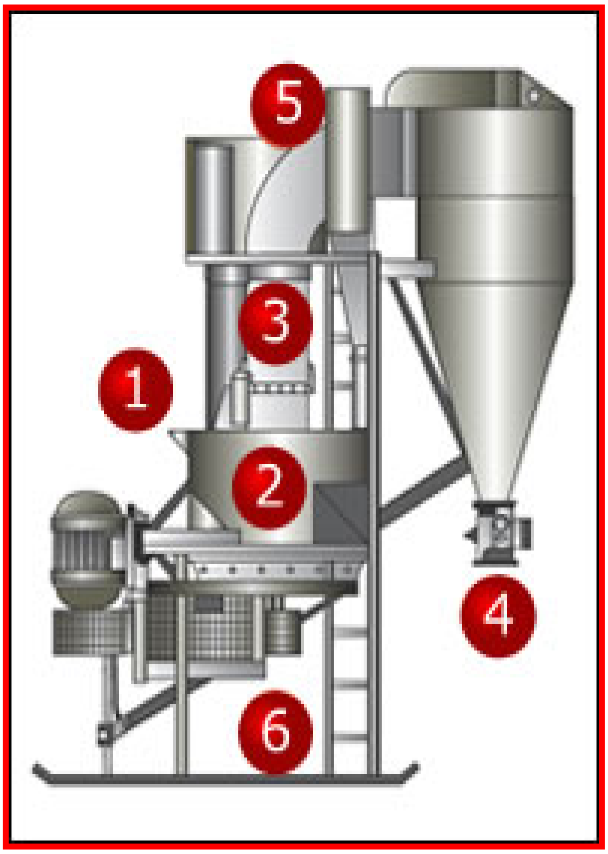
Material change for
a better environment

Final Report

A New Approach to Paper Mill Sludge



As part of its programme to encourage the economic use of recycled fibre, WRAP identified a novel process in Canada – the KDS Micronex, which uses relatively low energy input to treat paper mill sludge through centrifugal action to produce a commercially dry material which can be separated through vibrating screening into a fibre fraction and a filler fraction.

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Front cover photograph: The KDS Micronex Machine Assembly Overview & Photograph

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Executive summary

INTRODUCTION

Paper mill sludge is a major economic and environmental problem for the paper and board industry. Around 1 million tonnes is produced annually, and losses rise as increased amounts of recycled paper is used in the process, with fibre shortening as it goes through repeated cycles until it is of little use for paper manufacture.

Sludge consists of cellulose fibre rejected by cleaning processes, fillers such as calcium carbonate and china clay, residual chemicals such as drainage aids and sizing, bound up with water – moisture content is typically up to 40%. The material is viscous, sticky and hard to dry, and even from the same mill source can vary in terms of viscosity and "lumpiness" quite markedly.

Disposal at present consists of:

- Disposal in landfill – which is increasingly costly, sites are progressively more difficult to find and transport is costly as considerable water is transported along with the sludge.
- Landspreading as an agricultural fertiliser, where the local soil is suitable (but which is banned in many EU countries and is likely to have only a short life as a disposal route in the UK) or
- Drying, which is expensive in energy usage and overall cost.

THE PROJECT

As part of its programme to encourage the economic use of recycled fibre, WRAP identified a novel process in Canada – the KDS Micronex, which uses relatively low energy input to treat paper mill sludge through centrifugal action to produce a commercially dry material which can be separated through vibrating screening into a fibre fraction and a filler fraction[1]. Following a reference visit to the experimental unit, WRAP determined to run a pilot scale trial in the UK to:

- Evaluate the Micronex process towards commercial viability;
- Establish methods to screen the product into fibre-dominant and filler-dominant fractions;
- Establish potential markets for the fractions; and
- Arrange trials with the products with potential users towards commercial uses.

Following an Open Competition, Aylesford Mill in Kent was selected for the study. Aylesford is a major UK producer of Newsprint from recycled fibre. The trials and market studies were run by Pendlepace Ltd.

THE MICRONEX AND ASSOCIATED PROCESSES

The Micronex is a relatively simple piece of equipment, consisting of a feed mechanism to introduce the sludge to the centrifuge, cyclone to separate finished material from water vapour, and discharge system. To this were added a screening system and other equipment such as bagging and pelletising lines.
Operation of the system had a number of teething problems, notably blocking with fibrous product within the unit, which reduced overall output and plant performance. It is clear that further debottlenecking work will produce a reliable and consistent result.[2]

- Operation of the vibrating screen system showed that separating the fibre fraction and the filler fraction has not as yet been resolved, because there is considerable entanglement of filler in the fibre mat, although some degree of separation was achieved.[3] The intention was to produce fibre and filler fractions in which the desired component was in excess of 70% but this was not fully achieved.

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[1] The exploratory work formed WRAP Report "Micronex Sludge Processing" (Powlson, D & Kay, S G, April 2004)

[2] These issues are covered in Chapter 4.

[3] These issues are covered in Chapter 6

Bagging and pelletising were achieved without undue difficulty.

MARKET STUDIES

There are a significant number of potential markets for by-products of the process, notably:

- Additives to brick, cement, road surfacing and plasterboard.
- Additives to paper products such as Corrugated paper, Millboard, Softboard and moulded paper products.
- Insulation products (heat and acoustic),
- Use as a fuel product[4]

These areas were explored through a programme of company interviews, from which a number were selected for product trials.

PRODUCT TRIALS

While the separated fractions both contained a higher proportion of the other fraction than was desired or was ideal, the products were classified as Fibre Fraction and Filler Fraction. These were process tested as below:

Fibre Fraction:

- Millboard
- Road Surfacing Additive
- Softboard
- Absorbent Kraft Paper, and

Filler Fraction:

- Acoustic Plasterboard
- Brick additive,
- Cement
- Insulation Board[5]

A number of these applications are worthy of further work, although the separation into fibre and filler fractions needs to be improved.

ECONOMICS

Finally, the economics of operation of the Micronex as compared with alternative conventional drying, and of use in cement production and as a fuel were explored.[6]

[4] These are covered in Chapter 9

[5] These areas are covered in Chapter 12

[6] These areas are covered in Chapter 13

CONCLUSIONS

1. The Micronex unit used in the trails was, necessarily, a pre-production model, on which a number of issues affecting results were discovered, many of which were resolved. A unit installed commercially in a paper mill would have these issues designed out, and should be installed against performance and reliability guarantees from the manufacturer. Operating reliably and with known parameters for output, dryness and with routine cleaning intervals, the unit will, it is believed, produce a reasonably consistent product.

2. It is clear that the filler portion of product is closely entangled with the fibre component, and may indeed be subject to the effect of static electricity as well as mechanical forces. Screening, even with ultrasonic assistance, did not produce the expected split of fibre and filler. More experimental work is required in this area.

3. With alternative disposal routes expensive, and possibly to be closed in the relatively near future by EU legislation, even the successful drying of wet sludge has considerable economic and disposal benefits.

4. If a more closely defined fractionation can be developed, then it is clear that a number of useful and potentially cost-saving outlets can be developed for the products, notably into cement and brick additives.

5. Use as a fuel substitute should not be ignored. With a calorific value about half that of wood, pelletised raw product can be burned in any biomass boiler, and the economics of this should be explored further. This outlet would eliminate issues of fractionation and is less dependent on highly controlled moisture levels. Demand for biomass fuel is rising quite rapidly, and selling the pelletised dried material within an economic radius will be attractive as a disposal route to paper mills.

Abbreviations

A	
a	Annum; year
ANL	Aylesford Newsprint Limited
B	
Baldor MCC	
BD	Bone dry moisture content
BTU	British thermal unit; 1 BTU/lb = 0.646 KWhr/tonne
C	
^oC	Degree Celsius
CFC	Chlorinated fluorocarbon
cm	Centimetre
D	
d	Day, 24 h
E	
F	
FASC	First American Scientific Corporation
G	
g	Gram
g/m^2	Grams per square metre
H	
Hz	Hertz; cycles per second
I	
i.e.	id est (in other words)
J	
K	
Kc	Kilo calorie
KDS	Kinetic Drying System
Kg	Kilogram
Kpa	Kilo Pascal
KW	Kilowatt; unit for (electric) power. 1KW = 3.6MJ
KWhr	Kilowatt-hour; unit for (electric) energy; 1 kWh = 860 Kc = 3.6 MJ = 3412 BTU
L	
Lb	Pound weight
LM	Light microscopy
Ltd	Limited
M	
m	Metre
MJ	Mega Joule; 1MJ = 239 Kc
mm	Millimetre
min	Minute
m^2	Square metre
m^3	Cubic metre
N	
N.B.	Nota Bene (note well)

O

P

p.a.	Per annum; per year
PLC	Programmable Logic Controller

Q

R

RBPC	RB Plant Construction

S

s	Second
SEM	Scanning electron microscope
SMA	Stone mastic asphalt

T

t	Tonne; 1,000 kg
T	Therm ; 1T = 105.5 MJ
tm^{-3}	Tonnes per cubic metre
tpd	Tonnes per day

U

UK	United Kingdom

V

VOC	Volatile organic compound

W

W/mK	Watts per metre per degree Kelvin (measure of thermal conductivity)
WRAP	Waste & Resources Action Programme

X

Y

Z

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1.0 Introduction

Total UK generation of paper mill sludge (from a number of different grade mills) is approximately 1 million tonnes/annum, and little or no profitable use for this waste product has previously been identified. This acts as a barrier to increased utilisation of recovered fibre within the UK paper industry. Utilisation of paper mill sludge has been limited due to its high moisture content (approx. 36 -40%), and its make-up of fibre and mineral fillers.

The WRAP umbrella project PAP0022 was originally designed to develop the opportunities for recycling paper mill sludge into new products. Employing innovative technology from Canada and developed by First American Scientific Corporation (FASC), the first KDS Micronex sludge processing plant to be evaluated in Europe, was installed (by WRAP) at Aylesford Newsprint in Kent and became operational during the third quarter of 2005.

R B Plant Construction (RBPC) were contracted for production of the project scope document, design, engineering, project management, site construction supervision, training, operational hand-over and development for the KDS Micronex plant installed at Aylesford Newsprint Mill.

The claimed unique feature of the KDS Micronex plant is its ability to dry the sludge down to 10% moisture and to separate the product into its individual fibre and filler components.

The resulting output offered a potential source of raw material for subsequent manufacturing processes; in either the paper or other/associated industries. Laboratory tests were conducted to define the specification of the final fibre and filler products.

Optimising the Aylesford plant required fine-tuning modifications to the production plant, in addition to testing and refining of operating procedures. These were successfully addressed by FASC and RB Plant, so that regular production conditions and product were established in early November 2005.

Potential markets were identified and prospect lists established. Manufacturing trials were arranged of the proposed fibre-product, and laboratory trials of the filler material.

Early Market Development focused on the fibre fraction, which had an unregulated and easier to access market, with the potentially highest value. Applications were in corrugated case materials, softboard, insulation and panel materials. A small number of manufacturing trials were secured and the outcome of these is documented later in the report

During the early part of the marketing project, it became clear that in the case of Aylesford sludge processed by the Micronex plant, the fibre content of the fibre fraction product failed to exceed 60% of bone-dry weight, and it was therefore found to be unsuitable for most of the potential fibre outlets. The possibility of using fibre for combustion in power generation and brick making was investigated.

Marketing effort was therefore focused on the applications for the filler fraction, and particularly brick and cement manufacture, cement products, plasterboard and insulation.

The Market Development Project also involved quantifying the economic benefits available through the adoption of the Micronex technology and the manufacture of the current range of products. The study identified the barriers to utilising the materials, and actions required to overcome obstacles.

1.1 Project Partners

1.1.1 WRAP (the Waste & Resources Action Programme)

WRAP (the Waste & Resources Action Programme) is a major UK programme established to promote resource efficiency. Its particular focus is on creating stable and efficient markets for recycled materials and products, and removing the

Barriers to waste minimisation, re-use and recycling. A not-for-profit company, WRAP is backed by substantial Government funding from DEFRA, DTI and the devolved administrations in Scotland, Wales and Northern Ireland.

1.1.2 PendlePace Ltd

PendlePace Ltd, formed in 2001, (UK Registration No 4206073), provides services for the pulp, paper and packaging industries, focused on business development including market studies, financial and economic evaluations, technical and marketing issues.

The PendlePace team consisted of Andrew Rothwell and Geoffrey Éclair-Heath.

Contact details for PendlePace Ltd are:

Office	01200 445 928
Mobile	07960 609 334
E-mail	PendlePace@aol.com

1.1.3 RB Plant Construction

R B Plant, which was formed in 1969, is a consulting company, registered in the UK (No 1798668), providing multi-discipline services throughout the range of process industries, including Paper
The RB plant team was managed by Jonathon Fernandez.

Contact details for RB Plant Ltd are:

Telephone	01622 858387
Web Site	www.rbplant.co.uk

1.1.4 Aylesford Newsprint Limited

Aylesford Newsprint Limited is a joint venture between SCA and Mondi, manufacturing 400,000 tonnes/annum of newsprint from 100% recovered newspaper and magazines. Over 500,000 tonnes/annum of recovered paper is recycled into newsprint on 2 paper machines.

Contact details for Aylesford Newsprint are:

Telephone	01622 796 000
Fax	01622 796 001
Web Site	www.aylesford-newsprint.co.uk

2.0 Project Outline

2.1 Project Background

The main waste stream from a deinking-fibre plant is "paper mill sludge", as much as 40 % of the fibrous and chemical input of Tissue, Printings & Writings Mills and 25 % of Newsprint Mills. As the average paper fibre length decreases, and customer quality requirements and landfill costs rise, the volume and cost of sludge disposal is a barrier to the paper recycling industry. Approximately one million tonnes of paper mill sludge is produced in the UK each year and there are very limited applications for this material. Most of this sludge is either landfilled, land-spread or incinerated, with significant cost and environmental implications.

Land filling will become more costly and is becoming difficult to find suitable locations. Land spreading is not permitted in parts of the EU and this method of disposal is not a long-term solution. Incineration currently leaves a residue, which may require further treatment (to reduce the % of active lime) before the sludge can be transported and disposed.

Typically sludge consists of approximately 37 % moisture, 22 % fibrous material and 41 % fillers. Fillers are mainly Calcium Carbonate and China Clay. The fibre and filler fractions cannot readily be split by conventional means.

2.2 Project Objectives

The aim of this project was to reduce the moisture content of the sludge, then to separate the fibrous and filler fractions. The individual fractions can then be marketed to users for whom they could be a useful raw material feedstock - not just a recycled material without any true benefit to the user.

The maximum economic value and environmental benefits are therefore obtained through re-use.

2.2.1 Methodology for Process Plant

Design, Installation, Start-up, Process and Future Development

The project objective was to install and utilise the KDS Micronex machine, supplementing it with ancillary equipment designed and engineered to enable continuous processing of raw de-inked paper sludge.

The processed sludge (dried and opened-up) would be delivered to a separation plant where it would be split into fibre and filler fraction.

Target objectives from the Micronex were:

- To process the raw sludge (containing up to 37 % water) to a dried 'free' form with a moisture content of less than 15%.
- To achieve a raw sludge input rate in the range of 1000 – 1500 kg/hr to split the processed sludge to:
  - Filler fraction = less than 25% fibre content
  - Fibre fraction = less than 25% filler content
- The Micronex process plant had three sections:
  - Storage and feeding of the sludge
  - The Micronex machine (drying and forming)
  - The Separation plant

2.3 Project Structure

2.3.1 The Micronex Process for Sludge Treatment

Commencing in 2003, WRAP sought to find new ways to dispose of increasing amounts of paper mill sludge derived from the increased reprocessing of waste paper into everyday products.

This process involved:

- Surveying the world for new approaches to sludge treatment;
- Identifying the "Micronex" process; one of very few novel approaches which displayed potential;
- A competition among UK Papermakers to determine where a UK pilot Micronex machine could be installed;
- Tendering for the engineering, operation of the plant and for test marketing the output and reporting the finding;
- Design and Installation of Main Plant, controls and ancillary equipment;
- Commissioning;
- Plant optimisation;
- Market Development;
- Trials of alternative sludges from other UK mills wishing to participate in tests; and
- Dissemination.

First American Scientific Corporation (FASC) offers a grinding and drying technique, the "KDS Micronex". This offers considerable process benefits and potential for cost reduction and reduced environmental impact. Details of the machine can be found at www.fasc.net

The Micronex utilises kinetic energy to open up the sludge through a dry beating process, as large volumes of air are brought into contact with the material. The result is that it is claimed that moisture can be reduced from around 40 % to levels below 10 %. With increasing use of energy, the moisture in the output stream can be reduced further. The air and particles are subsequently separated in a cyclone, producing a dry material, which is of a fluffy nature. There is then the potential to split this material into its individual fractions.

A KDS Micronex was installed and successfully trialled in early 2003 at a Canadian paper mill. In this project the application is developed by automating the process, and dry screening the "fluff" to separate the fibre and filler fractions. Dry screening was a through a Russell-Finex vibrating screen (with two screen meshes run in series).
As a result of an industry competition it was chosen to run this project at Aylesford Newsprint where a KDS Micronex was installed, together with a control system, splitting equipment, a briquetter and other ancillary equipment such as conveyor, tanks, pipework etc.

The trial was run at Aylesford Paper Mill, Kent.

3.0 Process Plant Design

3.1 Background

The KDS Micronex was relatively simple to work with; it only required electrical energy to function, had one product inlet, one product outlet and vapour vents. There were no other utility requirements and no other waste streams were produced. The KDS Micronex regulated the process design throughput through rate parameters.

There was a period of time to commission the plant and also address snags and equipment that did not perform as originally specified. This assessment and refinement time d led to other components being added to the trial process as well as modifying existing equipment.

The project objective then moved to analysing the KDS Micronex's performance in detail and in a variety of conditions. e.g. varying de-inked sludges, varying feed rates etc and also monitoring the energy consumption of the machine in comparison to the targets set by the trial.

Finally, focus progressed to the separation plant, with the objective of achieving the targets outlined above (or to optimise or modify the plant to achieve this).

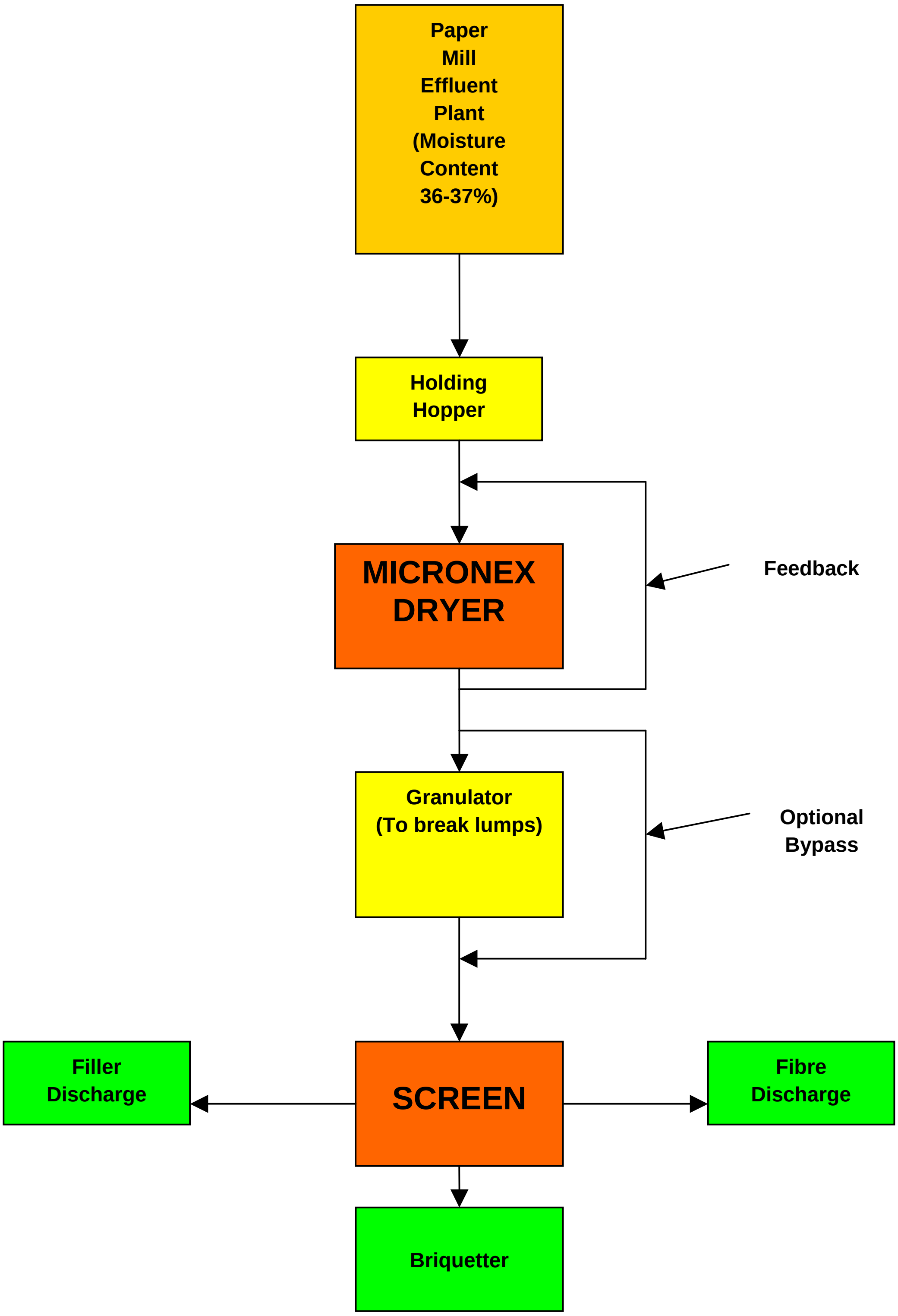
Concurrent with the site work, the Market Development study was taking place, in order to establish a variety of potential uses of the processed sludge in its various fractions.

The process is described as:

- A block diagram of the process;
- A detailed process flow diagram, showing the equipment and material flows;
- A plant layout with dimensions; and
- Detailed descriptions of the plant components.

3.1.1 Block Process Diagram

Figure 1 Block Process Diagram



The block diagram represents the process and the following notes will assist in its interpretation

Sludge containing 37% moisture was brought to the plant from the paper mill in 4 tonne buckets and loaded into the hopper.

- The sludge was discharged from the hopper on to a conveyor, which metered it into the Micronex dryer.
- A proportion of the dried material is fed back into the Micronex, and this controls the moisture level of the output.
- The output from the Micronex dryer passes through (or bypasses) a granulator to break up any clumps.
- This material passes to a screening system.
- The output from the screen can be sent to a briquetter (pelletiser) or directly to collection bags for fibre and for filler.
- Figures 1 and 2 provide detail regarding the material flows and the dimensions of the plant.

