance of the machined parts required to ensure the necessary leak tightness. Although precoat filters offered even better filtration rates, they were also not a viable option for Torsten Jores because of their huge consumption of filter aids. For the same reason, multi-stage filtration processes with filter cylinders or cartridge filters were also rejected. But another factor that played a significant role in the renewed decision to opt for the MAXFLOW was its compact design. Just 1.6 m in diameter and 2.5 m high, it compared favourably with other solutions involving tanks of five to six metres in length, equipment footprints that were simply out of the question for Jores due to lack of space. Another winning feature of the MAXFLOW system for the company in Bad Sobernheim is its cleanliness.

There is no loss of the cooling lubricant through transportation, which has a positive effect on consumption and disposal costs. Due to the high purity of the filtered oil, the components are not only more precisely dimensioned but also cleaner, which lessens the load on the washing process. This improves the overall efficiency of the downstream processes. Furthermore, the high purity of the MAXFLOW filtered cooling lubricant prolongs the service life of the grinding disks. Finally, the closed system with its ejection of dry briquettes also improves the cleanliness of the working environment and creates more pleasant working conditions for the staff. The sum of all these advantages convinced Torsten Jores once again to make a clear decision for the GKD concept. "For me, MAXFLOW is a high performance, compact filtration solution with a quality of service far beyond anything I have experienced so far," he says, summing up his arguments for choosing this GKD filter system.

GOING GREEN IN THE LAND OF 10,000 LAKES

Voith Meri Environmental Solutions Inc. (www.meri.de) is helping to set higher standards for wastewater treatment with the addition of the Effluent Treatment Plant (ETP) at Liberty Paper Incorporated (LPI) in Becker, Minnesota.

LPI is located in the state of Minnesota in the Midwest of the United States. The state is known as 'Land of 10,000 lakes' due to the tremendous amount of lakes dispersed all around the state. LPI is a state-of-the-art paper mill that recycles old corrugated containers into new paper for packaging. The mill manufactures recycled paper from more than 200,000 tons of old corrugated containers each year. As part of the Liberty Diversified International (LDI) family, LPI is extremely involved in their community.

LPI's need for this facility was sparked by their steady

growth and desire to maximize production. When Meri and LPI began negotiations for an ETP, the local water treatment facility had reached its capacity and LPI had outgrown the wastewater infrastructure, which was provided by the municipality. Either the city had to upgrade their operations to treat the increased carbonaceous biochemical oxygen demand (CBOD) load or the burden had to be taken off the city.

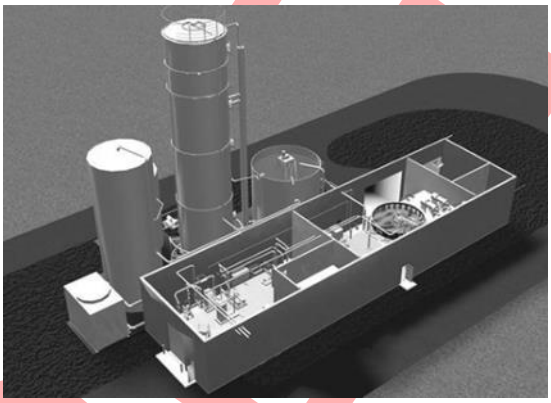
LPI's original intent was to do a complete design. A project including engineering, procurement and construction, a complete turn-key project approach. As they got further into the project development they discovered the potential cost saving through a unique partnership with Meri. LPI started to consider playing the role of general contractor but they needed a partner that would be more than just a vendor. A partner to take a leadership role, therefore removing some of the risk from LPI. LPI had never approached a project quite like they approached this one.

Larry Newell, LPI Vice-President Manufacturing, explains, "I think it was more of a custom approach to this project, it was more of a risk for us, more of a risk for Meri as well, and the outcome was very good. The outcome was one that I would replicate again. I think it was a very good way to approach a project." Tom Murphy, ETP Manager at LPI, agrees, "We like things managed as a one-stop-shop. We don't want five companies with their hands in it – we want to be able to go directly to one company – Meri. No matter what the problem was, Meri was always willing to deal with it. I think I've learned this year that a single vendor in charge of a project is vital to success."

Chuck Legatt, LPI Mill Manager, preferred the low risk approach, "We're a single mill operation. We needed to build up a pretty high level of confidence in the Meri team that they could deliver to the expectations of the mill. We're a unique company, somewhat risk averse… we would have been the first effluent treatment plant of its kind installed in the United States by the Meri Group, so we had to build up a high level of confidence in the Meri team in order to be able to partner up with them. Also, the fact that they stuck with us, staying engaged and trying to meet our needs as we refined our scope, was pretty valuable in developing that relationship. I know that the mill and Meri invested a lot of energy into trying to get a scope that we all could agree with and that could meet all of our needs."

The Start-Up Phase

The wastewater was introduced to the ETP on December 3rd, 2012, about two weeks ahead of schedule. Chuck Legatt described the process: "There was a lot of risk in meeting that commitment with construction starting in the Spring and being able to start up in the winter and still be able to hit that mark. The start-up phase, I think went well, I think we were staffed well and we had good technical resources in the Meri team that was here with ours. In fact, the start-up was a bit of a non-event."



Meri's Anaerobic Effluent Treatment Technology at a Glance

Anaerobic processes are used for the treatment of highly loaded effluents. Anaerobic bacteria in the form of biopellets are used for the conversion of dissolved COD in to methane (biogas). In the paper industry anaerobic technology is mainly used in board and packaging mills.

Cooling Tower: Reduces the temperature of the mill effluent in order to meet the requirements of the subsequent biological process steps.

Pre-Acidification: This stage balances volume and load and serves as an initial step for further anaerobic degradation.

R2S Anaerobic Reactor: 5.9 m in diameter and 24 m tall. Effectively degrades dissolved organic waste materials in an extremely small environment with a minimal space requirement.

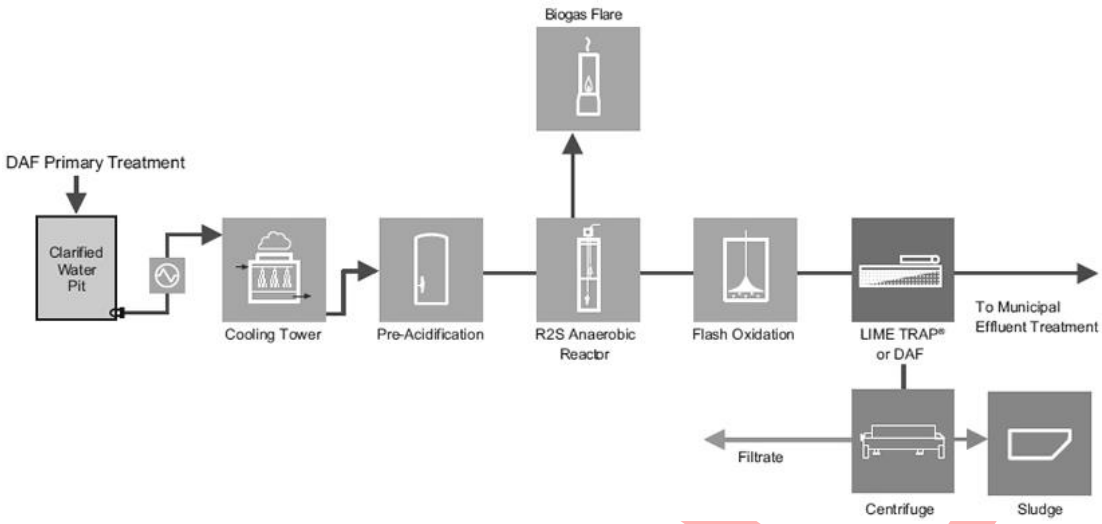
Biogas Flare: Safe and reliable treatment of biogas. This process step helps to reduce odour, can remove some of the remaining COD and triggers the precipitation of calcium.

Sludge Dewatering: Centrifuge and/or belt press.

DAF - Lime Trap®: The elimination of calcium in the process effluent with the Lime Trap® enables an optimized operation of succeeding aerobic equipment.

Advantages of Anaerobic Effluent Treatment Technology

Anaerobic treatment of wastewater has found a perfect application in industrial wastewater treatment, especially in applications with high COD concentrations. Compared with aerobic treatment, the main advantages of anaerobic treatment could be summarized as reduced footprint, lower energy consumption and minimum sludge production.



Reduced Footprint

Among the different anaerobic reactor technologies available, the R2S Reactor achieves volumetric loads as high as 25 kg COD/m^3/day. Considering that the required tank size for most conventional activated sludge systems is 1.5 kg COD/m^3/day, the R2S has a definite advantage. One other important consideration is the fact that the R2S is up to 30 m in height, which significantly reduces the footprint required for effluent treatment plants.

Lower Energy Consumption

Aerobic treatment requires oxygen to oxidize the organic compounds. This oxygen is introduced into the system by means of blowers and other devices that have a high energy consumption. A system designed to treat 10,000 kg COD/day, for example, would require 15 MWh per day. On the other hand, each kilogram of COD treated in an anaerobic system yields 2.4 kWh – a difference of 39 MWh per day!

Minimum Sludge Production

Aerobic treatment yields a large amount of biological sludge that needs to be removed from the system and dewatered or stabilized in order to optimize sludge disposal costs. Depending on the system, up to 60% of the converted COD will be converted to new sludge. This number contrasts with the average sludge growth observed in anaerobic systems of 2% to 5%.

Current Situation in the United States

Paper mills in general, including old corrugated container (OCC) mills like LPI, require large amounts of water and therefore require a large wastewater facility to cope with the high COD and calcium levels typically found in this application. The state-of-the-art R2S Reactor design allows for continuous and efficient removal of calcified biomass.

LPI produces around 750 sTon per day, the COD discharge is 9,700 kg COD per day. The ETP system utilizes a cooling stage followed by a pre-acidification tank and the R2S Anaerobic Reactor. The process continues with a CO_2 stripping reactor, which facilitates hydrogen sulphide conversion for odour reduction and calcium carbonate precipitation. The last step is a Lime Trap® for calcium carbonate and solids removal as well as a decanter centrifuge for sludge thickening.

In Conclusion

The effluent treatment plant has proven to be robust and efficient since the start-up. With an average soluble COD removal greater than 90% and 98% for BOD_5, the plant reduces the COD from the average 9,700 kg COD/day to 863 kg per day.

(Product Developments continue on page 84)

The FILTRATION Society

www.filtsoc.org

THE FILTRATION SOCIETY

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ABOUT THE SOCIETY

The Filtration Society was formed in London in 1964. It is a charitable, non-profit organisation established to advance knowledge in the design and use of filtration and separation in industry, commerce and other walks of life.

The official journal of the Society is the internationally renowned FILTRATION. The journal keeps members up-to-date with company and product information and contains technical papers on many aspects of filtration and separation technologies.

Membership is open to interested individuals and to Corporate Associates; most members work for manufacturers and users of filtration and separation, and for universities and research organisations. The Society organises regular technical meetings that cover the breadth of filtration technologies. The meetings aim to be informative and offer the opportunity for members to keep up to date with advances in filtration and separation and their applications, and enable members to refresh their knowledge of established technologies.

Several filtration societies around the world can trace their origins back to The Filtration Society which currently has members in more than 20 countries. Members can be found around the world, including in Australia, India, Japan, Taiwan, USA, South Africa, the Middle East and most countries in Europe.

The Filtration Society News is collated by the Honorary Secretary to whom any comment should be sent.

CHAIRMAN'S REPORT

My term as Chairman of the Filtration Society has started in a positive way with new members of the Council who I am sure will make a positive contribution to the society. I would like to welcome Sue Jones from G. Bopp UK, Ian Marshall from Ricardo-AEA and Morten Christensen from Aalborg University. I am sure that you will be hearing more from them in the future.

One of the other positive aspects is the financial position of the Society, which has been mentioned before but the importance cannot be stressed enough. The Society was formed 50 years ago in 1964 and as a non-profit making organisation we spend what we earn. The Council try to spend monies in the most appropriate manner to help promote and educate on the topics of filtration and separation, and as a Council it is our responsibility to make sure that the Society is well run. One of our aims is to hold a minimum of two technical meetings each year for the benefit of members, and also to attract new members, by providing a platform for individuals and groups to show the work they have either completed or programmes that are on-going. At the same time we are aiming to inform our members in a range of formats. For instance, we will also aim to hold a training course, normally around the time of the Annual General Meeting in November.

In organising events the Society make a financial and time commitment, so it is important that we get the word out to attract delegates. We try and keep the cost of meetings at a reasonable level to enable as many people as possible to attend. Please keep an eye on the programme on the website. With the next meeting coming up in May it would be great to have a high attendance.

The new Council is in place and are finding their feet, Andrew Chalmers as Treasurer and Neil Burns as Vice-Chair, with all of us under the guidance of the Honorary Secretary Steve Tarleton. We, and the rest of Council, are approachable people and always happy to get suggestions for technical meetings from the membership, and if this came along with a venue or assistance in the organisation that would be well received. We are already planning the 2016 and 2017 programmes, including technical visits. If a company or group would like to show off their premises with a technical tour then please contact the Honorary Secretary.

So I look forward to the coming months and with the support of Council and the Membership I plan to leave the Society in as good a state as I found it and at the same time fulfil the obligations that were agreed when the Society was formed in 1964.

Mark Crooks

AIR AND GAS CLEANING, EMISSIONS AND STANDARDS CONFERENCE

14 May 2015, The Heath Conference Centre, Runcorn, UK

The Filtration Society invites you to a conference that aims to cover a number of important aspects in air and gas filtration that impact both industry and society in general. The range of topics to be presented is relatively diverse which reflects the widespread need to have clean air and gas available for things that affect our everyday lives.

The technical programme will appeal to users and producers of filtration products, or indeed anyone with an interest in the wider topic of 'Air and Gas Cleaning, Emissions and Standards'. It is expected for discussions during the break times to bring up many synergies between the topics and we look forward to welcoming you to this meeting.

Conference Programme

- *Considerations to be Made During the Testing and Reporting of Results for Gas Filters*, Ian Marshall, Ricardo-AEA
- *Cleanroom Standards – A Pragmatic Approach*, Peter Knott, PMT GB
- *Effective Air Filtration for City Buildings*, Peter Dyment, Camfil
- *The Application of Aerosol Spectrometers in Filter Testing Standards*, Stephen Smith, Filter Integrity
- *The Effect of Filter Design and Operational Parameters on the Performance Characteristics of Air Filters*, Iyad Al-Attar, Consultant, Kuwait
- *Compressed Air Testing to ISO 12500 Parts 1-4*, Simon Wise, Walker Filtration
- *The Filtration of High Temperature, High Pressure Syngas*, Andy Bevis, Porvair
- *Cost Efficient Gas Turbine HEPA Filtration*, Edward Owen, Fram International

Venue

The Heath Conference Centre, Runcorn, is a well-established venue in the North West of England. Delegates can benefit from a range of facilities, including free car parking.

the heath
business and technical park

The venue is well served by a network of motorways and rail links, as well as Manchester and Liverpool International Airports which are both relatively close by.

PRODUCT DEVELOPMENTS AND CASE STUDIES (cont.)

NEW HELICOPTER FILTER GAINS FAA APPROVAL

Pall Corporation's recently launched PUREair Dry Barrier Filter has been awarded Federal Aviation Administration certification. The recently introduced helicopter product is a direct replacement for oil wetted filters. Using advanced synthetic dry media technology, it is cleaned using water only and Pall says it virtually eliminates maintenance associated with conventional filters. The company adds that the Dry Barrier Filters are also highly durable and resistant to corrosion.

"Oil wetted inlet barrier filters are adapted from 1950s automotive air filtration products and have been due for updating to 21st century technology for years," said James Hardy, Global Product Manager for Pall Aerospace. "We're pleased to introduce the next product in our PB portfolio and give more operators an opportunity to experience oil free filtration."

The PB100D filter for the Airbus Helicopter AS350 joins the PB110D for the Bell 206L/407 as the first in a planned series of certifications for direct fit replacements for Bell 206L/407 and Airbus Helicopter AS350 barrier filter installations.

FIL-

www.afssociety.org

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The American Filtration & Separations Society (AFS) is a technical educational nonprofit organization started in 1987 to provide a forum for exchange of information among engineers, scientists, and technologists in all areas of the filtration, separation and coalescence.

Each year the Spring and Fall conferences present more than 200 papers on a wide-ranging list of subjects. The Spring Conference tends to cover a variety of applicable subject, while the Fall Conference focuses on a specific topic. Exhibitions at both conferences showcase products and services by industry related exhibitors.

Short courses on basic filtration and specific filtration topics are also scheduled during each conference. Custom designed short courses are available for companies to bring on-site for employee training.

The AFS News is collated by the Executive Manager to whom any comment should be sent.

AFS CONFERENCES

The AFS Society is hosting its Spring Conference, ***Filtration & Separations in Power Generation***, April 28-29, 2015, at the Sheraton Charlotte Hotel.

The AFS Spring Conference provides a forum for the exchange of information among engineers, scientists and technologists in all areas of filtration, separation and coalescing.

The Spring Conference features three tracks:

- Unmet needs in power generation and utilities
- Filtration solutions available
- Presentations in theoretical and applied sciences.

The Spring Conference features an **exhibition** with 8' x 10' booths and tabletops, a student **poster competition** and a new industry **poster presentation**. Two optional **tours** to the Alevo facility and the Allen Plant are being offered on Thursday.

Plenary sessions feature John Litynski from the Department of Energy, Jeff Gates from Alevo and Brandon Delis from Duke. The Spring Conference includes **16 technical sessions** in two formats, either with four formal presentations or a panel discussion.

Register now to attend the ***Filtration & Separations in Power Generation*** conference in Charlotte, NC, April 28-29. Online registration is available at http://spring.afssociety.org

AFS offers a number of unique filtration and separations training **Short Courses** one day prior to the beginning of the Spring and Fall Conferences. Short Courses are scheduled at the Spring Conference in Charlotte on Monday, April 27. Learn more about Short Courses offered at http://spring.afssociety.org/short-courses

The **AFS 2015 Fall Conference**, 'Advanced Technologies in Filter Media', is scheduled for October 6-7 at the Franklin Marriott Cool Springs, outside of Nashville, TN. Short courses are being offered on Monday, Oct. 5. Visit the AFS Society website for more information and updates at http://fall.afssociety.org. Abstract submission opens in April.

THE CHANGING NATURE OF DIESEL ENGINE FUEL FILTERS FOR HIGH PRESSURE COMMON RAIL (HPCR) DIESEL INJECTION SYSTEMS

Bradley Crook (brad@lubricare.com.au)
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Over recent years the world has gradually witnessed the introduction of diesel engines equipped with advanced High Pressure Common Rail (HPCR) fuel injection systems. The introduction of new designs is primarily the result of new emission regulations, which now requires these engines to improve their overall performance and reduce harmful pollutants with the culmination of requirements being 2015 when all new diesel engines shall be rated to Tier 4.

In order to reduce emissions, advanced HPCR injection systems operate at pressures in excess of 30,000 psi and in some designs, pressures approaching 40,000 psi can be achieved. These advanced systems are capable of multiple injection events per cycle and involve clearances between moving parts in the order of 1 -4 µm. For these reasons, HPCR systems are far less tolerant to contamination than previous Electronic Unit Injector (EUI) designs. This increased demand on diesel fuel cleanliness presents new challenges to engine based contamination control solutions and the fuel filters that are intended to protect the injector and high pressure pump from damage or failure.

To protect HPCR components, much lower concentrations of fine particles and water need to be maintained within the fuel system than were previously accepted. This paper will discuss some of the challenges that are faced and provide recommendations to achieving the required reliability.

HPCR FUEL INJECTION

By far the greatest advancement over the past 10 years in engine design has been the development of the High Pressure Common Rail (HPCR) fuel injector. These remarkable devices have been the cornerstones to advances in combustion efficiency and the ability for an engine to achieve the stringent new emissions levels according to the engine Tier ratings.