Figure 2 Process Flow Sheet

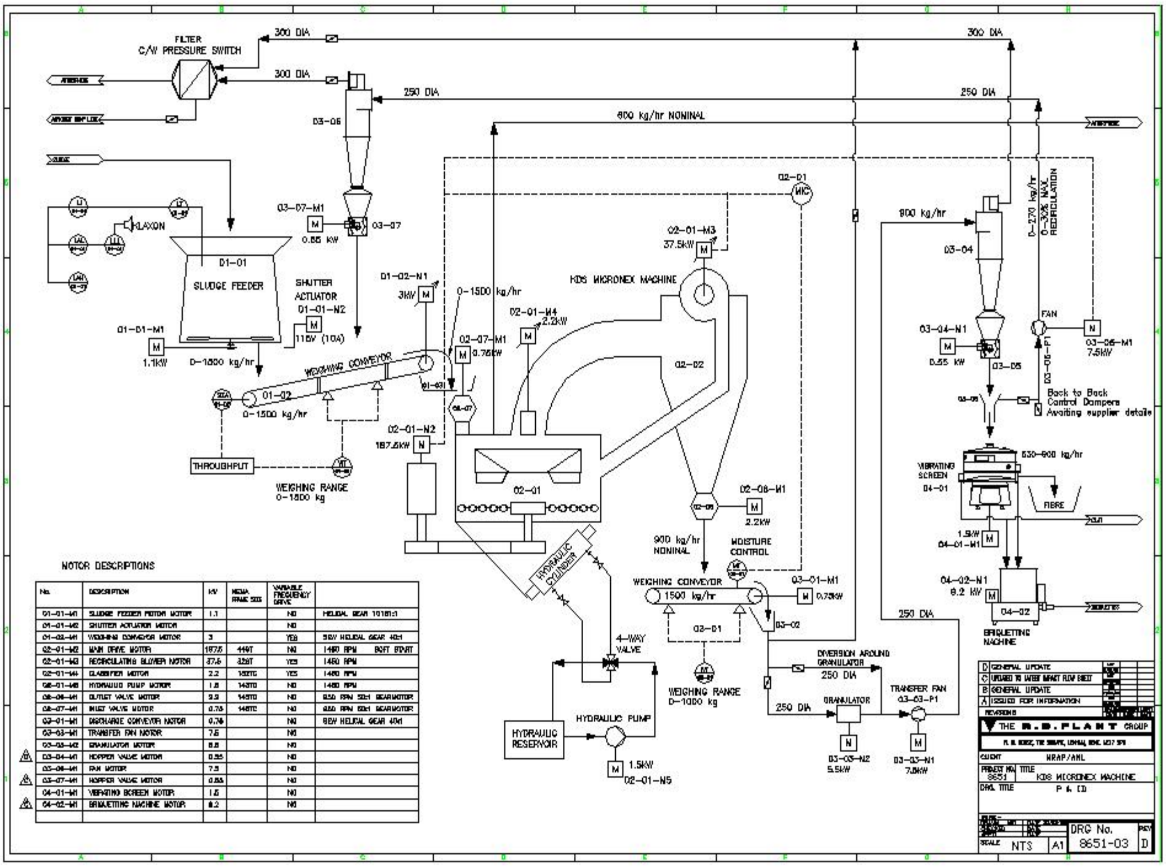


Figure 3 Plant Layout

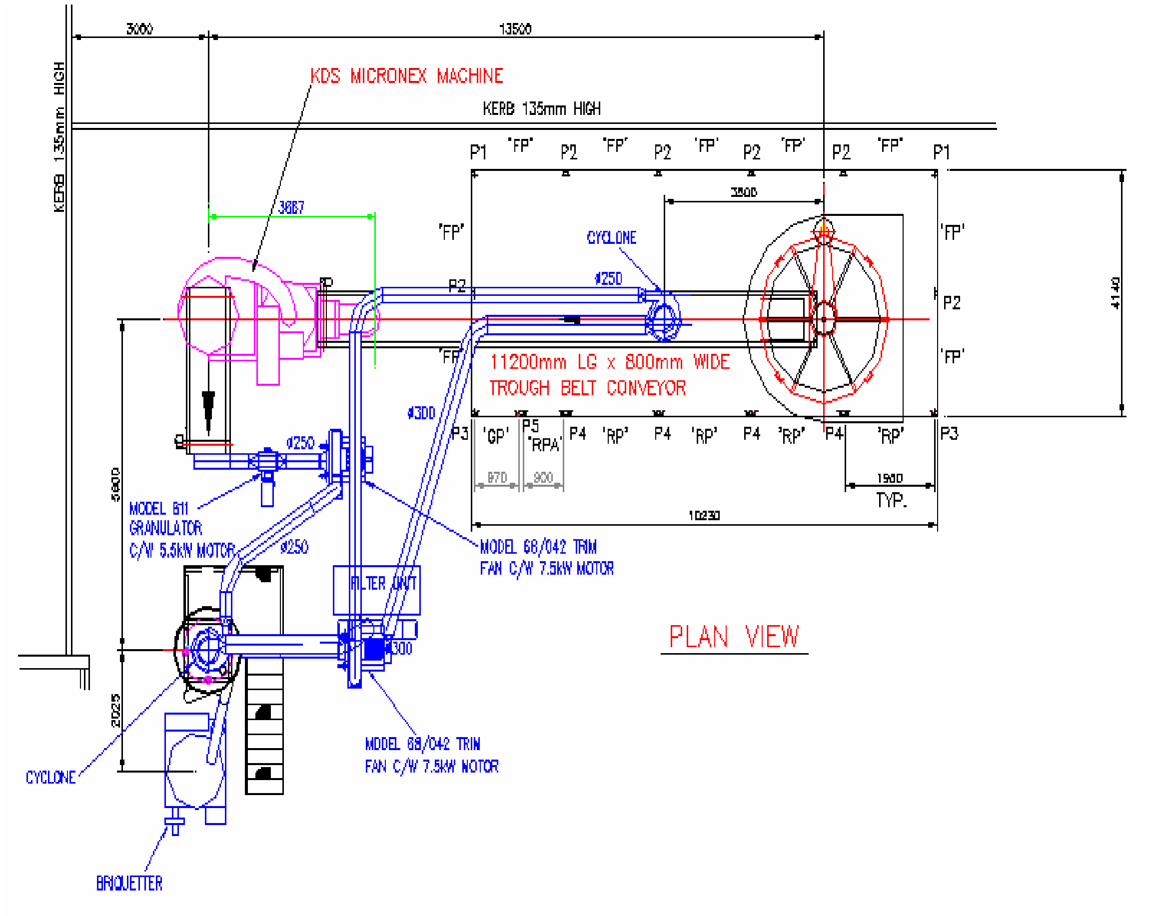


Figure 4 Photograph of Installation

3.2 Sludge Feeder

3.2.1 Design Considerations

The Sludge feeder was designed to receive, and deliver raw de-inked sludge. The sludge was loaded using large 4-tonne shovel loaders and, due to the requirement for low-manning levels, the sludge feeder held up to 8 tonnes of raw product.

De-inked paper sludge is very sticky; its flow characteristics are often unpredictable and very poor. Compaction and bridging are potential problems which were encountered, and which limit most applications to make use of sludge as a recycled material.

The KDS Micronex's design throughput capacity is the main factor dictating process flow rates and the feeder had to be designed to provide the raw sludge to meet a minimum requirement of 1500kg/hr.

3.2.2 Design Specification

The design specification is as detailed below:

- Main drive – 150mm to 100mm reducing shaft.
- Main drive – Flender Helical gear - 65,000Nm Torque, 0.46 RPM, 9000:1 reduction.
- Rotor – 100 x 100 box section, 6 paddles – braced together for load distribution.
- Feeder Vessel – Inclined walls to minimise product adhesion.
- Feeder Vessel – Funnel style top to allow large shovel to load.
- Feeder Vessel – 10mm Rails to support the rotor and minimise the frictional resistance.
- Shutter Mechanism – Drive – Power Jacks electrical ram.
- Shutters – 3 off stiffened shutters.

3.2.3 Design Overview and Discussion

Generally, the feeder worked very well. However, the sludge could create higher forces than calculated and it was assumed that this was due to the compaction of the sludge under force which increases its resistance and

Figure 5. Sludge Feeder

Subsequent load on the drive. The starter overload would then trip out due to overload.

A shutter arrangement was incorporated in the design of the sludge feeder to prevent sludge falling freely from the hopper onto the belt and to aid control of the flow to the Micronex KDS. The shutter arrangement was comprised of 3 shutters connected via a linkage mechanism to a Powerjacks electric actuator specified to provide enough torque at the leading edge of each shutter to overcome a linear force of 1500kg

It was noted that:

- The shutter arrangement at the discharge proved to have limited use in feeding sludge.

- The shutters were effective in undertaking the job they were designed for, which was to stop the sludge continuously falling on the conveyor. However, due to the fluid movement of sludge at times, as soon as the shutters opened the sludge freely fell and overloaded the belt.

- After the initial installation a hopper was fitted at the bottom of the feed conveyor to limit sludge from overloading the conveyor. The hopper was fitted with a sliding gate, which metered product onto the belt. The metering gate worked well for the majority of the time. However, if the process was not run continuously, or if there were large lumps of sludge in the feedstock, the metering gate could become blocked and very little sludge would be fed to the belt. This caused dust problems if the process was left unattended in automatic mode. The residual product was constantly being re-circulated and dried by the air system and the drier it became the greater the volume of dust that was expelled from the process.

3.3 Feed Conveyor

3.3.1 Design Considerations

The feed conveyor was installed to provide a transfer mechanism for transferring the raw sludge from the sludge feeder to the KDS Micronex. It provides a receiving point for the recycled fibre and its subsequent delivery to the KDS Micronex.

It also incorporated a belt weigh system providing PLC and local feedback of throughput to the KDS Micronex.

3.3.2 Design Specification

The conveyor was designed to have the capacity (and speed) to deliver raw and recycled fibre at a maximum rate of 1500 kg/hr and a minimum running rate of 450 kg/hr. It was designed to be over-ridden by a high level current (high load) set point. This was essential to ensure that the KDS machine did not become overloaded with sludge and cause belt or drive damage.

The conveyer belt weigh system was designed to provide throughput measurement in the range of 0 – 1500 kg/hr.

3.3.3 Overview and Discussion

The feed conveyor and discharge conveyor were supplied by ELCO, a mechanical handling company. The conveyors caused a few issues during start-up, but following these being resolved, performed reasonably well.

The conveyors operated consistently for the trial, but caused lengthy delays in plant start-up due to late delivery.

It became evident that the weighing systems were incorrectly mounted and an error had been made in their specification.

The weighing system was designed to weigh a larger range than was specified and was also installed too close to the head roll. Consequently the belt tension changes at the top caused increased interference to the load cells. Once this was addressed it functioned correctly.

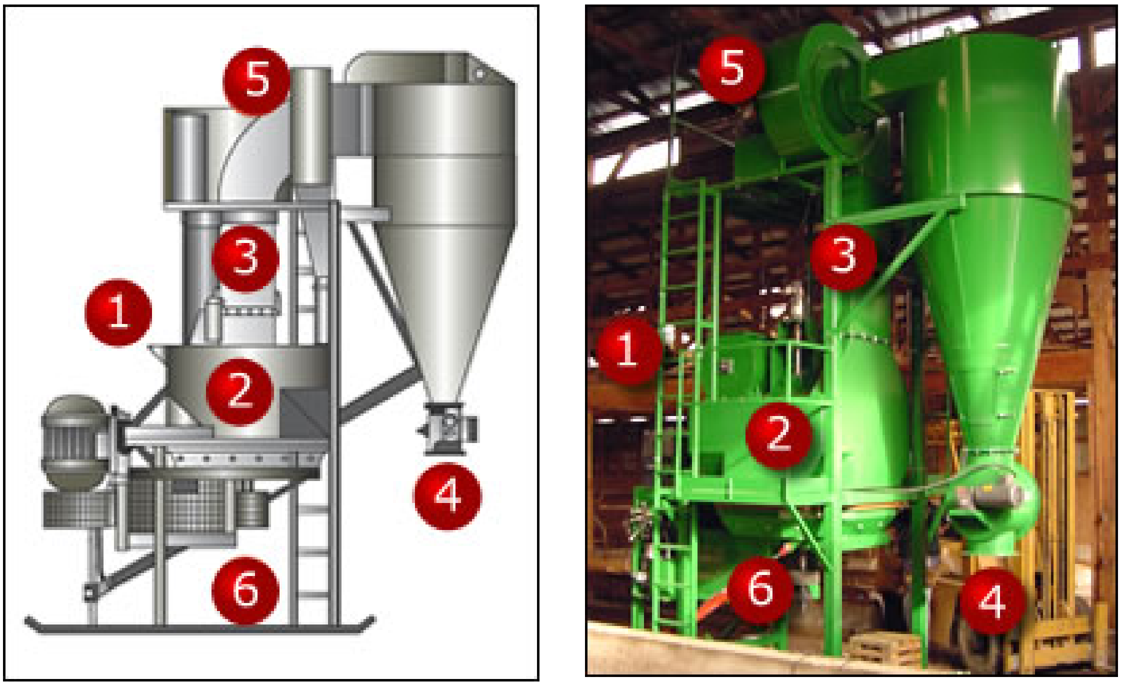
Also, the minimum feed-rate which, due to lack of control from the feed hopper, was found still to be running at too high a speed. The geared drive unit was changed to allow slower minimum belt speed. This provided the solution.

The feed conveyor worked well during the trial, although for future installations it should be re-designed to be enclosed (as the recycled product is dropped on the belt) to prevent dust being released to the immediate atmosphere. There is a requirement for viewing windows at the lower end of the conveyor to ensure that product is not accumulating or compacting etc.

3.4 The KDS Micronex

3.4.1 Overview of Operation

Figure 6 Machine Assembly Overview & Photograph



Source: FASC Website

The process for sludge treatment in the Micronex plant is as follows:

1. Raw material containing up to 37 % moisture is dropped into the throat of the KDS Micronex™ where it passes through an air-lock gate valve that eliminates blowback and dust.
2. Material enters the torus rotor chamber where it falls onto spinning bars and is subject to enormous centrifugal accelerations. The bars spin with a tip speed of about 400 mph. The material is "fractured" as it impacts repeatedly with the bars and the strike plates on the sides of the torus. Liquid water is squeezed out of the material due to the compressive action of the impacts.
3. Heat created from the kinetic energy of the impacts evaporates some of the moisture in the material. When appropriate particle size reduction is achieved, airflow in the torus lifts the particles upwards towards the classifier. Because some of the water removal occurs due to mechanical forces, less energy is consumed than in thermal dryers – usually, only 500 to 900 BTU per pound of water removed (323 to 581 KWhr/tonne) – and less than the latent heat of water. No heat/energy input is used - only electricity.
4. The classifier sorts the "fractured" material and can be adjusted for the desired particle size. Selected particle sizes pass through the classifier and larger particles are forced back to the torus to repeat the impact process.
5. Finished material is pneumatically conveyed out of the machine into the cyclone where dry powdered finished material falls through the bottom air-lock gate valve into a collector or onto a conveyor.

   Air containing water vapour and water-droplets leaves the top of the cyclone back into the blower and subsequently to the grinding chamber. Water vapour and droplets leave the chamber through the vapour vents.
6. The floor of the torus, i.e., the clam, opens easily for maintenance. Replacing the bars or chains can be accomplished in ten minutes or less.

The Micronex machine installed at Aylesford Newsprint was originally fitted with four solid bars and not chains.

Overview of Material Flow in the Micronex

The Micronex machine is a relatively simple design with product transfer within the machine working through balanced airflows. Air pressure within the cyclone is negative, which creates negative pressure in the torus through the airflow being drawn through the product duct (the duct that transfers material from the main processing chamber to the cyclone). The returned air (positive fan side) is passed down to the torus chamber via internal jets, which distribute the air evenly to the chamber. Air passes down into the chamber and the majority of it is drawn back to the cyclone via the product duct. Air is introduced to the inside of the machine via the inlet rotary valve air being held in the product and also by the discharge rotary valve due to the vortex created in the cyclone. Excess air is then vented with separated water vapour from the machine via the vents located on the outside of the chamber. The chamber is of such design that the water vapour is forced to the outside and exits with the surplus airflow.

3.4.2 Installation Modifications

KDS Micronex - Initial installation

The KDS Micronex unit was delivered in two main process parts,
Interconnecting product duct, the main drive and rotor assembly.

The installation of the KDS was very straightforward being skid mounted, and it was assembled with relative ease:

The following key points were noted after the unit was installed:

- The discharge cyclone outlet was higher than as illustrated on the design information provided by FASC The discharge conveyor height had to be adjusted

- The top platform for the blower fan access protruded from the machine approximately 500mm more than as shown on the design data. This caused an obstruction to the feed conveyor and required modification.

- The access ladders and platforms did not comply with UK legislation for access ways etc., and these were modified.

- For the purpose of the trial, mobile access equipment was used as required.

- These were relatively simple issues to resolve.

Figure 7 Photograph of KDS Micronex

3.5 Discharge Conveyor

3.5.1 Design Considerations

The discharge conveyor:

- Provided a transfer mechanism from the processed sludge to the air system, and which could also act as a delivery point for processed sludge that was not required to be separated;
- Allowed a suitable point at discharge for the Moisture meter analyser to be mounted; and
- Was mounted on load cells and incorporated a speed sensor to provide feedback to the PLC of the output throughput (kg/hr) of the processed sludge.

3.5.2 Design Specification

The design specification (in terms of its speed range and weight measurement range) was the same as that for the feed conveyor.

3.5.3 Design Overview and Discussion

The discharge conveyor performed efficiently as a transfer point for the processed sludge and also as a bed on which to monitor the moisture.

The weighing system, however, was incorrectly applied, with the load cells being sized (for static measurement of the weight range) between 0 – 2000kg. Due to the excessive range the load cells lacked the sensitivity to provide accurate dynamic throughput measurement and feedback. It was agreed not to change the weigh system but instead to apply other measurement methods to achieve the process mass balance.

3.6 Inline Moisture Analyser

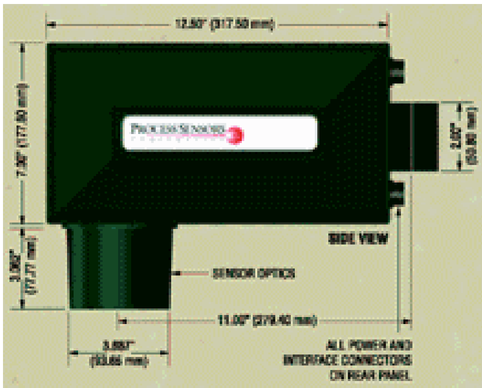
3.6.1 Design Considerations

The moisture meter was incorporated in the design to provide feedback and system control.

Moisture data feedback to the PLC by the meter was used, in conjunction with the feed rate data, to indirectly measure the performance of the KDS Micronex i.e. its efficiency in moisture removal.

The moisture controller directly controlled the amount of re-circulated product diverted to mix with the raw sludge in order to achieve the (operator controlled) moisture target set point by the controller modulating back-to-back dampers at the transfer cyclone discharge.

Figure 8 Inline Moisture Analyser Design Specification



The design specification of the unit was dictated by the product type (Aylesford Newsprint's de-inked Sludge) and a required moisture range of 0-50% water.

Since the target moisture content in the output product was in the range of 10 – 15%, the PLC upper limit for moisture measurement was set at 20%.

3.6.2 Design Overview and Discussion

The unit performed very well, although due to its physical location and system time delay, the control loop could be improved. This is discussed later in the report.

When trying to run an alternative source of de-inked sludge, it became clear that the unit did not give moisture content of various paper sludges, but instead required calibration for different sources of material. The unit accommodated this by allowing different calibrations for alternative materials.

3.7 Pneumatic Product Conveying System

3.7.1 Design Considerations

The process had the following requirements from the pneumatic conveying system:

- To provide a vacuum point in the form of a hood at the discharge conveyor head end;
- To convey product to the vibrating screen via a high efficiency cyclone to remove the air;
- To provide a vacuum point at the transfer cyclone discharge which, through control of modulating valves would allow metering of some/all of the product to be transferred to the feed conveyor as part of the moisture control function;
- To pass the recycled product through a high efficiency cyclone to remove the air.
- To filter the air exhausted from the cyclones; and
- To provide the option of granulation of the processed sludge to clumps with a surface area of no more than 2.5mm2.

3.7.2 Design Specification

Detailed specification of the pneumatic system was undertaken by the supplier (Impact Air Systems).

3.7.3 Design Overview and Discussion

The system proved to be capable of handling the varying conditions and throughputs with which it was challenged.

The transfer discharge cyclone outlet arrangement had to be modified due to excessive mechanical reduction causing product gradually to build-up on the inner walls and bridge across the gap. This modification was simple involving removal of the bottom section and fitting of rectangular flanges for hood connection.

The filter unit proved to be inadequate for the high level of dust loading created within the process. This was not due to poor design, as the amount of dust that would be created under the trial conditions was unknown. The cyclones (although high efficiency) were found to remove approximately 5% of the total solids (fines) with the exhausted airflow, and under continuous operating conditions at 1000kg/hr the static filter elements blinded in a period of some hours. Manual cleaning of the filter bags proved both impractical and inefficient, as their original (totally clean) state could not be regained.

The pneumatic system was modified so that 90% of the transfer fan airflow was re-circulated to the transfer fan suction; thereby significantly reducing the load on the filter and also minimising the solids being conveyed out of the system. Despite this modification, and the reduction in air going to the filter, the filter could still not handle the load for an extended period.

A pulse jet filter was added to the process to overcome this problem, and this is discussed further below.

The recirculation line was similar in design to the transfer line, but with the fan suction air path being dictated by the modulating dampers, controlled by the moisture controller.

The Y-type damper arrangement allowed for 0 - 100% suction from atmospheric air and directly proportional 100% - 0% from the transfer cyclone discharge. Working back-to-back the arrangement provided a means of regulating the quantity of recycled product fed back to the Micronex.

The Granulator also proved to perform very well under controlled operating conditions. Granulator efficiency reduced as the moisture content of the product increased. Prolonged running under these conditions (where the moisture was > 22 %) gradually increased the load on the blades and subsequently the drive, causing the starter overload to trip.

The granulator reduced the size of the clumps of fibre, but this was achieved at the cost of further degrading the quality of portions of the fibre (those cut directly by the blades).

The benefit of the granulator in improving fraction separation was not evident and its use should be disposed of in future installations.

3.8 Air Pulse Filter

3.8.1 Design Considerations

The issues experienced with the originally installed filter described briefly above, and subsequent system changes made caused extended loss of trial time and the decision was made to hire a filter known to be capable of a very similar duty to the trial plant.

3.8.2 Design Specification

The filter utilised during the trial work was a Donaldson Torit Reverse Air Pulse Jet Filtration Plant, Model 3DF6-5 Downflo., which was capable of handling an airflow of approximately 4800 cfm, fitted with 6 ultra web filters. The compressed air was supplied by a 150psi compressor.

3.8.3 Design Overview and Discussion

The filter and compressor arrangement performed efficiently in handling the duty of the trial process, and also at removing the very fine dust particles.

3.9 Vibrating Screen

3.9.1 Design Considerations

Once the correct dry form of the sludge was achieved, the goal was to separate the fibre and filler fractions to the levels as previously detailed - less than 25% filler in the fibre fraction and less than 25% fibre in the filler fraction.

The throughput capacity of the screening equipment had (at least) to have the potential to match that of the KDS Micronex.

3.9.2 Design Specification

The design specification of the separation equipment was based on the material specification and the ability to split the filler fraction (particle size less than 50 micron) from the fibre fraction (variable fibre length) at a throughput of approximately 1000kg/hr.

3.9.3 Design Overview and Discussion

The Vibrating screen proved to have the capability to separate the fibre and filler. However, due to limitations
On development of the separation plant caused by production issues during the trial, the screen's performance was not optimised enough to prove that it could achieve the trial targets.

Figure 9 Russell Finex Vibrating Screen

Analysis of a number of the samples obtained from the Russell Finex vibrating screen trialled under varying conditions is detailed later in the report.

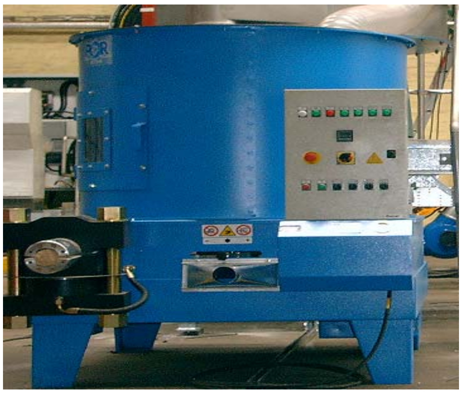
3.10 Briquetting machine

3.10.1 Design Considerations

The briquetting (or pelletising) machine was included as part of the process equipment for two key reasons;

- When the sludge is dried and processed (either as a mixed product or split fractions) the bulk density is very low (0.1 - 0.2 tm^{-3}), which makes transport of the products uneconomical, due to the amount of air being carried with the product.
- By briquetting or pelletising the product, the bulk density is far higher and economical. Environmental constraints also limit the transport and landfill of the filler fraction, although in briquette form this is not an issue.

Figure 10 Briquetter - Plant Photo



3.10.2 Design Specification

The design specification was based on the material specification, throughput requirements and moisture content variation

- Material specification – Typical raw sludge described in 2.1.1

- Product throughput – 1000 kg per hour
- Moisture content range – 10 – 18% moisture

3.10.3 Design Overview and Discussion

Figure 11 Briquettes

The briquetting machine was a simple piece of equipment utilising electrical power to drive a hydraulic system and compress the material into a cylindrical briquette or pellet.

The unit was very efficient and was found to be capable of manufacturing briquettes across all the variations of the processed sludge and across a moisture range from 8% to 25%.

4.0 Critique of Process Plant

4.1 Site Observations of the Machine

4.1.1 Summarised Diary of Process Plant Trial

The machine was started up on 30 June 2005. The table below summarises events over the project. More detail is provided in the text of this report.

Figure 12 Diary of Process Plant Trials

Action	Date
Machine Start Up	30 June 2005
Air recirculation Loop Added	10 August 2005
Setting and Optimisation	29 August 2005
Product Processing	1 September 2005
Sludge Feeder Repairs	21 September 2005
Pulse Jet Filter Installed	1 November 2005
Belt and Bearing Issues	16 December 2005
Product Duct Blockage	31 January 2006
Blower Fan Seized	6 February 2006
Micronex Vent Issues	7 February – 11 April 2006

The running time between milestone events was also affected by other issues

4.2 Project Plant Observations Summary Points

As detailed earlier, initial observations raised awareness that feed rate and physical delivery of the sludge to the KDS Micronex inlet was a critical factor to consistent loading and effective processing of the sludge.

During process optimisation phase the following main observations were made as detailed in the following sections.

4.2.1 KDS Micronex - Initial Start-up

Start-up on the machine was slightly delayed due to a number of issues configuring the Baldor Speed invertor. However, once these were overcome the machine started and achieved a steady running state.

Product was then introduced to the machine with the objectives of making the required adjustments to the classifier and blower fan speed in order to optimise the performance of the machine in achieving moisture removal from the product.

It quickly became apparent that in processing de-inked paper sludge, neither of these issues was important, as the classifier had no effect on the sludge retention or form. At the least it just created an obstacle to which the wet product could adhere. The blower fan's speed was adjustable in to vary retention time of the product inside the machine.

Fan speed required to be at maximum in order to optimise the cyclones efficiency, and to prevent damp product being retained within the machine.

When the settings on the machine had all been set to the maximum, the machine was ready to process product. It became clear that the main factors in the Micronex's performance were the feed rate and its delivery to the inlet rotary valve.

The main rotor of the unit is a high-speed unit and in order to achieve this speed torque is sacrificed. It was evident that heavy loading of product on the rotor caused the current to rise very quickly and the drive belts to become very noisy.

Heavy loading is not the same as high feed-rate; the delivery of raw sludge required to be fine - tuned in order that the product was evenly and thinly spread on the belt. A large cross-sectional area of product on the belt resulted in heavy impact loading on the rotor, causing the current to rise.

At the same feed-rate, with a smaller cross-sectional area of product on the belt, and higher belt speed, the Micronex processed the sludge efficiently and the electrical current remained reasonably stable.

Further discussion on the KDS Micronex's performance is given later in the report. A number of particular problems are described below.

- The machine takes approximately 30mins to reach an efficient running state, (i.e. warmed up).

  The machine process dries the sludge by mechanical forces developed by the high-speed rotor and torus chamber walls. The rotor shears moisture from the fibre as well as passing heat energy to the product. Relative vapour pressure techniques are applied in the design to force moisture from the product to the air stream. The heat energy generated by the mechanical forces (inside the machine) gradually heats the air being recirculated as well as the chamber walls. Once these have all reached running temperature the machine is considered to be in its efficient running state.

- The machine took an excessive time (up to 2 hours) to reduce the moisture content below 18% when using the automatic control system.

  The moisture control within the plc system works by modulating the recirculation dampers as previously described. Once product moisture has been analysed, product then passes through the air system (minimal time delay). The recycled product again passes through the respective air system (minimal time delay) onto the feed conveyor belt. The product then has to travel two thirds of the belt length before it enters the KDS Micronex, is processed and eventually returns to the measuring point at the moisture meter. This process considerably increases the delay to the control system, which coupled with slow modulation of the control dampers causes the system to oscillate for a period until it settles.

- Controlling the recycling rate manually proved to be effective in stabilising the consistency of the moisture output; however the proportion of recycled product was around 50% of the total throughput.

  Without modifying the process to overcome time delay issues, the solution proved to be to manually adjust the amount of recirculation. The level of recirculation was started at 100% (first pass drying never exceeded 18% moisture) and as the moisture started to decline the amount of product being recirculated was gradually decreased by reducing the percentage opening of the recirculation damper. The settling time for the system was approximately 30 minutes after the machine was warmed up.

- The processing throughput was observed to be 1250kg/hr reducing the moisture to approximately 14.5% with 50% recycle (625kg/hr raw product).

  At the start of the trial the machine processed de-inked sludge at a rate of 1250 kg/hr from a raw moisture of 38% to 18-20%. This level of processing slowly dropped and within a short time the throughput fell to around 800 – 900 kg/hr with output moisture of 18%. Any increase in throughput reduced the level of drying.

- **T**he machine could achieve a moisture reduction from 38% to 10-12%. Raw material throughput is estimated to be approximately 200 kg/hr.

  In order to decrease the output moisture of the sludge, recycled processed sludge had to be back-mixed as described earlier in order to reduce output moisture below 18%

  In order to achieve output moisture of 12%, the volume of recycled product had to be increased to over 50% of the total throughput, reducing the flow of raw sludge entering the system to below 200 Kg/hr.

- The performance of the machine slowly deteriorated to processing about 400 kg/hr raw sludge with a minimum moisture around 16%.

  Following the commissioning period in July 2005 and observed slow decline of the machine's performance, the machine settled to a production rate of 400kg/hr (raw sludge) with output moisture content of 14-16%.

  The decline of the machine's performance was monitored over a period of 21/2 months, during which the machine only ran for approximately half of this time, and for no more than 8 hours per day. The suppliers

(FASC) were kept informed of the machine's performance and were asked to make a site visit at the end of August 2005. This event and the outcome are discussed below.

- The machine was a development model that lacked any internal feedback technology indicating production faults. Maintenance access was very poor.

  There is further discussion on this point below.

4.3 Project Plant Performance Review

Further to the performance summary provided above, the following section covers the issues experienced during the trial with regard to the Micronex. Suggested modifications to the Micronex are noted below.

Following machine start-up and verification of the machine's processing capabilities (in terms of raw product throughput and consistent moisture removal as described above) machine performance slowly decreased until the maximum throughput achievable was 400kg/hr with approximately 80kg/hour water removal. The suppliers of the machine were requested to make a site visit and evaluate the machine.

The supplier's opinion was that inadequate venting had caused the machine to retain excess moisture, and this in turn caused internal product adhesion and build-up, which led to excessive product build-up inside the cyclone, main Torus chamber and product duct. The affected areas were cleaned and the classifier removed, as of no benefit in the sludge application, except as an internal structure to which product could adhere. The original machine vents were removed and new vents installed.

Once rectification work was complete the machine returned to its former performance. The machine was then run with back-mixing to ensure the moisture content was below 18%, thereby minimising the effect of processing excessive wet product. The future machine operating procedure was to run dry at the end of an operating period for about 10 minutes (before shut down) to ensure that all wet product was removed and the machine remained dry.

The machine's performance again slowly dropped to a processing level of around 400 kg/hr raw product, but would reduce the moisture to below 12% by increasing the back-mixing as described previously. The machine was run for a period of time under these conditions and proved to be reliable at this level.

With the exception of the belt and bearing issues which were experienced in late 2005, the machine continued to process dried de-inked sludge at a production rate (and to a moisture level) that allowed the trial to focus on achieving the target separation levels.

Early in 2006 the blower fan seized and the machine was once again stripped and fully cleaned. Product had been building up in the vent ducts, which had caused a slow build up of in the duct, around the blower fan and in the visible internal duct chambers. These observations showed that despite regular inspection there was a lack of access points to monitor the internal condition of the machine. This showed the effect of venting on the machine performance and the need for further development work in that area.

Further to the above and subsequent overhaul the machine was re-started. However, performance was inferior to that previously achieved. The machine was limited to an output moisture content of 14.5% irrespective of the level of back mixing and throughput rate.

A performance review including a measured process balance was undertaken; the outcome of which highlighted that approximately 200kg of product was unaccounted for. Further investigation and removal of the ducts uncovered that the machine was forcing very dry product from the machine through the vapour vents.

Figure 13 Fibre Build-up

It is considered that the blower fan seizing was due to it being run at a reduced speed early in the trial, thereby causing product build up and continued running at a lower fan speed than that indicated.

The suppliers offered a number of suggestions, all of which were addressed, although none produced a positive effect. This continued for a further two months, preventing planned separation plant optimisation and causing repetitive machine cleaning following each attempt to solve the problem.

The suppliers were requested to make a further site visit to address the problem. Outcomes were that two internal air distribution chambers were partly blocked with product. The internal chambers had not been previously mentioned and were totally invisible. Access to the chambers was not part of the design and the chambers had to be cleaned by access through the vent points on the machine.

This proved a very significant design flaw and one, which the supplier has advised, has been rectified in newer machines. Following cleaning of these chambers the product venting issues were rectified and the original machine performance regained.

The Micronex unit used was a development unit and the trial proved the machine's best performance when processing de-inked paper sludge. In addition design flaws were uncovered and addressed with the supplier allowing for its development, which will make a fully developed machine a viable production unit within the UK paper industry.

4.3.1 PLC control system review

The KDS Micronex was supplied with a Baldor MCC with manual controls mounted on the panel for control of the drives. The Baldor MCC had to be modified to accommodate software control.

The control system provided control functions allowing the process to be run in automatic mode, the performance of which is reviewed below.

Once the sludge was discharged from the KDS Micronex the moisture was analysed by the 'Process Sensors' moisture analyser. Depending on the moisture set point designated by the operator, the PLC modulated control dampers located at the transfer cyclone discharge to either increase or decrease the amount of product being sent back to the feed conveyor to mix with raw sludge and aid reduction of the overall sludge input moisture.

Problems with the control system included the physical location of the recycled product cyclone and discharge hopper. The delivery point to the feed conveyor was approximately two thirds of the total conveyor length away from the KDS machine. This distance caused periodic system oscillation, which increased the settling time of the control system to achieve the required moisture level. An additional factor related to the feed rate from the sludge feeder. With high moisture, the product recycling rate is increased and the raw feed rate requires to be decreased. Due to the lack of ability to vary automatically the quantity of raw sludge being delivered to the feed belt the system when under automatic control, could become overloaded with product. The proposed solution to overcome this issue is described below

The feed-rate of sludge (both raw and recycled) to the Micronex was also controlled by the PLC. The feed conveyor was fitted with a weighing system, the output of which was fed back to the PLC system. Corrective action to achieve the manually inputted feed-rate was controlled by the PLC. When the Micronex was becoming overloaded with product (set point at 220 Amps), the PLC would override the control software and stop the feed conveyor. The conveyor was restarted once the current had decreased below 200 Amps.

5.0 Process Plant Developments

5.1 Refinements to Original Process Design

5.1.1 Introduction

The following information details the observations and technical findings for the relevant process plant and the process itself.

This section has been divided into sub-sections summarised as follows

- Development of the plant from initial installation to the end of the trial;
- Performance summary of each area of the plant; and
- Plant performance and discussion of the trial analysis.

5.1.2 Trial plant development

The following upgrades were made to the process:

Modification to Sludge Feeder to feed conveyor transfer point

The transfer point was modified by adding the hopper and sliding gate arrangement, both of which significantly improved the control and delivery of sludge onto the belt. However, even with the hopper and gate modified, the system still required frequent attendance by the plant operator to clear blockages and modulate the metering gate to meet the requirements of the production parameters.

It was observed on numerous occasions that although the feed-rate to the KDS Micronex was set at a fixed rate, the conveyor could not physically deliver it, because the feed point had become restricted by product compaction or lumps within the raw sludge.

The solution to overcome this issue is covered below:

Modification to transfer fan exhaust air line

As a result of the original filter issues (above) the recirculation line was installed as described.

The line airflow and pressure were balanced using two dampers; one was installed at the entry to the filter and the second at the entry to the conveyor hood. These dampers were set-up to balance the air being supplied to the conveyor hood, so that the airflow was less than the suction of the transfer fan. Any deviation from this caused dust to be expelled from the conveyor hood.

The airflows were set-up so that only 10% of the total air was exhausted to the filter and the remaining 90% was used in the air loop to convey the processed sludge.

The benefits of recirculating the air were that it reduced the load on the filter, and that the loop temperature was increased by the heat energy lost by the processed fibre, and once raised remained fairly consistent. Warmer air in the loop further aided the drying of the processed sludge, with evidence that around 2-3% moisture was being removed between the KDS Micronex discharge and the Vibrating screen. The modification also greatly reduced the fines that were previously being conveyed out of the process with the exhausted air.

Further system upgrades are proposed in section 5.2.2.

Addition of a pulse jet filter

Despite modification, the static filter still proved to be very inefficient.

The decision was made to add a pulse jet filter with the operating capacity easily to handle the process airflow requirements.

A new line was installed from the air inlet side of the static filter to the new filter, and the original filter exhaust to atmosphere. This used the original filter quite as a junction point in the ductwork, with the ability to balance both inlets and outlets.

The new filter operated efficiently under the system pressures and airflows. At a KDS Micronex discharge moisture of 15%, the filter bin (with a capacity of approximately 10 kg) required emptying every 6-8 hours. This frequency increased as the moisture content of the processed sludge reduced e.g. at 12% moisture (KDS Micronex discharge) the bin required emptying every 3-4 hours.

No upgrade was however proposed for this piece of equipment

Addition of Bag handling systems

Bag handling equipment, as described below, was added to reduce the lost production time incurred when making bag changeovers for receiving the finished product. This also minimised site manual handling and allowed ease of product movement and weighing of the finished product.

The bag handling equipment consisted of the following:

- Large gantry runway beam and 1.0 tonne chain block and pulley, located at the vibrating screen fibre discharge point.

- Bulk bag (1 tonne big bags) mounting pallet cages, for manoeuvring with a pallet truck or forklift.

These were located at the Briquette and filler collection points.

Figure 14 Screen & Bag Handling Equipment

Separation plant Development

Analysis of trial results is provided in section 6.0.

Further discussion on the Russell Finex Vibrating Screen is provided in section 5.27.

Due to the screen not providing adequate separation to meet the project targets, the following development work was undertaken.

Addition of Ultrasonic vibration on the Vibrating Screen

Following the initial process optimisation phase, where the processed sludge could be delivered to the vibrating screen at a moisture content between 10-12% (and various screen configurations had been trialled and the best results obtained), the requirement for better separation led to Russell Finex supplying an ultrasonic vibration unit.

The unit's vibration probe was attached to the bottom screen in an attempt to maximise the clay and fibre separation and clay volume. The unit works by using very high frequency vibrations to encourage movement and separation.

There was not a significant improvement when using the ultrasonic vibration assistance.

Elimination of Static bonding – Anti-Static System

It was considered that a combination of the forces within the Micronex machine and the static generation characteristics of air flowing through ductwork/fans could be creating a static electricity bonding force.

As a result four ionising bars were fitted to the transfer cyclone discharge, in order that the static in the product was neutralised before the product reached the screen.

Following a trial run, test samples were collected and sent for analysis. The lab analysis showed a slight improvement. The improvement achieved was inadequate to raise the fraction qualities to the target quality specification required. It was concluded that static induced in the process was not the major part of the bonding force between the fibre and filler.

5.2 Suggested Future Process Plant Developments

5.2.1 Introduction - Proposed process system development

The trial outlined within this report had the primary objective of proving that de-inked paper sludge could be economically processed and marketed in its various forms. The secondary goals were to achieve a market derived quality standard in the separated fractions.

Through experience gained over the duration of the trial, the efficiency, performance, reliability and maintainability of the KDS Micronex were identified. In addition to this, the process and control system that were used to feed the Micronex and then handle, screen and pack the processed product were also analysed.

5.2.2 KDS Micronex – development suggestions

It is important to note that whilst discussing development of the Micronex machine, these proposals do not address the actual internal process design and possible improvements. There is insufficient understanding of the internal dynamics and this development knowledge is confidential to the machine supplier.

Non-conforming access steelwork

The KDS Micronex was delivered with access ladders on both sides, providing access to mid level platforms. The ladder on one side of the machine also extends to a high-level platform providing access to the blower fan.

- The ladders require redesigning to include hoops;
- The mid-level platforms are too narrow;
- The high level platform needs to be fitted with a self-closing gate; and
- Suitable access steelwork would also be beneficial to provide access to the cyclone access hatch.

In order to achieve this, the existing steelwork would require complete removal and conforming access steelwork conforming to BS5395-1-2000, or equivalent, installed.

Maintenance access

The most significant production issue experienced during the trial was lack of maintenance access to areas where this proved necessary. Under perfect operating conditions, perhaps the machine would require very low frequency maintenance and therefore the downtime involved would become more acceptable and economic. The manufacturer has addressed maintenance access in newer models.

Trial experience involving maintenance issues describes the scenarios and conditions that led to the necessity for access and frequent cleaning, attributable in the main to very simple causes. The areas of access requirements are as follows:

Cyclone access for cleaning

The current access hatch is too small, and its extending nature hinders the cleaning of the inner wall.

Access to the top of the cyclone (as documented in the manufacturer's operating manual) is achieved by an operator entering through the current access hatch and climbing up the inner walls. This would be unacceptable to most of potential end-users, and where physically possible would require the application of 'confined space regulations' and correctly certified companies to do so.

Access would be significantly improved by adding a removable flush mounted access plate on the top of the cyclone and modifying the top-level steelwork to meet the maintenance and health and safety requirements.

In addition to the fortnightly cleaning requirement, frequent access was required to view the inside of the cyclone to ensure that there was not excessive sludge build-up. Access steelwork would provide safe access, and within many production environments would be the output of an operational risk assessment.

Product duct access and removal

The product duct proved to be vulnerable to product build-up and in extreme cases completely blocked.

The duct had to be removed three times during the trial period and each time took excessive time to clean, in addition to labour and lifting equipment. This problem could easily be overcome by designing it in three separate sections with the addition of two access windows

Micronex internal chambers

Air distribution around the Torus chamber is achieved via internal air ducts, created by a double walled design within the chamber. These are vulnerable to product build-up and consequent blocking. It is impossible with the current design to view the internal ducts and very impractical to access for cleaning.

The ducting system either requires re-designing so that the air ducts are external to the main machine, or are removable internally. The simplest solution on the current machine is to modify it and install access hatches, which should be flush-mounted to the machine.

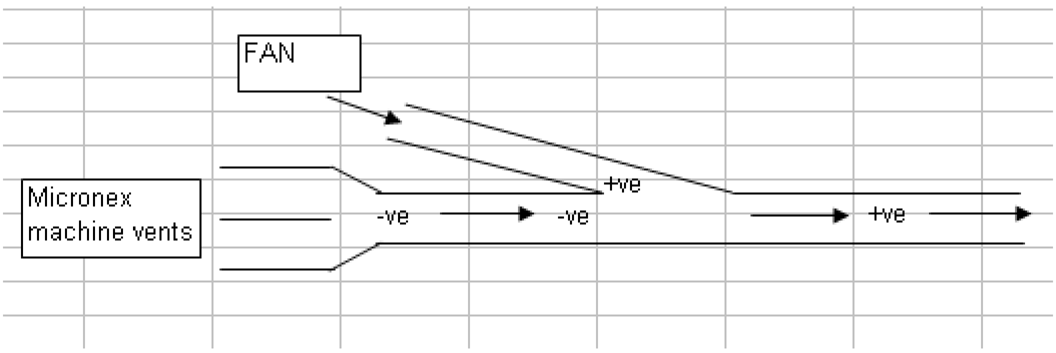
Machine Vents

Most production issues on site were related to poor machine venting, mainly due to an imbalance in the airflow through the vents and the effect of any change within the machine on the vents.

It would be beneficial if the vent airflow was controlled. This could be achieved by placing a fan in the line so that it was blowing in the direction of the vent see Figure 15.

This would prevent any product effect on the fan. In theory, the fan speed could be controlled in proportion to the air pressure within a specific part of the machine; thereby ensuring the air balance was maintained.

Figure 15 Proposed Machine Venting Solution



Fault sensing / alarms

Production efficiency throughout industry is dependent on being able to prevent maintenance issues and subsequent downtime where ever possible or at least being able to manage the frequency of required maintenance giving the ability to plan it, and schedule it into routine plant shut downs.

The KDS Micronex currently has no fault sensing hardware, no physical observation points or relief systems that provide the operator with feedback to notify of a fault/ production issue, or prevent the machine from continuing in the fault state and eventually completely failing, leading to a complete overhaul.

To comply with the requirements of an efficient production process the machine designers and manufacturers require to give this concern further consideration and apply the features described above.

5.2.3 The Sludge Feeder – Development Suggestions

The main rotor and drive

Due to forces occurring within the vessel and the compacting effects of various sludges the torque of the main drive should be increased by a factor of 1.5 to 90,000 Nm

The shutter mechanism can be removed

The discharge of the sludge feeder should be fitted with a high torque screw feeder, designed with a large centre shaft for strength and shallow flights for accurate feeding of the sludge.

5.2.4 The Feed Conveyor – Development Suggestions

The application of the screw feeder would remove the requirement for the hopper and sliding gate arrangement that was retrofitted to the feed conveyor. This can be achieved by the screw feeder being fitted with a variable speed drive that would be controlled by the weigh system feeding the Micronex.

The feed conveyor should be redesigned to include a hood for totally enclosing the conveyor (where possible).

5.2.5 The Discharge Conveyor – Development Suggestions

The discharge conveyor (width and length) could be increased in order to slow the belt speed and subsequently improve the analysis of the dried sludge by the moisture analyser. Increasing the length of the belt would also allow for the majority of its length to be covered, thereby minimising dust being released to the atmosphere.

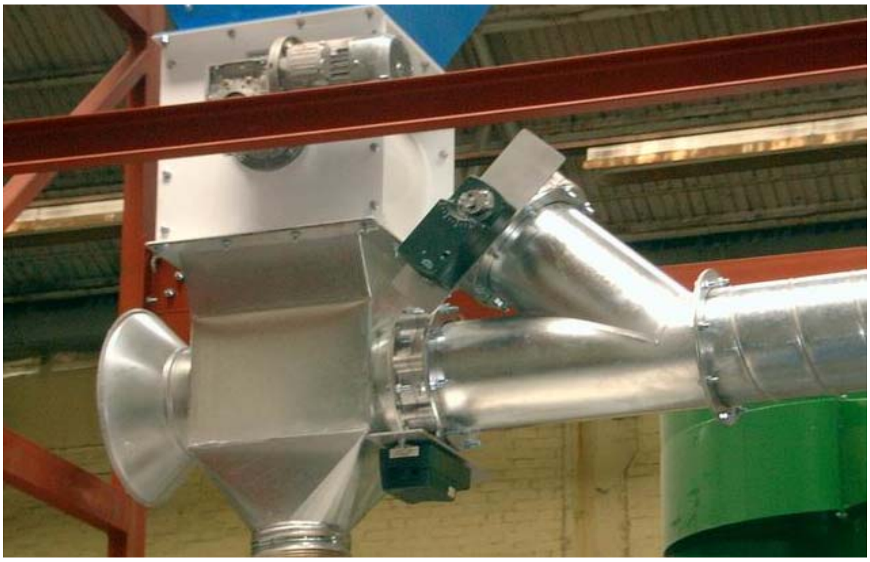
The load cells also require to be upgraded to meet the original design specification. This will provide feedback of the output rate from the KDS Micronex. This measurement could then be used as part of the fault sensing system, by relating to the input moisture manually setting a limit for the maximum moisture removal. Should the output throughput be excessively lower (outside of the set limit) than the input rate this would be an accurate indication of a fault.

5.2.6 Air Transfer System – Development Suggestions

The following proposals are put forward for the air transfer system:

- The receiving hood requires to be designed to snugly fit the conveyor but also to be easily removable;
- All ductwork should be solid laser welded type (fully sealed) specifications;
- All duct runs should be reduced to minimum required lengths and with logical break points in the event of a blockage; and
- The fans should remain as present.

Figure 16 Current Recycling Arrangement



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- The present arrangement for recycling product (to provide back-mixing) incorporates the suction of the recycling fan at the rotary valve discharge. The fan suction has a modulating damper, which regulates the amount of product being pulled by the fan for reprocessing;
- Certain activities dictate the use for the transfer path to the screen, although this is not required for the back-mixing. However, without the recycle fan running there is excessive dust created at the hopper discharge;
- The required modification to this arrangement would be the inclusion of a one-way air flap – or equivalent non-return valve installed on the suction mesh, the principle being that under pressure it would be closed and under vacuum it would open;
- In order to overcome the system delay caused by recycled product being dropped onto the feed conveyor so far from the belt discharge, recycled product should be delivered as close to the Micronex inlet rotary valve as possible;
- This could be achieved by the current recirculation cyclone being relocated near the top of the belt; the limiting factor is the available height at any potential future production site for this plant.;
- In the event that the required height is not available, a second feed conveyor could be installed also allowing better feeding into the Micronex. The addition of a second belt (inclined from an operator accessible level) also adds the benefit of further process flexibility and a second system unloading point. With the addition of a divert valve at the recycled cyclone discharge or the ability to move the tail-end of the second conveyor the product can be delivered into trucks, bins, etc ;
- To allow for further system flexibility and optimisation, a suction point should also be located at the vibrating screen discharge. The pick-up will be a flexible connection, allowing it to be placed under one of the screen discharge points. This line should have the option to be sent to the recycled product cyclone or the transfer cyclone (i.e. delivered back to the screen); and
- Further Air system modifications are offered for consideration below in the system variations section.

5.2.7 The Vibrating Screen

Further trial work is required using different screen configurations and preferably different types of screen material, weaves etc. Retention time of the product on the screen is quite low and this is also a possible area for further development.

Development time in this area was not possible due to the issues experienced with the Micronex machine.

5.2.8 PLC control System

The main issue affecting the PLC control system has been addressed in section 4.3.1.

Further PLC control system development must be considered alongside relevant system upgrades.

5.2.9 Viable System / Process Variations

The trial and equipment (as detailed within this report) were predominantly designed and selected to aid the KDS Micronex in processing the raw sludge to a dry fluffy form. The separation plant was, however, selected to receive and separate the dry formed product.