Whilst the HPCR fuel injector is a more recent development in engine design, the concept of common rail fuel injection is not; in fact common rail fuel injection has been around in a basic form since the early 1920's having been first used in Doxford Submarine Engines. Modern HPCR fuel injection systems are practically simple in their overall design, however; they comprise a number of highly complex interacting key components in order to function reliably and efficiently. These components are listed and illustrated in Figure 1. Unlike older Electronic Unit Injector (EUI) designs, the HPCR fuel injector does not develop its own pressure during engine operation.

The pressure for injection is developed by the high pressure fuel pump (1), which is mechanically operated by the engine. A common fuel rail connects each injector from the fuel pump (3); hence where the terminology of Common Rail originated. The design of this system is such that a constant fuel pressure is available at the injector 100% of the time during engine operation which provides a higher available mean time injection pressure over EUI designs. This feature ensures that fuel droplets are small the moment they leave the injector nozzle. As EUI systems must develop the fuel pressure over the injection event, they have a tendency to form larger droplets at the start and end of each injection event. HPCR injection systems are also able to regulate fuel injection pressure based on engine requirements, speed and duty using the engine ECU combined with the fuel pump.

The modern HPCR fuel injector is unlike its EUI predecessor and are far more susceptible to contamination related problems. Unlike EUI systems, which typically inject fuel once or twice per engine revolution, HPCR fuel injectors can provide up to 5 injection events per single compression stroke of the engine. Putting this

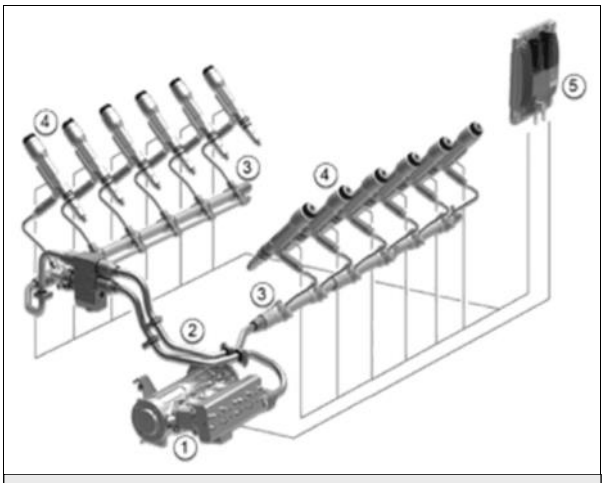

Figure 1: HPCR fuel injection system (courtesy of MTU). (1) High pressure pump; (2) High pressure lines; (3) Rail system; (4) Injectors; (5) Electronic Control Unit (ECU).

into perspective, with a large diesel engine operating at 1400 rpm, the fuel injector is capable of injecting fuel into the combustion chamber in varying quantities depending on the ECU outputs, up to 1750 times per minute, or 29 times per second with the fuel exiting the injector tip at speeds in excess of 700 miles per hour.

FUEL CLEANLINESS LEVELS

Most industrial diesel engine OEM's have determined that fuel being dispensed into assets must meet or exceed a cleanliness level of ISO18/16/13. The Worldwide Fuel Charter (WWFC) also supports this. Leading HPCR fuel injector manufacturers around the world have now identified and communicated that the components they manufacture require diesel fuels at Ultra-Clean levels with some identifying that cleanliness levels as low as ISO12/9/6 and beyond are required to maintain ultimate performance and reliability. Table 1 represents the different cleanliness levels that are sought by these parties.

It is here where we see an enormous mismatch in what the fuel injection OEM desires as a fuel cleanliness level to what the engine OEM's and the WWFC are advising the industry. The cleanliness levels required by the fuel injector OEM's at the fuel injector are 64x cleaner than what the industry is being advised as an acceptable standard for engines to be filled. It is fair and reasonable therefore to assume that the engine fuel filter must have improved over this time in order to meet the new and extreme cleanliness level. For this reason the nature of the diesel engine fuel filter has now changed.

DIESEL ENGINE FUEL FILTERS

It is a common belief that the engine fuel filter installed by the OEM will provide the required level of contamination protection in order to achieve reliable operation. This is a fair and reasonable assumption to make because the intended function of a diesel engine fuel filter is to 'achieve a fuel cleanliness that will enable the fuel injection components to function reliably and within their designed operating parameters throughout the life of the component'. However, there are several key aspects regarding the application of engine fuel filters that call into serious doubt the ability of many to neither achieve such a result nor the desired cleanliness level now being sought by HPCR fuel injector manufacturers.

A typical diesel fuel filtration system installed on a HPCR injected engine uses both a primary filter and a secondary filter to achieve the desired cleanliness level. The primary filter is typically installed to the suction side of the low pressure fuel pump with the secondary filter on the pressure side. Again, OEM's will modify these designs depending on the requirements of the engine and their research into what they believe works best. The primary filter is generally required to remove larger particles that can damage the low pressure pump and also separate undissolved water from the fuel. The secondary filter is generally designed to remove the smaller particles around 4 µm, which are known to damage downstream engine components such as the high pressure fuel pump and the fuel injectors. Some new filter designs use a single-stage system that incorporates the water removal capability of the primary filter with the high efficiency particle removal of the secondary filter.

Two-stage systems sometimes use a coalescing or silicon treated filter for water removal and a surface filter for particle removal. The two-stage system typically uses media based on cellulose or a cellulose/glass composite. The secondary filter can be a finer cellulose composite media or in the most advanced systems now being used on HPCR injection systems, a fully synthetic glass fibre filter media will be employed. Single-stage systems typically use a single filter with a multilayer composite structure. The current state-of-the-art filter designs now use a meltblown glass media formed on, or laminated to, a nanofibre substrate support which is typically bonded with a phenolic or epoxy resin. Figures 2 and 3 show some examples of filter media.

TESTING AND REPORTING OF FILTER EFFICIENCY

When referring to diesel fuel cleanliness levels and the ISO4406:1999 cleanliness code, the most critical part of the code is the first digit (ISO12/9/6). This is the digit that represents the concentration of 4 µm particles in the fuel, which are the most damaging as they are at a similar level to the critical clearances in the HPCR injector and the high pressure fuel pump. For a diesel engine fuel filter to remove contamination from the fuel system it must be very efficient at and below 4 µm. The efficiency of a filter is typically reported as a Beta Ratio and it is the recognised industry standard for reporting filter efficiencies. The Beta Ratio is defined as the difference between the number of particles larger than a given size upstream of a filter to the number of particles of the same size downstream of the

Company	Specified ISO cleanliness level
Worldwide fuel charter	18/16/13
Engine OEM's	18/16/13
Fuel injector OEM	12/9/6

Table 1: Diesel cleanliness levels.

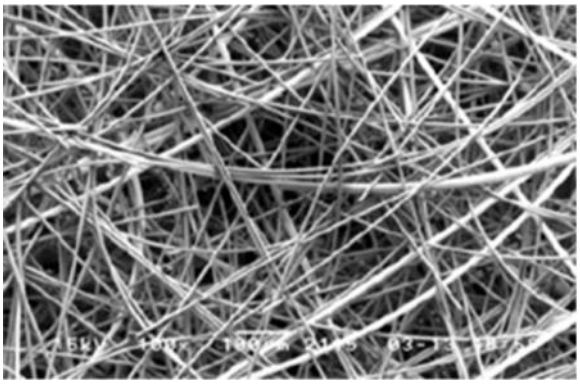

Figure 2: Synthetic wetlaid microglass filter media (100x mag).

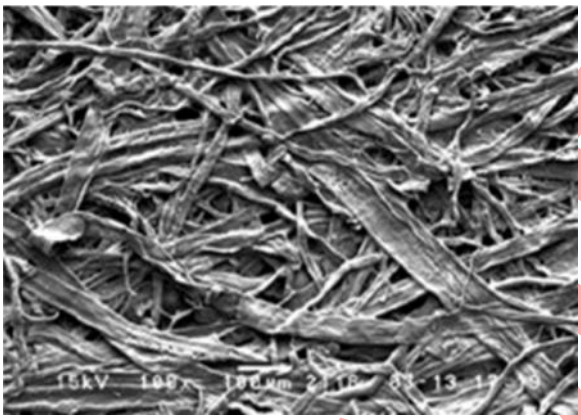

Figure 3: Cellulose wetlaid filter media (100x mag).

filter, i.e.:

$$\beta_N = \frac{\text{number of upstream particles} > N\ \mu\text{m}}{\text{number of downstream particles} > N\ \mu\text{m}} \quad (1)$$

Filter Beta Ratios are tested using the ISO16889 muti-pass test standard and the test system is represented in Figure 4. Interestingly, some filtration suppliers will choose not to report the filter efficiency as a Beta Ratio and prefer instead to report the efficiency as a percentage (%) efficiency. The efficiency of the filter can be calculated directly from the Beta Ratio because the percent capture efficiency is:

$$\left(\frac{\beta - 1}{\beta}\right) \times 100 = \text{Efficiency} \quad (2)$$

For example, the % efficiency of a filter with a Beta Ratio of 10 at 4 µm is calculated as follows:

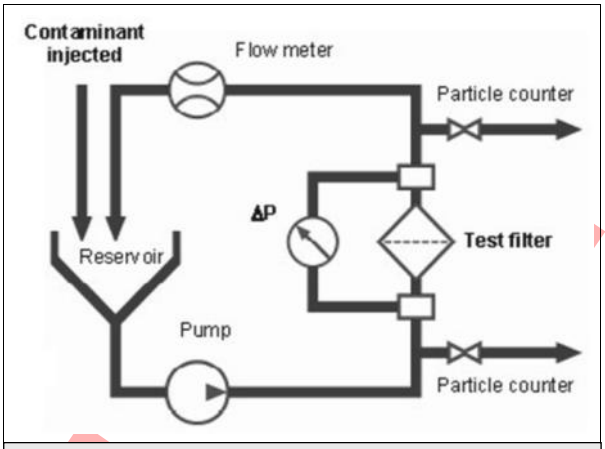

Figure 4: ISO16889 multi-pass test circuit.

$$\left(\frac{10 - 1}{10}\right) \times 100 = 90\% \quad (3)$$

Because of this high percentage number (90%), the casual observer may be drawn to the conclusion that the filter is highly effective; 90%, after all, is a very high number. It is in fact not the case. In terms of the quantity of damaging particles passing through the filter, the differences are significant and have enormous implications in terms of wear protection for the fuel system. Table 2 identifies the two reporting methods and their corresponding data. The example assumes a total of 100,000 x 4 µm particles challenging the filter.

Traditionally diesel fuel filters utilised in EUI injection systems have had efficiency requirements of Beta 75 at 10 µm ($\beta_{10} \geq 75$) or 98.7% efficient. The latest HPCR injection systems now require Beta 1000 at 4 µm ($\beta_4 \geq 1000$) or 99.95% efficiency in order to obtain a far cleaner fuel downstream and protect the components.

The multi-pass ISO16889 test method was primarily designed to test the efficiency of filters intended for systems involving fluid recirculation, such as those found in oil based hydraulic and lubrication systems. As such, the ISO16889 test system recirculates the

Beta Ratio	% efficiency	Number of downstream particles
10	90	10,000
20	95	5,000
75	98.7	1,333
200	99.5	500
1000	99.9	100

Table 2: Filter efficiencies (100,000 x 4 µm before filter).

entire volume of fluid, and thus through the filter, multiple times. Diesel fuel filters installed on engines also use this test method to determine their efficiency. The problem with using the ISO16889 test procedure for such filters is that an engine fuel system does not recirculate the entire volume of fuel. A filter within a diesel engine fuel system is termed a 'single-pass' filter application. The filter is only able to capture the contamination once before it is passed to the injectors and used. This is unlike the ISO16889 test where the filter has multiple chances to capture the contamination until it's terminal differential pressure is reached.

Reporting a diesel engine fuel filter efficiency using the multi-pass ISO16889 standard is somewhat deceptive as to its actual performance in the application because the test does not accurately model how the engine fuel filter is used in a real world environment. The reported Beta Ratio or filter efficiency can mislead a prospective client as to the performance in a diesel engine application. The efficiency of a filter in a single pass application such as an engine fuel system is vastly lower than a traditional multi-pass application as modelled in the ISO16889 test.

Many engine filtration suppliers and OEM's, however, actively market their products to the contrary by suggesting that engine fuel filters have a high Beta Ratio and will thus perform at the ISO16889 standard as well as achieving a low cleanliness level. Moreover, little or no information is provided to the end user on what the performance of the product will be when installed onto the engine. What must be understood is that a diesel engine fuel filter installed into an actual diesel engine fuel system does not perform even close to the efficiency levels that most are advertised at.

There are numerous other test procedures that are sometimes used to test fuel filters under different conditions and with different contaminants. They all, however, cause additional confusion for the end user and do not accurately simulate a real world installation. One such test is the ISO19438:2003 test. This test was specifically designed to evaluate the performance of internal combustion engine fuel filters with a constant flow rate of between 50 and 800 litres/hour, but is again a multi-pass filtration test, with a constant flow rate, and something that an engine fuel filter does not see in the real world. Other test methods known to exist are as follows:

ISO4020: Road Vehicles – Fuel Filters for Diesel Engines

ISO/TS13353: Diesel Fuel and Petrol Filters for Internal Combustion Engines – Initial Efficiency by Particle Counting

ISO19438: Diesel Fuel and Petrol Filters for Internal Combustion Engines – Filtration Efficiency using Particle Counting and Contaminant Retention Capacity

JIS D1617: Automotive Parts – Fuel Filters for Diesel Engines Test Methods

SAE J905: Fuel Filter Test Methods Section 4: Filter Capacity and Contaminant Removal Characteristics

SAE J1985: Fuel Filters – Initial Single Pass Efficiency Test.

MARKETING SMOKE AND MIRRORS

Whilst the reporting of Beta Ratio or % efficiency remains widely accepted as the standard method for reporting filter efficiencies, even the most reputable manufacturers of engine fuel filters do not always employ it as a means of advising their customers of their performance. In some cases it is almost impossible to find the information in marketing materials or technical documents.

There are many manufacturers that prefer to use slogans or descriptions rather than hard data to advertise filter efficiencies and rather rely on the strength of branding as a reputable means of advising customers of the performance. Slogans such as 'ultra high efficiency' or 'advanced' are often used to indicate that the filter has an extreme level of performance above and beyond a standard product. However, it is only when the test data of the filter is observed does the meaning become clearer. One particular filter that reflects this example, having been advertised as 'ultra high efficient' actually has an efficiency of 98.7% above 4 µm ($\beta_4 > 75$) according to the ISO16889 multi-pass test. Clearly this is well below the required level of filtration efficiency for a HPCR engine fuel system and well below what a customer would expect from an ultra high efficiency filter.

PERFORMANCE IN THE FIELD

Testing of engine fuel filters under actual engine operation conditions can show a dramatic difference to the efficiencies that are reported from laboratory testing such as the ISO16889 multi-pass test.

With engine based fuel contamination control, it is important to understand a few issues, which are often forgotten or overlooked. The first issue is that of the fuel tank and the cleanliness level of the fuel. Once fuel enters the fuel tank, tests have shown that the cleanliness level can rise by 1-2 ISO codes due to the contamination left in the system or that generated during operation. Tests have shown that cleanliness levels prior to the primary fuel filter can be in the order of ISO22/19/16 when fuel is filtered into the tanks with an ISO18/16/13 cleanliness.

Effects of Engine RPM

Fuel flow through an engine filter is not consistent, however, most test methods do not simulate this in the majority of filter element tests. In a real world application, as engine speed increases, so too does the velocity of fuel flow through the filter. As such, engine fuel filters are continually challenged by flow surges over their life cycle and as filtration efficiency is directly affected by the flow of fluid through the media (flux rate), flow surges can dramatically affect the ability of the fuel filter to remove contaminants or retain previously captured particles. This issue becomes even more challenging with particles below 4 µm. Figure 5 represents the effect of flow surges on a typical diesel engine fuel filter.

The rapid rise and high quantity of 4 µm particles shown on Figure 5 is a direct result of increased vehicle acceleration and fuel flow through the filter. During these periods, the level of contamination downstream of the filter was 10 times dirtier than that under steady low flow conditions and at its peak reached a cleanliness level of approximately ISO26/13/11. A key point of note here is the enormous gap between the 4 µm code (26) and the 6 µm code (13). The gap clearly shows that particles around the 4 µm size range are dramatically affected by engine speed and fuel flow. These particle sizes cause the most damage within the fuel system. Such massive changes in downstream fuel cleanliness levels are alarming.

Existing fuel filter test standards do not yet consider flow surges. However, the proposed ISO DIS 23369 multi-pass method for evaluating filtration performance of hydraulic filters under cyclic flow conditions may provide a more accurate means of measurement. It is, though, as yet not widely used.

Effects of Vibration

Vibration is an additional cause for concern regarding the efficiency of engine fuel filters. As fuel filters are typically mounted directly to the engine, they experience extreme levels of high frequency vibration under highly variable conditions. These include the actual engine vibration due to engine operation and the movement of the vehicle over rough terrain. Vibration is known to directly affect the contamination retention capabilities of filter media, however, little has been done to simulate these issues with suitable testing procedures or standards.

According to Cummins, Figure 6 illustrates the effect of vibration on contaminant removal in a laboratory environment. The test monitored upstream and downstream contamination levels of a low Beta Ratio rated filter while subjecting it to random vibration at known, constant levels of acceleration. The results indicated that the vibration adversely affects particle removal efficiency with the Beta Ratio of the filter decreasing with higher levels of vibration. Interestingly, the analysis also shows that the steady-state Beta Ratio (at a given acceleration) decreases with increasing magnitude of the acceleration. The test clearly identifies that contaminant removal data obtained using existing filter test standards in the absence of vibration is an overestimate of the removal efficiency under real world conditions. The illustration also shows two dips in the data where the Beta Ratio actually drops below a value of 1. This is clear evidence of a filter unloading more contamination than is being captured when certain

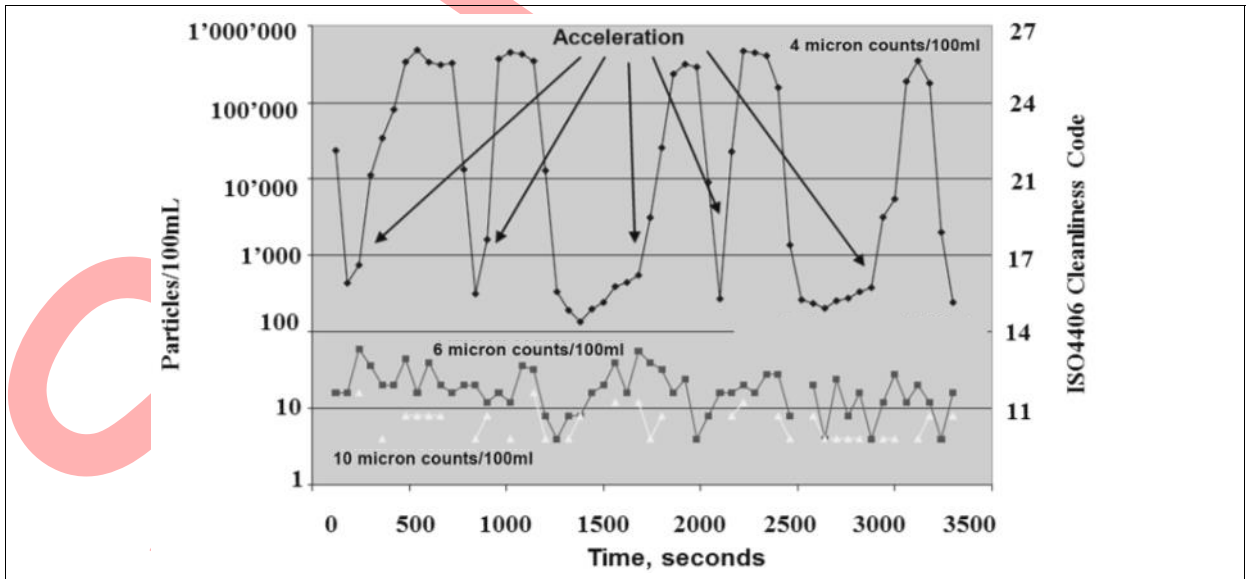

Figure 5: Effect of flow surge on diesel engine fuel filter. Image courtesy of Cummins Filtration; data is not representative of a Cummins Filtration branded product.

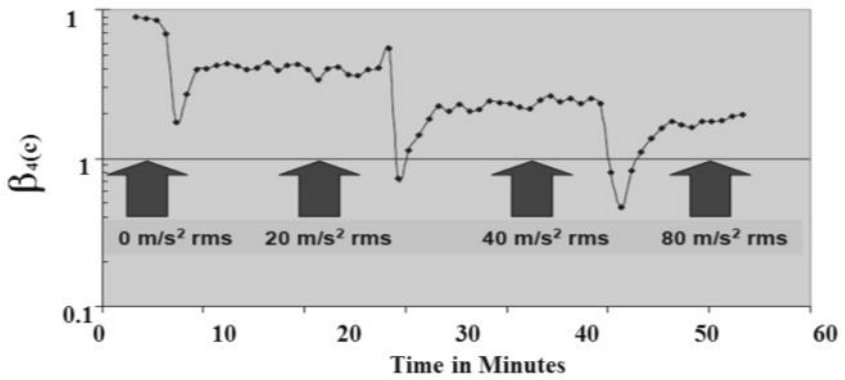

Figure 6: Effect of vibration on a diesel engine fuel filter. Image courtesy of Cummins Filtration; data is not representative of a Cummins Filtration branded product.

Figures 7 and 8: Live testing of fuel cleanliness levels.

conditions are met.

Further evidence supporting the detrimental effects of flow surge (acceleration) and vibration can be observed from tests conducted on a Caterpillar 793C haul truck at a large Australian iron ore operation. The test involved live testing of fuel cleanliness levels using an on-line laser particle counter from both the engine fuel system and the fuel before and after the dispensing fuel filter on the bowser during the refuelling process. Relevant photos are shown in Figures 7 and 8 whilst Table 3 illustrates the results of the tests.

The data in Table 3 identifies that contamination levels in the 4 µm code rose from a code of 13 when filling the truck with fuel to a code of 16 in the engine fuel system at 1500 rpm and after the engine fuel filter. This represents an increase of 3 ISO Cleanliness Codes or 8 times dirtier. To put this into perspective for an engine fuel filter to achieve a cleanliness level of ISO12/9/6 when being presented with ISO18/16/13 fuel, the filter must remove contamination that is a minimum of 64x dirtier (possibly 128x) than required by the injector OEM, do it in a single pass of the filter, under high cyclic flow surges and when subjected to high frequency vibration. All of these issues call into serious doubt the ability for most diesel engine fuel filters to provide cleanliness levels at or better than ISO12/9/6 when vehicles are fuelled with an ISO18/16/13 cleanliness fuel as recommended by most OEM's.

	ISO4406 cleanliness level
Before bowser filter	19/17/11
After bowser filter	13/6/1
Truck @ 700 rpm	15/8/5
Truck @ 1500 rpm	16/13/8

Table 3: Effect of vibration on diesel engine fuel filter.

FILTER LIFE

The distribution of particle sizes within diesel fuel is vastly different from other fluids seen in industry. Lubrication oils, engine oils, and hydraulic oils typically have a wide distribution of particle sizes within a given

sample. A typical sample of diesel fuel, however, comprises of approximately 80-97% of particles at or below 4 µm in size. With such a high percentage of particles in the fuel at the same level which causes the greatest damage in a HPCR injection system, filter companies have responded by reducing the filtration rating on engine fuel filters to below 4 µm. This transition to a lower micron rated filter has resulted in additional pressure on the life of the filter element. Correspondingly most fuel filters have not increased in their physical size in order to combat the additional load.

Typically, for diesel engines used in industries such as mining, mission critical applications, and rail and marine, the fuel filters are changed on a time based planned maintenance strategy that is measured in hours worked. The frequency of fuel filter changes is also streamlined with other critical planned maintenance (PM) such as oil changes or additional filter changes on other systems. The OEM of each asset typically advises the PM event timing along with additional information being provided by industry specialists. Most OEM's in most locations around the world typically schedule engine fuel filter changes between 250 and 500 hours.

As filter micron ratings have reduced to target contaminants below 4 µm, we are now starting to see some OEM's advising their customers to once again reduce the PM intervals on fuel filters from their current 500 hour intervals to 250 hours on new equipment that is fitted with HPCR injection systems. This new requirement is starting to place additional pressure on maintenance strategies with companies now being forced into refining all PM intervals in order to ensure assets are not being taken out of service just for a fuel filter change and to ensure that other productive assets remain in the field or that other engines are available for use. Many are now looking for solutions around this problem by simply choosing to look at other engine OEM's.

Reducing the PM interval of an engine fuel filter from 500 to 250 hours is a direct response by filter manufactures to ensure that the engine fuel filter will not completely block during its time in service because of the reduced micron rating. It is, however, a false economy and not required should the asset fuel tank be delivered with a fuel cleanliness that does not overload the engine fuel filter in the first place. Engine fuel filters do not employ a bypass valve, which would enable fuel to bypass the filter in the event that it becomes blocked with contaminants. Rather, the engine management system constantly monitors engine fuel filter differential pressure and will regulate the fuel flow to the engine based on the condition of the filter. If the engine management system indicates that a filter has a high differential pressure, fuel flow is automatically reduced causing a loss of horsepower, speed and eventually, production or power.

The situation again circles back to the specification of fuel cleanliness levels being delivered to the machine at refuelling. Whilst the filter micron rating has reduced to a level where the majority of contaminants in the fuel are being targeted, what has not occurred is a reduction in the specified fuel cleanliness level being filled into the asset fuel tank; it remains at ISO18/16/13. The answer employed by the OEM is to simply change out the engine fuel filter sooner. What should change is the cleanliness of the fuel entering the fuel tank in the first place and the cleanliness levels at which stationary fuel tanks are maintained.

Filters are not intelligent devices; they remove contaminants within the fuel as they are presented to the filter media. Reducing the level of contaminants being presented to the filter each hour will increase its service life; this is an undeniable fact. It is therefore difficult to understand why OEM's are not advising their customers of such an option. By reducing the fuel cleanliness level at the point of refuelling to ultra-clean levels (ISO12/9/6), operators can begin to challenge OEM's regarding the mandated 250 hour or even 500 hour filter changes. Taking a look at a real world example from the mining industry, it is easier to understand why. Consider the following:

Engine:	Cummins QSK Series 2
Truck:	Hitachi EH4000
Fuel burn:	170 litres/hour
Filter PM:	500 hours
Fuel:	ISO12/9/6.

In the example, the engine will consume ~85,000 litres of diesel fuel in a 500 hour period. With a fuel cleanliness level of ISO12/9/6 being presented to the vehicle fuel tank, the volume of contaminants challenging the engine fuel filter over its life is only ~0.66 grams. Depending on the manufacturer, a typical engine fuel filter will hold anywhere from 60-140 grams of contamination in a real world environment. Using the same example but filling the vehicle with a WWFC or OEM recommended fuel cleanliness of ISO18/16/13, the volume of contamination challenging the filter is dramatically increased to 87 grams over the same 500 hour period. The maximum capacity of typical diesel engine filter elements is thus approached.

As fuel filter elements are challenged with contaminants other than dirt, it is easy to understand why some filter companies and OEM's are now advising their customers to change filters at 250 hours. What can also be concluded is that diesel engine operators can challenge these new PM intervals by simply improving the fuel cleanliness level at the point of fill.

CONCLUSIONS

Technology is changing at a rapid pace as too are the challenges being faced in order to maintain supreme reliability from diesel equipment and their fuel systems. New HPCR fuel injection systems require a vast improvement in fuel cleanliness levels in order to maintain this high degree of reliability and as such, advancements must be made in the way we deal with the ever growing problem that fuel contamination brings. What diesel engine operators and OEM's must begin to comprehend is the different role that the engine fuel filter must now play. It can no longer be used as the major tool for reducing contamination within the fuel system. Certainly the technology has improved, however, the physical size of filters has changed little to offset filter life and nor have the problems of vibration and flow surges reduced.

Achieving ultra-clean diesel (UCD) fuels at levels of ISO12/9/6 is possible and such improvements have been shown to provide millions of dollars in benefits both in direct savings and the overall reliability and performance for the engine, which far outweigh the cost of capital equipment or the cost of ongoing consumables. What must change, however, is the reliance on the engine fuel filter to achieve the goal of UCD fuel at ISO12/9/6. Certainly the filtration technology used in today's engine fuel filters has improved, but the physical size of filters has changed little to offset filter life and nor have the problems of vibration and flow surges reduced. Simply expecting the engine fuel filter to do all of the work is no longer a viable solution and as such operators must look towards alternative solutions by using contamination control technologies throughout the diesel distribution system and at the bowser in order to reduce contamination levels. In this manner the engine fuel filter can perform its design function which is to 'achieve a fuel cleanliness that will enable the fuel injection components to function reliably and within their designed operating parameters throughout the life of the component'.

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DEFINITIONS, ACRONYMS AND ABBREVIATIONS

AAM	Alliance of Automobile Manufacturers
ACEA	European Automobile Manufacturers Association
CM	Condition Monitoring
CO_2	Carbon Dioxide
DPM	Diesel Particulate Matter
EMA	Truck and Manufacturers Association
EUI	Electronic Unit Injector
HPCR	High Pressure Common Rail
ISO	International Organization for Standardisation
JAMA	Japan Automobile Manufacturers Association
MARC	Maintenance and Repair Contract
MCRS	Modular Common Rail System
NOX	Oxides of Nitrogen
OEM	Original Equipment Manufacturer
PM	Planned Maintenance
RE	Reliability Engineering
ROIC	Return on Invested Capital
SAE	Society of Automotive Engineers
UCD	Ultra-Clean Diesel
WWFC	World Wide Fuel Charter

EVALUATION OF THE FILTRATION PERFORMANCE OF A RAPID PROTOTYPED SINTERED FILTER ELEMENT

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Laser Sintering is a Rapid Prototyping (RP) technique used for the direct manufacture of solid objects layer by layer, with the aid of CAD models. In this investigation, a sintered bronze filter element was produced by the Direct Metal Laser-Sintering (DMLS) process and its performance data obtained and compared to more conventional elements. The tests showed that the elements had a narrow pore size distribution, a high pressure drop and a low contaminant holding capacity compared to a random fibre element of a similar rating. The ISO 16889 multi-pass β = 1000 rating was 12 µm which was maintained up to the maximum test differential pressure of 10 bar.

The element would be unsuitable for conventional filtration as its limited dirt holding capacity would mean a very short service life, but it could be suitable for Last Chance Filter applications or backwash and blowback applications. Further development would produce an optimum configuration.

INTRODUCTION

Rapid prototyping (RP) processes are a group of technologies that have revolutionised product development and manufacturing. These processes are capable of producing complex geometric components directly from three-dimensional computer generated models. All RP techniques build parts layer by layer, with each layer containing the cross-section of the CAD file data. The applications of RP have been shown to greatly reduce the design to manufacturing cycle, resulting in reduced cost and increased competitiveness[1].

Although RP processes used to be mainly utilised as a visualisation tool or for assembly testing, they are now seen as a viable manufacturing technique. These additive processes are in contradiction to more traditional manufacturing techniques such as subtractive methods like turning or milling machines, and/or formative processes such as forging or injection moulding that use a tool to create the part. While traditional manufacturing processes must make a large number of parts in order to amortise the costs of tooling, Laser Sintering machines can respond to any demand, low or high volume and even completely customised products. There is no tooling cost and therefore the cost per part is not dependent upon the production volume.

There are many commercially available RP systems such as Stereolithography, Laser Sintering, Laminated Object Manufacture, Fused Deposition Modelling, Solid Ground Curing and Three-Dimensional Printing. All RP systems have a limited range of material types from which prototypes can be manufactured. Of these systems, laser sintering is the most attractive because of the wide range of materials available for product manufacture, including several polymers, sand and metals.

Laser Sintering RP processes can be split into two categories: Indirect laser sintering referred to as Selective Laser Sintering (SLS) and the Direct Metal Laser Sintering (DMLS) process. The SLS process produces parts when a laser scans the CAD data onto a bed of polymeric powder (metal particles coated with a thermoplastic polymer material). The interaction between the laser and the powder raises the temperature above the 'glass' transition temperature for the polymer, and just below the melting temperature. As a result the exposed particles deform and fuse with neighbouring particles[2]. The DMLS process on the other hand uses a powerful laser to fuse the metal powder particles together without the use of a thermoplastic binder. Powders are typically composed of low and high melting point metal particles.

One of the main advantages of either of these laser sintering processes is how they are able to produce parts with complicated geometry which would be impossible to manufacture using traditional techniques. As there is no tooling required, the design constraints normally associated with the traditional methods of manufacture are highly reduced, giving more possibilities in the design and improving the performance of products[1].

In the SLS build process (Figure 1) a roller (B) spreads the thermoplastic powder (A) over the surface of a build cylinder (C). The piston in the cylinder (D) moves down one object layer thickness to accommodate the new layer of powder. The powder delivery system (E) is similar in function to the build cylinder. Here, a piston moves upwards incrementally to supply a measured quantity of powder for each layer. The CO_2 laser beam then traces over the surface of the tightly compacted powder to melt and bond it to form a layer of the object. The fabrication chamber is maintained at a

temperature just below the melting point of the powder so that heat from the laser need only elevate the temperature slightly to cause sintering, thereby speeding up the process. The process is repeated until the entire object is fabricated. After the object is fully formed, the piston is raised to elevate it. Excess powder is simply brushed away and final manual finishing may be carried out. No supports are required with this method since overhangs and undercuts are supported by the solid powder bed.

The DMLS process has hitherto become the most common RP technique for the direct production of tools for die casting, injection moulding and functional parts. DMLS parts produced through this process are permeable, but no infiltration is required. Parts fabricated via SLS require post-process sealing by infilling with molten copper, bronze or epoxy resin[2] as most applications require fully dense parts for both durability/strength and long life. The DMLS parts, however, can be used in applications that require porous parts[3]. Porous metal parts can be used for a wide range of applications and can generally be classified into three groups:

- *Filtration Applications*: Include diffusion and control of gases and liquids.
- *Mechanical Applications*: Self-lubricating bearings that can be used for light bearing applications, i.e. small electric motors, spindle bearings for high speed machining.
- *Other Applications*: The suppression of noise and sound damping (e.g. silencer barrels for firearms and catalytic converter components), the production of moulds for the vacuum forming process as their porosity allows air to be drawn out from the mould while providing structural integrity. The die casting industry can also use this process for producing mould veins for dies, as trapped air can escape via the porous metal inserts, resulting in improved part quality.

Parts can be manufactured on the DMLS machine using a variety of scanning parameters such as laser scanning speed, hatch spacing and border scanning. These parameters affect the pore structure of the part and hence determine the likely application area[1]. It is therefore essential to set the correct build parameters to optimise the product performance. The sintering and densification is greatly affected by the laser scanning speed and strategy, laser type, power and radius, mechanical layering of powder (layer thickness) and atmospheric control[4]. The scanning strategy is the most straightforward to modify and can therefore be used to adjust the density of the part. Parts can be produced using a variety of the skin and core scanning strategies. The skin principle involves scanning the border of the part and then hatching the internal part area while the core principle involves hatching the internal part area only without hatching the border. The hatching strategy can also be varied in the X or Y/X and Y directions on the same layer and alternating layers.

The aims and objectives of this work were to investigate the use of the DMLS process for the manufacture of a sintered filter element and its suitability and functionality when subjected to a range of tests in order to evaluate its performance. The results were compared to a more 'standard' or conventional filter element from a leading global supplier. The powder used in the sintering process consisted of a bronze/nickel mixture containing a small amount of copper-phosphide, marketed as 'DirectMetal' or 'DM' (available as DM 50 µm and DM 100 µm). The low melting point component was used since it required less laser energy and time

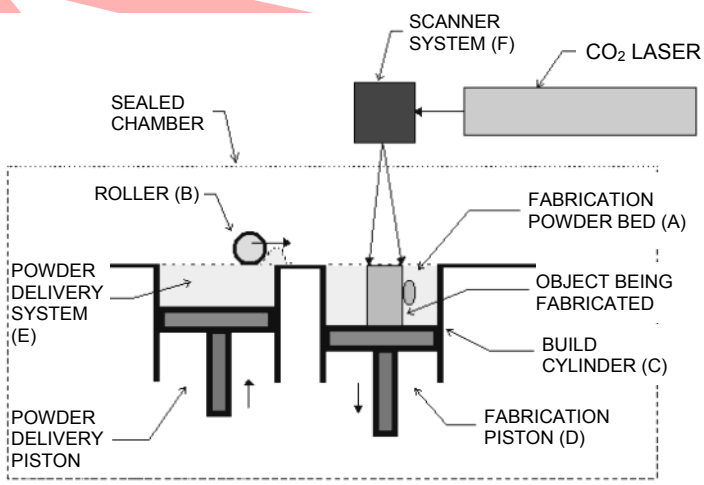

Figure 1: Configuration of the Selective Laser Sintering (SLS) process.

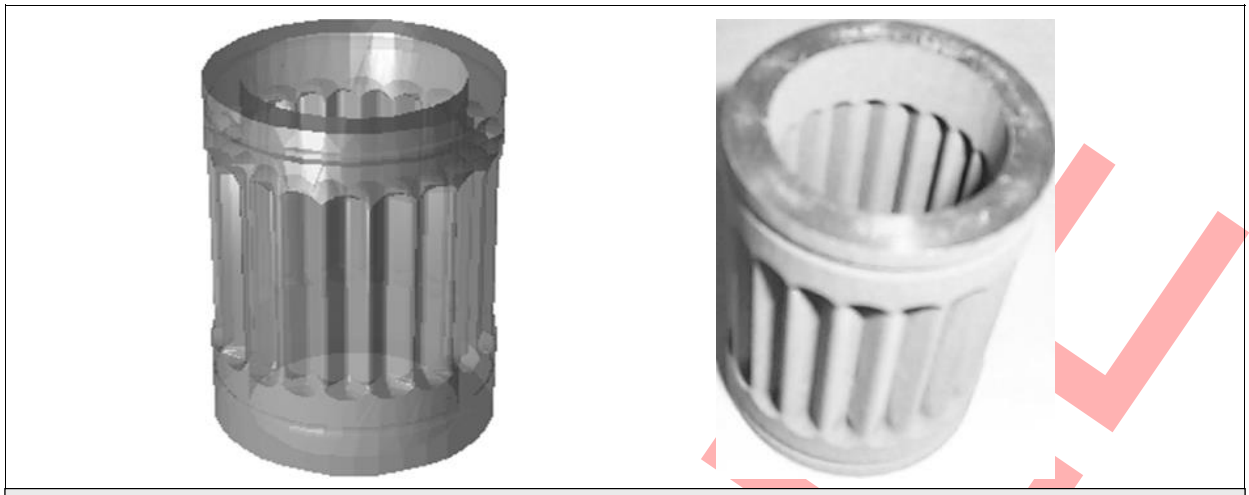

Figure 2: Test element CAD model (*left*) and view of the sintered filter (*right*).

to melt the metal powder. A standard laser scanning speed of 500 mm/s and hatch spacing 0.1 mm were employed in the study.

TEST FILTER DESIGN AND MANUFACTURE

A filter element was designed to incorporate similar design features and dimensions to commercially available hydraulic filters in order to aid testing (i.e. fitting to existing jigs and test equipment). It was built in the vertical direction to add uniformity to the pore structure and also to reduce the need to incorporate supports. The filter measured approximately 60 mm in length with the internal and external radii of the cylinder being 30 and 40 mm, respectively. It featured 20 triangular shaped axial channels designed to increase the surface area (Figure 2). The surface area was calculated as 60 cm^2 and rated as 6 µm by the method described in British Standard BS 6277[5] which is based upon the first bubble point. However, much larger filters could be manufactured, as the build volume of the machine used was 250 x 250 x 150 mm.

Two filter elements, 'DMU A' and 'DMU B' were manufactured from the bronze DM 50 µm powder utilising a core scanning strategy to add uniformity to the pore structure and density, while improving permeability, which could therefore increase performance of the filter.