Experience and knowledge gained through the trial raised the awareness of both the requirement to bridge the gaps where the process lacked efficiency and also the possibility to apply completely different technology to achieve the desired results.

A number of potential possibilities are detailed in the following sections.

Steam Drying

Given the amount of energy used by the KDS Micronex to dry the sludge, coupled with the amount of recirculation required to achieve low moisture content, an economical solution for a paper mill would be the use of a steam coil dryer to pre-dry the sludge before it enters the Micronex.

Surplus steam is often available within many paper mills and therefore the cost relates to the capital cost to purchase the dryer and supply the steam. The electrical energy used to rotate the coil and maintenance costs should be comparatively low.

Pneumatic flash drying / retention drying / dehumidifying

The trial also indicated that the pneumatic air system provided product drying which removed around 3% moisture at relatively low moisture levels.

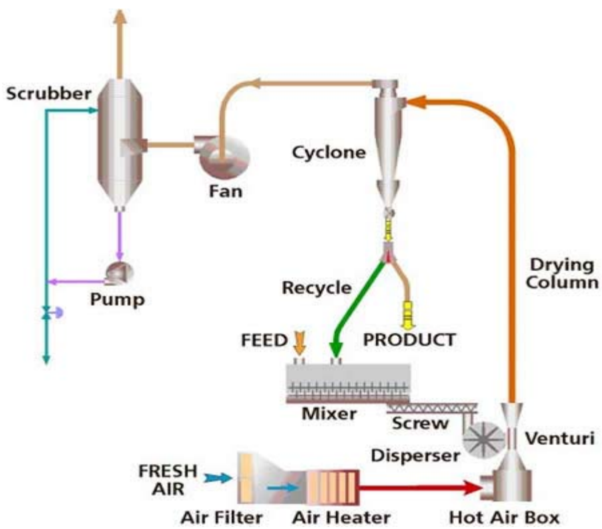
With the addition of dehumidification units and/or a system with a designed product retention time i.e. long duct runs with numerous direction changes, this very simple low power consuming system could be used to provide much higher levels of post-Micronex drying.

Pneumatic flash drying

This system could be developed to include the pneumatic flash drying system shown.

The justification for this would be dependent on product throughputs and moisture level requirements.

Figure 17 Potential Pneumatic Drying System



Air cyclone technology

Air cyclone technology has been a proven method of product or dust separation for many years. Experience through the trial provided evidence that the dust carried through the air stream was identical to that being separated in the filler fraction by the screen.

Working on the principle of 95% efficiency, i.e. that 5% of the solids in the air stream are carried to the exhaust of the cyclone; a series of cyclones could be designed to provide the plant separation and also to provide product drying at the same time.

Considering the air system both as a method of drying and as a method of separation, the plant could be designed to consume less energy than shown in the trial. A further significant finding was the effect of the air system fans on the raw sludge product. At the early stages of the project, during the commissioning of the pneumatic system, raw product was used as the test material. The raw material that passed through the system came out with a very similar form to that seen as product from the KDS Micronex.

Figure 18 Processed Raw Sludge

This could have a significant effect on process design, with the pneumatic system having the potential to dry, form and separate the product. The Micronex workload could significantly reduce the plant energy consumption and increase the plant throughput. Plant throughput would be increased by utilising the KDS Micronex (for a lighter duty) in terms of moisture removal, for example from 25% water to 18%, with steam drying providing a reduction to 25% and the pneumatic system providing drying from 18% to 12%.

Other vibrating screen technology

There are numerous designs and technologies for separation on the market, the majority being for powders, etc. of the vibrating bed-type. Samples were provided to third party suppliers (where possible) but none proved capable of achieving better separation than that achieved on the trial plant. There was a limitation of the production of quality-processed sludge available to send to third party suppliers and further work is recommended in this area.

5.2.10 Summary

KDS Micronex

- Conforming stair and access steelwork.
- Modification to include 6 inspection/maintenance hatches.
- Modification of the moisture vents to include forced venting of external ductwork or at least solid ducting that consists of quick release couplings for easy maintenance.
- Fault sensing equipment integrated to PLC control system.

Sludge Feeder

- Torque capabilities of drive need to be increased to 90kNm+.

- The shutter mechanism to be changed for a large shafted feed screw.

Product conveyors

- Both conveyors need to be enclosed with hoods and possible negative low-pressure airflow to filter to minimise dust.
- Discharge conveyor would benefit from being wider and longer and subsequent lower belt speed.
- Discharge conveyor weigh system needs to be sized correctly for the dynamic measurement of product throughput.

Air handling system

- Dust control for the plant requires to be integrated within the air system design.
- Recycled product needs to be delivered as close to the Micronex inlet as possible in order to minimise control system delays.
- The air system would benefit the drying efficiency of the plant by integration into the process for a drying function in addition to transferring of product.

Vibrating Screen

- The Russell Finex screening equipment was not trialled to its full potential due to production issues and further trial work needs to be undertaken.

6.0 Sludge Separation Trials and Analysis

6.1 Target Specifications

At the outset of the project, the performance of the Micronex (on UK sludge) was unknown, although its performance in Canada had been documented.

During the preliminary discussions, leading up to the project, lengthy debate led to a minimum specification for the two main split fractions.

Figure 19 Minimum Target Specification

Fraction	Fibre (%)	Moisture (%)	Filler (%)	Moisture (%)
Fibre Fraction	>75	<10	<25	<10
Filler Fraction	<25	<10	>75	<10

To achieve marketable products to potential customers, it was considered necessary to achieve the % fractions shown. It was, however, anticipated that a superior separation of the appropriate filler and fibre contents in the individual fractions could be achieved.

It was recognised that a fibre fraction with a filler/ash content at 25% was the maximum that was commercially usable at potential customers, and that if a filler/ash content (in the fibre fraction) approaching 10% could be achieved the potential opportunities for use as a meaningful fibrous raw material would increase substantially.

For the filler fraction, a similar rationale was applied, in terms of setting the minimum specification, but again with the anticipation that superior separation would also be achieved.

6.2 Micronex Plant Performance Measurement

6.2.1 Performance Measurement Overview

An understanding of the performance of the Micronex plant is crucial to assessing the economic benefit of utilising the process.

To create an economic model, it was determined that certain of the main plant parameters should be measured during processing trials. It would be possible to determine, particularly, relationships between the moisture level in the output materials, the power input required to achieve the moisture reduction and the production rate that could then be expected.

The opportunity was also available to test the plant with a deinking waste material from M-Real New Thames mill. This material had the same water content as the Aylesford sludge, and very similar proportions of organic and inorganic material. The M-Real inorganic content had a higher proportion of calcium carbonate to clay than the Aylesford sludge.

Two trials were conducted in which the complete performance of the plant was measured:

- In the first trial, the machine was stabilised so that consistent moisture content was achieved in the output stream from the Micronex of 13.5%. This material then went to the separation process and the separation efficiency was measured. Measurements were also made of the power consumed and the time taken to process 1 tonne of input sludge. In the second trial, the machine was stabilised with the output from the Micronex at a moisture content of 18%. The measurements were repeated.
- From earlier work on material dried to 3.9% moisture at the exit from the Micronex, a number of comparisons were made to show how separation efficiency could vary with the dryness of the mixed material fed to the screening process. This material originated from Aylesford mill, but inclusion of the results is seen to be valid

as the raw sludges from the two mills had many common characteristics; particularly almost identical moisture content.

The results of the above trials are as shown in the tables below:

The first table shows the machine characteristics during the trial, where the sludge was separately dried to 13.5% and 18.0%

Figure 20 Trial Results at 2 Different Moisture Contents

Measurement Parameter	Moisture (13.0%)	Moisture (18.0%)
Feed rate including recirculation	800	1000
Moisture of input material (lab Test) %	36.0	36.0
Moisture meter reading at exit from Micronex % (nb.indicative only – not calibrated)	25.0	33.0
Moisture at exit from Micronex (lab test) %	13.5	18.0
Weight of wet sludge processed kgs	1000	928
Bone Dry weight of sludge input kgs	640	594
Weight of fibre collected kgs	502	621
Moisture of fibre (lab test) %	15.1	18.0
Weight of filler collected kgs	226	104
Moisture of filler (lab test) %	9.2	18
Bone dry weight of material collected kgs	631	594
Losses unaccounted kgs	9	0
Time to process hrs	3.92	2.0
Power consumed Kwh	388	198
Power consumed per input tonne	388	213
Moisture removed kgs	272	204
Moisture removed per hour kgs	69	102
Rate of processing wet sludge kgs/hour	255	464
Wet Sludge Ash content at 575 deg, bone dry %	67.3	n/a
Dry Fibre Ash content at 575 deg, bone dry %	63.8	n/a
Dry Filler Ash content at 575 deg, bone dry %	73.6	n/a

N.B. Trial utilised sludge from M-Real New Thames Mill

Additionally, tests were carried out to identify the screening characteristics of the input and output material at 13.5% (sample A) and 3.9% (sample B) exit moisture content, and these are shown in the table below:

Figure 21 Second Series of Tests at 2 Different Moisture Contents

Test Result	Sample	Raw Sludge	KDS Output	Fibre Fraction (Screened)	Filler Fraction (Screened)
Moisture (%)	A	36.0	3.3	3.9	3.9
Moisture (%)	B	36.0	13.5	15.1	9.2
Ash (575° C)	A	70.1	65.8	51.2	68.9
Ash (575° C)	B	67.3	66.8	63.8	73.6
Ash (900°C)	A	44.6	42.9	34.3	46.2
Ash (900°C)	B	42.8	42.3	40.6	47.0
$CaCo^3$ (%)	A	58.0	52.0	38.3	53.7
$CaCo^3$ (%)	B	55.8	55.7	52.8	60.4
Clay (%)	A	12.1	13.8	12.9	18.0
Clay (%)	B	11.6	11.1	11.1	13.2
Fibre (%)	A	29.9	34.2	48.8	28.3
Fibre (%)	B	32.7	33.2	36.2	26.4
Gross (CV cals/gm)	A	900	1590	2010	1400
Gross (CV cals/gm)	B	1010	1400	1435	1240

N.B. Trial utilised sludge from M-Real New Thames Mill

Sample A = 3.9 % moisture
Sample B = 13.5 % moisture

It was noted that the moisture meter had to be recalibrated for every different material that is processed because it gave inaccurate readings of the moisture at the exit from the Micronex. This was confirmed when the meter read 25.0 % moisture and the bone dry laboratory test was calculated to be 13.5 %.

6.2.2 Micronex Moisture Reduction Performance (Utilising Sludge from M-Real)

Two sets of results for drying characteristics were produced. The superior moisture removal rate was achieved by a higher processing rate, although at a higher output moisture. The starting moisture was 36%.

In this way it was possible to achieve moisture removal of 102 kgs per hour at an output moisture of 18%. Once the moisture in the output was reduced to 13.5%, the processing rate dropped and the moisture removal fell to only 69 kgs per hour.

The processing rate for wet sludge was 464 Kg per hour at 18% output moisture, but was reduced to 255 Kg per hour at 13.5% output moisture.

Power consumption was 213 KWhr/wet tonne and 388 KWhr/wet tonne for 18% and 13.5 % output moisture respectively.

The requirement to reduce to the lower moisture, and indeed below this, to give screening an opportunity to be effective as a separation process is described in the following section.

6.2.3 Screening Performance (Utilising Sludge from M–Real)

Summarised in the table below are the screening performance comparisons at differing input moisture contents.

Figure 22 Screening Performance Comparisons

Moisture % (exit Micronex)	**18**	**13.5**	**3.9**
Fibre fraction as % of total output weight	86	69	30
Filler fraction as % of total output weight	14	31	70

- The results reported at 18.0% and 13.5% correspond with the machine performance data reported in Figure 55. The results on very dry 3.9% moisture output do not have corresponding complete production data.
- The separation achieved at 13.5% was disappointing. The “fibre” proved to be only 36% fibre, a small improvement from 32.7% in the raw sludge.
- However, the screening at 3.9% moisture achieved 48.8% fibre from a Micronex output that contained only 34.2% fibre.
- There is thus evidence that for screening to remove a useful amount of filler from fibre, the material screened needs to be drier than 13.5%
- Conversely, the fibre contamination in the filler rose so that the filler had 73.6% ash when screened at 13.5% and 71.7% ash at 3.9% moisture.
- The proportion of material that passes through the screen, and is thus classified as filler, depends on the dryness of the material out of the Micronex as shown in the following table. At high input moisture most material is held on the screens and classified as “fibre fraction”. At very low moisture, most passes through the screen and is classified as “filler fraction”.

In these trials the validity of the system in being able to make a significant separation was demonstrated. However, the following observations apply:

- The rate of production of dried mixed sludge from the Micronex is below the manufacturer’s expectation; and
- The degree of dryness has to be improved (probably below 10% moisture), to give a screening separation, which will deliver acceptable and marketable fractions.

6.3 Effect of Moisture Content on Separation

At intermittent time-points over a two-month period, a series of samples (No’s 1 – 7) were taken from the production process to assess the effect of the degree of drying in the Micronex, on subsequent separation in the screening process.

These samples were taken both when processing Aylesford and M - Real recycling sludges.

The results are shown in the table 6-5 below:

Figure 23 Analysis of Intermittent Samples

No	Sample Source	% Fibre in Fibre Fraction	Moisture (%) in Fibre	% Filler in Filler Fraction	Moisture (%) in Filler
1	Aylesford	39.7	14.8	69.8	10.3
2	Aylesford	44.7	5.6	68.8	2.5
3	Aylesford (Super-screen)	46.9	10.9	69.8	9.7
4	M-Real	48.8	3.9	71.7	3.9
5	M-Real	36.2	15.1	73.6	9.2
6	Aylesford	37.3	15.9	69.3	8.5
7	M-Real (Superscreen + balls)	63.8	3.9	n/a	n/a

A number of modifications and enhancements were also made (for trial purposes only) to the screening regime.

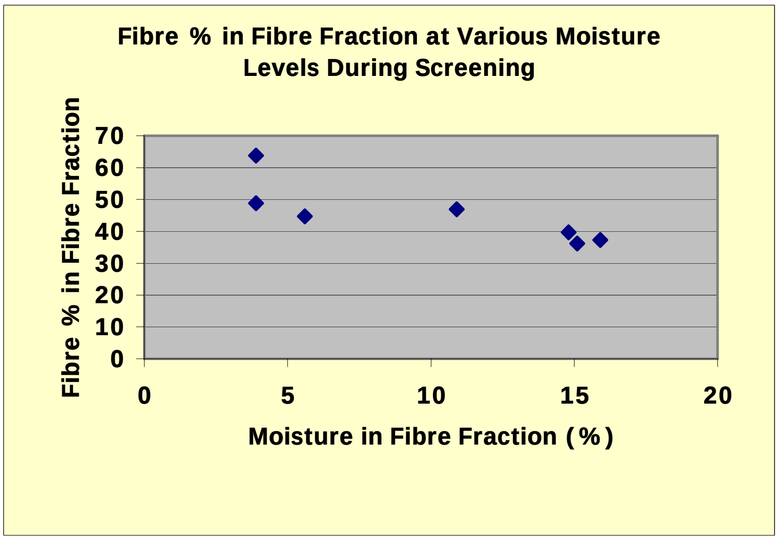
In one specific trial (No 3), screening was repeated 3 times on the fibre product. The results of this trial are shown in the table as "Aylesford Super screen".

In a second enhancement (No 7), one hundred golf balls were added to the lower, finer screen to enhance agitation. Additionally, the screen exit was blocked to retain fibre on the screen for a longer time period (i.e. 20 minutes). This fibre was then reprocessed five times. This is shown as "M - Real Super screen with balls".

This repetitive enhanced screening of a very dry material produced a fibre fraction with 63.8 % "fibre", which was the highest % fibre separation achieved. However, the yield was low and the production rate unacceptable, although the principle that screening very dry material can separate fibre from filler was demonstrated.

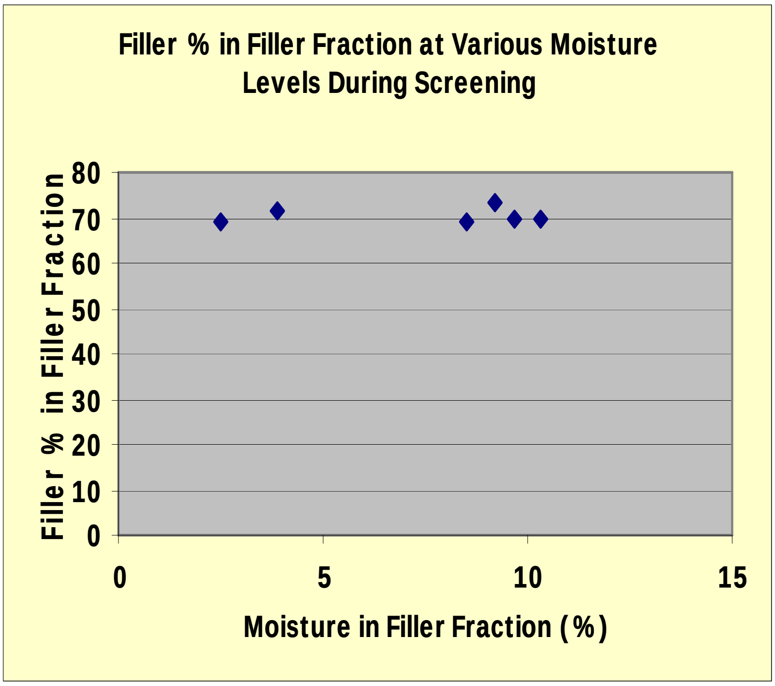
The trial results are also shown graphically below, and the improvement in separation as the materials become drier can be clearly identified.

Figure 24 Effect of Moisture on Separation Efficiency – Fibre



The graph below demonstrates (for the filler fraction) the relationship between % moisture of the final product and the % of non-filler material (in the filler fraction). There is little or no improvement in the efficiency of separation (and therefore purity) of the filler fraction with varying moisture content.

Figure 25 Effect of Moisture on Separation Efficiency - Filler



The lack of increased separation of the filler fraction (at different moisture content levels) is in direct contradiction to the improvements achieved with the fibre fraction.

The reasons for this are unknown, although a potential reason may be action brought about by increased work input in the Micronex. This may break down some fibres into sizes that will pass through the finest screen and into the filler.

6.4 Trials to Improve Separation Efficiency

6.4.1 Sludge Product Tests (Key Properties)

The energy content of the materials, and the proportions of carbonate and clay are the main variables. Typical values for raw and processed products are shown in the table below.

Figure 26 Typical Product Volumes

Material	Moisture (%)	Gross Calorific Value (KWhr/t)	Calcium Carbonate Bone Dry (%)	Non Carbonate Filler Bone Dry (%)	Total Filler Bone-dry	Fibre Bone Dry (%)
Wet Sludge	37	1383	37.5	28.5	64	34
Fibre Fraction	11	2490	28	25	53	47
Filler Fraction	8.5	1913	40	30	70	30

It should be noted that these results relate to initial production and to a single pass through the Russell Finex screen.

6.4.2 Super-Screening (5 – Stage) of the Processed Sludge

The Micronex machine has a capability of producing an output with a moisture content measured at around 10 to 15%. The original screening target for product of this moisture content was to produce two streams of material as follows:

- The fibrous fraction containing 75% fibre; and
- The filler fraction containing mainly mineral and only 25% fibre.

The Russell Finex screening process consists of two screens, the top being the most open. The material collected from the surface of the top screen is expected to be fibre, whereas the filler falls through to a collector. During the early part of the project it was noted that the separation had failed to meet the original target, and was producing a fibre fraction containing over 50% filler, with the filler fraction containing 30% fibre.

A multiple-screening trial was undertaken, passing the fibre 5 times through the vibrating screen process to remove more filler from the fibre, and seeking to achieve a fibre fraction containing 25% filler or less. This would have a similar effect to utilising a much higher capacity screen and increasing the dwell time on the screen.

The sludge used for the 5 –pass-screening trial was supplied by M – Real (New Thames Mill)

10 Kg of the M-Real dried mixed sludge from the Micronex process was fed to the centre of the top screen. The screen was run until all this material had been processed either through the screens or out of the outlets from the screen surfaces.

The quantity of fibre (material from the surfaces of the screens) was weighed at the end of each pass. This material was then fed back to the centre of the top screen. This process was repeated until the material had been passed through the screen five times.

At the end of the fifth pass the weight of fibre and of filler was measured and samples of each were taken for laboratory analysis of the ash. This demonstrates the degree of separation being achieved.

Visual observations of the trial showed that there were an optimum number of screen passes, before the smaller fibres started passing through the fine screen to the filler fraction.

The results of the trial are as shown below:

Figure 27 Effect of Number of Screen Passes

Pass through Screen	Weight of fibre (Kgs)	Weight of filler (Kgs)	Fibre Fraction Ash Content (%)	Filler Fraction Ash Content Ash (%)
0	10	-	-	-
1	3	-	51.2	71.7
2	2	-	-	-
3	1.5	-	-	-
4	1	-	-	-
5	<1	8	40.0	70.5

The losses during the multiple handling were about 1 kg or 10% of all the material used in the trial.

The 575 deg ash content of the fibre after one screening was measured as 51.2% on a bone dry basis. The measurement after the fifth pass was 40%.

The 575 deg ash content of the filler after one screening was measured as 71.7% on a bone dry basis. The measurement of the accumulated filler after the fifth pass was 70.5%.

It was concluded from the trial that continually re-screening the fibre fraction does reduce the mineral content. The reduction from 51.2% ash to 40% ash is significant, though still insufficient for market needs. However the trial does offer a degree of success and confirms the requirement for a superior means of separation.

6.4.3 Screening Disturbance and Enhancement Trials

The Micronex machine has a capability of producing an output with a moisture content in the range of 10 to 15%. Screening this output was targeted to produce two streams of material

- A fibrous fraction targeted to be 75% fibre
- A filler fraction containing mainly mineral/filler and with only 25% fibre.

The process of screening used two screens, the top being the most open. The material collected from the surface of the top screen was expected to be fibre, whereas the filler was expected to fall through the screen to a collector. During the trial process, it was determined that separation had only achieved the fibre fraction containing 50% filler, and the filler fraction containing 30% fibre.

It was believed that there was entrapment of the filler within the fibre flocs and that this was impeding separation. It was considered that greater disturbance of the material on the screen might aid separation, and as an experiment solid plastic balls were placed on the screen surface to reduce screen blinding, and as a mechanism to aid separation of the filler down to a level of 25% or less.

During the experiment the solid plastic balls were randomly and quite evenly spread across the screen. They were also very active, moving around the screen and vibrating on it.

The material collected from the top of the screens after the experiment was extremely light and fluffy.

In this trial the fibre was retained on the screens for 30 minutes, and this was expected to produce a similar effect to the five – pass screening process detailed earlier in the report.

This trial took a great deal of time, and the use of the plastic balls (to agitate the fibre on the finer screen) had the effect of reducing the ash to 36% on a dry weight basis. This result was a significant improvement from the typical (and unsatisfactory) 50% ash level experienced since the plant was commissioned.

However this gain in separation was found to be significantly detrimental to the yield of fibre. At the end of the trial (although this was not accurately measured) it was estimated that the yield of fibre was approximately 10% of the original dried sludge fed into the screen.

6.4.4 Impact of Reduced Moisture by Changing Flow Patterns

Screening Results Using Material Dried by Air Flow

This trial is described which was carried out at the end of the project and in which the Micronex was used for only a quick single pass to open up the sludge. Drying was then effected by flowing air through the material using the air transport system.

Material was delivered to the screening system and the fibre material retained on the top two screens was then recirculated passing again and again through the air transport system and the screens. This had three effects:-

- Drying it through its further prolonged contact with the rapidly moving air in the transport system.
- Repeated opportunities for fines to fall out of fibre in the screens.
- Reduced damage to fibre from elimination of repeated mechanical action in the Micronex.

The results of this trial are shown in the table below. The definition of terms in the table are set out below the table.

Figure 28 Effect of Screening Time

Sample No	Sample Description	Moisture % (Measured)	% Fibre or (% Filler) in bone-dry sample
1	Fibre (as processed)	5.68	55.9
2	Fibre (0 mins)	7.34	59.0
3	Fibre (5 mins)	7.63	69.5
4	Fibre (10 mins)	7.36	68.2
5	Fibre (15 mins)	7.31	75.1
6	Fibre (25 mins)	6.82	73.8
7	Filler (0/100)	3.27	**(74.2)**
8	Filler (5/100)	2.96	**(74.8)**
9	Filler (0/150)	4.64	**(74.2)**
10	Filler (5/150)	3.33	**(73.2)**

The terms for individual samples in (parentheses) are to be interpreted as follows:

(as processed)	means sample taken after one passage through Micronex.
(0 mins) minutes dwell	means sample taken after one passage through Micronex plus screening with 0 on the screens.
(5 mins) minutes dwell	means sample taken after one passage through Micronex plus screening with 5 on the screens during which the material was recirculated through the screen air system.
(0/100)	refers to the dwell time (0) on a screen mesh size (100).