EXPERIMENTAL PROCEDURE AND DATA ANALYSIS

Initial test pieces (Figure 3) were built using various build strategies and parameters (laser scan speed, part orientation and part thickness) in the vertical direction. Tests were conducted to determine their pore structure using guidelines specified in British Standard BS 1752[6].

The apparatus used for the determination of the pore size index is shown in Figure 4. The experiment involved passing air through a test piece placed above a sealed chamber and covered with a thin layer of water. Air was allowed into the chamber using a control valve to gradually increase the pressure within the chamber and hence the differential pressure across the test piece. The pressure was slowly increased until the first air bubble broke away from the surface of the test piece. At this point, the pressure within the chamber was recorded using a manometer and the value used to calculate the diameter of the largest pore using:

$$\text{pore size } (\mu\text{m}) = 30\frac{\gamma}{P} \qquad (1)$$

where γ is the surface tension (dyne/cm) of the test liquid (water = 73), and 'P' the effective pressure (mmHg).

Bubble Point Test

The bubble point test is designed to evaluate the fabrication integrity of filters, in this case the success of the adaptation to fit into a standard hydraulic housing. The test was performed using an in-house method which

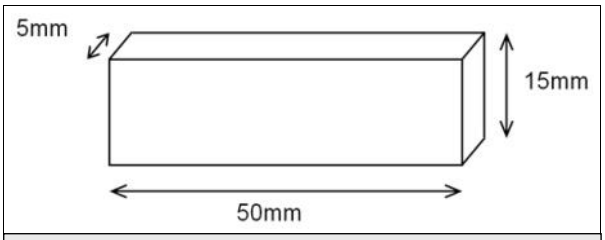

Figure 3: Test piece dimension.

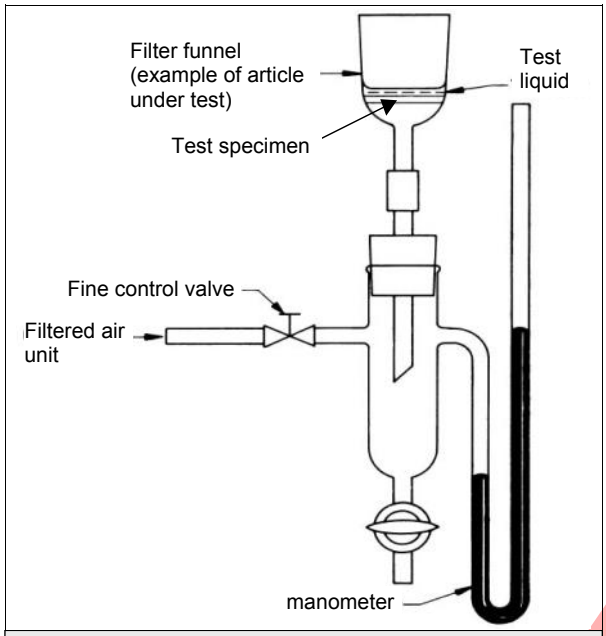

Figure 4: Apparatus for determination of pore size according to BS 1752[6].

evaluates the first bubble point pressure in a similar manner to that described in ISO 2942:2004[7] and BS 6277[5]. The test was continued to evaluate the 2nd, 3rd, 5th, 10th and 'fizz' or mass bubble point values. The test fluid was propan-2-ol which has a surface tension of 23.5 dyne/cm; an immersion depth of 12 ± 3 mm was used in the tests. The fizz point is effectively a measure of the minimum pore size. A combination of these two values gives a measure of the structure's permeability.

Flow/Differential Pressure Characteristics

The characteristics of the sintered filters were obtained up to 5 L/min using a 15 cSt fluid and generally in accordance with ISO 3968[8], except that it was only possible to obtain five data points due to the high pressure drop.

Multi-pass Filtration Performance Test

The tests were carried out generally in accordance with ISO 16889:2008[9] except that a lower base upstream gravimetric level of 2 mg/L was used (3 mg/L is the minimum quoted in ISO 16889), to extend the test time and ensure representative data. The test had to be performed at 2 L/min which was the minimum value for the rig and up to a differential pressure 10 bar. The pressure was deliberately limited as the likely collapse value of the test material was not supplied.

Performance measurements at >3, >5, >6, >8, >10 and >15 µm(c) were obtained regularly throughout the test and a terminal differential pressure of 4 bar was used for calculation purposes[10]. This test was used to determine the filtration rating of the filter and it also gives a measure of its dirt capacity. The test was performed up to a differential pressure of 10 bar.

It was not possible to test a conventional element of similar rating and envelope size, so performance data from a test at a higher flow density on an element with similar media is shown for comparative purposes. However, the differential pressure and contaminant capacity have been calculated for the sintered filter conditions.

Collapse Test

The collapse test was performed on Element 'B' by injecting contaminant into the collapse rig until a structural failure of the filter was observed as defined by ISO particle count standard, ISOMTD[10]. The maximum differential pressure was recorded and the element was examined after the test to identify the mode of failure.

RESULTS AND DISCUSSION

Pore Size Analysis

Inspection of the part orientation vs. pore size diameter

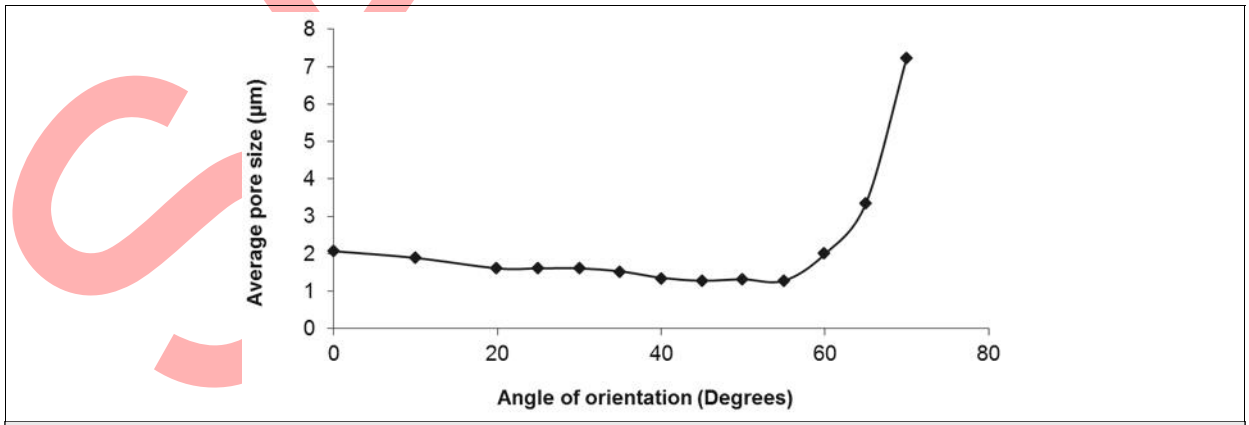

Figure 5: Part orientation vs. pore size diameter.

(Figure 5) showed that the pore sizes of the parts produced are dependent on the direction of manufacture. The pore size remained relatively constant at about 2 µm (bubble size) from 0º (perpendicular to the wiper blade in the X and Y axis) to 55º, but increased thereafter to a maximum of around 8 µm.

The sudden increase in pore size after 55º was due to the thin unsupported test pieces deforming as the wiper blade came into contact with their sides, resulting in the wiper blade not levelling thoroughly with the top of the newly fused surface. Parts from 70º-90º failed to be manufactured due to the effects of the wiper blade. However, this problem did not arise during the manufacture of the test filters as the filter walls mutually support each other. These results demonstrate that functional filters with relatively uniform pore structures can be built in the vertical direction and that the effects of the wiper blade on the pore size/structure are generally limited.

Examination of the laser scan speed vs. the pore size (Figure 6) showed that altering the laser scan speed and part thickness had little effect on the pore size of the parts produced. However, the thinner parts generally had a smaller pore size, but this is not a true indication of the average pore size because the pressure required to pass air through them was less. These results show that to obtain a lower pressure drop across the structure, the wall thickness must be kept to a minimum.

Bubble Point Test

The test data obtained is shown in Table 1. This test is effectively a repeat of the BS 1752[6] test except for the fact that the test liquid was propan-2-ol. The procedure involves increasing the pressure inside the filter progressively to determine the first bubble pressure. Although not part of the ISO test, the pressure was further increased to measure higher bubble point values including the 'mass' or 'fizz' point. The applied standard flow rate for this test is 12 L/min. This represents a high flow density for the DMU element (2000 L/M-m^2) and resulted in comparatively high values. Additional 'fizz' values were obtained for the air flow rate characteristics (inches WG = 0.8Q + 18.8) and corrected the DMU data to a 'standard' flow density of 324 L/M–m^2.

Flow/Differential Pressure Characteristics

The flow/differential pressure characteristics are presented in Figure 7. The values at 2 L/min were 1.6 and 1.3 bar for Elements A and B, respectively. A typical result for a KS grade element of a similar envelope size is 0.02 bar, which is substantially lower.

The DMU filter elements had relatively high pressure loss characteristics compared to a conventional element of similar rating and envelope size. This is due

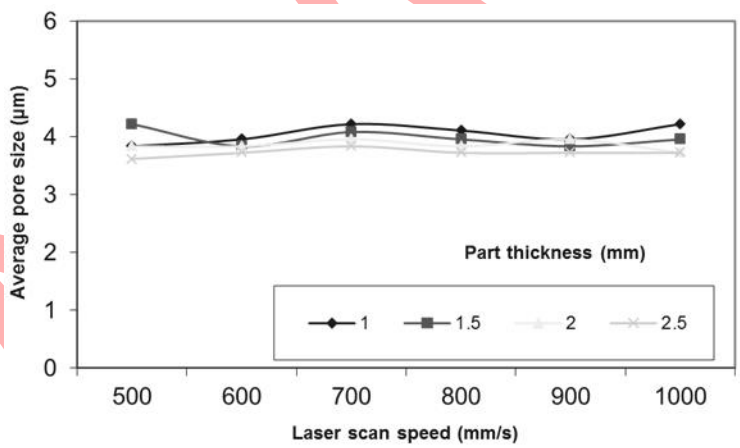

Figure 6: Graph of laser scan speed vs. pore size.

Element	BPt no.	Bubble point pressure – inches WG					
		1st	2nd	3rd	10th	Fizz at 12 L/min	Fizz at 324 L/M-m^2
DMU 'A'	L399	14.8	15.0	15.2	16.0	32.0	20.2
DMU 'B'	L398	15.6	16.6	16.7	16.9	31.3	19.7
Conventional (KS)	Typical	7.0	-	-	-	-	13

Table 1: Bubble point test data.

to the low flow area, as the element is not corrugated to the same extent, and to the thickness of the structure.

Filtration Performance

The filtration performance data is summarised in Table 2 whilst the individual datasheets are presented in Tables 3 and 4. The data for the 'standard' element was taken from a test on KS media and both the differential pressure and dirt capacity have been corrected for 2 L/min.

The gradient of this relationship is a measure of the pore size distribution of the filter and the pore size distribution is slightly narrower than the coarser KS media. A test for repeatability of the DMU filter was good indicating a consistent pore size distribution. A measure of the efficiency of particle removal is the filtration or β ratio, and the higher the β value the more efficient is the filter[9]. The ISO test gives the variation of β with particle size and is a measure of pore size distribution and the filter's response to a polydispersed contaminant as defined in the standard. The filtration capabilities of the filter are given in Figure 8 where it is compared to a similar test on a hydraulic filter of similar rating.

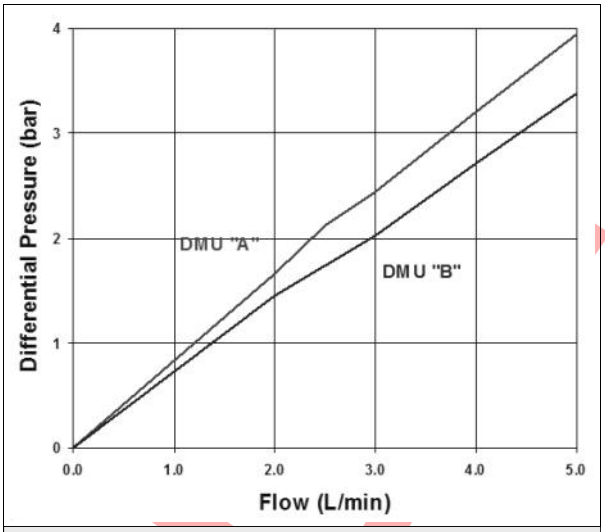

Figure 7: Flow/differential pressure characteristics.

From the gradients of the data for the two filters it can be seen that the pore size distribution, and hence the

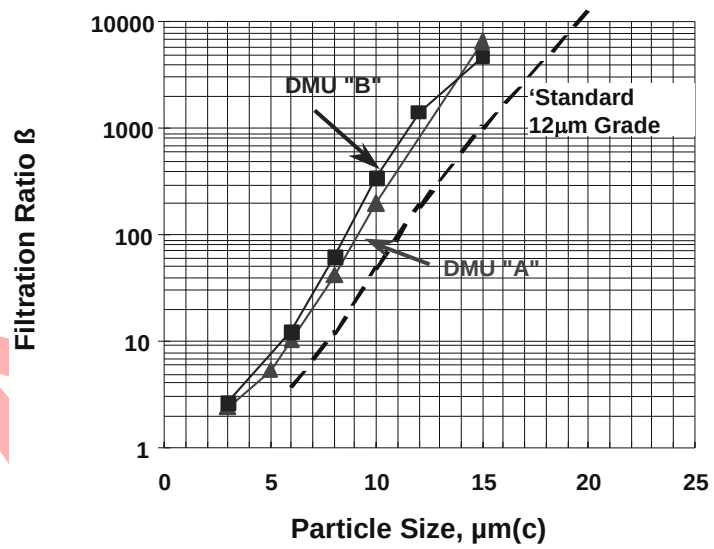

Figure 8: Variation in filtration ratio with particle size.

Filter	ISOMTD added to 4 bar	Average filtration ratings (µm(c)) at					
		β = 2	β = 10	β = 75	β = 100	β = 200	β = 1000
DMU 'A'	0.11 g	<3	6.0	8.7	9.1	10.0	12.3
DMU 'B'	0.30 g	>3	5.6	8.2	8.5	9.4	11.5
Standard	4.5 g	<6	7.7	10.7	11.0	12.1	15

Table 2: Summary of ISO 16889 multi-pass test data.

Filter and Element Identification			
Element ID: SINTERED: A			Expected rating: 10 µm(c)
Operation Conditions			
Test Fluid:			
Type:	Esso Univis J13	Ref: MIL-H-5606	Batch no. n/a
Viscosity:	15 mm^2/s		Fluid temperature: 40.0ºC
Anti-static added?	yes	Type: Stadis 450	Conductivity: >2000 pS/m
Test Contaminant			
Type: ISOMTD	Batch no: 4854M#L		
Test System			
Test flow rate (L/min): 2	Test system volume (L):	Initial: 8	Final: 8
Base upstream gravimetric G_b (mg/L): 2.0			
Injection System			

Injection parameters	Initial	Final	Average injection parameters	
System volume (L)	9	6.3	Injection flow (q_i, mL/min):	100
Concentration (mg/L)	40	40	Concentration (G_i, mg/L):	40

Counting System			
Counter ref	Sensor ref	Flow rate (mL/min)	Dilution ratio
Upstream	P524	50	4
Downstream	P525	50	0

Table 3: ISO 16889 multi-pass test data sheet for DMU Element A.

removal capability of the sintered filter, is comparable with the standard conventional hydraulic filter. This suggests that laser sintered filters are suitable for use in fluid filtration. The similarity in the data of the two test samples showed that the reproducibility of the process was good. The data shown in Figure 8 is the average of all the data collected to 10 bar differential pressure.

The characteristics exhibited by sintered filters 'A' and 'B' (referred to as DMU A or DMU B), as shown in Figure 9 are typical of the build-up of a porous surface 'cake' of contaminant, and blockage by this mechanism dominates. There is a considerable difference in the blockage characteristics of the two filters and as Figure 8 shows the elements have similar removal characteristics; the differences in the blockage curves are considered to be due to differences in formation of the 'cake'. The Pall KS media was only marginally affected by this mechanism.

Scrutiny of the filtration ratio with element differential pressure (Figure 10) showed that as particles accumulated on the surface of the filter so it became clogged and the filtration ratio increased. This is partly due to the pores becoming blocked by contaminant and partly because of the development of a porous 'cake' of contaminant on the surface of the filter. The variation in performance displayed in Figure 8 could be considered to result from the development of the surface 'cake' rather than differences in the structure.

Although data was obtained regularly throughout the

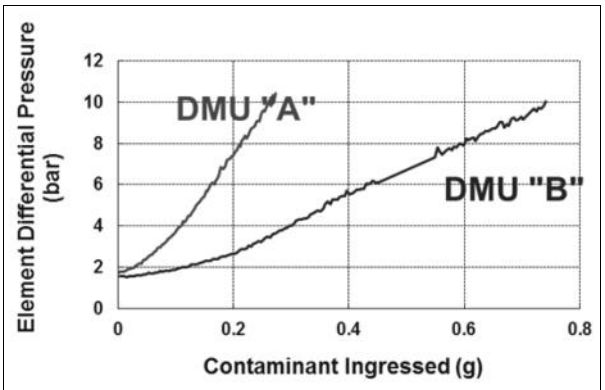

Figure 9: Filter blockage curves.

Filter and Element Identification			
Element ID: SINTERED: B			Expected rating: 10 µm(c)
Operation Conditions			
Test Fluid:			
Type:	Esso Univis J13	Ref: MIL-H-5606	Batch no. n/a
Viscosity:	15 mm^2/s		Fluid temperature: 40.0ºC
Anti-static added?	Yes	Type: Stadis 450	Conductivity: >2000 pS/m
Test Contaminant			
Type: ISOMTD	Batch no: 4854M#L		
Test System			
Test flow rate (L/min): 2	Test system volume (L):	Initial: 8	Final: 8
Base upstream gravimetric G_b (mg/L): 2.0			
Injection System			

Injection parameters	Initial	Final	Average Injection parameters	
System volume (L)	9	1.6	Injection flow (q_i, mL/min):	100
Concentration (mg/L)	400	400	Concentration (G_i, mg/L):	400

Counting System			
Counter ref	Sensor ref	Flow rate (mL/min)	Dilution ratio
Upstream	P524	50	4 :1
Downstream	P525	50	0

Table 4: ISO 16889 multi-pass test data sheet for DMU Element B.

test, plotting all these data proved to be confusing. To enable the data from the two tests to be more easily compared, the data contained in 10% time increments was averaged in the same way as detailed in ISO 16889[9]. Also, only four out of the six sizes are shown. The 100% value is the amount injected at 4 bar differential pressure.

Figure 10 indicates that the efficiency of particle removal improves with time as the surface 'cake' builds up and progressively removes smaller particles. The difference in 'cake' build-up between the two tests can be clearly seen. The data at the larger sizes (>12 µm (c)) does show variability and this is a result of particle count statistics, where the transmission of a single particle has significant effect. Averaging the data within the 10% time bands reduces this effect compared to the individual data, and could be reduced in future tests by increasing the rate of contaminant addition.

Collapse Test

Only Element B was tested and a collapse occurred at 86 bar, with a rupture of the sintered structure in the trough of a single 'corrugation' (see Figure 11). There was also some fracturing of the material at the top of the same corrugation.

Comments

The DLMS process generates a structure with a relatively narrow pore size distribution that will generate a distinct 'cut-off' in relation to removal characteristics. Unfortunately, the elements' particle removal characteristics could not be totally demonstrated in these tests. The need to reduce the contaminant addition rate (BUGL) to have an analysis period of sufficient duration to acquire valid data during stable conditions, meant that the data at the larger sizes was subject to particle count statistics. The reduced numbers of particles in the influent resulted in the presence of single particles downstream having a significant lowering effect on the resulting β measurements.

The narrowness of the pore size distribution and the number of pores caused the element to have both a high pressure drop and a low contaminant capacity for the flow area compared to a random fibre element. This performance would not be acceptable in applications where consistent removal of contaminant is concerned (also known as wear control filters), but could be acceptable in a 'last chance' application. The pur-

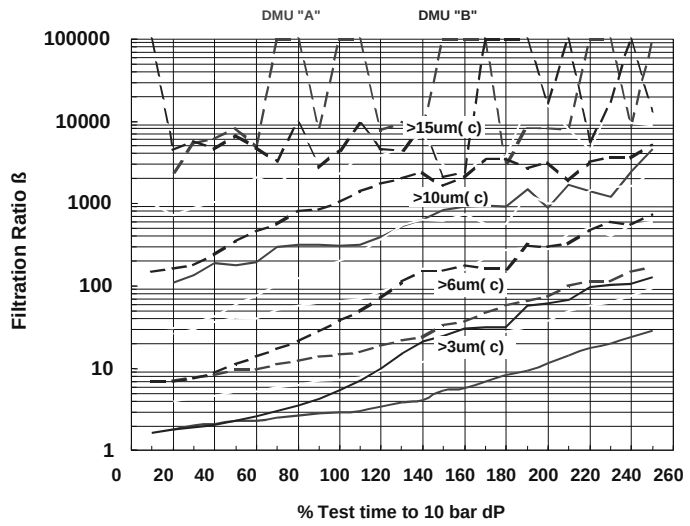

Figure 10: Filtration ratio vs. element differential pressure.

pose here is to protect a component from critically sized particles; the burden of removing and collecting contaminant is performed by another filter elsewhere in the circuit. These unfavourable characteristics can be lessened by increasing the flow area by more pronounced corrugations, and by reducing the thickness, much like a conventional filter. The characteristics displayed by the sintered element could also be utilised in backwash or blowback applications, but may need a smaller mean pore size created by the use of finer powders.

The element demonstrated stability in performance, and its performance improved at pressures up to 10 bar differential – the maximum value used in these tests. Such behaviour has to be attributed to the development of a surface 'cake' resulting from the use of ISOMTD and hence blockage was dominated by this mechanism.

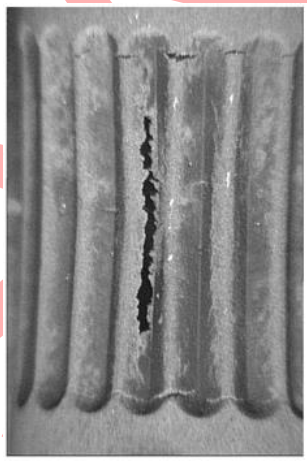

Figure 11: Photograph of damage sustained during the collapse test.

CONCLUSIONS

In recent years, there has been a move from Rapid Prototyping to Rapid Manufacturing with commercial application. Laser sintering technologies represent a considerable interest to industrial companies and academic institutions because of the possibilities they offer when it comes to the design, performance and implementation of products.

Sintered filter elements obtained from the DMLS process were analysed and their performance assessed to show that they performed successfully at removing contaminants from hydraulic fluid. The pore structure was uniform with a mean pore size of about 8 µm. However, these parts in their present configuration would not see general use in the hydraulics market as the pressure drop is too high and the dirt capacity is too low. Although the results of the reported trial look promising, these limitations need to be overcome before the concept is suitable for use in hydraulic filters. However, in its present form, filter elements manufactured using the DMLS process are eminently suited to low viscosity applications (<5 cSt) and where moderate flow densities are concerned.

FURTHER WORK

The pressure drop across the sintered filter could be reduced through a combination of methods to include: decreasing the wall thickness by lowering the density, increasing the scan speed or hatch spacing of the la-

ser, and/or by using a lower grain size powder such as the DM 100 µm powder. The reduced wall thickness or part density will result in increased permeability of the part, thereby reducing the resistance to fluid flow and hence reducing the pressure drop across the structure. However, the parts produced will have reduced strength and problems may arise during their manufacture (i.e. thin sections may fracture due to loading during the recoating process).

Maximising the filtration surface area of the filters would increase the dirt capacity of sintered filters. The dirt capacity can also be increased by reducing the density of the parts resulting in an increase in the number of pores/internal volume, hence increasing the volumetric/dirt capacity of these parts.

ACKNOWLEDGEMENT

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DEVELOPMENTS IN LARGE SCALE FILTRATION PLANTS

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Filtration is a well known and effective method for dewatering slurries in the mining and mineral processing industries. Filters have principally been utilised for mineral concentrate dewatering where tonnages are moderate and the separation is targeted to producing cakes dry enough for transport. Water as a resource is becoming scarce and there is legislative pressure to utilise desalinated water or increase the water consumption efficiency of mineral processing operations. The scale of operation has increased dramatically with the trend towards tailings dewatering, forcing equipment manufacturers to adapt and increasing the size of equipment to suit.

Tailings filtration, with a focus on water recovery and dry stack characteristics of the filter cake, has different requirements to product dewatering. Ore variability is significantly higher than the variability of products and plant reliability is essential for robust solutions in tails dewatering. Equipment scale changes have a large effect on the infrastructure required for operation and filtration plants are being developed to integrate the ancillary services required, and to facilitate safe and effective maintenance.

INTRODUCTION

Many of the good design practices that work on a small scale can lead to inefficiencies in large scale plants. This paper examines some of the factors that affect the capital cost of installing pressure filters. For instance, issues such as building elevation and materials handling have a large influence. Batch processes have operational philosophies that can have significant effects on the size and nature of supporting ancillaries. In some cases a reduction in the total investment cost may be achieved by increasing the filter size. There are also implications in the transition to and from batch operations that may have an effect on other unit operations. Looking at a wider scope and avoiding the pitfalls of departmental accounting often results in a different conclusion as to the correct requirements for upstream equipment.

FILTRATION PLANT DESIGN

When designing a large filtration plant for tailings applications many factors affect the equipment selection and installation. Process variables such as grind size, ore type and filterability are the major factors considered. Filters are heavily influenced by the performance of upstream equipment and there is a tendency to make them fit with the resultant conditions rather than treat the system as interactive.

A good example of this upstream equipment effect is the use of high rate thickeners. With standard high rate thickeners the achievable underflow density is limited and improving thickening by the use of high compression thickeners can substantially improve the subsequent filtration rate. Good control systems ensure that the effect of overdosing flocculants is minimised which can cause cloth problems and capacity reduction in filtration.

Ore variability represents one of the most significant risks to plant design. Testing should evaluate the entire range of mineral types expected during the life of the mine and consider the implications of unplanned dilution from adjacent ore bodies, particularly if clays are present. Performing test work on a pilot scale level still provides the most accurate equipment sizing and evaluation.

Materials Handling

Material handling issues are the most significant factor to determine process requirements. Despite the focus on water recovery it is the material transport and disposal properties which will define the product moisture. Achieving water recoveries beyond the stacking moisture is quite energy intensive and rarely makes economic sense.

Filter cake handling is difficult at best with poor flow and high shear stress being generally associated with moist filter cakes. Jenike type material testing provides valuable information when designing chutes and silos, and tests should be performed at the design moisture and at a slightly wetter upset condition. Good general principles include vertical surfaces in transfer chutes and the avoidance of temporary storage in bins or silos. Feeder conveyors can buffer the high batch loads and deliver near constant discharge to transfer conveyors

Filtration Plant

Equipment maintainability and plant safety are the most important factors in a modern large scale filtration plant. Separation of personnel from moving components and potential hazards can significantly improve plant safety. With large filters most parts are large and too heavy for manual lifting. To facilitate safe maintenance requires overhead cranes and access platforms to be designed into the filter building. Where possible, for maintenance the equipment should be stopped only to interchange components and not to effect repairs which should be conducted on components away from the operating plant. Replacement modules and consumable parts logistics help to ensure high plant reliability.

With the filtration of tailings all filtered material is transferred to the disposal site and there is no requirement for temporary storage. This separation of cake storage from filtration areas gives significantly more freedom to design the filter floor as hose down and spillages are significantly less important factors.

Materials handling issues are the predominant factor that determines filter plant elevation where the most cost effective option for pressure filters is at as low an elevation as possible. Aside from the obvious structural savings pumping energy and maintenance costs are a significant factor that should be considered when defining the plant elevation.

Filters

Pressure filtration has been established for a considerable time and while there have been many innovations the same basic concept persists. Most pressure filters utilise multiple filter elements between rigid end plates and maximising the number of plates for the process conditions minimises the investment cost. A significant stage in their development was the invention of synthetic fabrics which allowed the increase of process pressures. Filter fabric design remains one of the critical components and continuous fabric development is a key to the reliable and low cost operation of pressure filters.

While there are many filter manufacturers, with each taking a different path to adapt their technologies to the demands of industry, the focus has shifted from the process drivers of pressure and area, towards scale and technical efficiency in order to achieve the in-

crease of capacity required for tailings filtration. The number of filter plates and the size of ports determines the velocity of process fluids that pass through the ports on the first plate; this velocity then limits the number of plates than can be used in a single unit. For duties with low filtration rates in small filters there can be as many as 160 plates per unit, however, as the size and filtration rate increases so the number of chambers decreases.

With the number of plates being limited, filtration equipment development has trended towards the design of larger filter plates. For a number of years this was limited to 2000 mm x 2000 mm but today several manufacturers have produced filters with 2500 mm x 2500 mm filter plates and plates up to 3500 mm are in production. The increase in plate size has pushed the unit size to 2000 m^2 which is the scale of filter area required for tailings filtration. Even with these large units multiple filters are required to meet the design capacity of a tailings filtration plant. The issue of sequencing their operation will have a significant effect on the installed cost of the plant. As pressure filters operate on a batch basis they can share ancillaries provided they are sequenced so as to not require that ancillary at the same time.

From the equipment suppliers perspective the maximum filter capacity can be achieved where each unit has its own dedicated ancillaries. From a capital equipment cost perspective the sequencing of two or three filters will minimise cost. Any more than three filters is usually an unmanageable solution where one or more filters are waiting for a slower unit. Once any ancillary is shared between filters then all the filters are locked together and they will operate with the same cycle time as that of the slowest filter. Variations between filter cycle times can be in the range of 5 to 10%, and hence a similar loss of capacity can be expected from the faster filters.

If any part of the cycle is sequenced then the designer might as well share all of the ancillaries. The cost effective solution is to compare the ancillary savings of sequenced operation with a 5 to 10% increase in filter size.

Process Pumps

Depending upon the type of pressure filter, slurry feeding may be achieved with centrifugal pumps. The pumping of abrasive slurries at high heads will cause pump wear. For instance, when the pressure is around 600 kPa the wear is moderate, however, increasing the pressure requirement to 1000 kPa usually pushes operating speeds to the limit of current pump design and high wear and maintenance rates should be factored into the operational design. Pumping for filter feeding creates cyclic variations between off duty low pressure no flow through high flow low pressure to high pressure low flow and back again every 10 minutes. These conditions are demanding for slurry pumps and the cycling creates a challenge for pump wear and gland seal reliability. Minimising the pumping pressure substantially reduces the energy consumption and has a significant effect on maintenance costs.

Good plant designs capture cloth wash and filtrate water to a sloped bottom tank rather than discharging to the floor and clean-up sumps. This significantly reduces clean-up and enables the plant operator to concentrate on more productive tasks.

Process Targets

In contrast to many applications the performance required for large tailings filtration plant is governed by the geotechnical properties of the filter cake[1] and maximum water removal is generally not the optimum design point. While water recovery may be important, and in some cases can limit production, generally the selection of filtration for tailings dewatering is based on the decision to apply dry stacking of the tailings.

Dewatering tailings produce a filtered wet cake that is normally transported by conveyor or truck, deposited, spread and compacted to form an unsaturated tailings deposit. The solids fraction varies depending upon the particle size, shape, distribution and method of filtration. For slurries with a composite of fines and coarse particles, a typical moisture content of less than 20% can be achieved by using filtration systems, and with slurries that are low in fines then moisture contents as low as 12% w/w can be achieved.

For a typical cake with 80% w/w solids, almost 90% of the process water can be recycled. At the limit of presently available filtration systems capability, a cake of about 88% w/w can be achieved which represents a 94% recovery of process water.

Zero-Air-Void Unit Weight

The specific gravity of any cake can vary with the level of compression while the solid and water density are constant; the zero-air-void density is inversely proportional to water content. For a given solids and water content the best possible compaction is represented by the zero-air-voids curve. The actual compaction curve will always be below the saturated limit. This is demonstrated by the standard Proctor compaction test of 12,400 ft lb/lb^3 which corresponds to a pressure of about 5.9 bar (Figure 1). This compaction is achieved in civil construction by adding water and compacting soil.

By contrast, for filtration, sedimentation causes a reduction in void fraction and dewatering follows the zero air void curve. At a certain point the driving force (gravity) limits the degree of compression and no further liquid removal is possible. Sedimentation alone rarely achieves the compaction required for a stabile structure with the sedimented solids being above the

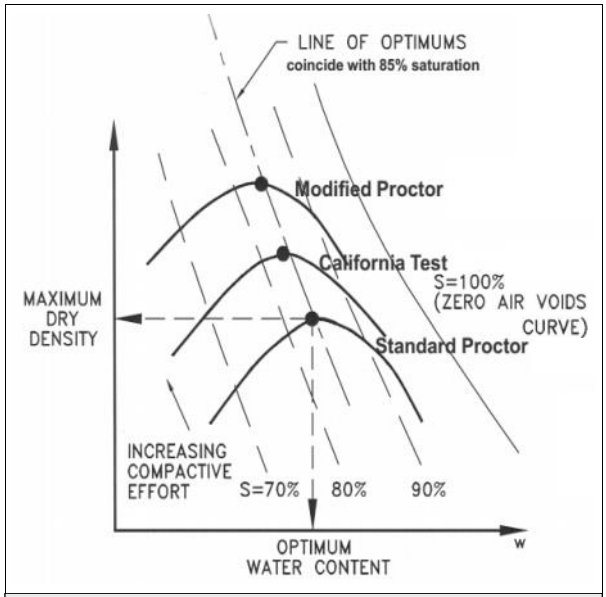

Figure 1: Representations of Proctor tests.

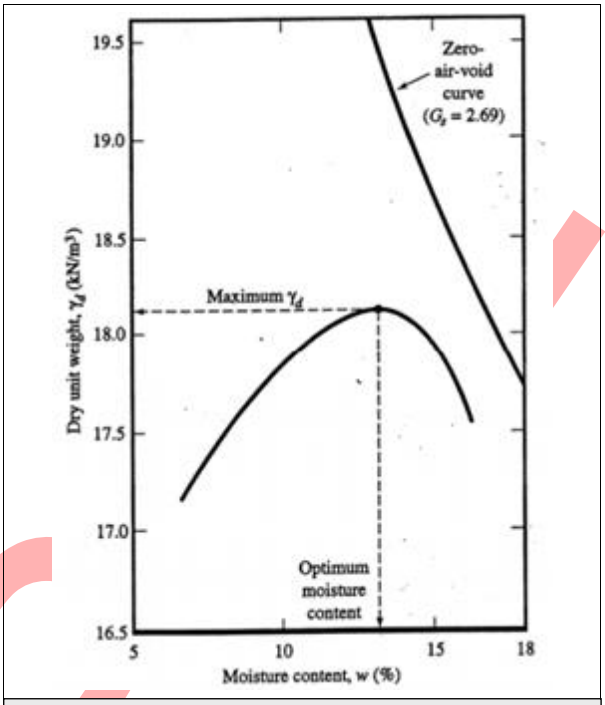

Figure 2: Dry unit weight vs. moisture content.

plastic limit. In tailings treatment solids can be left in dams for decades with the drainage liquid being slowly removed, then the surface is atmospherically dried to achieve a stable structure that is rehabilitated. The limit of sedimentation as a process solution is the limit of pumpability which is well below the moisture required for a stable structure.

Civil design studies by Gurtug and Sridharan[2] proposed some correlation for the optimum moisture content and the plastic limit of soils. These show the optimum moisture to be 65% of the plastic limit and can be represented by the following:

$$w_{opt}(\%) = (1.95 - 0.38\log(CE))(PL) \quad (1)$$

$$Y_{(d\max)}\left(\frac{\text{kN}}{\text{m}^3}\right) = 22.68\exp(-0.0183 w_{opt}) \quad (2)$$

where *PL* is the plastic limit (%), *CE* the compaction energy (kN m/m^3), w_{opt} the optimum moisture (%) and $Y_{(d\ max)}$ the max dry unit weight.

By shifting to filtration the magnitude of compression can be increased thereby allowing further movement along the zero air void curve to achieve the required moisture. Air blowing creates a horizontal shift to the left which removes water and replaces it with air. In order to achieve the required moisture some air should also be introduced into the cake which can be achieved by blowing, compressing to a higher level of compaction, materials handling or by desiccation of the filtered cake (Figure 2).

In general terms finer particles require more water or higher cake moisture than coarse particles. The method of materials handling, compaction strategies and site climate will all have an influence on the required cake moisture. Proctor testing provides valuable information on the process targets required from a tailings filtration plant. The similarities between Proctor testing and filtration tests warrant further investigation.

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STANDARDS FOR THE COMPRESSED AIR INDUSTRY

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Standards for the compressed air industry are broadly divided into two categories, those for the measurement of compressed air purity specification and compressed air treatment equipment performance. The ISO 8573 series of standards for compressed air purity measurement contains 9 parts of which Part 1 enables manufacturers and end users to specify compressed air purity. Compressed air treatment equipment can be validated against ISO 7183 for air drying technology or to ISO12500 Parts 1 through 4 for the removal of oil aerosol, oil vapour, particles and bulk water, respectively.

Combined with the vocabulary standard, ISO 3857 Part 4 Vocabulary they number in total 15 published standards that have been in development since the mid 1980's under the management of ISO Technical Committee ISO/TC 118/SC4 'Compressed air treatment technology'. Over the last 18 months the working group has completed a full review of all standards in the series and set priorities for the changes required to meet environmental legislation and where appropriate to adopt new methods since they were first published. As a priority the working group has identified that significant changes are required to ISO8573-2:2007 'Test methods for oil aerosol content' due in no small part to recent EU regulations and the availability of suitable reagents to undertake the infrared (IR) analysis method detailed.

This paper discusses the changes that are being proposed and provides an overview of a timetable for their adoption.

INTRODUCTION

Compressed air is a power source that is used worldwide in many industries and manufacturing processes. It is claimed that approximately 70% of all companies use compressed air for some aspect of their operations[1]. Considered by many to be the 4th utility[2] after electricity, gas and water, compressed air is generated on-site and on demand to provide motive power in applications as diverse as snow making machines and microchip fabrication, or beverage manufacture and mine tunnelling equipment. Due to the multitude of applications and diversity of their operating parameters a need for standardisation of the way air purity is expressed, and the way in which that purity is determined, is required.

ISO 8573 COMPRESSED AIR PURITY CLASSES AND PURITY MEASUREMENT STANDARDS OVERVIEW

The standards that detail air purity classes and air purity measurement methods are covered by the ISO 8573 series of documents (see Table 1). Part 1 of the series was developed to allow both manufacturers and users air to specify the compressed air purity with respect to the main contaminants experienced in compressed air generation, distribution and application. An overview of these air purity classes is given in Table 2.

The designation principle of the purity class of compressed air at the specified measuring point shall include the following information separated by a colon:

ISO 8573-1:2010 [Particles : Water : Oil]

In some cases users of this system omit to include the year of the document to which they are referring and as there have been a number of revisions since the document was first released the purity statement cannot be relied upon. A purity class statement relates to the maximum concentration of one of the 3 primary contaminants found in the compressed air. An example of compressed air purity requested by a prospective customer is given as follows:

ISO 8573-1:2010 [1 : 2 : 0]

In this case the customer has requested a purity of

Standards for compressed air purity	Title
ISO 8573-1:2010	Contaminants and purity classes
ISO 8573-2:2007	Oil aerosol content
ISO 8573-3:1999	Humidity measurement
ISO 8573-4:2002	Particle content
ISO 8573-5:2001	Oil vapour and organic solvent
ISO 8573-6:2003	Gaseous contaminants
ISO 8573-7:2003	Microbiological contaminants
ISO 8573-8:2004	Solid particles
ISO 8573-9:2004	Liquid water

Table 1: Table of standards currently in the ISO8573 series for the specification of compressed air purity and the measurement thereof.