Interpretation of Results

The trial demonstrates the potential of screening dry material to achieve a separation of fibre and filler in Aylesford sludge. It achieved the targets for the purity of the fibre and of the filler i.e. 75% fibre in the fibre product and 75% filler in the filler fraction. Data in the final column of the table shows the effect as the dwell time in the system is increased (at a reasonably constant moisture around 7%) the separation of fibre from filler trends to a steady state. That steady state is at 75% fibre content.

The trial measured the capability to effect a successful separation using screening as the mechanism. The question is unanswered regarding the production rate possible.

However, the Micronex has been shown to operate at around 1 tonne of sludge per hour as designed, when there is minimal recycling to the machine. The air system and the screen system then need to be of the right scale to allow this level of throughput to be maintained when product is recirculated through these systems. The system would need to be measured to determine the energy used and the economics.

6.5 Possible Reasons for Variance from Target Specification

It is apparent from the results obtained from splitting the dried sludge (fluff) into its constituent parts of fibre and filler that, in general, the efficiencies were not as good as anticipated, with the arbitrary targets set at the start of the project generally not reached. The results are discussed in more detail earlier in this section. There are a number of possible reasons for this.

A detailed microscopy analysis was undertaken by SCA Graphic Research AB in Sweden. This used two types of Microscope:

- SEM, Scanning Electron Microscopy, maximum magnification: x900,000.

- LM, Light Microscopy, magnification x50-1000.

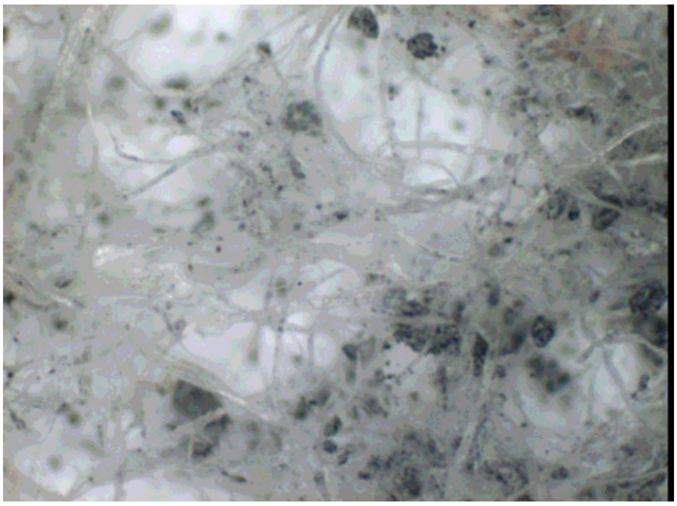
A full report detailing all images taken during this analysis is available from WRAP. However, key images are given below and potential findings discussed. It should be noted that these results are to some extent speculative but the results may clearly give a better understanding as to the reasons for the disappointing splitting results.

6.5.1 A Good Splitting Efficiency?

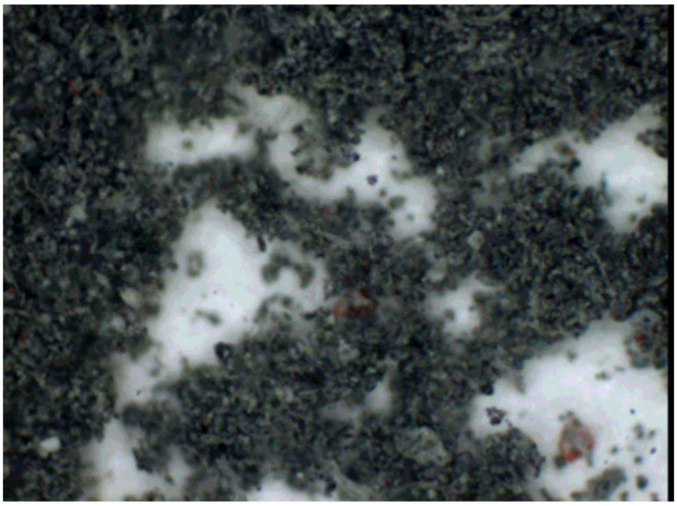
At first glance, the results show the splitting efficiency to be quite good:

Figure 29 Microscopy Analysis 1

Fibre Fraction (LM). *Although filler particles are clearly evident, it can be seen that the sample is predominantly fibre.*



Filler Fraction (LM). *Although some fibre fragments are evident, it can be seen that the sample is predominantly filler.*

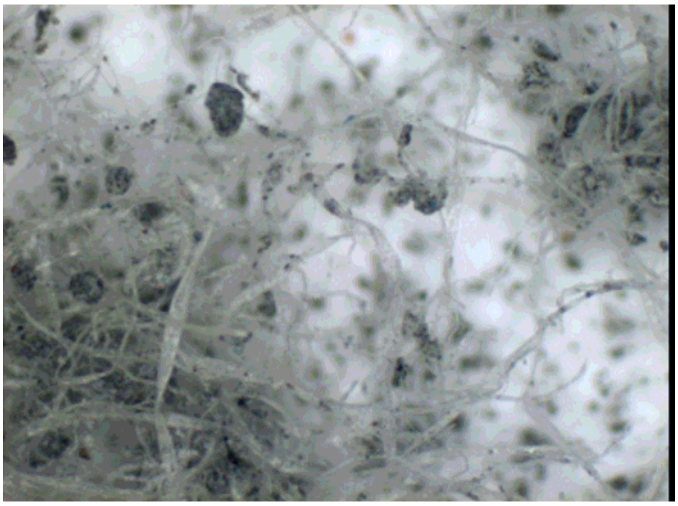


6.5.2 Filler particles entwined within the fibres

Where the fibre fraction is looked at in more detail it can also be seen that filler particles often seem to be “entwined” within fibre flocs. With this being the case it would be almost impossible to fully split the fibre from filler using the existing screening equipment.

Figure 30 Microscopy Analysis 2

Fibre Fraction (LM). *Filler particles can be seen to be "entwined" to the fibres, especially in the top right and bottom left of the slide.*

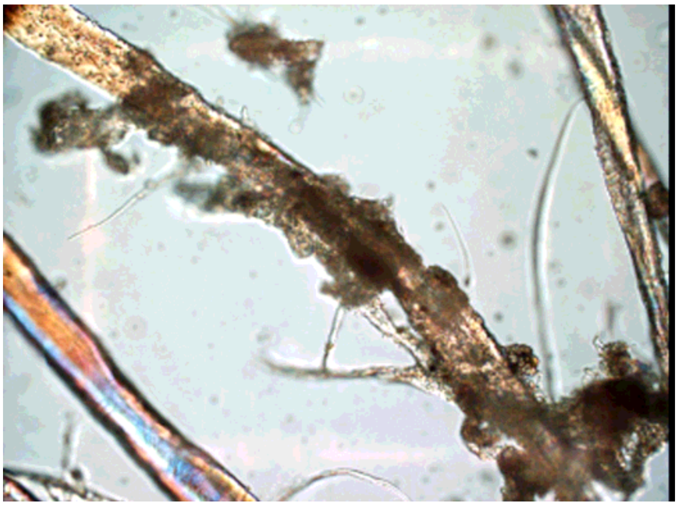


6.5.3 Filler particles attached to the fibre

Where the fibre fraction is looked at under higher magnifications it can be seen that filler particles often seem to be "attached" to the fibre. This could potentially be due to the high forces provided in the KDS Micronex; again it would be difficult to remove these particles using screening.

Figure 31 Microscopy Analysis 3

Fibre Fraction (LM). *Filler particles can be seen to be "attached" to the fibres.*

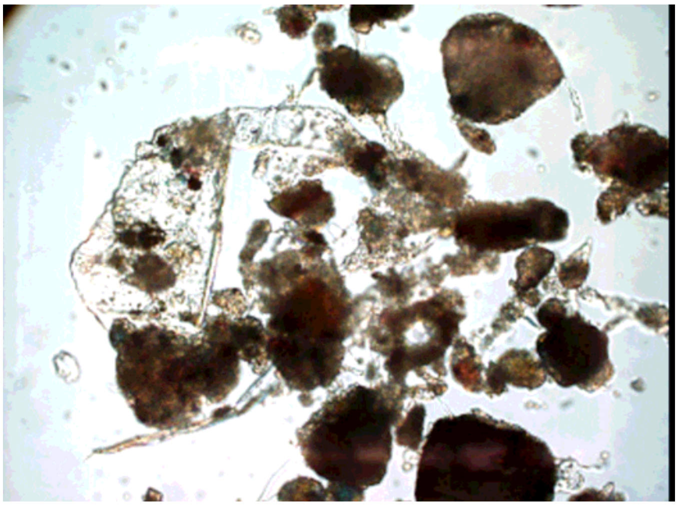


6.5.4 Higher levels of fines in the filler fraction

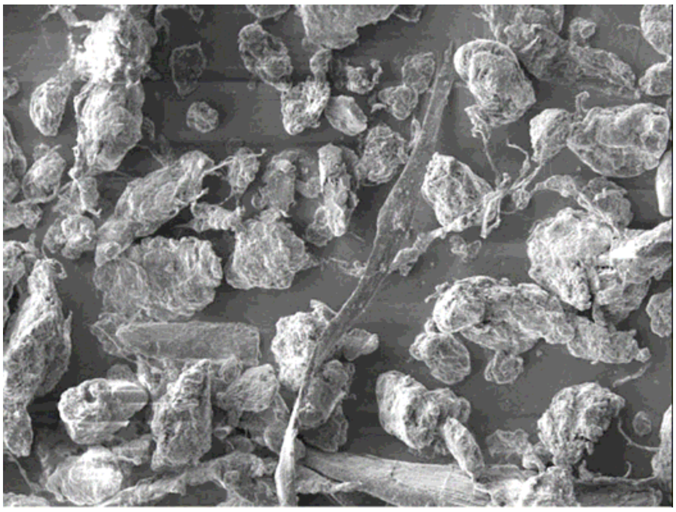
Where the filler fraction is looked at in more detail it can be seen that there are higher levels of fibre fragments, known in the paper industry as fines, in the fraction than was originally evident. A relatively high level of fines would be expected in a paper mill sludge, as the sludge is a reject stream from a paper mill. The fines are similar in size to filler particles and would therefore be classified as the same type of particle by the screening system.

Figure 32 Microscopy Analysis 4

Filler Fraction (LM). *A significant level of fines can be seen within the slide.*



Filler Fraction (SEM). *A significant level of fines can be seen within a further slide using alternative microscopy.*

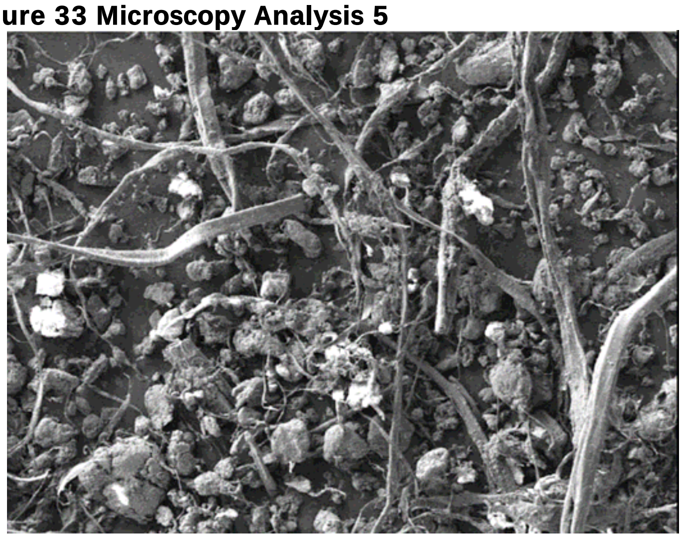


6.5.5 Higher levels of filler in the fibre fraction

It can be seen that through SEM microscopy that there are also apparent high levels of fines in the filler fraction. The reason behind this is not clear as the sample has to be spread out prior to being analysed, thus the overall structure of the sludge will have changed.

Figure 33 Microscopy Analysis 5

Fibre Fraction (SEM). *A significant level of filler can be seen within the slide.*

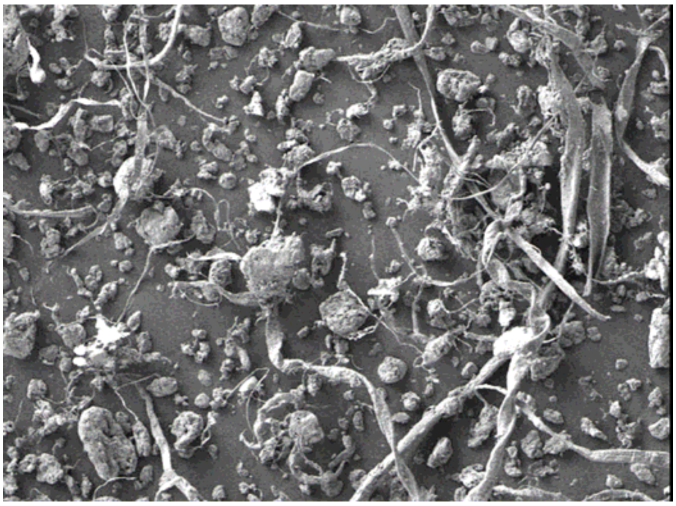


6.5.6 Other observations

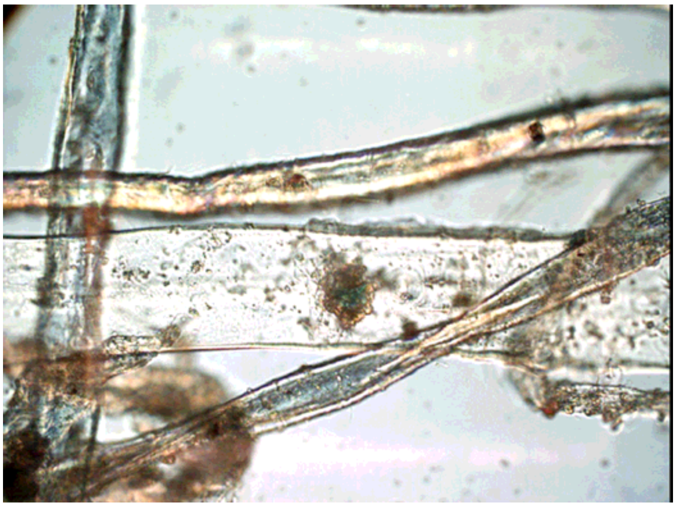
Clear observations from these slides, not related to the splitting efficiency, are that the fibres are very long, within minimal external fibrillation and are surprisingly flat and twisted. The reasons for this are uncertain, and could be consequences of Aylesford's recycled fibre plant, the KDS Micronex or the method slide preparation for microscopy.

Figure 34 Microscopy Analysis 6

Fibre Fraction (SEM). *Long flat twisted fibres are evident.*



Fibre Fraction (LM). *A low level of external fibrillation is also evident.*



7.0 Pelletising Trials

7.1 Background

The Micronex machine produces dried materials, which are finely divided, and when handled there is substantial dust. To manufacture marketable materials, particularly for use as absorbents and as animal bedding, it was considered useful to prepare the material in the form of small pellets.

A trial took place at Amandus Kahl GmbH, a company specialising in manufacturing pelletising equipment, who provided facilities in their pilot plant.

The objective of the trial was to evaluate the options for pelletisation of the output from Aylesford sludge (dried in the Micronex) and from the fibre and filler fractions from the same process. Additionally, to determine (on behalf of Aylesford) whether incinerator ash from the mill waste burner can be pelletised to prevent dust (which is a current problem for the mill in disposing of this material), and also to allow the manufacturer to assess the equipment requirements through measurements made on the pilot plant while processing the Aylesford materials.

During the early stages of the trials it became evident some further decisions were required concerning pellet size, and trials of 4 mm and 6 mm diameter pellets were made. The differences in some properties were measured, particularly the water absorption capability. The trials focus on 6 mm pellets.

The moisture content at which pellets are made was found greatly to affect the subsequent moisture absorbency of the pellets. Indicative measurements are reported here. Further work would be required to optimize a process to make water absorbent pellets.

7.1.1 Methodology

Kahl have a laboratory scale pelletising machine (Capability is 100 kg/hour) and a small-scale production unit making approximately 1000 Kg per hour. Both machines were used with pellets being produced in the smallest possible ratio of length to diameter.

The moisture content of material was monitored throughout the trials using an automated device made by Sartorius.

All pellets were assessed for moisture absorbency, having regard to the possible applications in industrial absorbents and animal bedding sectors. With very accurate equipment supplied by Kahl, measurement was possible of the absorption of the pellets during a 6 minute immersion in water. In addition, Kahl engineers measured the capability to produce pellets at varying degrees of moisture content in the material fed to the pelletiser. Pelletising is generally made easier by wetting, and quantities of additional water were required to be added to the Aylesford sludge based materials to develop the most efficient production rates, even though pellets could be produced from the very driest material (5.4% moisture) sent from the Micronex.

7.1.2 Observations

It had been expected that only dry sludge could be pelletised. The trials showed that wet sludge could also be pelletised well. The properties of pelletised sludge made with dry and wet sludge are quite different.

It was observed that by pelletising dry material (up to 15 % moisture) a relatively non-absorbent pellet is produced, which will absorb up to only 25% of its own weight in water.

However, if the material is pelletised at 35% moisture, the resulting pellet can absorb a further 280% of its original weight. During this process these pellets break down into a mulch. If that same pellet is dried back from 35 % to 11 % moisture, it can still absorb 121 % of its dried weight. The material is clearly less dense, and the surface allows more channels to the inside of the pellet. These dried pellets retained their structure after absorbing 121 % additional moisture.

Kahl make equipment to dry these pellets after they have been formed, as part of a range of machines largely aimed at pelletising animal feeds. It requires a source of low-grade steam, which would be available as a waste product stream in most paper mills.

The moisture and the nature of the sludge were variable during the trial. Sometimes the feed material was light and fluffy, and at other times it was much heavier and more powdery. This was also evidenced by fluctuations of motor loadings in the pelletising mill as different consistencies of material reached the dies. In a production set up the machine will accommodate the fluctuation (by adding water, or reducing feed rate automatically), but this indicates the variable nature of the sludge supplied.

7.1.3 Results

In order to understand the behaviour of pellets, samples of each production from the pelletiser were subjected to a moisture absorption test. A sample of approximately 5 grams was immersed in water for 6 minutes, and the weight then measured again. In addition two samples were tested over 1.5 and 2 hours to see the effect over time.

Shown below are the results of the water absorbency tests on the trial fibre and sludge pellets:

Figure 35 Pellet Water Absorbency Test Results

Trial No	Pellet Size Material	Moisture Content of Pellet	Initial Weight (gm)	Pellet Weight after 6 min (gm)	Weight after 90 min (gm)	Weight after 120 mins (gm)	Moisture Take up as % of original weight
0	4mm Fibre	15% (water added during pelletising)	5.072	-	-	7.503	47.9%
1	4mm Fibre	15% (water was added during pelletising)	5.103	6.204	-	-	21.6%
2	4mm Fibre	35%	5.442	19.500	-	-	258.3%
5	4mm Fibre	35% (while forming pellet by adding water, then pellets dried to 11.3%	5.113	11.306	-	-	121.1%
3	4mm Fibre Kahl archive sample	na	5.317	9.644	-	-	81.4%
4	6mm Fibre Kahl archive sample	na	5.368	7.347	-	-	36.8%
6	6mm Fibre	7.7% (moisture content as delivered)	5.400	6.651	-	-	23.2%
7	6mm Sludge	15.7% (water was added during pelletising)	5.389	6.711	7.804	-	24.5%

The concern was that an exterior case of hard material is formed as the cylinder wall of the pellet. This is hard and glossy and potentially could resist wetting and water penetration. The drier the material, the more the pellet wall is heated and the harder the “case”.

The pellet test results appear to confirm this. The table shows the absorption by pellets of different sizes and with different moisture contents, and with different pelletising conditions.

7.1.4 Conclusions

The trials clearly confirm the potential to manufacture pellets which are highly absorbent, and which offer a potential market product.

Other comments on the trials are as follows:

- It is clear that the sludge, fibre and filler are materials from which it is very easy to make pellets;
- The test machine could be run at maximum output provided the moisture level of the feedstock is around 15%.;
- If it is necessary to utilise a drier feedstock (perhaps because this dryness was needed to effect separation on the Micronex/screen), then the Kahl equipment can add back 5% moisture to facilitate pelletising;
- Pellets can successfully be produced without the requirement for the Micronex drying the sludge; and
- However, optimising pellet production requires control of the moisture in the material being pelletised, and may also require drying after formation. Some form of drying needs to be combined with the pelletising machine.

The nature of the pellets varies considerably, depending on forming conditions. If it were required that pellets must absorb 300% (or more) of their own weight, then a programme will be required to identify the appropriate conditions for manufacture

The key finding of the pelletising trial was that contrary to initial assumptions, it was not necessary to dry sludge to the levels targeted using the KDS Micronex in order to make pellets.

8.0 MARKET DEVELOPMENT

8.1 Objectives

8.1.1 Market Development

The f objective was to manage the market development of the sludge products. This included the following:

- Identification of potential markets for the 4 main outputs plus 1 input fractions from the KDS Micronex plant. These fractions were:
    - Standard paper mill sludge (37% moisture).
    - Dried sludge fluff at 10% moisture.
    - Split fibre fraction.
    - Split mineral filler fraction.
    - Split fibre fraction in briquette form.
- Identification of individual companies to approach, within the potential markets.
- Approaching the individual companies and seeking to obtain cooperation for 5 evaluation trials of one or more of the sludge fractions.
- Assisting the target companies with the sludge utilisation/evaluation trials.
- Ensuring WRAP was updated with progress throughout the project, and submitting a final report detailing the market development work and the outcome of the trials.
- Quantifying the potential economic benefits of adopting the Micronex technology and thus making the target products.
- Identification of barriers to using the materials, detail of the actions required, and estimated timescale to overcome the obstacles.

The Market development process quantified the potential economic benefits available through the adoption of the Micronex technology and the manufacture of the current range of products.

8.2 Methodology (Market Development)

This included:

- Defining an agreed offering from the project, in terms of how the fractionated products have enhanced the opportunity to use paper residues in industrial products and
- Which of the manufactured Micronex products offer the best opportunities.

Customer brief and the proposed products specifications were drafted, including technical information, projected customer benefits, costs and price aspirations. Information was in the form of a presentation to potential users, and time was allowed for this. The customer brief incorporated input from the whole project team.

A 2-page marketing brochure was written and printed describing and illustrating the products.

A further objective was to identify and prepare a list of organisations with manufacturing in the UK, drawn from a list of target markets. This initial list, which contained 50-60 companies, was qualified to ensure that the initial contact phase focused on the most promising targets.

Experience defined that the initial contact had to be at the highest executive level, one at which decisions could be made l. This was at CEO, MD, or Divisional MD, where responsibilities spanned marketing, production, product specification, costs and profitability. The target was to achieve approximately twenty senior level face-to-face/detailed discussions, at which to present the full case for the customer to consider the proposition. This led to further meetings with a number of the organisations, including their own evaluation of the proposition, preliminary laboratory work, etc; with the objective of reaching a decision to go to a trial.

The aim was to bring five potential customers to the trial stage, and to support them during the trial and in the post-trial evaluation process. This objective was exceeded.

Examples of the target markets to be included in the market development are as shown below:

Figure 36 Target Markets

Target Market
Cement Bonded Board
Softboard
Hardboard
Oriented Strand Board
Plasterboard
Medium Density Fibreboard
Cement Blocks
Moulded Pulp
Fuel Briquettes
Horticulture
Recycled Paper
Animal Bedding

The potential markets include the construction applications in PAP 009-011, which focussed on:

- Cement bonded board;
- Softboard;
- Hardboard;
- Cement blocks; and
- Medium density fibreboard.

These were judged to be the most technically and commercially viable construction material applications, where existing raw material streams could be substituted, while making a technically acceptable product within the industry's regulatory framework.

The key issues which were to be included in the Market Development (Part 2) were as detailed below:

- Testing the important or critical characteristics of these products (e.g. calorific value, moisture, fibre & filler content, contaminants such as heavy metals, etc.), which affect potential users;
- Running trials with sludges from other paper mills, to determine differences in reprocessed product specifications;
- Determining the costs of drying sludge (Aylesford's initially) in a Micronex plant, (n.b. the drying cost is not linear with degree of drying), to provide a basis for cost/ benefit analysis in the applications for the products made;

- Deriving the economic value for cement manufacture, by comparing the Micronex-dried sludge to wet sludge (which consumes energy as it first dries during the cement making process);
- Determining the same economic value for a sludge combustor:
  - Where the sludge combustor is unlimited by capacity; and
  - Where a saving in capital is realised from increasing capacity.
- Determining the increased economic value from power generation from drying waste; and
- Estimating the potential transport benefits from moving (to end-users or landfill) dried products instead of wet sludge.