	Mass concentration (particles/m^3)			Water	Total oil
Class	0.1 < d ≤ 0.5 (µm)	0.5 < d ≤ 1.0 (µm)	1.0 < d ≤ 5.0 (µm)	ºC pdp/mg/m^3	mg/m^3
0	As specified by equipment user or supplier and more stringent than Class 1				
1	≤ 20,000	≤ 400	≤ 10	≤ -70	≤ 0.01
2	≤ 400,000	≤ 6,000	≤ 100	≤ -40	≤ 0.1
3	-	≤ 9,0000	≤ 1,000	≤ -20	≤ 1.0
4	-	-	≤ 10,000	≤ +3	≤ 5.0
5	-	-	≤ 100,000	≤ +7	> 5.0
6	0 - ≤ 5 mg/m^3			≤ +10	-
7	5 - ≤ 10 mg/m^3			≤ 0.5 g/m^3	-
8	-			0.5 ≤ 5 g/m^3	-
9	-			5 ≤ 10 g/m^3	-
X	> 10 mg/m^3			> 10 g/m^3	-

Table 2: Overview of the purity classes in ISO8573-1:2010.

Class 1 for Particles, followed by Class 2 which is equal to or drier than -40ºC pressure dew point for Water Vapour and Class 0 Total Oil. In turn the supplier is able to begin to specify equipment to meet the stated requirements and a given set of conditions.

Class 0 is often misinterpreted and does not mean that there is zero contamination. In itself it is not a purity level statement excepting that it is more stringent than the maximum concentration or 'upper' limit assigned to Class 1 for the contaminant of interest. Thus, a Class 0 statement for Total Oil would have an upper limit of less than 0.01 mg/m^3 as is the case for Class 1 for this contaminant. It is therefore a statement that needs to be agreed between two parties, and could well be that it aims to match with some other more stringent requirement to control Total Oil. In addition, it is worth noting that if claims are made for a purity level outside of the detection range identified in the relevant standard, then the precise way in which the measurement will be made must be agreed also.

Of further interest is the statement for 'Total Oil' which is the combined concentration of oil aerosol and oil vapour. By way of example, coalescing filters that claim to provide air purities of Class 1 can only do so in relation to oil aerosol since they do not impact the oil vapour concentration, or oil in the gaseous phase, in the compressed air. The oil vapour concentration in the compressed air at any one time depends upon the oil type, age, air temperature and compressor running conditions. Hence, in this case without a suitable adsorption stage for the oil vapour the class claimed may not be achieved in reality. In the same way, on site measurements that do not include the vapour content in the total oil statement cannot claim to meet a purity class since the magnitude of the oil vapour component of the statement is unknown.

ISO 12500 AND 7183 EQUIPMENT PERFORMANCE STANDARDS OVERVIEW

The primary contaminants in compressed air are water, oil and particulates, either having been ingested by the compressor from the atmosphere or produced as a result of the compression process and the mode of distribution. Equipment to remove these contaminants is available from a broad range of manufacturers all with their own claims regarding performance. As such, in 2007 the first compressed air standards were published and these detailed test methods for equipment marketed for the removal of liquid and gaseous contaminants. Table 3 provides a list of the standards detailing equipment performance covered by the ISO12500 series for oil aerosol, oil vapour, particles and bulk water. In addition ISO7183, revised in 2007, details compressed air dryer equipment test methods for water vapour removal.

Further additions to the above standards are under consideration including a method that aims to determine the energy consumed whilst operating a compressed air filter over its design life. This reflects sev-

Test methods for equipment for compressed air	Scope
ISO 12500-1:2007	Oil aerosols
ISO 12500-2:2007	Oil vapours
ISO 12500-3:2009	Particulates
ISO 12500-1:2009	Water
ISO 7183:2007	Compressed air dryers Specifications and testing

Table 3: Table of standards currently published for the determination of equipment performance.

eral industry led initiatives to control and reduce energy consumption and greenhouse gas emissions for which a standardised means of assessment and rating would be required.

Over the last 10 years the focus of the ISO/TC118/SC4/WG1 working group has been the development of new standards for equipment verification with the publication of ISO12500 Parts 1 through to 4, the amendment of ISO 7183 and ISO 8573 Parts 1 & 2. It is now time to review and prioritise any changes required due to new improved techniques and pressure bought to bear by legislation.

NEW WORK ITEM. ISO8573 PART 2: TEST METHODS FOR OIL AEROSOL CONTENT

The measurement of liquid oil content in its various forms in compressed air is detailed in Part 2. As shown in Table 4, depending upon the oil concentration expected it is possible to select one of two methods. Method A which employs coalescing filters and Method B using a membrane that is subsequently analysed by solvent extraction and infra-red (IR) spectroscopy (see Figure 1).

Method B requires that a sample of compressed air is passed through a membrane holder containing three layers of high efficiency microfibre glass filtration media and any oil aerosols collected on the membranes are extracted by solvent washing and subsequently by IR analysis. Since publication, initiatives derived from the Montreal Protocol (1987) on substances that deplete the ozone layer[3,4] and subsequently under the Kyoto Protocol (1997) to reduce greenhouse gas emissions have reduced the availability of suitable reagents. Subsequently, the majority of reagents with the transparency required in the alkane C-H stretching region of the IR spectrum have been taken out of production and/or their use directly banned by enforcement of international legislation.

One such mandate is European Regulation (EC) No 1005/2009 on substances that deplete the ozone layer and identifies a list of controlled substances in Annex 1 that included such reagents as tetrachloromethane (or carbon tetrachloride as it is perhaps more commonly known) and trichlorotrifuoroethane (TCTFE, CFC-113) as having high levels of ozone depleting potential. Subsequently, EU Regulation 291/2011 on essential uses of controlled substances mandated that such substances could no longer be used, for among other things, such purposes as the cleaning of components, or for the determination of hydrocarbons, oils and greases in water, air or waste.

Without a suitable solvent for IR assays ISO8573-2 Method B is no longer relevant, effectively limiting the detection ranges to those of Method A. Hence, concentrations of oil aerosol in air lower than 1 mg/m^3 can no longer be measured. This has further implications when testing coalescing filters for oil aerosol removal in accordance with ISO12500-1 since the majority of equipment performance claims are below that of 1 mg/m^3. Oil aerosol downstream of the test filter is measured by means of ISO8573-2 and without recourse to Method B the scope of ISO12500-1 becomes narrowed.

In lieu of the issues relating to solvent availability for ISO8573-2, for Method B a full review and literature search was undertaken by the Working Group throughout 2012/13 which identified two potential candidate methods that would be considered further.

Solvent Extraction Using Tetrachloroethylene and IR Analysis

An analysis procedure that applied tetrachloroethylene (C_2Cl_4, also known as tetrachloroethene or perchloroethylene) in IR assays of oil and grease in water was published by Kaloudis *et al.* in September 2005[8]. This was followed by an application note by Perkin Elmer[9], namely 'Determination of oil content in membranes used in compressed air sampling by IR spectroscopy' in 2011. Both papers use tetrachloroethylene solvent for the extraction procedure. Library spectra[10] of pure tetrachloroethylene shows no interference bands in the 3000 cm^{-1} wavenumber region (Figure 2) which would make this reagent seemingly ideal for hydrocarbon analysis.

Parameter	Method A Full flow	Method B1 Full flow	Method B2 Partial flow
Contamination range	1 mg/m^3 to 40 mg/m^3	0.001 mg/m^3 to 10 mg/m^3	0.001 mg/m^3 to 10 mg/m^3
Max. velocity in filter	See 7.1.2.10	1 m/s	1 m/s
Sensitivity	0.25 mg/m^3	0.001 mg/m^3	0.001 mg/m^3
Accuracy	± 10% of actual value	± 10 % of actual value	± 10 % of actual value
Max. temperature	100 ºC	40 ºC	40 ºC
Testing time (typical)	50 h to 200 h	2 mins. to 10 h	2 mins. to 10 h
Filter construction	Coalescing line filter	Three-layer membrane	Three-layer membrane

Table 4: Extract from the ISO8573-2:2007 guide for the selection of test method.

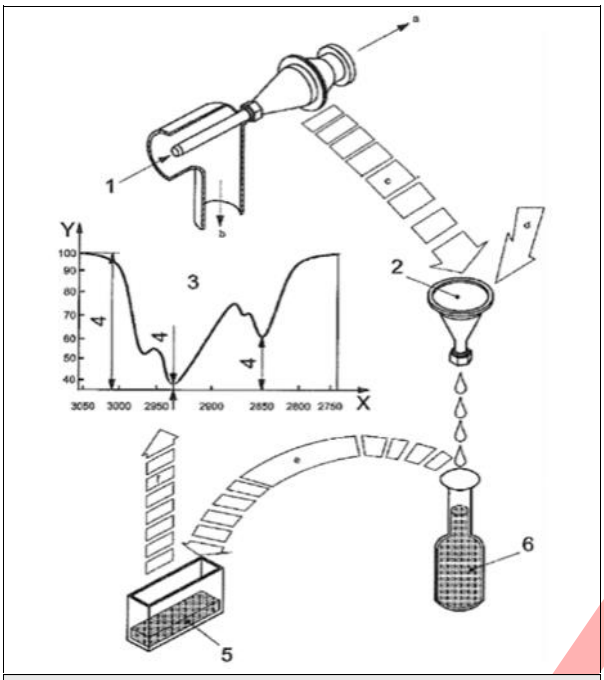

Figure 1: Oil recovery from the membrane using solvent extraction in accordance with ISO8573:2.

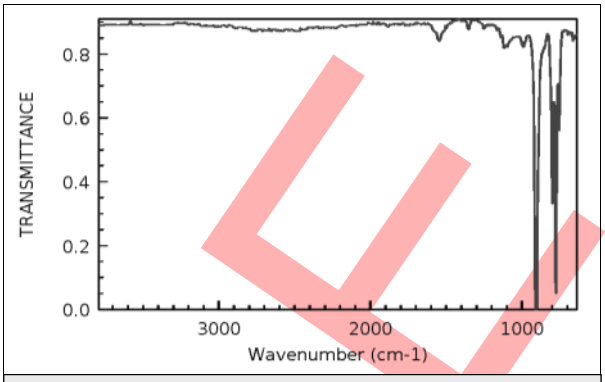

Figure 2: IR transmission spectra of pure tetrachloroethylene[10].

However, to make it practical to store and distribute this reagent, stabilisers are commonly added which then introduce a strong absorbance at typically 2875 cm^{-1} wavenumbers (see Figure 3) that interferes with the C-H peak expected at 2860 cm^{-1} wavenumbers for oil.

The above would suggest that tetrachloroethylene is of limited use, however, work undertaken by Atlas Copco Airpower, Belgium developed a method where the number of peaks measured is reduced from 3 to 2, and the cuvette pathlength is selected to suit the concentration range. As a result, interference from the stabiliser in this region can be minimised and the accuracy required by the existing standard maintained.

In their proposal the absorbance '*A*' of the sample is determined from the average for the absorbance of each of the two peaks selected for a given cell pathlength and concentration (equation (1)):

$$A = Avg\left[A_1 : A_2\right] \tag{1}$$

where *A* is the average absorbance. A_1 and A_2 are the absorbance of each of the two peaks produced for a given concentration. The absorbance for each peak is determined as follows:

$$A_2 = \log_{10}\left(\frac{I_0}{I_n}\right) \tag{2}$$

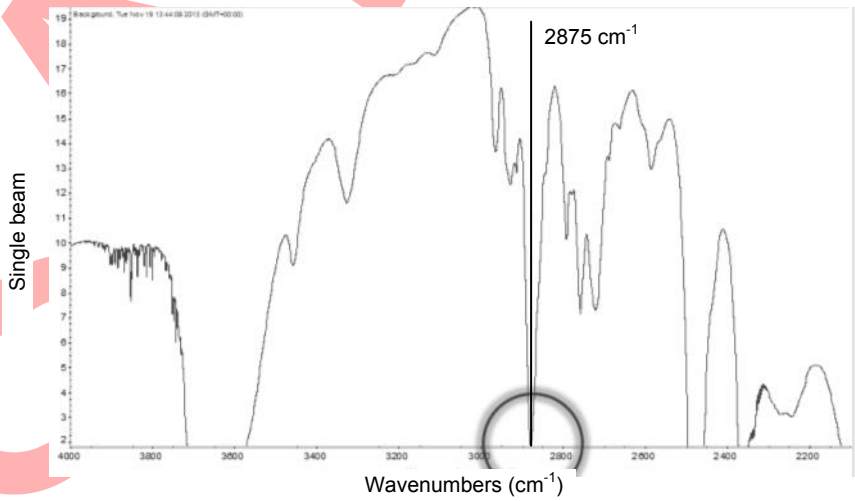

Figure 3: Typical IR transmission spectra of commercial grade tetrachloroethylene in quartz glass cuvettes where it can be seen that there is a strong absorbance in the region of 2875 cm^{-1} wavenumbers.

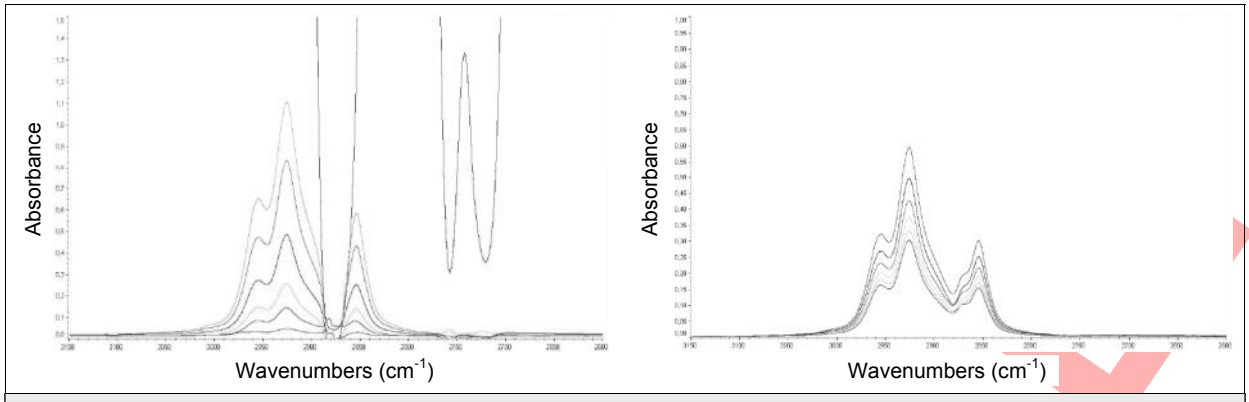

Figure 4: Absorbance spectra obtained from a 4 cm pathlength cuvette (*left*) and 1 cm pathlength cuvette (*right*) with tetrachloroethylene and compressor oil analytes. Note: The absorbance spectra for the 4 cm cuvette is shown with the interference peak from tetrachloroethylene against air overlaid for reference.

where A_n is the absorbance of the selected peak, I_0 the baseline intensity of the selected peak and I_n the overall intensity of the same peak.

Calibrations have been performed using 1 cm and 4 cm pathlength cuvettes in the range 60 to 120 µg ml^{-1} and 1 to 60 µg ml^{-1}, respectively. Analysis by least squares regression resulted in a fit of between 99.74% and 99.96% to that of a straight line corresponding to the Beer-Lambert law for IR transmission through a substance.

In one example the new proposal developed by Atlas Copco uses an integration of the areas under the curve for two peaks observed here at 2960 cm^{-1} and 2925 cm^{-1} rather than the three peaks as detailed currently. It is perhaps worth noting that the exact peak locations are oil specific and as such their location needs to be determined by measurement of the actual oil in the compressed air system. Initial trials conducted by the Working Group are encouraging and if proven to be suitable then this modification to the existing method could be more easily adopted by existing users of the Part 1 standard.

Solvent Extraction Using N-Hexane and Analysis by Gas Chromatography

The determination of hydrocarbon vapours in compressed air is well documented in the method described in ISO8573-5 Test methods for oil vapour and organic solvent content. This document was first published in 2001 and is a modification of the methods described in ISO9486 and ISO9487, workplace air determination of vaporous chlorinated hydrocarbons and vaporous aromatic hydrocarbons, respectively.

In place of the above approach which relies upon solvent extraction using carbon disulphide of a sample tube packed with activated carbon, the proposal is to extract collected oil from the membrane using n-hexane and the amount determined by gas chromatography with a flame ionisation detector (GC/FID). The approach has found favour with a number of users and has proven reliable for them over the years and if

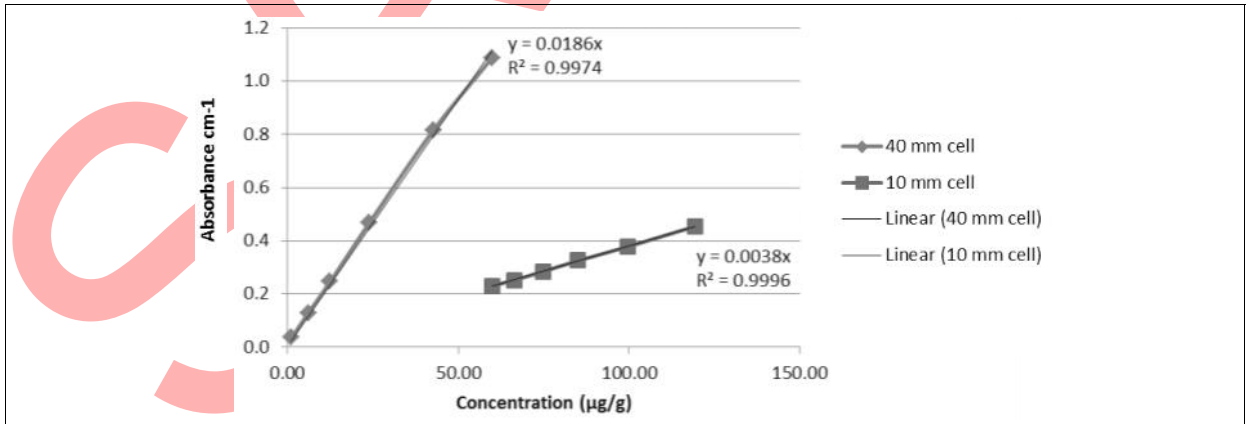

Figure 5: Calibration curves obtained for 1 cm and 4 cm pathlength cuvettes with tetrachloroethylene and compressor oil analytes.

adopted alongside the existing IR method would enable a wider application of the ISO8573-2 standard than at the present time.

Work undertaken by the Institute for Energy and the Environment (IUTA), Duisburg, Germany using a gas chromatography with flame ionisation detector (GC-FID) has shown that a chromatogram can be obtained for the analyte extract obtained from the membrane wash process. The concentration of oil in solution is proportional to the area under the chromatograph within the limits of n-decane (C10, boiling point = 175ºC) and n-tetracontane (C40, boiling point = 525ºC). This area is compared with oil standard solutions (synthesized with reference oil taken from the compressor before measurements if possible) and the amount of oil is calculated with regard to a regression graph produced during calibration.

The proposed solute for this method is n-hexane which is known to be available widely, to be of good purity and is relatively inexpensive. Alternatives such as n-pentane and n-heptane would also be suitable but due to the diverse nature of compressor coolants and lubricants it is good practice to investigate the suitability of the chosen reagent with the oil of interest regarding solvency.

Calibration of the GC-FID response for the oil of interest is conducted having produced 10 ml of each calibration standard in the range 20 µg/ml to 300 µg/ml along with a blank n-hexane sample. Where several oils are known to be present then the response for these is determined separately. If the source of the oil cannot be identified then a 'reference' oil can be used to which all results are stated as being equivalent to. By analysis the area under the chromatogram is computed and obtained from the GC-FID between C_{10} and C_{40}.

A plot of Peak Area for an average of three repeat samples against the 10 individual aliquots is produced, an example of which can be seen in Figure 7. In this case by least squares regression a fit of 99.93% was

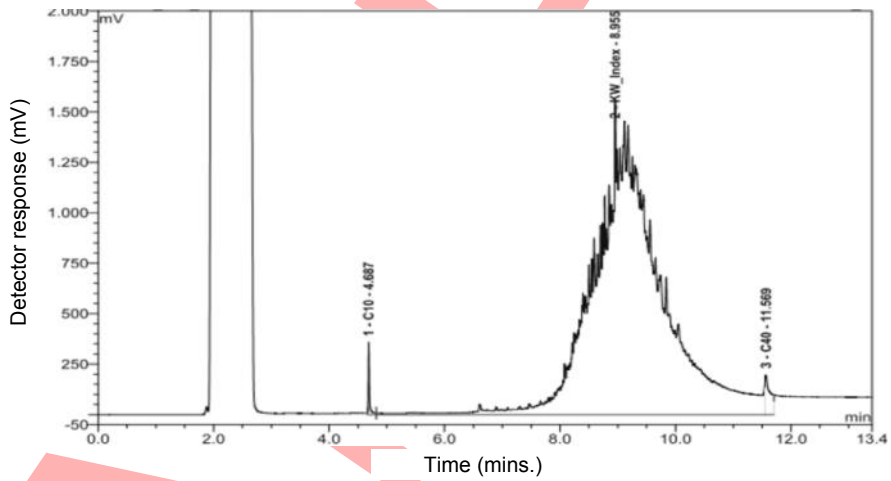

Figure 6: Typical chromatogram for compressor oil after elution with n-hexane. The C_{10} and C_{40} markers can be clearly seen.

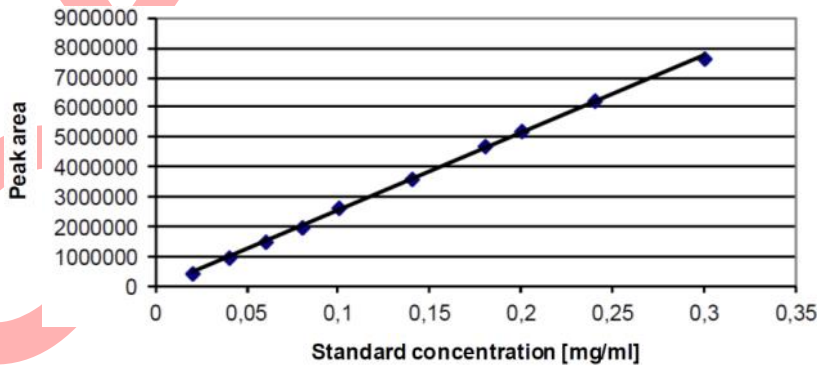

Figure 7: GC-FID Peak Area response for calibration oil samples in the range 20 µg/ml to 300 µg/ml in n-hexane. Detection down to 4 µg/ml has been demonstrated.

achieved to that of a straight line which demonstrates the linearity of the technique over a broader range of concentrations than is currently possible using IR. Once the total mass of oil extracted from the membrane has been determined by either of the proposed methods the concentration of oil in the compressed air can be calculated.

PROJECT PLANNING

Having now been accepted as a New Work Item Proposal (NWIP) by ISO/TC118/SC4 further work will identify the efficacy of these proposals. A 2 year project plan has been established (see Figure 8) to set within the confines of the ISO process for the revision of a standard.

To establish the repeatability and reproducibility of both proposed methods the working group agreed at the October 2014 meeting to conduct an exchange of samples using one oil type at three levels of concentration when applied to membrane discs by one laboratory. Results from the test program will shared between the members prior to the next working group meeting scheduled for March 2015. At this time a Draft International Standard (DIS) will be ready for release.

CONCLUSIONS

Under the guidance and control of ISO working group ISO/TC 118/SC4/WG1 there are now a total of 16 published standards that have been in circulation commencing in the mid-1980's. The drive up until now has been on the generation of new standards, initially for the measurement of compressed air purity, but in more recent years for compressed air equipment performance validation. A review of the full suite of documents throughout 2012/13 revealed that a number of users were experiencing difficulties complying with ISO8573-2 oil aerosols.

Due to the Montreal and Kyoto protocols, restrictions on the use of controlled substances to protect the ozone layer and reduce global warming have come into force. More recently these initiatives have resulted in local regulation, such as that of EU Regulation 291/2011, which prevent the use of such reagents for oil analysis. This has direct implications for working in accordance with ISO8573-2 when measuring oil aerosol concentrations below 1 mg/m^3.

A modification to the existing method has been reviewed to enable solvent extraction with tetrachloroethylene and in addition a new method centred on the use of GC/FID instrumentation and membrane extraction with n-hexane has been proposed. Initial work suggests that both new methods provide the necessary level of linearity across the range of concentrations of interest. The next step is to widen the trials to include five participating laboratories in order to establish repeatability and reproducibility of the two proposals. The results of the lab trials are due to be available before the end of November 2014 at which point a decision on whether to expand the trials will be taken. A two year project plan has been developed with the aim of publishing a new version of the Part 2 standard for oil aerosol measurement before the end of 2016.

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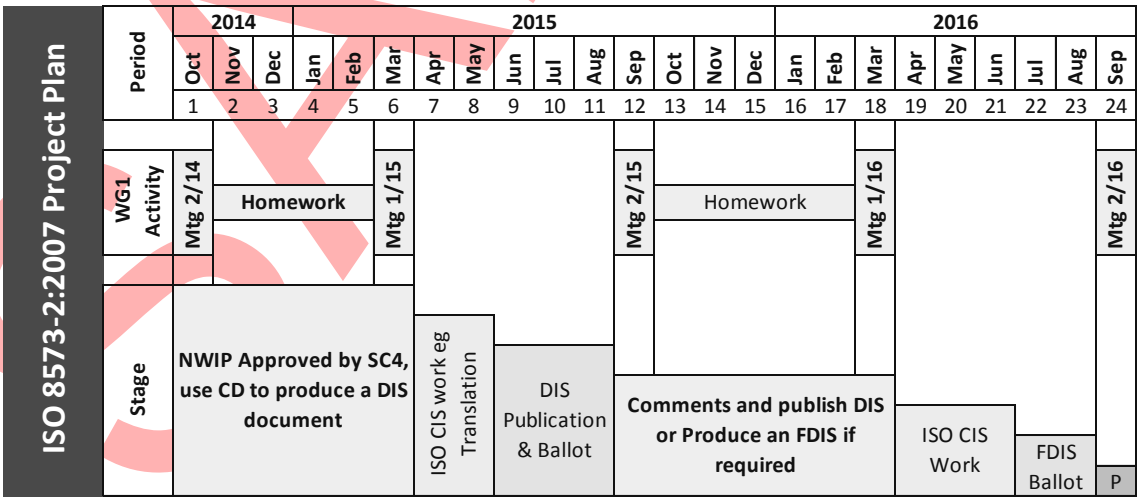

Figure 8: ISO two year project plan.

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ASPECTS OF THE DESIGN AND USE OF SEDIMENTING CENTRIFUGES

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The effects of bowl geometry on the liquor clarification and solids dewatering characteristics of solid bowl decanting centrifuges are discussed. The requirements for centrate clarity and throughput are contrasted with those required for dry decanter cakes and high solids capacity on the assumption that the solids in the decanter feed are crystalline and incompressible. The aim of this paper is to provide a basic understanding of some of the compromises necessary in the selection of decanter centrifuges.

INTRODUCTION

Solid-liquid mixtures may be separated into their constituent solid and liquid phases by sedimentation where gravity forces cause the (usually) heavier solid particles to settle out from the less dense liquid. The rate of sedimentation depends on the difference in densities between the solids and liquid, the viscosity of the liquid, the size and shape of the solid particles, and the magnitude of gravitational acceleration (which is also known as '*G*'). The speed of the process can be greatly increased by carrying out the process in a rotating bowl where very high *G* is generated by centrifugal effects. A decanter centrifuge (Figure 1) uses a combination of sedimentation and filtration drainage, which is enhanced by centrifugal *G*, to continuously separate solid-liquid mixtures into their component parts.

Referring to Figure 1, the slurry is fed through a stationary pipe (1) into the interior of an imperforate bowl (2) that rotates at high speed. Centrifugal forces cause the solid particles to sediment through the liquid and settle on the inside surface of the bowl. A helical scroll conveyor (3) with blades (6) closely conforming to the inside of the bowl rotates at a differential speed to the bowl (typically a 0.5-5% differential) by means of a fixed ratio epicyclic gearbox or hydraulic motor (4). The slow differential rotation between the bowl (2) and conveyor (3) pushes the sedimented solids towards one end of the bowl while the liquids can flow freely towards the opposite end through the open channel (5) created by the blades (6) forming the helical scroll (3). At the solids discharge end, the bowl and conveyor are conically tapered inwards (7) so that the conveyor 'lifts' the solids out of the pool of liquid and ejects them out of the bowl through discharge ports (8) while still retaining the liquid. The depth of the liquid (or pool) within the bowl is controlled by plates fitted into discharge ports at the liquids discharge end (9).

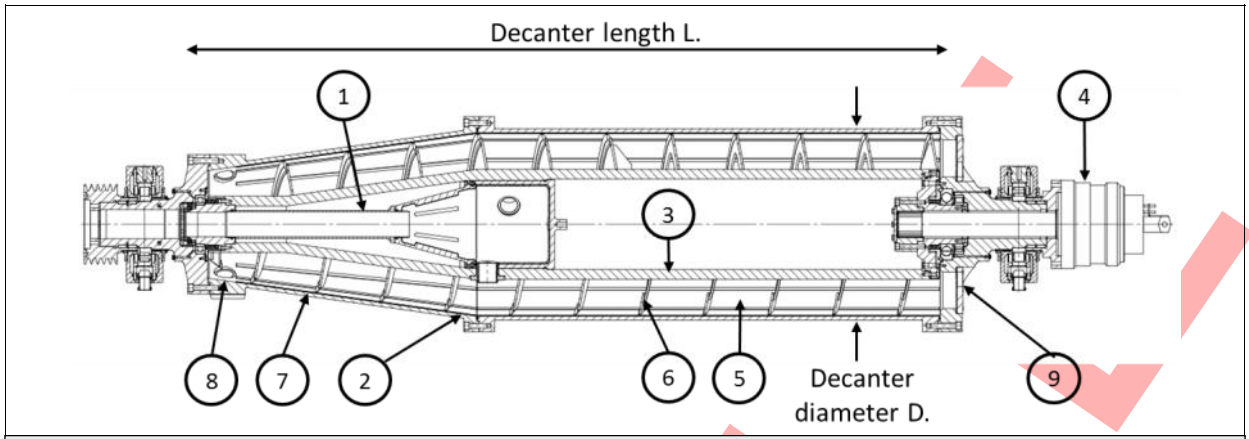

Figure 1: Typical solid bowl decanter centrifuge.

The relative proportions of the decanter bowl overall length allocated to deliquoring the solids (conical section) and clarification of the liquor (parallel section) has a significant effect on the overall performance of the decanter. Whilst adjustments can be made to an existing decanter to alter its process performance (e.g. bowl speed, differential speed, pool depth, feed rate etc.) the overall diameter and length are fixed at manufacture. It is therefore important to understand the balance between allocating bowl volume to liquor clarification and solids deliquoring. These two aspects are considered in more detail in what follows.

LIQUOR PROCESSING CAPACITY

A significant amount of work has been published on the characteristics of liquor clarification within a solid bowl decanter centrifuge as shown in Figure 1. Many comments below are based on the work of Madsen[1], Madsen[2] and Records & Sutherland[3].

Figure 2 shows the parallel portion of the decanter; the key dimensions referred to in the text are marked. Unless the decanter is being used in a classification application, the goal is generally to remove as much of the solids matter from the liquor as possible to produce a clear liquid discharge or 'centrate' from the decanter.

One approach to analysing decanter clarification performance is to assume plug flow of the liquor down the channel formed by the conveyor blades and use Stokes' law to calculate the smallest spherical particle that can settle through the pool depth in the time it takes the feed liquor to move from the point where it enters the bowl, round the helix formed by the conveyor to the liquor discharge ports.

For a particle of diameter d in a fluid of dynamic viscosity μ where the density difference between the solids and fluid is $\Delta\rho$, the settling velocity in a uniform acceleration G is proportional to[4]

$$V \propto \frac{d^2 \Delta\rho G}{\mu} \qquad (1)$$

If the feed particle size distribution is known then the

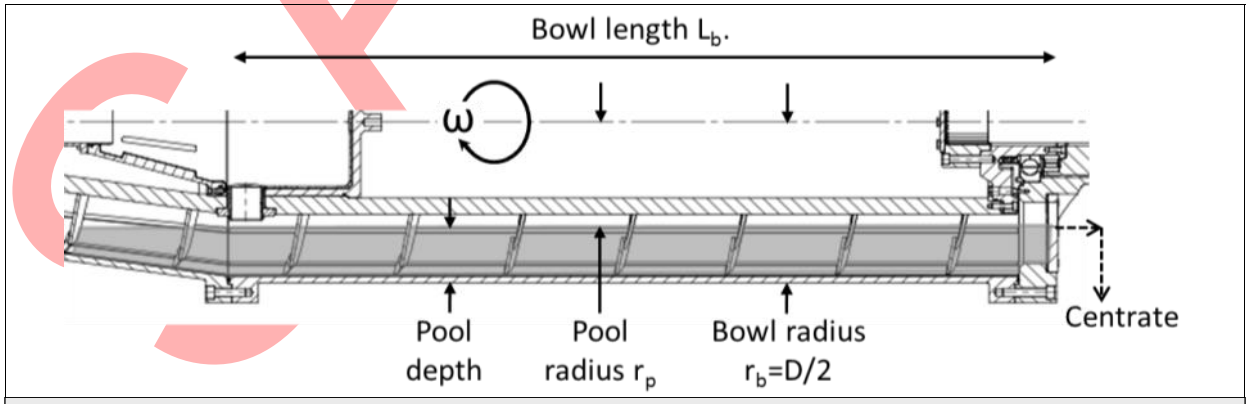

Figure 2: Parallel section of bowl showing liquor pool.

decanter feed rate necessary to give a liquor residence time just sufficient for all particles above a specified size to settle to the bowl wall and be conveyed to the solids discharge can be calculated. In practice this procedure doesn't work well. Madsen[2] reports that the separating capacity achieved is between 10-50% of the theoretical value. Likewise published test data[1] give a calculated maximum centrate particle size of 1.5 µm against an actual result of 5 µm.

Another well-known approach originated by Ambler in 1952[5] is the Sigma (Σ) theory. This follows a similar methodology to the settling of a spherical particle under Stokes' law. There are many formulae based on Ambler's initial work[4,6]; one such expression is

$$\sum = \frac{2\pi\omega^2 L_b}{g}\left(\frac{3}{4}r_b^2 + \frac{1}{4}r_p^2\right) \qquad (2)$$

where g is the acceleration due to gravity, ω the angular velocity of the bowl and L_b the length of the bowl. Making the further simplification of replacing r_b and r_p by the bowl diameter $r_b = D/2$, and substituting $G = D\omega^2/2g$, the expression becomes

$$\sum \propto GDL_b \qquad (3)$$

where G is the centrifugal acceleration. Σ is useful when scaling up from test machines to plant scale where liquor clarification is the important parameter. However, it does not work well when scaling between differing centrifuge types or between differing geometries within the same centrifuge type. To address these issues some centrifugal manufacturers have developed modified forms of Σ theory, adjusted to fit extensive in-house test data, which can be applied more widely; see for example[4].

The approaches described for understanding decanter clarification performance are deficient and the innovative work by Madsen[1] and Madsen[2] goes a long way to explaining why.

Implicit in the Stokes' settling and the Σ approach is the assumption that the whole length of the clarification section of the decanter bowl (i.e. the parallel portion L_b in Figure 1) is active in the sedimentation process. Investigations by Madsen[1] using a decanter bowl constructed from transparent material allowed the liquor flows within the decanter to be studied. The results showed how the sudden tangential acceleration of the feed material as it enters the pool produces high velocity gradients in the pool surface layers where the new feed material enters the decanter giving a flow profile very different from that assumed in plug flow. As the liquor flow proceeds towards the discharge the viscous damping effects eventually stabilise the flow into something closer to plug flow. Only at this point, possibly half way down the parallel portion of a typical decanter, do the assumptions used in Σ (equations (2) and (3)) or Stokes' law (equation (1)) start to apply.

Figure 3, taken from Madsen's paper[2], shows a qualitative view of the flow patterns seen in the transparent decanter. Note the high velocities at the surface of the pool which will tend to carry large particles to the liquor outlet, thereby reducing the decanter clarification performance. For full details of the test work also see[1].

Based on the stated understanding of the conveyor liquor flows the following descriptions consider the effects of diameter, length and G on decanter clarification performance. The effects on solids drying performance are considered in the section 'Solids processing capacity'.

Effects of Parallel Bowl Length

Increasing the length of the parallel section of the bowl increases the value of Σ for the decanter - see equations (2) or (3). However, the increase in Σ is non-linear. For example, in a decanter with an overall length to diameter ratio (L:D) of 3:1 perhaps half the parallel length from the feed to the mid-point of the parallel section is taken up stabilising the flow to something approaching plug flow. The remaining half from the midpoint to the liquor discharge then contributes to the settling of the solids. If the decanter overall length to diameter ratio L:D is increased from 3:1 (comprising 2 parts parallel bowl + 1 part conical bowl : diameter) to 4:1 (3 parts parallel + 1 part conical : diameter) then Σ would increase by 100% rather than by 50% as

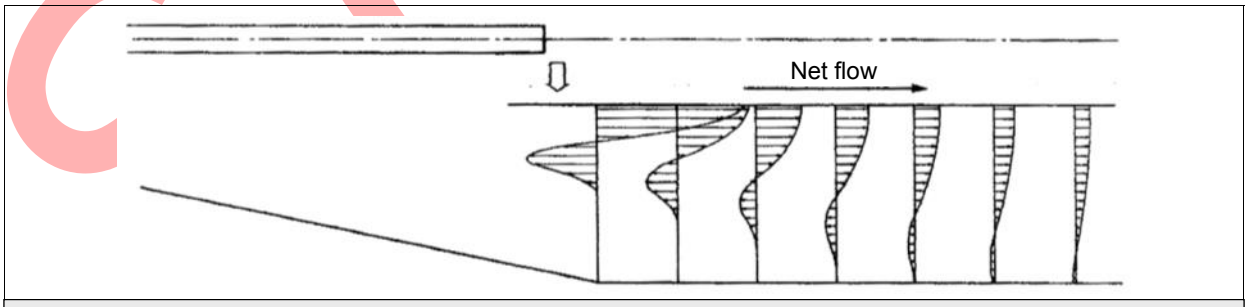

Figure 3: Decanter bowl flow patterns, adapted from Madsen[2].

would be expected from equations (2) or (3).

The resulting improvement in Σ can be used for increased capacity, or to capture a larger proportion of the fine solids in the feed. Increasing the parallel bowl length is also attractive from a manufacturing standpoint. Simply making the decanter longer generally involves the least modification to the design and has the lowest manufacturing cost increase. It is for these reasons that most modern decanters have a high *L*:*D* ratio of perhaps 4:1 or 4.5:1 where centrate clarity and high liquid capacity are the important goals.

For safe and reliable operation it is normal for the fundamental whirling natural frequencies of the decanter rotating components to be kept significantly above the running speed by a margin of 25-30%. If the running speed is too close to the natural frequency of the bowl or conveyor then severe vibrations will occur in operation, which can lead to mechanical failure. If the lengthening of the decanter reduces its lowest natural frequency (typically that of the conveyor) to the point where the running speed has to be reduced to maintain the margin of 25-30% then the benefit of the additional length is lost. Further discussions are presented below.