A summary spreadsheet has been included to exhibit the following information:

- All applications for sludge, filler and fibre;
- The potential tonnage into each application (derived from an overview analysis of the application's scale in the UK);
- The potential value created in each market channel (e.g. the value in cement, the value in brick, etc.); and
- The barriers to conversion of the prospective applications and the actions and time taken to achieve conversion.

9.0 Overview of Products from the Process

9.1 Products and Development

To achieve its targeted economic performance, the Micronex requires to process 1 tonne per hour, reducing the product moisture from 37 % to 10 %. This is based on a power consumption of 85 kWhr per tonne, as achieved by previous applications of the KDS Micronex.

The machine was fully commissioned during November 2005 and proved capable of reducing the sludge moisture content down to 4 %. However, this degree of drying is below the required target moisture content and is excessive in power consumption and has an adverse effect on throughput

Practical performance indicates that a reduction to around 13% moisture can be achieved at a rate of 500-600 kg per hour, with power consumption of 260 KWhr per tonne. There are variables within the machine, which require greater understanding specific to sludge, including airflows, and eliminating a build up of material, which affects efficiency. Experience shows that the machine can condition the sludge (as required) but output rate and energy use require to be optimised.

In the specific case of the Aylesford test site, the bone-dry (BD) proportions of the raw sludge were 36 % fibre and 64 % filler.

Targets (based on successful marketability) were established to produce a filler fraction, which contained a minimum of 75% inorganic filler material, and a fibrous fraction (with attached organic compounds) in which the fibre (including organic content) is 75% (i.e. with a maximum filler content of 25%). These were designed to open the way to marketing materials on the merits of the individual fractions.

The best results achieved (prior to marketing activities) were a filler fraction in which inorganic material was 70 % on a bone-dry basis. The equivalent best result for the fibre fraction (including organic matter) was 60%.

The fibre fraction was a fluffy grey fibrous material with a bulk density around 0.2 t m^{-3}.

The filler was a fine grey free flowing powder with particle size below 50 μm and a bulk density around 0.8 t m^{-3} at the outflow from the machine. This compacts in transit, but remains free flowing. The difference between the two products and with the original sludge is striking.

9.2 Detailed Description of Products from the Micronex

9.2.1 Combined Fibre and Filler Fluff

Dry paper fibre and filler fluff was produced by removing moisture in the Micronex process and collecting dry material without screening.

The resulting material is a light fluffy mass of fibrous appearance with dust retained among the fibres. Some of the dust is freely released by shaking. The material has a tendency to clump together, but the drying process makes it much more free flowing than wet sludge, which accumulates into clumps up to 5mm across, and requiring work to break these clumps down. By contrast the processed dry sludge breaks apart very easily. It has a musty smell and is grey in colour.

Figure 37 The Combined Fibre and Filler Fraction

Characteristic	Typical Specification
Appearance	Fibrous/dusty grey mass
Moisture	10 -15 % depending on degree of processing
Organic weight	34 %
Inert Fillers	66 %
Calcium Carbonate	37%
China Clay (+other inert fillers)	29 %
pH	7.5 – 8.0
Density	Typically 0.3 tm^{-3}
Hazards	None

Figure 38 The Combined Fibre and Filler Typical Specification ANL Sludge

9.2.2 The Fibre Fraction

The dry recovered paper fibre fraction is made by drying in the Micronex process and then separating the fibre from the filler in the two-screen process. The first screen removes longer fibre, before a second finer screen is used. The products from the top of these two screens are collected as the fibre fraction. The “fibre fraction” also contains organic residues such as printing inks. The actual quantity of fibre is estimated at about 50% of the total organic material in the sludge.

This material is a very lightweight grey fibrous mass. It contains filler dust, but has a lower tendency than dried sludge to compact in transit. It can have a density as low as 0.2tm^{-3} when dried to 10% moisture.

Figure 39 The Fibre Fraction

Figure 40 The Fibre Fraction Typical Specification ANL Sludge

Characteristic	Typical Specification
Appearance	Light grey fibre mass
Moisture	10 %
Mixture of fibrous/organic material	47.0 %
Filler (Clay + Calcium Carbonate)	53.0 %
Typical fibre length	Approx. 2.0 mm
Fibre characteristics	Similar to TMP with less fibrillation
pH	7.5 – 8.0
Gross Calorific Value	2490 KWhr/tonne

9.2.3 The Filler Fraction

The recovered filler fraction is the material collected from the bottom of the screening process. It is a very fine dusty product with a particle size below 50 microns, as would be expected given that its origin was as a filler and coating material in paper. In its dry form it will blow around in the wind. In bulk, it is quite dense and settles so that the density of a bulk quantity lies in the range 0.8 to $1tm^{-3}$ depending on how intensively it is shaken. It has a slight odour. The photograph below shows the filler fraction with a thumbprint in order to exhibit the nature of the fraction.

Figure 41 The Filler Fraction

Figure 42 The Filler Fraction Typical Specification ANL Sludge

Characteristic	Typical Specification
Appearance	A free flowing light grey powder
Moisture	Approx. 10.0 %
China Clay	30.0 %
Calcium Carbonate	40.0 %
Fibre + organic Material	30.0 %
Mean Particle Size	< 50 Micron
Bulk Density	0.8 – 1.0tm^{-3} (Depending on settlement)
pH	7.5 – 8.0
Hazards	None

9.2.4 Compacted Fibre Briquettes

Paper fibre has a calorific value, which can be released by burning as a fuel for industrial heating or in power generation as a supplement or as an alternative to conventional solid fuels such as coal.

The dry fibre fraction containing around 10 to 13 % moisture (which contains fibre and organic material) can be extruded as briquettes or pellets. These are formed under pressure and are dense. They retain integrity when handled.

In the trial plant the briquettes were made so as to form an easily handled log. For burning in energy generation different sizes of briquette or pellet could be made. Pellets as small as 3mm diameter were made in trials, without additional wetting. The fibre material makes a very good pellet and does so very easily from a manufacturing perspective.

Figure 43 Compacted Fibre Briquettes

The Gross Calorific Value of the briquettes approaches that of wood.

Figure 44 Compacted Fibre Briquettes Typical Specification ANL Sludge

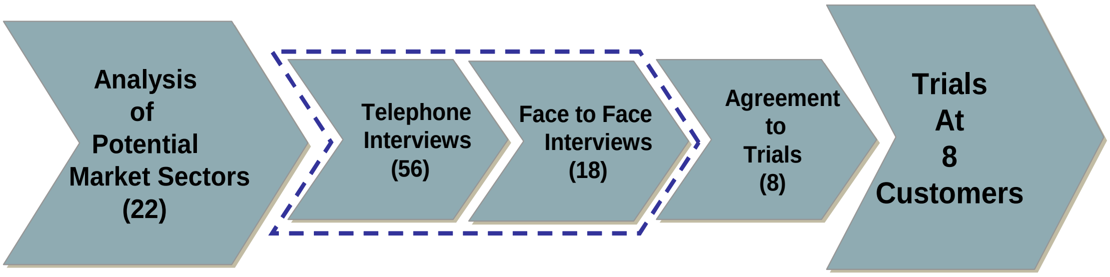
Test	Test Result
Diameter	100 mm
Length	205 mm
Briquette Weight	0.5 Kg
Gross Calorific Value	2490 KWhr/tonne

10.0 Approaching the Market for Sludge Products

10.1 Process Overview

The process used for the marketing of the sludge fractions is as shown below.

Figure 45 Process Overview Diagram



The process involved identifying suitable sectors, then focussing on specific users within those sectors. This was followed by a series of 56 telephone interviews, which resulted in a total of 18 face-to-face (or detailed structured telephone) interviews.

Following the interviews a total of 8 potential customers indicated a wish to move forward to either laboratory trials, or in a smaller number of cases full machine trial evaluations.

10.2 Potential Sectors for Usage of Sludge Fractions

A list of sectors, which were considered as potential targets for one of the fractions from the Micronex plant, was compiled. The potential target customers in each sector were also identified at this stage. A summary of the segmentation of the individual markets is shown in the table below.

Figure 46 Target Sectors

Target Sector	Sub Sector	Potential Customers	Fraction Potential
Fibre Consumers (Paper Mills)	Moulded Pulp	3	Dry Fibre
	Tissue/Towelling	1	
	Corrugated Case Materials	12	
	Wastepaper Merchants	4	
Building Materials	Hardboard	4	Dry Fibre
	Asphalt	1	Dry Fibre or Mixed Fibre + Filler
	Cement Particle Board	1	
	Fibre Cement Products	3	
	Softboard	1	
	Insulation	4	
Building Products	Cement	3	Dry Filler
	Bricks	6	
	Building Blocks	4	
	Paving	2	
	Plasterboard	3	
Power Generation/Incineration	Power Stations	2	Dry Filler/Briquettes
	District Heating	1	Briquettes
	Commercial Burning	1	
	CHP Plants	1	
Others	Cat Litter	1	Dry Fibre or Mixed Fibre/Filler
	Animal Bedding	1	
	Compost (Peat etc)	3	

10.3 Overview of Potential Sectors

10.3.1 Brick Making

Brick making is a highly varied manufacturing process. The raw materials differ by origin and there are different firing methods. The main constituents are clay, sand and fuel, with other materials such as fuel ash added as well as drying aids such as sawdust. Adequate water is added to allow the raw material mixture to be shaped to form "green" bricks. These are dried slowly, and then fired in a kiln at a temperature between 1000 and 1200°C. The bricks are heated from the outside and the fuel incorporated in the brick mix (often coke, but also sawdust) also fires the brick from within.

At these high temperatures, the clay is "metamorphosed". All the water is driven off, and anhydrous minerals are formed, which are stable at high temperatures. On completion of firing, the bricks contain an interlocking network of long, thin mullite crystals, quartz, and some super-cooled liquid (glass), which make the brick hard and strong.

Colour is determined by mineral content and the availability of oxygen during firing. Most natural clays contain iron minerals, either oxides or hydroxides. Iron can exist as ferrous iron in the reduced state (iron II), in which case it forms dark grey oxides and hydroxides, and this causes some sediments to be dark in colour. After firing, however, this iron may be oxidised to the iron III state, or ferric state, which forms the red-brown iron oxide haematite. The method of firing and even of stacking the bricks can determine whether the colour is grey or red.

Other minor metal constituents in natural clay include Calcium (Ca^+), Sodium (Na^+) and Potassium (K^+), and these can cause melting by forming silicate liquids, which speed up the alteration of the clay minerals. Calcium Carbonate has the effect of turning a red brick into a yellow brick, when fired.

In some cases the brick-maker may wish fibre to go into the mix, to provide improved drying characteristics prior to and during firing. In another manufacturing method the by-products from the combustion of the fibre can be positively harmful to the kiln.

The UK market for bricks is approximately 4 billion per annum representing a weight of approximately 4 million tonnes. At a low addition (say 2%) rate (which seems quite feasible from these trials) there is potential to use some 80,000 tonnes of fibre and filler.

10.3.2 Cement

Joseph Aspdin of Leeds, England first made Portland Cement early in the 19th century by burning powdered limestone and clay in his kitchen stove. By this crude method he laid the foundation for an industry, which processes limestone, clay, cement rock, and other materials into a powder so fine it will pass through a sieve capable of holding water. Cement is so fine that one Kg of cement contains over 350 billion grains.

Portland Cement, the basic ingredient of concrete, is a closely controlled chemical combination of calcium, silicon, aluminium, iron and small amounts of other ingredients to which gypsum is added in the final grinding process to regulate the setting time of the concrete. Lime and silica make up about 85% of the mass. Among the materials used in its manufacture are limestone, shells, and chalk or marl combined with shale, clay, slate or blast furnace slag, silica sand, and iron ore.

Each step in the manufacture of cement is checked by frequent chemical and physical tests in plant laboratories. The finished product is analysed and tested to ensure that it complies with all specifications.

Two different processes, "dry" and "wet", are used in the manufacture of portland cement.

When rock is the principal raw material, the first step after quarrying in both processes is primary crushing. Rock is fed through crushers capable of handling pieces as large as an oil drum. The first crushing reduces the rock to a maximum size of about 6 inches. It then goes to secondary crushers or hammer mills for reduction to about 3 inches or smaller.

In the wet process, the raw materials, properly proportioned, are ground with water, thoroughly mixed and fed into the kiln in the form of a "slurry" (containing enough water to make it fluid). In the dry process, raw materials are ground, mixed, and fed to the kiln in a dry state. In other respects, the two processes are essentially alike.

The raw material is heated to about 1,500 degrees C. in cylindrical steel rotary kilns lined with special firebrick. Kilns are up to 4 metres in diameter and are mounted with the axis inclined slightly from the horizontal. The finely ground raw material or the slurry is fed into the higher end. At the lower end is a roaring blast of flame, produced by controlled burning of powdered coal, oil or gas under forced draught.

As material moves through the kiln, gases are driven off. The remaining elements unite to form a substance with new physical and chemical characteristics. The new substance, called clinker, is formed in pieces about the size of marbles.

Clinker is discharged red-hot from the lower end of the kiln and is brought down to handling temperature in coolers. The heated air from the coolers is returned to the kilns, which saves fuel and increases burning efficiency.

A cement manufacturer uses Calcium Carbonate and energy, so it is logical to conclude that the deinking sludge is a natural raw material. However, sludge contains approximately 40 % water, which is costly to transport. Additionally, the fibre material can probably realise higher value in other applications. Consequently, a dried material reduces transport cost and supplying just filler focuses on the main requirement for cement, which is Calcium Carbonate.

The potential usage for paper mill sludge in the cement industry is very large.
(Source: Portland Cement Association)

10.3.3 Plasterboard

Plasterboard is made from gypsum ($CaSO_4.2H_2O$), which is a naturally occurring rock. "Stucco" is made by crushing gypsum, which is heated to remove the water of crystallization reducing it to ½ H_2O. In this form it becomes a free flowing powder called stucco. Plasterboard is made by pouring stucco (mixed with a stoichiometric quantity of water) onto a moving sheet of paper, and gluing a second sheet to the upturned paper edge. The paper thus forms a sandwich, and the plaster is rolled flat and allowed to set (crystallize) while moving down a long conveyor. The plasterboard is finally dried with hot air after the crystallization reaction has ended. Initial flow is important to spread the plaster. Setting time is critical (the plaster must be set at the end of the line) and there is a cost to drying if more water than the ideal is used in the process.

The rate at which the plasterboard sets can be increased by additives. Adding gypsum to the stucco increases the rate of setting at the lowest cost.

10.3.4 Soft Board

Softboard is primarily used for pin boards, and construction applications (including insulation and fireproof applications)

There is one manufacturer of softboard in the UK, the manufacture of which is a unique process, consisting of a wet-end forming area, where a large sheet of thick wet pulp is formed. From the wet-end the sheet passes to a high intensity press, (where water is removed and the calliper – thickness - is reduced to the required specification), and thereafter to the drying tunnel to reduce the water content to the final moisture level.

Softboard is generally manufactured from old newspapers, which runs easily on the manufacturing machine, and which produce a final product with a high caliper.

The raw material fibre is short in length and grey in colour, and must be as low in ash as possible (ideally less than 10%) to obtain the maximum caliper in the final product.

10.3.5 Additive to Road Surfacing Material

A small number of companies manufacture fibre bitumen modifiers to enhance the properties of road surfacing materials, in various formats to suit individual Stone Mastic Asphalt (SMA) mixing facilities. The use of these products is to reduce the noise traffic makes when passing over a road surface.

With enhanced elasticity and load spreading ability, bitumen modifiers have demonstrated their effectiveness in holding bitumen in position around the stone aggregate during the laying process, producing road surfaces with optimum performance characteristics.

Once dispersed in the SMA, fibre products are designed to hold the bitumen in place by creating a lattice, which binds the material together, without impairing the bitumen's ability to adhere to the stone aggregate.

The lattice created by the long, interwoven fibres gives the SMA more elasticity, making it less brittle and more able to withstand continual heavy loading, in addition to superior stiffness and improved load spreading ability with a greater capacity to hold bitumen in position around the stone aggregate.

This is particularly important in thin pavement structures, where the benefits associated with thinner road coverings are complemented by excellent durability and longevity.

10.3.6 Corrugated Paper

Corrugated material has been used as a packaging medium since 1871, when Albert L Jones first obtained a patent for the use of a corrugated paper for wrapping fragile items, such as bottles.

Today, corrugated packaging is one of the largest sectors within the total packaging industry. In the UK, it accounts for almost 30% of all packaging consumed.

The raw material for the production of paper for the manufacture of corrugated cases is predominantly recovered old corrugated cases (with smaller amounts of old newsprint etc) in the United Kingdom. The total consumption of corrugated cases in the UK is approximately 2.0 million tonnes, with imports of virgin-based products of approximately 0.5 million tonnes.

The manufacture of paper for the corrugated industry is similar to that used for manufacturing all paper, whereby the waste is slushed with water in a pulper and is then cleaned and diluted to a consistency of approximately 1% prior to passing to the paper machine. On the paper machine, the fibre is formed into a wide continuous web, which is pressed and dried, prior to reeling-up.

The advantages of packaging made from corrugated paper are its low cost, strength, versatility, lightweight nature and recyclability.

10.3.7 Millboard

Millboard is a recycled paperboard product also manufactured from 100% recycled fibre. The product ranges in grammage from 1000 up to 5000 g/m², and is used in the automobile industry, shoe industry, furniture, luggage and leather products, and in the packaging and stationery industries.

Millboard is a very hard board with high density and is manufactured by hard rolling (calendering) the semi-wet intermittent sheet on a solidboard machine.

The Millboard opportunities, in the UK, for using the sludge fibre fraction as a raw material are limited. Successful use of the fibre fraction in Millboard would allow increased potential in the corrugated paper manufacturing industry to be a more viable option.

The inclusion of high filler (ash) in the fibre fraction would however be detrimental to the final Millboard quality, particularly in terms of caliper (thickness)

10.3.8 Moulded Pulp Products

Moulded pulp products have been produced since the early 1940's. Egg trays were the first product manufactured, but the range of products manufactured has increased s since that time, to include fruit trays, simple containers, furniture corner protectors, industrial product packaging/partitions, and disposable products for catering and hospital applications.

With the increasing use (and varieties of design) of moulded pulp products, production equipment and techniques have also evolved. New techniques for producing smooth surfaces, precise shapes and dimensions have been developed by the introduction of the Thermoforming process.

Moulded pulp products have traditionally (and predominantly) been manufactured from recycled fibre, normally containing high percentages of pre-consumer newsprint.

Recycled fibre is pulped in conventional papermaking equipment, cleaned and then diluted, prior to passing to the wet-end of the mould-forming machine.

Fibre, with additives, is formed on a mould die that uses a screened surface, which extracts (by vacuum) the water from the fibre to form the desired geometric shape. After the shape has been formed, and whilst still containing a high percentage of water, it passes to the drying stage where water is removed. This takes place in an oven, hot plate or in the mould and gives the dried shape and surface finish of the moulded pulp product.

The UK moulded pulp industry is relatively small with 4 main manufacturers, all serving different market sectors.

The options to supply the fibre fraction to the moulded pulp industry were limited, unless the ash content of the fraction could be reduced to a maximum of 10%.

10.3.9 Loose Insulation (Fibrous)

A new generation of high performance insulation products, manufactured from 100% recycled and fiberised newsprint, is now available for the provision of effective insulation in housing, commercial premises and public buildings. Combining the highest levels of thermal performance with good environmental credentials, these products deliver the capability to downsize space heating requirements, maximise heat retention and provide a healthy living environment.

With a low thermal conductivity value (k) of only 0.036 W/mK, performance of these products is enhanced by their ability to create a high level of air-tightness, thereby preventing thermal convection currents.

Innovative methods of application ensure the insulation provides a complete seal to minimise heat loss, eliminating gaps, cracks or other cold bridges.

The fibrous insulation does not contain any added formaldehyde and is free from CFCs, volatile organic compounds (VOCs) or other toxic substances.

These new insulation products are resistant to fire, which is achieved through the addition of simple inorganic salts, enabling the final product to meet the fire protection standards required for timber-frame construction and conventional lofts.

10.3.10 Acoustic Insulation (Loose)

A new generation of high performance insulation products, made from acoustic insulation products, manufactured from 100% recycled and fiberised newsprint has recently been developed. This is a highly effective sound insulation for new-build applications. Developed for installation into timber frame structures (floors and walls), these offer a simple and cost-effective solution to airborne sounds from adjacent rooms or property.

One of the main applications is in intermediate floors in residential or commercial buildings; for example, separating apartments or offices, with internal and party walls also being major users of the material.

Products are also manufactured from 100% recycled waste newspaper, which gives good environmental credentials. The acoustic performance is derived from the raw material base, where the fibre length has been re-engineered for optimised sound absorption.

The final product is free from CFCs, volatile organic compounds (VOCs) or other toxic substances and produces virtually no formaldehyde emissions. Formidable protection against fire is achieved through the addition of simple inorganic salts, as is the product’s resistance to biological and fungal attack and infestation by insects or vermin.

10.3.11 Heat and Power generation

The generation of heat and power from environmental fuels (e.g. Biomass) is being encouraged by government through schemes, which enhance the returns for investors and mitigate the environmental risk involved. It is likely that fuel made from processed sludge can meet the criteria and could be incorporated in a mix of fuels in the production of “green” energy.

The fibre fraction of the Aylesford sludge, after drying and separation in the Micronex, can be pelletised or briquetted with ease. In this form it can be burned in a typical fluidised bed reactor. The heat released is approximately 50% of the value of wood. The benefit of using the separated material, in preference to raw sludge, is that it contains a lower proportion of non-combustible material, which has to be disposed after burning.

There is currently a surplus of fuels available compared with the capacity to generate green energy, and so the value of the fibre as a green fuel is potentially low.

10.3.12 Conversion to Fuel

Sludge is comprised of organic materials, which can be burned, and inorganic materials, which change their chemical nature during burning. Sludge is normally burned in a fluidised-bed reactor. Wet sludge can be burned and the process yields sufficient heat to be self-sustaining and to allow some heat to be extracted.

Dry sludge has a higher calorific value from reduced water using heat from combustion in evaporation.

Because sludge contains 65% inorganic materials, the ash produced may present a disposal problem. Consequently, it is desirable to remove as much ash as possible, which enhances the calorific value.

The dry fibre has been used in fluidised bed reactors, but in loose form it is not ideal as it burns above, rather than in, the bed. This can be overcome by forming the fibre into pellets or larger briquettes, which reach the combustion bed.

The calorific values that can be obtained from the Aylesford sludge fibre fractions are compared as follows:

Figure 47 Calorific Value Comparisons

Fraction	% Moisture	KWhr per tonne
Wet sludge	37	1383
Dry sludge	12	2163
Dry Fibre from Micronex	11	2490
Typical Wood	Approx 40	4300
Typical Coal	-	8260

10.3.13 Fibre Cement Products

Fibre cement products are manufactured using Portland cement, ground sand or quartz rock, cellulose fibre and water. The fibre used has changed from asbestos to cellulose.

Fibre cement products have been used for many years in residential and commercial building applications and when correctly installed, do not rot, warp, burn, or become affected by termites. Fibre cement is manufactured into a range of products, including wall and floor cladding sheets, planks, blocks and hollow columns and pipes.

The combination of cement and cellulose fibre provides a matrix with properties such as strength, durability, flexibility and fire resistance, which are desirable in the building industry. The products are long lasting in a variety of applications and require very little maintenance during their lifetimes.

In the manufacturing process, the raw materials are blended together to form a slurry which is sieved and deposited onto a porous conveyor belt or felt; where a layer is built up to the required thickness and compressed by roller into a continuous sheet. The wet sheet is then cut to the desired sheet or plank size using high-pressure water jets. Individual pieces are stacked for pre-curing prior to autoclaving. The products are steam cured in an autoclave using high temperature and pressure. Edges and surfaces of autoclave-cured products are finished by sanding or grinding and trimming.

10.3.14 Building Blocks

Concrete blocks are made by foaming concrete, which is extruded and wire cut to size. The foaming process requires high silica content in addition to the cement, obtained from pulverized fuel ash from power generation. There is some use of calcium carbonate. Clay is excluded from the process, so china clay in the filler product is a problem. Gypsum and anhydrite are used to control the speed of the process, which is conducted at a maximum temperature of 180°C. so there is no burning-out and consequent void formation, if fibre is present. However, fibre is a problem as it clogs the cutting wires, which cut the blocks

10.3.15 Paving

Paving materials may be natural or formed from cement and aggregates. The aggregate combines with the cement for strength and appearance. In this second category, it is possible to use the filler as part of the mix from which the paving is made.

10.3.16 Cat Litter

Cat litter is made from natural clays, and from a range of recycled products. Sepiolite and vermiculite may also be used. The material used must be absorbent, and additives may be included to help prevent odour. Many cat litter products are based on waste paper, which has good absorbency and is a cheap raw material.

A measure of absorbency is the multiple of its own weight that a material can collect. In contact with water or oily materials, clay absorbs around its own weight. However, materials engineered to make them absorbent can collect between 3 to 5 times their own weight. When used in industrial absorbents, the high pick-up is a benefit as it reduces the total quantity of material to be disposed when dealing with a spill.

Dried fibre has the potential to be a good absorbent. However its dry fluffy, easily blown nature makes it difficult to use. However, it is possible to process the fibre into pellets, which would make a satisfactory product.

The market for cat litter has been estimated at close to £50 million per annum at retail values.

10.3.17 Animal Bedding

Straw is still widely used in the agricultural business for keeping chickens, cattle and other common farm animals. It has the benefit of being seen as a natural material and it can be used as a soil conditioner as a component of well rotted manure.

Straw is relatively expensive, and costs up to £40 per tonne. Clean paper mill sludge has been used, even in its wet state at 37% moisture, as a material on which animals can be kept. The absorbency of the material is good by comparison with alternative materials, and it forms manure, which can be used in the traditional way.

10.3.18 Compost

Waste paper and sludge can be composted with other materials. However, there is a surplus of waste organic materials available as raw material for composting, and so there is no value created supplying to composters. Additionally, there will be a cost to the originator of the sludge to have it used in the production of compost.

11.0 Customer Interviews

11.1 Summary of Interviews

Initial contacts were made with 56 potential customers across all market sectors. Telephone discussions were held with all 56 customers, and where appropriate, samples of the individual fractions were despatched to the potential user for preliminary evaluation.

Feedback from potential users determined whether a follow-up visit would be made to discuss in detail the attributes of the fractions, and the opportunity for use in their process.

A total of 19 face-to-face (or detailed telephone) interviews were held with interested users, who wished to explore the potential for specific fractions of the sludge.

The names of customers are withheld to ensure confidentiality about their businesses. In some cases there is continuing work by the customer, which may lead to commercial exploitation, and it would be inappropriate if customer identities were released. Customers are referred to generically or as customer "A", etc.

The list of those customer types who expressed an interest is as shown in the table below:

Figure 48 Customer Sectors with Expression of Interest

<table>
<tr><th>Target Sector</th><th>Sub Sector</th><th>Fraction Potential</th></tr>
<tr><td rowspan="2">Fibre Consumers/Paper Mills</td><td>Fibre Board</td><td rowspan="2">Dry Fibre</td></tr>
<tr><td>Paper Mill Filler</td></tr>
<tr><td rowspan="5">Building Materials</td><td rowspan="2">Cement Particle Board</td><td>Dry Fibre</td></tr>
<tr><td rowspan="4">Dry Fibre
or
Mixed Fibre
+
Filler</td></tr>
<tr><td>Fibre Cement Products</td></tr>
<tr><td>Softboard</td></tr>
<tr><td>Insulation</td></tr>
<tr><td rowspan="5">Building Products</td><td>Cement</td><td rowspan="5">Dry
Filler</td></tr>
<tr><td>Bricks</td></tr>
<tr><td>Concrete Bricks</td></tr>
<tr><td>Paving</td></tr>
<tr><td>Plasterboard</td></tr>
<tr><td rowspan="2">Power Generation/Incineration</td><td rowspan="2">District Heating</td><td>Dry Filler/Briquettes</td></tr>
<tr><td>Briquettes</td></tr>
<tr><td>Others</td><td>Compost</td><td>Dry Fibre
or
Mixed Fibre/Filler</td></tr>
</table>

11.2 Summary & Outcome of Interviews

The outcome of the 19 interviews with potential customers was to reduce the potential applications as issues emerged.

The list of the 10 customers who indicated their agreement, with reasons to move to a trial stage (laboratory evaluation or full trial) were as detailed below

Figure 49 List of Agreed Customer Trials

Product Application	Customer	Objective
Plasterboard (Acoustic)	A	Filler to improve board flexibility
Bricks	B	PFA and sand replacement
Bricks	C	PFA and sand replacement
Bricks	D	Drainage improvement
Cement Process	E	Fuel combined with lime material
Millboard	F	Recycled fibre replacement
Softboard	H	Recycled fibre replacement
Additive to Road Surfacing Material	H	Recycled fibre replacement
Insulation Board	J	Filler replacement
Absorbent Kraft Paper	K	Virgin Fibre Replacement

11.2.1 Overview of Customer Expectations

Cost Benefits

Customers indicated their willingness to undertake trials to research a commercial benefit to their process. To a large degree, their concern for using a recovered material (with an environmental handle) was of secondary importance. Customers were seeking to reduce their input costs, and in addition were seeking to achieve a technical advantage (where possible) from the inclusion of one of the sludge fractions.

Technical Benefits

From the above table, the key technical reasons for the trialling of the different fractions can be identified as follows:

For the manufacture of millboard and softboard, the use of the fibre fraction is as an alternative to recycled waste (either corrugated or newsprint). The minimum requirement for use in both millboard and softboard was that the fibre fraction achieved the minimum performance of the existing recycled fibre. Of more interest was whether the fibre fraction would add technical merit to the product by enhancing its properties or performance specification (e.g. thickness, bulk, stiffness etc).

For use as an additive to road surfacing material, the minimum requirement was to be a partial replacement for the current fibrous material. No superior properties were sought, unless the same effect could be achieved at a lower addition rate.

Cement manufacturers use calcium carbonate as a base material, and this is converted to lime (calcium oxide) by the effect of heat. This reaction commences at a temperature of around 820 deg C. To achieve this temperature in a kiln, fuel has to be burned. Typically the fuel is supplied by various waste materials. Mixed sludge contains both calcium carbonate and organics and is therefore both a raw material and a useful fuel. The benefit of the fuel is increased if it is dry, which reduces the transport cost and enhances the net calorific value (as there is less water to evaporate in the kiln). The materials used in cement making are very low cost, but the dry combined material is an attractive feedstock for the industry.

In the plasterboard process it is possible to make finished materials with a range of physical characteristics. In making certain grades (to achieve particular effects), the material can become somewhat brittle. One solution to this is to add a percentage of filler material, which must not adversely affect the processing or the function of the finished product. The filler product derived from Aylesford possesses the required characteristics, although the fibre in the filler fraction has a deleterious effect; soaking up water that requires to be taken up in the chemical rehydration of the gypsum. The requirement is to utilise the purest possible filler, devoid of fibre content. The separation of products is vital to the application, which, even in niche applications, runs to many thousands of tonnes.

Tests were conducted in three brickworks utilising both the clamp method and the tunnel kiln method. These trials used all the filler, fibre and mixed materials in dry and wet forms, as produced at Aylesford. The materials were incorporated into the brick itself. It was also considered that, with sufficient separation of the filler from the fibre, the fibre could be
Combined with coke as a fuel for the clamp bed. However, this has not been tested.

In the brick manufacturing process filler assists as a plasticiser, preventing cracking in the brick. It is normal to add materials for this purpose. The addition of fibre is beneficial as it provides pathways for moisture to escape from the wet brick.

The addition of pure fibre or pure filler, as opposed to mixed wet sludge, gives the brick maker control over drying, and simultaneously allows the quantity of calcium carbonate, which can affect appearance, to be incorporated appropriately.

Insulation Board is a combination of fibrous and mineral materials. The mineral material must not contain volatiles, and when virgin material is used in manufacture there is a significant cost. The insulation board industry requires consistent filler, mineral material from recycled sources, which would have a lower cost as a result of being a by-product.

12.0 Trials of Sludge Products

12.1 Fibre Fraction Trials

12.1.1 Millboard (Customer F)

Customer F manufactures millboard and other products. The fibre preparation process is very similar to a conventional recycled fibre plant using OCC (Old corrugated containers) as the main raw material.

Customer F evaluated a small quantity of the fibre fraction from Aylesford in standard millboard product.

The fibre fraction material (approx 5.0%) was added to the pulper, simultaneously with the old corrugated waste. Comments at this stage were that the fibre fraction was very dusty, although it did dissolve in the pulper without any problem.

The fibre was pulped and processed for the same time period as the standard product, and also went through the mill's existing fibre cleaning process prior to passing to the paper machine.

The conclusions from the trial were that the fibre fraction performed identically to the existing product and there was no positive or negative influence on the final specification of the finished product. Unfortunately, the company closed before a second trial could be agreed.

12.1.2 Additive to Road Surfacing Material (Customer H)

Customer H evaluated the fibre fraction (sourced from Aylesford sludge) in the laboratory.

Comments by Customer H on their laboratory evaluation were as follows:

- The fibre fraction was damp to the touch.
- The fibre fraction was blue in appearance.
- The product failed the bitumen drainage test.
- Potential reasons for fibre fraction failure are:
  - Ash content was too high; and
  - Cellulose content was too low.
- Target specification required by Customer H:
  - Ash content Less than 20%
  - Cellulose content Greater than 80%
  - Moisture content Less than 7%

Conclusions by Customer H were that performance of the fibre fraction was promising, but that it must comply with their specification to enable a commercial arrangement and on-going usage to become a reality

The fibre fraction samples were (in terms of fibre composition) found to be relatively near the required technical specification, although the filler content of the fibre fraction was in excess of the target specification for use in the main line products of the company.

Customer H is prepared to take a further trial, if the fibre fraction can achieve its specification.

12.1.3 Softboard (Customer G)

Customer G received a tonne trial of the fibre fraction for evaluation in their softboard manufacturing process. The key test results for the trial were as detailed in the table below:

Figure 50 Softboard Test Results

Board No	Mould No	Caliper Post Press (mm)	Caliper Post Dryer (mm)	g/m²	% R.H. After 2 days	Final Moisture Content (%)	Specific Gravity (SG)
1	1	20.1	20.0	-	18.6	-	-
2	2	20.0	21.0	14310	14.7	2.87	0.68
3	1	18.1	16.7	12830	8.7	1.13	0.77
4	1	17.8	16.2	12623	5.0	1.54	0.78
5	1	13.0	12.2	9897	5.0	2.26	0.81

Comments on the trial at Customer G, on both the physical processing of the fibre fraction, and the technical outcome were as listed below:

- There were 2 negative issues reported by Customer G; which were the bad smell (unacceptable) and the manual handling and dust problems, when loading the pulper.
- The bags for loading into their pulper were too heavy. Should another trial be agreed then smaller bags would be required.
- The fibre behaved differently to the existing fibre used by Customer G.
- The final board produced was considered weaker than the board made from Customer G's existing fibre (Old Newsprint), and possibly because of this cracked when going round the turning rolls in the dryer.
- The cracking problem did not occur with thinner board.
- The cracking on thick grades may be related to the board drying quicker. The machine speed was set to standard, which was possibly higher than the Aylesford fibre would permit.
- The stock consistency after the pulper was found to be higher (although not identified by the in-line consistency measurement) than operating under normal conditions, which resulted in the initial boards produced being very high in caliper.
- As the change in consistency was not identified by the consistency measurement devices, little or no water was added, resulting in a higher than normal consistency.
- The physical appearance of the pulp gave the impression it was very thin and watery, when in fact gravimetric tests proved the opposite.
- The final boards produced had a very smooth and even appearance, and the caliper was even. The board did not shrink during drying.
- The final board produced was much denser than the existing quality (for equal pressing time)
- Final moisture content of the boards was approx 2.0% v the normal level of 7.0%
- Overall comments were that the finished board was weak and there was severe delamination on the thickest calipers. It should be noted, however, that splitting on the corners of thick boards (i.e. 20 mm) is quite common (even with the standard ONP furnish).

Conclusions from this trial were that the dusty nature and smell of the fibre fraction were unacceptable, and these require to be reduced substantially or eliminated before a second trial is considered.

Processing the fibre fraction was achieved without problem, although the final softboard product produced during the trial was too dense, indicating that the filler content was too high, and the fibre content was too low.

Customer G is prepared to take a second trial of the fibre fraction if a product with an ash content of less than 10% can be achieved.

12.1.4 Absorbent Kraft Paper (Customer K)

Fibre fraction samples were evaluated at two paper mill laboratories in India, for inclusion in the middle layer of absorbent kraft paper.

The fibre fraction samples were found to contain too high a percentage of filler. The requirement is for a fibre product with a filler content less than 10%

Customer K is a potential future outlet for the fibre fraction, should development of a product with a lower % of filler be achieved.

12.2 Filler Fraction Trials (Description & Outcome)

12.2.1 Acoustic Plasterboard (Customer A)

Laboratory Trial at Customer A

A series of laboratory scale tests were carried out in the quality control laboratory at Customer A. The grey filler from Aylesford used in these tests was made on 1 September, before the Micronex was optimized. The material supplied contained 57.5% filler, 31.7% fibre and 10.8% water according to Aylesford tests. These results were at a substantial variance from the targeted specification of 22.5% fibre (after allowing for the water content).

Tests were conducted with the objective of finding the maximum level of filler that could be added to the plaster, while still allowing economic production. The tests were repeated sufficiently to be confident of the results. The tests showed remarkable consistency.

US Consistency Test

The test involves making a plaster by adding water to stucco and dropping a measured quantity from a fixed height onto a glass plate. The standard procedure is that 50 grams of stucco mixed with 36 grams of water will make a 75mm spread. The key to success is the 36 gram of water because an increase in this number means that the excess has to driven off during curing and drying by applying more heat than usual. The spread is required to ensure the material flows correctly during the rolling process in which sheets of plasterboard are formed.

In this test (with 10% filler added) it required 38 grams of water to achieve the spread. This is an increase of 5.5% water to be driven off. This could be partly due to the large proportion of fibre in the Aylesford filler. The fibre absorbs water.

Set Time Test

A pre-determined quantity of stucco with a standard volume of water added is spread on a glass plate and the set time is measured by drawing a wire through the plaster until this leaves a clean line in the plaster, which is then judged to have set. The standard set time for pure stucco was 7 min 45 secs. This simulates the setting process on the production line. The plasterboard is on the rolling line for this time. The mixture containing 10% filler took approximately 11 minutes to set.

To prevent this becoming a barrier, it is possible to include additives to speed the reaction, the lowest cost accelerator being crushed gypsum.

The appearance of the plaster in the wet state, including 10% filler by weight, is noticeably grey. However, the dry plaster containing 10% filler was white. Any difference in colour between pure plaster and plaster containing 10% filler, was considered acceptable.

It is not yet known if the filler is the most successful additive to achieve the objective of reducing the brittleness of some grades of plasterboard. However, the tests have shown that even a filler containing fibre can be incorporated in plasterboard. A purer filler extract is likely to be even more successfully incorporated.

Further Actions

Further lab trials have shown that the material can be used without adverse effect at 5% and possibly 7%. It is not yet known if the filler was the most successful product in obtaining the desired changes in the performance of the plasterboard.

12.3 Bricks

Coordinated from their central Technical centre, the customer tested the use of all the Aylesford materials, both processed through the Micronex and as raw sludge.

These trials were conducted in three works using 3 different processes. For reporting purposes these are described as customers B, C and D.

12.3.1 Bricks (Customer B)

Customer B employs a gas fired tunnel kiln to make 1 million bricks per week, out of a UK market worth 60 million per week. It uses 100 tonnes of PFA (pulverised fuel ash) per week, which is not an ideal additive in brick, giving (at Customer B) a problem of surface scumming, which affects the appearance of the brick.

PFA is filler used to assist drying, and it was thought that the dry Aylesford filler might be a substitute. A particle size of 100 to 150 microns would be desirable. The Aylesford filler fraction is typically under 50 micron. The calorific value of the filler fraction, derived from the fibre constituent, would be a bonus, as PFA has a lower calorific value than the filler. However, there was concern at the level of carbon dioxide that would be given off by the carbonate. Regulatory pressure and cost are important and growing over carbon dioxide emissions.

A quantity of 50 Kg of filler and fibre were delivered in late December 2005 to Customer B, for an initial technical assessment by the Technical manager.

On a laboratory scale, Customer B, initially, made trial bricks with a 6.5% addition rate of dry filler material. In view of the high level of calcium carbonate in the filler, there was concern that a colour change could occur (the carbonate can become a cause of brick turning yellow when fired).

There was no change in colour, and the assessment was that up to 9% filler could be added without changing appearance.

There was also no “bloating” (misshaping) of the brick.

A test by Customer B measured the 2378 Dioxin level (chlorinated dioxins) and found a level of 2.5 nanogram per Kg. Concern would arise if the level were 50 plus, so this is shown not to be an issue.

Customer B asked that any sludge supplied should be clean deinking sludge and not effluent sludge to minimize smell.

Customer B ordered 1 tonne of sludge in early April 2006 and incorporated it in a trial making at 2 to 3 % addition rate. Customer B added the material in place of PFA, on a conveyor to the mixer where all the components are brought together.

Wet bricks moulded from the resulting material were of slightly higher volume for the same wet weight, but otherwise were considered technically satisfactory. There was no discernible physical difference in appearance.

After drying, the wet brick was fired in the continuous kiln.

A physical examination of the brick showed there to be no change from the usual appearance. There were no accumulations leading to any spots.

This one tonne trial is now to be followed by 20 tonne bulk trials with a view to commercial exploitation.

The current assessment is that Aylesford sludge can be used as a substitute for PFA up to a level of 7% of the total wet brick weight.

12.3.2 Bricks (Customer C)

Customer C is similar to Customer B, with the same kiln technology. The raw material is different, and the clay preparation plant has different degrees of shear applied to the wet mix, as a result of different mixing equipment. However from a process point of view, the two plants are very similar.

Customer C received a 1-tonne trial of wet mixed sludge in April 2006 and completed manufacture at the beginning of May 2006.

Before adding sludge to the overall mix, it was first combined with coke breeze by turning with a mechanical shovel. This was to ensure that the sludge would be well dispersed in the mix.

This mixture of coke breeze and sludge was then added to the feed conveyor to the mixers. This first trial used 1% sludge in the overall weight of the brick.

At this level there were no adverse effects on moulding wet bricks and the bricks fired without problem. There was no change in appearance as a result of the change in composition, and there were no blemishes of any kind.

This trial confirms the findings at Customer C that it is possible to incorporate sludge into bricks.

12.3.3 Bricks (Customer D)

Customer D makes bricks by a significantly different technique called the Clamp Method. This traditional method still requires a mix, which is first moulded, after which the wet bricks are allowed to dry before stacking on a coke bed, which is lit to fire the stack. A typical stack is 30 metres x 10 metres x 4 metres

It was initially believed that the dry fibre briquettes might be a useful fuel substitute for expensive coke, and could be used in the coke bed in the clamp. However, it became evident that the Aylesford plant could not achieve the 75% fibre content in the "fibre" line. There was concern that the coke bed could be "doused" or put out, by the large quantity of ash that would remain after the fibre burned. This trial was not pursued. If the fibre were made to specification this opportunity should be re-visited.

The trials therefore focused on adding fibre, then filler, and then wet sludge to the brick mix.

In all cases, at approximately 2% addition rate, the brick was satisfactory except for the appearance of white spots on the surface after firing. There was no evidence of the spots before firing, and this suggests that agglomerations of calcium carbonate were not adequately dispersed during mixing and became visible when converted to lime (CaO) during firing.

12.3.4 Conclusions from the Brick Trials

It is clearly possible to use even raw wet sludge in bricks and to take advantage of the calorific vale of the waste as a substitute for coke. It is also possible to benefit from the clay content and calcium carbonate as a way to build-up the body of the brick with low cost material.

It appears that mixing is crucial to preventing "specks" of white appearing, adversely affecting the face appearance of bricks.

It has been shown in the laboratory that structurally sound bricks can be made at 6.5 % sludge content.

It has been shown in practical production trials that up to 7% wet sludge can be incorporated in certain processes without any adverse effect.

12.4 Cement (Customer E)

12.4.1 Discussion Points

The volume requirements for raw material to run a cement works are very large. To be seriously considered as a potential supplier, it is necessary to show that supplies exceeding 5000 tonnes per annum are available and contracted for a number of years. The pilot plant at Aylesford, running at specification, is capable of this rate of supply.

The raw materials required for cement making are calcium carbonate and clay (china clay as used in paper is one of the best clays). The Micronex filler product is therefore interesting.

Critical limits apply to the amount of Sodium (Na) and Potassium (K) in the raw material. The Aylesford material was approved in this regard.

The material requires to be very fine and capable of passing a 90 micron screen. (The Aylesford filler material complies)

The calorific value of the filler has yet to be determined. Cement makers are awash with fuels, and whilst it is beneficial to have a fuel content, there are other sources available, and which produce the following burning capability:

- Animal meal producing (16 MJ/kg);
- Mechanical Biological Treatment (municipal waste) (18 MJ/kg);
- Waste solvents (22 MJ/kg); and

- Old tyres (32 MJ/kg).

It should be noted that the Canadian dry mixed fibre and filler produced 12 MJ/kg and the Aylesford dry material 7.8 MJ/kg

12.4.2 Trial

After the initial evaluation, Customer E elected to test dried mixed sludge. In this way the calorific value is higher than wet sludge, and there is a good proportion of the carbonate and clay required for cement making.

The Micronex plant was however closed before this trial could be made

12.5 Insulation Board (Customer J)

Customer J expressed interest in the filler material as a lower-cost addition to their insulating panels.

The material required to pass a chemical analysis to show that organics were present only in acceptable quantities.

This test revealed that 31.2% of the material being produced as “filler” was in fact organic in nature. (This analysis was conducted by using a “burn off” oven to drive off the organics at high temperature. In the process a number of materials are oxidised.)

This level exceeded the acceptable level for the purpose.

Customer J considered whether it might be possible to “burn off” the organics, but concluded that this would be uneconomic. However, the chemical analysis of material produced as a result of burning off was made. The table shows the chemical make up expressed as a percentage of the original sample of filler. (There are chemical changes during the oxidation, which change the total mass of the residue. Hence the sum of the numbers is not 100%)

12.5.1 Burn-Off Trial

The chemicals identified during the burn-off trial were as shown in the table below:

Figure 51 Burn-off Trial Results

Chemical	%
Na_2O	0.06
MgO	1.89
Al_2O_3	8.10
SiO_2	14.08
P_2O_5	0.08
SO_3	0.11
K_2O	0.21
CaO	24.12
TiO_2	0.18
V_2O_5	0.00
Cr_2O_3	0.00
Mn_3O_4	0.02
Fe_2O_3	0.32
ZnO	0.01
SrO	0.05
Y_2O_3	0.00
ZrO_2	0.01
BaO	0.01
Chemicals (Sub-Total)	**49.25 (%)**
Moisture	3.50
Organics	31.17
TOTAL	**83.92**

During laboratory analysis, the level of organic content proved unacceptably high and Customer J decided this could give serious problems. It might be possible to burn off some or all of these organics before use but this could be costly in energy and might cause environmental issues.

12.5.2 Screen Analysis

In addition an analysis was made of the particle sizes of material in the filler product, and this is repeated here for completeness of reporting the work.

This screening trial uses multiple screens in a stack, and the proportions of the original material that are stopped at each stage are recorded.

Figure 52 Screen Analysis Results

Mesh (Micron)	% Retained	% Retained (Cumulative)
250	0.13	0.13
150	0.19	0.32
125	1.94	2.26
63	17.82	20.08
Pan*	79.92	100.00

*Pan – material that passes through all the screens and is then collected.

The analysis shows (for example) that 20.08% of particles by weight exceeded 63 micron in size. This implies that 79.92% by weight was composed of particles smaller than 63 micron.

The outcome of the laboratory trials was that Customer J considered it was not possible to use the product for Insulation Sheet.

12.6 Trial Summary and Conclusions (Technical)

12.6.1 Summary of Trials - Fibre Fraction

The summary of the trials on the fibre fraction is as shown in the table below.

Figure 53 Summary of Fibre Fraction Trials

Application	Outcome	Opportunity
Softboard	Ash too high Fibre content too low Very dusty & Smells	Good if reduced ash fibre fraction is available
Millboard	OK Acceptable for use Dusty	Company closed
Loose Insulation	Ash too high Fibre content too low Moisture content high	Good if reduced ash fibre fraction is available
Fibre Replacement	Ash too high Fibre content too low	Good if reduced ash fibre fraction is available

It is clear that there are four major issues to be considered (and addressed) in terms of the technical acceptability of the fibre fraction as follows:

- The ash content is too high and must be less than 20.0%, and ideally less than 10.0%; in order to reach technical acceptability and give a technical advantage;
- The fibre content is too low, and must be more than 80.0%, and ideally more than 90.0%;
- The fibre fraction is too dusty. This probably due to the high ash content; and
- The smell in the fibre fraction is unacceptable.

However, there was considerable interest in the fibre fraction, as a lower value and higher performance fibre replacement, and on the basis that the above issues can be rectified, then there are good opportunities for the fibre fraction in all the identified (+other) fibre-using market sectors.