Effects of Diameter

Equations (2) and (3) show that increasing the diameter of the bowl *D* should have a similar effect to increasing the length L_b, it also allows the same *G* to be achieved with a lower rotational speed. However, it is generally more effective to increase the length rather than the diameter to obtain additional liquor clarification capacity through reduced turbulence (see above and Madsen[2]). Increasing the bowl diameter tends to increase turbulence. For example, consider a decanter feed zone where the pool depth is set to be a constant fraction *k* of the bowl radius r_b. To increase its velocity to $(r_b - kr_b)\omega$ to match that of the pool surface the feed must have its kinetic energy increased by *E* where

$$E = \frac{1}{2} m r_b^2 \omega^2 (1-k)^2 \qquad (4)$$

In providing this, a further amount of energy equivalent to equation (4) is lost in viscous drag and turbulence in the pool surface layers. It is such an energy loss that causes much of the turbulence referred to above. As $G = r_b\omega^2$ the total energy requirement for feeding becomes $mr_bG(1 - k)^2$, so for a constant *G* the energy (and therefore power) requirement increases with bowl radius as does the associated turbulence.

Effects of Bowl G

Equations (2) and (3) indicate that the higher the product GL_b so the better is clarification of the liquor. The strength of the materials used to construct the bowl and conveyor set an upper limit for the maximum *G* for a given bowl diameter for decanters with a low *L*:*D* ratio. As the *L*:*D* ratio increases a second constraint comes into play that limits the maximum rotational speed (RPM) and therefore the *G*.

The maximum safe decanter speed is highly dependent on the length of the conveyor which is typically constructed from a thin walled tube to which are attached the conveyor blades; the natural frequency of such a tube of length *L* is inversely proportional to L^2. As an example consider a decanter running at its maximum allowable speed (25% below the conveyor natural frequency). If the conveyor is lengthened by 10% then the natural frequency reduces to $1 / 1.1^2 = 0.826$ of its original frequency, so the rotational speed (RPM) must also be reduced to 0.826 to maintain the safety margin; centrifugal $G = 2\pi r_b(\text{RPM})^2/60$ so the *G* reduces to 0.826^2 or 68.3% of its original value. This is a very large reduction in *G* for a small increase in length, leading to reduced process performance – see equations (2) and (3).

For applications with low feed solids content requiring the highest centrate clarity several techniques exist to allow decanters with *L*:*D* up to 5:1 to operate at high G, see for example Madsen[2].

Based on the simple analysis outlined the best centrate clarity and throughput and lowest energy demand will be achieved with high *G*, small bowl diameters and a deep pool. Note that the deliquoring of solids present in the feed has not been considered. The next section looks at the effects of *G*, diameter and length on the processing of crystalline solids.

SOLIDS PROCESSING CAPACITY

Decanters are used to separate a variety of solids from liquids. The properties of the solids have a significant bearing on the optimum design of the conical section of the decanter. What follows highlights some important aspects for processing fine incompressible crystalline solids such as $CaSO_4$, $FeSO_4$, coal and PVC where the feed material contains 20-35% w/w solids.

The deliquoring of a filter cake against time is shown schematically in Figure 4 as three phases. Phase I shows the solids after initial sedimentation with the liquor surface above the cake. In Phase II the liquor has receded below the cake surface, and in Phase III the liquid adhering to the particles and at the contact points between particles by surface tension is removed.

The initial sedimentation of the solids and their transport up the portion of the conical section below the pool can be thought of as Phase I of the deliquoring process. Phase II, where the liquor level recedes

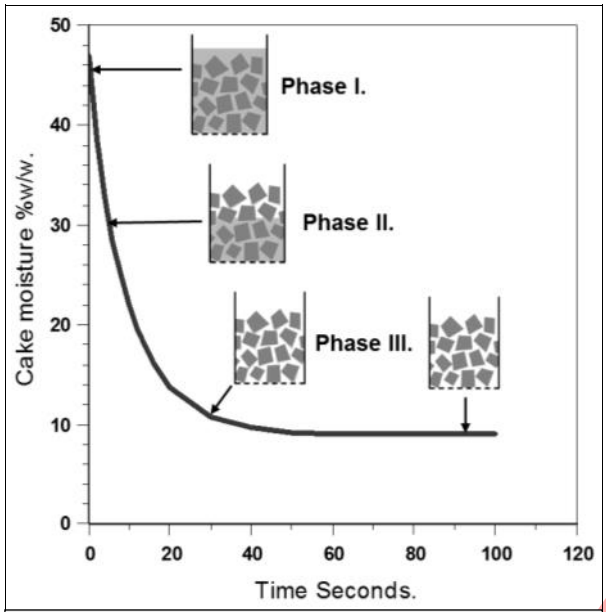

Figure 4: Typical deliquoring curve showing the basic filtration phases.

within the cake pile (generally triangular in cross-section for crystalline cakes in a decanter – see Figure 5), occurs during the transport up the 'dry' portion of the conical section. Typically the time to reach the limiting dryness shown in Figure 4 is several minutes for fine particles of 100 µm or below. As the solids residence time in a typical decanter is short (perhaps 2 -15 s) the filtration taking place on the dry beach is predominantly that of Phase II. Little Phase III drainage occurs within a decanter unless the solids throughputs are low or the particle size is large.

A basic theoretical analysis of the drainage of a uniform incompressible cake in a centrifugal field *G* shows that the average flow velocity through the cake in Phase II is constant regardless of the liquid level within the cake[7]. This can be used as the basis for a simple scale up model for decanter cakes. Tests indicate that to a reasonable approximation the parameter

$$S = \frac{Gt}{(h_p)^{0.5}} \qquad (5)$$

varies linearly with liquid content of the cake discharged from the decanter. Figure 6 shows the result from a variety of tests where *G*, dry beach time *t* and pile height h_p (see Figure 5) were varied and the resulting values of *S* are plotted against cake moisture. Note that this approximate empirical relationship only applies when:

- Cake deliquoring is of the type Phase II only
- The solids are crystalline and incompressible, it does not apply to sludges and pastes
- Moisture is surface moisture, inherent moisture is excluded.

The primary use for equation (5) is scale-up, however, it is also useful when optimising decanter solids deliquoring performance. By way of example the calculations presented below consider some elements of solids optimisation for a 1000 mm diameter decanter, with a cone half angle of 10º running at 1400 rpm with a fixed gearbox ratio that is processing 100 tonnes per hour of feed containing 20% solids.

Effects of Conical Bowl Length

Figure 7 shows the effect on mean *G*, pile height and dry beach time of changing the length of the conical section of the decanter. The diameter of the bowl and the solids discharge are taken as fixed and the cone angle is changed to alter the cone length. The *x*-axis of Figure 7 shows both the cone angle (6º-12º) and the resulting cone length (930-465 mm).

The length of the conical section has no effect on *G*, the longer cone increases the solids residence time and the steeper cone angle slightly increases the pile

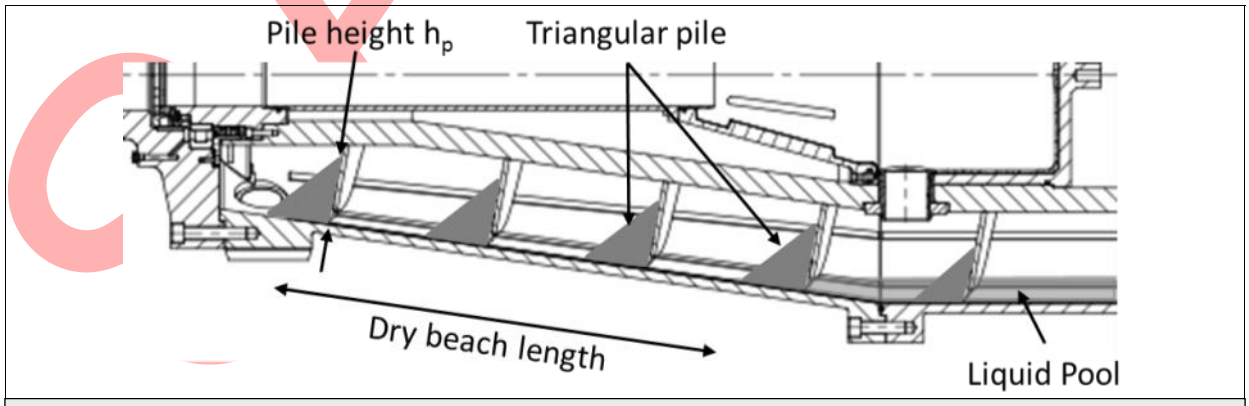

Figure 5: View of solids on the conical section of a centrifuge.

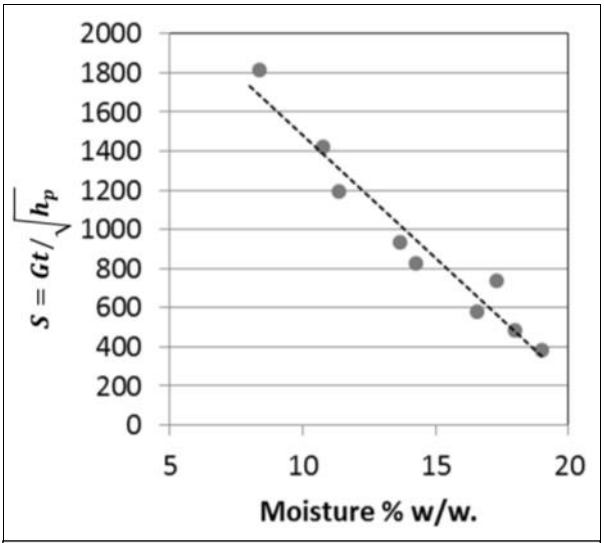

Figure 6: Variation of cake moisture with *S* for gypsum, D_{50} = 30 µm. Data points show the relationship between $S = Gt/(h_p)^{0.5}$ and moisture for a variation in *G* of 3.4, dry beach time of 4.5 and pile height of 2.

heights for a given solids loading. The net effect is for *S* to increase with bowl length, due primarily to the longer drying time provided by the longer conical section.

Effects of Diameter

As with the conical bowl length, changing the bowl diameter has significant effects on the internal geometry of the decanter, however, it also increases the *G* for a given bowl RPM. In order to investigate the effects of bowl diameter on *S* the bowl RPM is adjusted to maintain the same mean *G* over the conical bowl section. The pool depth and the solids discharge diameter are also scaled by the change in bowl diameter. Figure 8 shows *G* remaining constant, with the pile height reducing and the drying time increasing as the bowl diameter is increased, both of which contribute to increasing *S*.

Effects of Bowl G

For a given bowl diameter, higher *G* is produced by increasing the rotational speed, and as expected from *S* it will produce dryer solids. For a decanter with a fixed ratio gearbox a faster rotational speed will produce a faster conveyor differential and reduce the solids residence time. Also, for a give solids throughput the pile height of the solids transported by the conveyor blades will reduce. Changing the rotational speed therefore changes all three terms in *S*. Figure 9 shows the variation of the three parameters with bowl RPM. The *G* increases whereas the pile height and dry beach time reduce with increasing RPM; the net effect is to increase *S*, but not as sharply as might be expected from *G* alone.

DISCUSSION AND CONCLUSIONS

Figure 10 brings together the effects on *S* outlined in Figures 7-9. The changes to bowl speed, length and diameter have been chosen to give similar ranges in *S* (approx. 180-450). In the real world the normal operating value for this example application (incompressible crystalline solids) is around 270.

Figure 10 shows that, within the limits of the assumptions in the simple analysis, increasing the bowl *G* from 900 to 1800 increases *S* from 250 to 400, as does increasing the bowl diameter from 950 to 1300 mm (at constant *G*) or reducing the conical bowl half angle from 11º to 7º (length from 510 to 800 mm).

From the considerations presented earlier in the 'Liquid processing capacity' section it is clear that increasing the cone length may mean reducing the parallel bowl length, thereby reducing liquor clarification performance. Likewise increasing the diameter increases the power requirement for accelerating the feed liquor and creates additional turbulence within the feed zone which is detrimental to clarification performance. Reducing the turbulence and feed liquor power requirements by increasing the pond depth is generally not an option for applications with a high loading of incompressible solids as the deeper pool significantly reduces the dry beach length and therefore the dry beach time.

Increasing the *G* is a benefit to both solids dryness and centrate clarification, however, the same restrictions on pool depth mentioned above apply. Reducing the diameter and increasing the *G* (as favoured for best centrate clarification) also has limits as sufficient volume must be provided for the solids at the discharge end of the conical section or there is a danger of the solid pile filling the available volume and jamming the conveyor. For applications where the solids are sludges or pastes (i.e. not incompressible crystalline solids) filling the available volume can be an advantage as the solids are compressed and further dried as they approach the solids discharge area prior to being extruded out of the decanter.

For abrasive crystalline material, such as minerals, higher *G* increases the contact forces between the solids and the feed openings in the conveyor, the conveyor blades and the solids discharge openings in the decanter bowl – all of which can lead to accelerated wear and additional conveyor drive torque to overcome friction.

As might be expected the competing requirements of good solids drying compete with those of centrate clarity and the best combination of *G*, diameter and length depend on the application specifics.

Finally, a more complete study would also include aspects such as gearbox ratio, conveyor design and power consumption, and consider solids other than

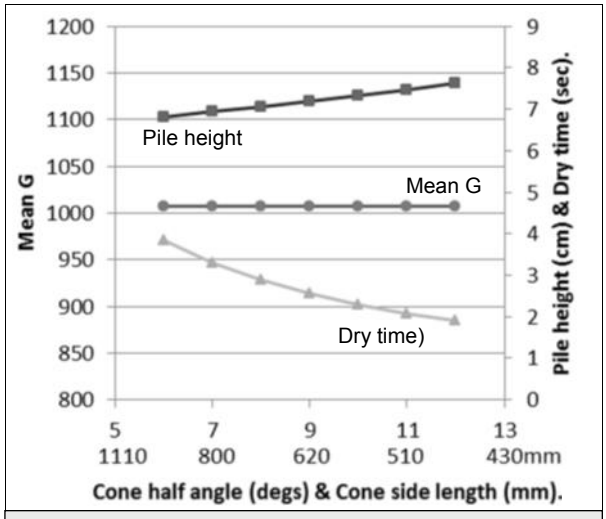

Figure 7: Effect of parallel bowl length on the operational parameters of a decanter centrifuge.

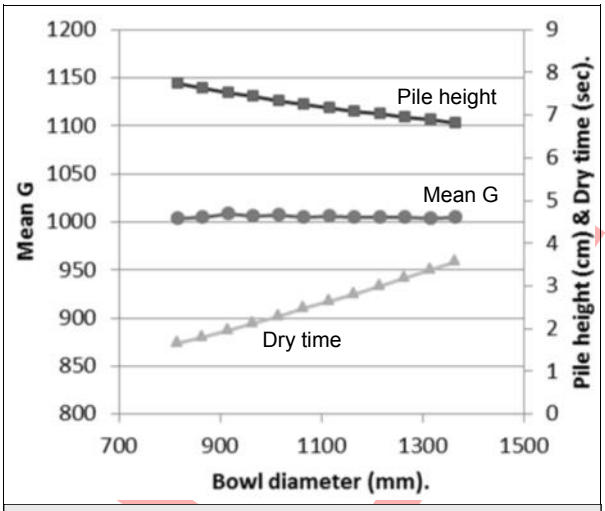

Figure 8: Effect of bowl diameter on the operational parameters of a decanter centrifuge.

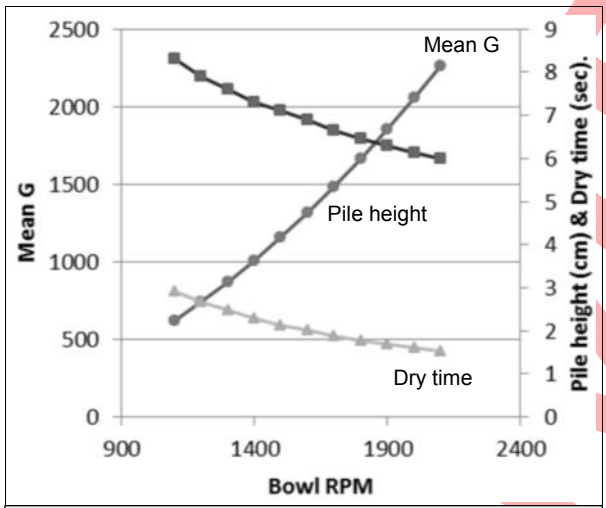

Figure 9: Effect of G on the operational parameters of a decanter centrifuge.

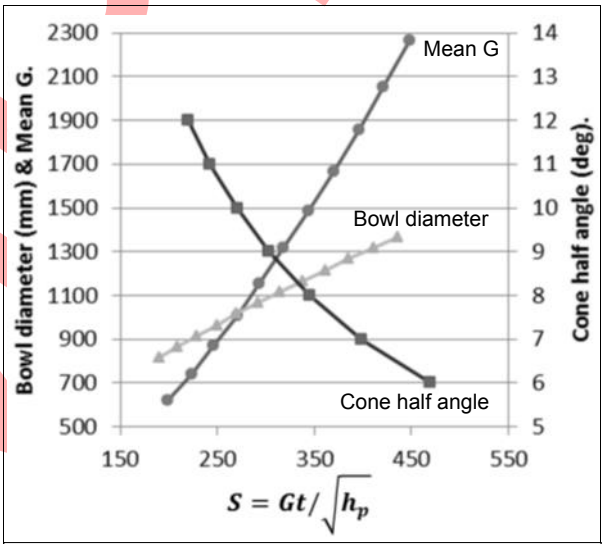

Figure 10: Variation of *S* with *G*, bowl diameter and length on the operational parameters of a decanter centrifuge.

incompressible crystalline materials.

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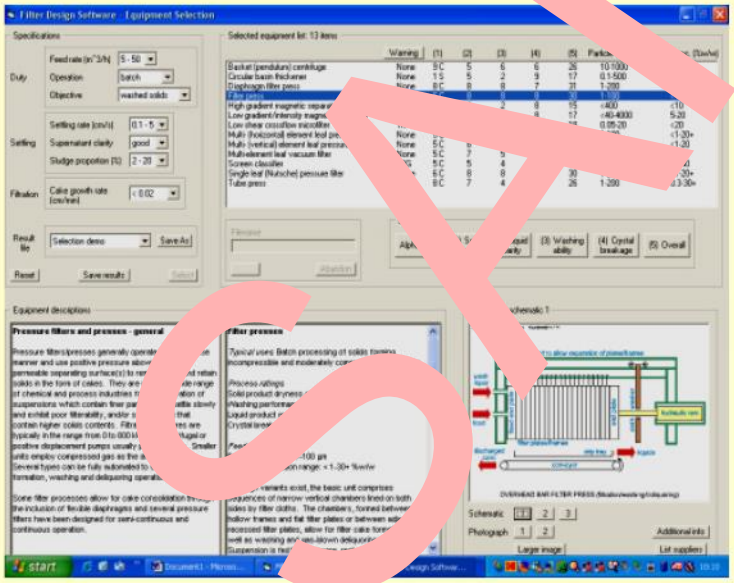

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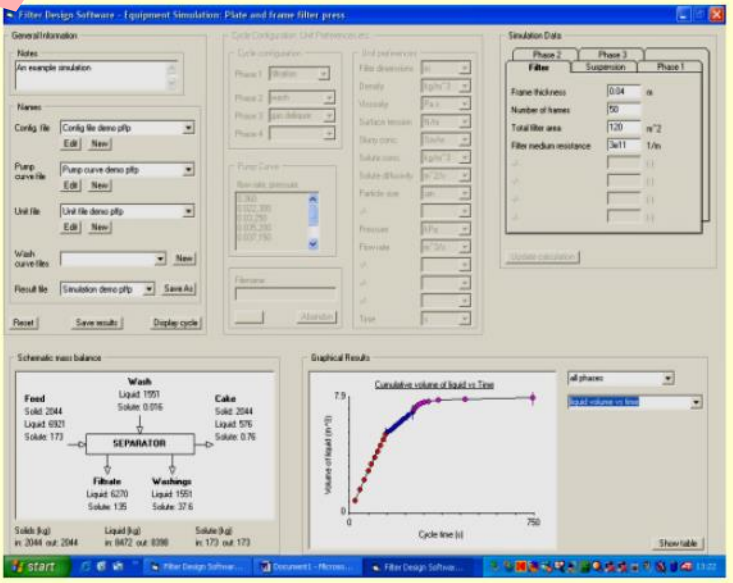

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