12.7 Summary (Outcome) of Trials – Filler Fraction

The summary of the filler fraction trials is as shown below:

Figure 54 Summary of Filler Fraction Trials

Application	Outcome	Opportunity
Acoustic Plasterboard as plasticiser	Laboratory scale trials were successful, incorporating 5-7 % filler	Possible use, if large scale evaluation is successful
Brick making Substitute for PFA	Paper mill sludge successfully used at 7% addition Minor adverse comment re smell	Good Larger scale trials needed to establish addition rate possible
Brick making Substitute for PFA	Paper mill sludge successfully used at 1% addition	Good Larger scale trials needed to establish addition rate possible
Brick making Substitute for town ash	Fibre, filler and mixed sludge all leave white spots on brick surface	Need to evaluate cause of "spotting"
Cement Source of Lime and source of energy	All lab tests positive. Larger scale trial material not available	Good Need to produce dried sludge for trial
Insulation sheet Mineral substitution	Lab tests show mineral content chemically OK. Organic content of filler too high	Opportunity if organic material can be burned off economically

It is clear that there are a number of positive/negative issues to be considered (and addressed where necessary) in terms of the technical performance of the filler fraction as follows:

- The filler fraction had a slight smell;
- The filler fraction can be used as a raw material additive for cement;
- The organic content of the filler fraction was considered too high for use in Insulation board;
- The filler can be used as a raw material additive in the manufacture of acoustic plasterboard; and
- White spots were evident in bricks produced at one of the trials. However, raw wet deinking sludge (from Aylesford) can be added to brick at up to 7% without any deleterious effects, and further trials may indicate the proportion can be increased.

12.8 Overall Trial Summary & Conclusions (Technical)

The tests and trials carried out with potential users, both for fibre and filler, realised a number of significant opportunities to develop uses for these sludge-derived products as raw material for other manufacturing processes. Some of these trials are now being pursued commercially.

The following conclusions may be drawn:

- The Micronex plant proved its ability (in conjunction with the air transfer system) to dry sludge to the required moisture content range (less than 10% moisture). However, this could only be achieved at low throughput rates.

- The target specifications for filler and fibre were not met, and this limited the potential applications, particularly for fibre.
- Potential customers for fibre prefer that the filler content in the “fibre” product is less than 15% and ideally less than 10%. This would allow use of this low-grade fibre in some paper making and softboard manufacture.
- Trials of fibre containing up to 50% filler simply failed.
- The filler product is also preferred with as little fibre as possible. Applications are available, and the trial shows that use in conjunction with construction material manufacturers would bring about the incorporation of the filler fraction into cement, plasterboard, and brick.
- At the end of the trial period, too late to pursue further in this study, remedial work on the Micronex, and using the air transfer system to assist drying, produced improved drying and separation, with particular improvement to the fibre product.

13.0 Economics

Decisions about the applications for sludge-derived products will be driven by economics. The economic benefits from the drying process are considered in this section.

In the base case the value to the paper mill of drying sludge is considered. This is the most complicated situation, since there is an effect on the capacity of the existing combustor and on the need for future capital, for an additional combustor. There are rising costs for disposal of both sludge and combustor ash, which are also subject to increasing levels of landfill tax. This situation is analysed.

Consideration is given to the positive economic effects of drying if sludge were used in either a cement works or a power plant. In each case there are savings in transport costs.

13.1 Micronex KDS (Running Costs)

A key question to be determined is whether the economics of operating a Micronex are viable. These are determined by running cost and by the revenue available for the product.

In this section direct costs are presented. Three trials were run drying Aylesford newsprint sludge, and one trial involving M-Real's recycling sludge from their waste paper reprocessing plant at Kemsley in Kent. All the running parameters (during all trials) of the plant were measured.

The results are compared in the table below, and against the manufacturer's information based on their experience in a paper plant in Canada. Additionally, the final column in the table below details the Micronex performance immediately after the overhaul of the machine by the manufacturers in April 2006.

The table shows that source material (wet sludge) with a moisture content of 36% was dried to different degrees. For each degree of drying, measurements were made of the time taken and of the energy consumed.

Figure 55 Economic Summary

Test Material	M-Real	Aylesford	M-Real	FASC (Canada)	Aylesford (Post Micronex Overhaul)
Source Material (Input % Moisture)	36.0	36.0	36.0	50.0	38.0
KDS Micronex (Exit % Moisture)	18.0	15.7	13.5	15.0	16.0
Input of Wet Sludge (Kg/hour)	464.0	400.0	255.0	1000.0	900
Exit of Dried Sludge (Kg/hour)	362.0	304.0	189.0	588.0	664
Power Consumption (KWhr/input tonne)	213.0	331.0	388.0	85.0	100
Process time per tonne (hours)	2.2	2.5	3.9	1.0	1.1
Electricity Cost (£0.04 per KWhr)	8.5	13.4	15.5	3.4	4.1
Operator Cost per Tonne @ £20 per hour	43.2	50.0	78.0	20.0	22.2
Total Direct Costs (per input tonne)	**£51.7**	**£63.4**	**£93.5**	**£23.4**	**£26.3**
Yield:Output tonnes per input tonne	0.80	0.80	0.70	0.60	0.74
Power costs per output tonne	10.9	17.6	20.9	5.8	5.5
Total Direct Costs (Per output tonne)	**£66.3**	**£83.4**	**£126.2**	**£39.8**	**£35.7**

Data taken from trials run on 21/12/2005 and 13/01/2006

13.1.1 Interpretation

To convert this data into costs a number of assumptions have been made as follows:

- If the plant were part of a continuous process with handling facilities delivering material and taking away product, there may be no dedicated operator required. The only direct cost is therefore energy. In this case, while the drying cost varies with the dryness of the output, it is in a range of £8.50 to £15.50 per input tonne. The power consumption in the trials was approximately 4 times the maker's expectation. The maker's expectation would have converted to £3.40 per input tonne.

- For the pilot plant an operator was required, the cost of whom is shown in the table. (This is an extreme situation and a full production operation should avoid the requirement for a dedicated operator.) The output from the plant was some 40% of the maker's expectation. The cost of an operator is between £43 and £78 per input tonne. This has been added to the energy cost to give "Total Direct Costs".

- During the trials the input and output streams (i.e. fibre and filler), were weighed. Water is evaporated, so that the output tonnage is less than the input. In addition, there are losses of material though the air system, and these cannot be measured. The "yield" shown is the measured weight of product out compared to wet sludge put into the system. It is used to convert the processing cost from £/input tonne to £/output tonne.

This limited trial and cost analysis shows that the incremental cost of drying increases as the output product becomes dryer, and becomes very high. Too high throughput makes for a high cost.

Immediately prior to the conclusion of the project, a major overhaul of the KDS Micronex machine was undertaken by the manufacturer (FASC). During this work a previously unidentified blockage, in an inaccessible location in the unit's internal ductwork was found and removed. This blockage had existed for several months and had resulted in significantly reduced processing rates and increased fugitive dust emissions from the unit.

After the blockage was removed, sludge feed rates returned to the expected 800-1250 Kg/hr of input and the output moisture ranged from 15-19%. The data from one run immediately after the overhaul are shown in the final column of the above table, where 900 Kg/hr of deinking sludge having a moisture content of 38 % was fed into the machine and 664 Kg/hr of product having 16 % moisture content was obtained. The total power consumption was 90 KW and the water removal rate was 236 Kg/hr.

The specific power consumption was 100 KWhr/tonne of input material and 136 KWhr/tonne of output product. The water removal energy was 381 KWhr/tonne or 1373 kilojoules per Kg of water removal, or 1.373 GJ/ton. The results achieved post April 11th, 2006 are consistent with the results achieved for de-inking sludge processed in Canada on similar KDS Micronex machines.

FASC reported that the probable reason the air passages in the KDS machine became blocked was because the blower fan had been run at a low speed, which allowed the sludge build-up in the ducts. They suggested that provided the blower is run at its recommended speed, sludge build-up should not occur.

13.2 Economic Value of Drying to a Sludge Combustor

13.2.1 Current Situation (Aylesford)

Sludge combustion is seen as a complete method for the disposal of de-inked paper mill sludge. Waste materials from the paper process are taken from the fibre preparation plant at 2% solids and that stream is concentrated progressively into a sludge with approximately 63% solids.

The concentrated material is then fed to a fluidised bed burner operating at ca. 1000° C. The calorific value of the sludge is sufficient to ensure continuous combustion, and heat can be extracted for power generation or process heating. The quality of steam generated is identical to that available from the primary gas fired mill boiler plant. The output from the combustion process also includes dry ash.

However, this assumes that all the processes run perfectly. Because buffer stock must be provided, there is a facility to store sludge at up to 65% solids. In practice, there is always a requirement to remove some material via this storage, because the burner is operating at its maximum processing capacity of 100,000 tonnes/annum, in order to keep pace with the mill's production.

An additional 30,000 tonnes/annum of sludge is also produced, and it is this material, which is usually sent off site to other disposal routes.

13.2.2 Burner Operation

The energy generation from burning the existing 100,000 tonnes/annum of wet sludge is valued at approximately £3.4 million, reduced by the disposal costs for the 31,000 tonnes/annum of dry ash produced by incineration.

There is a clear volume/financial process benefit in burning dry sludge instead of wet sludge. The incinerator can currently process 100,000 tonnes/annum of wet sludge, although the total volume of sludge produced by the paper mill is up to 130,000 tonnes/annum. A reduction in the moisture content of the sludge from its existing 37% moisture to 25% will enable the additional 30,000 tonnes to be incinerated.

However, there is a technical limit to the dryness of sludge that can currently be fed to the incinerator. Dry sludge tends to "flash burn". Instead of burning in a controlled manner within the fluidised bed, very dry material burns above the bed.

13.2.3 Disposal Methods for Incinerator Ash and Sludge

Disposal costs vary according to the method utilised, as follows:

- The lowest cost is to use an operator- owned landfill site estimated to cost £3 per tonne of waste disposed. However, this type of landfill will not be available in the near future.
- Landspreading is currently a method of disposal for wet sludge at a cost of £18 per tonne. Landspreading is not permitted in parts of the EU and this disposal cannot be considered a long-term solution.

- Disposal to third party landfill site involves transport, landfill tax, and a gate fee. Transport costs are £7-£10 per tonne with Landfill tax currently being £18/tonne (likely to increase in the future) charged on the dry weight. The total charge for 3rd party disposal is £36 to £39 per tonne.

- There are a number of hidden costs in the disposal of ash. New regulations limit the proportion of lime (CaO) in transported material to 10%. To comply, the ash must be treated with a small amount of water before transportation, and there are also processing costs. Therefore, the 31,000 tonnes of dry ash produced from incinerating 100,000 tonnes/annum of wet sludge, is increased to approximately 35,000 tonnes of slaked ash for transportation.

- The disposal to another organisation, for whom the sludge (or the ash) is a useful raw material, may be viable. Limited quantities of material have been sold in this way.

Of the above methods of disposal, only third party landfill is available on a longer-term basis with any certainty, and even this option cannot be guaranteed. However, the cost of this method is the reference basis to assess the economics of alternative disposal systems.

13.2.4 Methods to Increase Incineration Capability

There are two potential routes to increase the capability:

- Increase the capacity of the current burner by reducing the moisture in the feedstock; and

- Add a further incinerator.

Alternative costs are considered below.

13.2.5 Drying by Micronex

Although there are costs associated with drying sludge in the Micronex, it is possible that the Micronex plant could be used for drying only (and not for separation of fibre and filler). Whilst the Micronex uses electrical power, this is effectively self-generated as a result of the incineration process at Aylesford.

Information from the manufacturers of the Micronex implies that the energy cost to dry sludge from 37% to 15% moisture content would cost £3.40/tonne. Measurements of the plant during running conditions, established a power consumption of £8.50 per tonne in reducing from 37% to 18% moisture.

Power consumption per % of moisture reduction increases as the material becomes drier. So it would be reasonable to conclude that power to reduce from 37% to 25% would be £5 per tonne or less.

To dry 130,000 tonnes of wet sludge down to 25% moisture on the Micronex at £5.00/tonne would cost £650,000 per annum.
A large scale Micronex has the throughput to process approx. 30,000 tonnes/annum. The capital cost for this size of Micronex would be of the order of £250,000 per unit, and at least four would be required to process the total quantity of sludge at Aylesford.

Alternative methods of drying are available and there is a supply of low cost waste heat available at Aylesford to supply such a plant. No costings have been undertaken on alternative options.

13.2.6 Disposal Costs for 130,000 tonnes sludge

Figure 56 Model 1 - Burn 100Kt wet sludge, Landfill 30Kt wet sludge (Current Model)

Item	£ 000's
Revenue from burning 100Kt for energy generation	3400
Disposal of 35 Kt slaked ash from 100Kt sludge	(1400)
Disposal of 30 Kt wet sludge to 3rd party landfill	(1170)
Net gain before running cost and amortisation	830

Figure 57 Model 2 - Dry 130Kt of wet sludge to 25% moisture, Burn resulting Dry sludge

Item	£ 000's
Revenue from burning dried sludge for energy generation	4420
Disposal of 45.5 Kt slaked ash from 130Kt sludge (Nil wet sludge to dispose)	(1775)
Power consumption for drying	(650)
Net total gain before running cost and amortisation	1995
Net marginal gain compared to Current situation (Model1)	1165

(Note; All costs are before charging maintenance, labour and amortisation)
Capital Cost for Drying System £1-£2 million

Figure 58 Model 3 - Burn 130Kt wet sludge after installing Additional Sludge Burner

Item	£ 000's
Revenue from burning dried sludge for energy generation	4420
Disposal of 45.5 Kt slaked ash from 130Kt sludge (Nil wet sludge to dispose)	(1175)
Net total gain before running cost and amortisation	2645
Net marginal gain compared to Current situation (Model1)	1815

(Note; All costs are before charging maintenance, labour and amortisation)
Capital Cost for Additional Incinerator £4-£5 million

13.2.7 Conclusions

There is a sufficient improvement in the cost of disposal brought about by drying to justify the extra process, and the Micronex is one method of achieving the dryness required.

There appears to be a viable case to use the Micronex as the drying process for the sludge. However, there are other means of drying sludge, and with waste heat being available from the mill, these might be more beneficial.

13.3 Cement Manufacture

Sludge contains Calcium Carbonate, which is used in the manufacture of cement. It also contains water, which must be driven off, and a proportion of organic material, which provides energy when burned.

Sludge requires to be transported. The cost is directly influenced by the quantity of water that is transported along with useable solid materials. There is a transport saving achievable to the supplying paper mill.

Cement manufacture consumes energy during the process. Any reduction in the energy requirement from a specific raw material will result in a gain, and clearly the cost of fuel replaced will determine the value of the lower energy requirement.

The cement process uses low-grade fuels, which are waste derived, and high-grade fuel such as natural gas. Waste based fuels are effectively at no cost to the cement producer. Use in the cement kiln is a form of controlled waste disposal.

13.3.1 Energy Savings

In cement making, the ideal sludge would have 0% moisture. The energy requirement to dry 1 Tonne of sludge with a moisture content of 36% is the sum of:

- The heat to raise 360kg water from ambient to 100ºC @ 1cal/gram/°C = 28,800 Kcal
- The heat of vaporisation of 360kg of water @540 cal/gram = 194,400 Kcal.
- The heat further put into the 360kg of water vapour up to the temperature of the gas vented to atmosphere @0.48 cals/gram up to (say) 500°C. = 86,400 Kcal.
- The total energy to heat the moisture present in the sludge is 309,600 Kcal = 360 KWhr/tonne of sludge.

If the sludge is supplied at (say) 15% moisture, then the saving in energy is (36-15)/36 of this total or 58.3%. For this example, it is assumed that high-grade heat is saved (i.e. there is a reduction in gas consumption) at 4p/KWhr. This energy saving is therefore £8.40 per tonne of wet sludge.

13.3.2 Transport Savings

Transport cost depends on distance, so only an estimate can be made. However, if a vehicle movement costs £300 for 25 tonnes, the saving from reducing moisture is easily estimated.

One tonne of wet sludge at 36% moisture contains 640kgs of bone dry material. At 15% moisture, the weight is 752kgs. So the transport saving is 24.8%.

Thus every 36% wet tonne of sludge currently costs £12 to ship. Reduced to 15% moisture, the shipping cost is £9.02.

13.3.3 Overall

Figure 59 Energy Comparisons

Energy Saving by drying from 36% to 15% moisture per tonne of wet sludge	£ 8.40
Transport saving by drying 36% to 15% moisture per tonne of wet sludge	£ 2.98
Total saving derived from drying	£ 11.38
Compare to energy cost of operating Micronex system to achieve drying (see section 13) derived from trial data	£ 13.40
Compare to energy cost of operating Micronex system to achieve drying derived from manufacturer's data	£ 3.40

13.3.4 Conclusions

The economics depend on the efficiency of the Micronex system. Accounting for the energy used in the Micronex process, if the stated performance were achieved, using the Micronex would reduce the cost of the whole system of supply of sludge from a paper mill to a cement works.

However, at the production efficiencies during the trials this was not achieved, and these results are shown numerically in Figure 59.

13.4 Power Generation

The calorific value per tonne of sludge varies with its moisture content, and the highest value is achieved when moisture is at its lowest. In power generation, any ash is a waste product, which has to be disposed at a cost. The objective is to extract the maximum calorific value while incurring the lowest cost.

Tests on one particular sludge at 36% moisture yielded a gross CV of 1260cals/g. The same material at 15.7l% moisture yielded 1660cals/g.

On a bone dry basis at 900ºC, the sludge yields 48% ash. So to obtain 1MCal the following are the materials handling requirements with the wet (36%) sludge and the dry (15.7%) sludge

Figure 60 Power Generation Efficiency Comparisons

Material	Energy Output	Tonnes Sludge Input Required	Solids in Sludge	Ash Produced @ 48%
36% Wet	1 Mcal	0.79	0.51	0.24
15.7% Wet	1 Mcal	0.60	0.51	0.24

The trial results show that the only effect of drying is to reduce the materials delivered by approximately 24%. To achieve a given amount of energy, the same ash will be produced whether or not the material has been dried.

13.5 Economics - Summary & Conclusions

The running cost of the Micronex machine is dependent on how it is installed and manned. It could be part of an integrated system as part of the sludge treatment plant, or arranged so that the feed to the machine is automatic, controlled with all the other parts of the mill from a central control room.

In this scenario, the direct cost per tonne for drying is around £5 per tonne to reach 25% moisture from an original 35% to 37%.

With this variable cost, and a capital cost of perhaps £1 to £1.5million for four large Micronex machines, it is attractive economically to dry sludge so that the mill's existing burner capacity is increased. The revenue benefit for a capital outlay of £1.5 million is calculated at £1.165 million pa.

The installation of an additional sludge burner would cost at least £3 million more than putting in the dryer. It would create only a further £550k of revenue improvement. This option is however better known technology.

Drying sludge before it is delivered to a power generator, or a cement works, will contribute only transport savings to the whole system. The transport saving is likely to be less than the energy cost of operating the Micronex.

14.0 Marketing Results

14.1 Market Opportunities for Sludge - Fractions

Each of the market opportunities identified during this study has distinctive characteristics. The value per tonne available from marketing a sludge or a sludge fraction depends on the alternative, which it has substituted.

For example, fibre for burning might compete with many waste based fuels. These are available at low cost and there is a plentiful supply. Consequently in this market, fibre would also have a low value. However, if it were successfully used in the corrugated case materials market, then its value could be high.

To aid understanding of the market opportunities, the following table shows some key characteristics of the market sectors, and details the barriers to be overcome if sludge products are to be used

Figure 61 Market Opportunities for Sludge Fractions (Table 1)

Application	Volume of UK Production	Potential use of sludge product	Potential Value per tonne	Value of Material substituted	Potential value from UK wide application	Barriers to Implementation
Moulded Pulp	40,000 tpa	Potential for use in non-direct food contact applications.	Low value Waste Paper substitute at £10 to £20 per tonne	Good quality sorted waste at £30 to £40 per tonne	5000 tonnes valued at £10 per tonne, worth £50,000	Much better separation of fibre from filler required. Fibre content required to be 75% and better.
Newsprint	1.15 million tpa	Extraction of more short fibre that could go back into papermaking. Up to 1% of total fibre in making newsprint could be saved.	Value of good fibre is £40 to £45 per tonne.	Across UK production an additional 15,000 tonnes would be used and not burned or landfilled.	15,000 tonne valued at £40 per tonne is worth £600 k	The fibre fraction carries ink residues and too high a proportion of fillers even after processing.
Tissue	0.95 million tpa	None found due to fibre quality in fibre fraction being too low, and separation from filler inadequate.				Much better separation of fibre from filler is required, beyond the 75% target set for this project.
Corrugated case materials	1.68 million tpa	Extraction of more short fibre that could go back into papermaking.	Low value Waste Paper substitute at £10 to £20 per tonne	Good quality sorted waste at £30 to £40 per tonne	20,000 tonne valued at £10 per tonne worth £200,000 pa	Much better separation of fibre from filler required. Fibre content required to be 75% and better.
Compost	Not evaluated due to negative value created through charges made for composting operations					
Panel Construction materials	Not assessed	Fibre fraction can substitute for other fibrous materials	Low value Waste Paper substitute at £10 to £20 per tonne	Good quality sorted waste at £30 to £40 per tonne	Not assessed	Much better separation of fibre from filler required. Fibre content required to be 75% and better.
Asphalt Road Surfaces	20 to 30 million tpa	Fibre fraction can be added to top course at up to 0.5% to improve grip.	£10 to £20 per tonne	Waste paper or other fibre at £30 to £40 per tonne	20,000 tonnes valued at £10 per tonne worth £200,000 pa	Much better separation of fibre from filler required. Filler content required to be 20% or less

Figure 62 Market Opportunities for Sludge Fractions (Table 2)

Application	Volume of UK Production	Potential use of sludge product	Potential Value per tonne	Value of Material substituted	Potential value from UK wide application	Barriers to Implementation
Cat Litter	250,000 tonnes, of which most is clay based with some 6,000 t of waste paper based	The fibre-filler mix, suitably treated to avoid dust, could be formed into an absorbent material, and substitute for clay, which is usually imported to the UK.	Clay is valued at £40 to £45 per tonne at the dockside in the UK. Some cat litter materials are double this cost.	£20 to £40 per tonne, depending on presentation and additives to overcome dusting and smell.	As much as £5 to £10 million market size is available.	Presentation of the fibre- filler in dust free and sweet smelling form.
Animal Bedding for Cattle and Poultry	In excess of 0.5 million tpa	The fibre-filler mix, suitably treated to avoid dust, could be formed into an absorbent material, and substitute for straw, which is the dominant bedding material. The market may be restricted to farms which do not have cheap access to straw.	Probably £5 to £10 per tonne	Straw is £15 per tonne to produce and £30 per tonne to buy but is often produced on the farm and considered as zero cost. Dust free wood shavings up to £100 per tonne	Large variety of competing materials is used. So potential may be 20,000 tonnes valued at £100,000	Presentation of the filler in dust free and sweet smelling form.
Cement	11 million tpa	Combined dry fibre and filler acts as useful source of lime and of fuel to heat the cement kiln.	£0 per tonne delivered	Chalk ad other cement materials are close to zero cost	Approximately zero sales value.	Cement works are used for waste disposal and can effectively charge a gate fee, which may make use in cement uneconomic.
Bricks	4.8 million tpa	The filler can be used to substitute for PFA costing £8 per tonne. It can also substitute some sand and it contributes some calorific value substituting for coke.	Probably £5 per tonne delivered is the maximum economic value achievable.	PFA at £8 per tonne Sand at £8 per tonne	At addition rate of 3% the usage would be 144,000 tonnes valued at £720,000 delivered to brickworks	Development work with brickworks to establish the application.
Plasterboard	2.3 million tonnes, of which up to 200K tonnes are speciality	5% addition of filler fraction making 5000 to 10,000 tonnes annually.	£10-£15 per tonne	Gypsum at £12 to £18 per tonne	£60k up to £150k per annum	Full trial to prove the application

14.2 Barriers to Utilising Fractions and Actions Required

The main barriers to utilising the various sludge fractions are as follows:

- Technical - manufacturing of separated product at the paper mill.
- Technical – user application of products. Potential users have to overcome their own technical issues to permit the products to be incorporated in their own products.
- Marketing – the benefits of using these products has to be spread.
- Regulatory – the clear classification of the materials as products and not as a waste stream would assist. This needs to be accepted by the Environment Agency.
- Economic – the cost of producing and the price for selling the products has to be low as they substitute for low cost raw materials.

To overcome these barriers it is necessary to:

- Improve separation of the fractions, which in the main trials failed to reach specification. However, in some tests run at the end of the project, limited by the time available, some interesting results were obtained following modifications to the plant.
- Users have to modify their processes to accommodate new materials. This is costly. It is difficult to see how this can be overcome in the course of free market business. Some financial inducement may be needed. This has been used in other markets such as energy generation, where "green" energy is priced advantageously to the supplier to encourage its production.
- Advertising the use within products of recycled or waste materials is growing. High profile businesses like to demonstrate their good environmental credentials. Continuing support from the authorities for public awareness will increase the opportunity for fibre and filler materials.
- At the same time that new uses are being sought for waste materials, the regulatory burden on producers and users of these materials is increasing. Potential users are reluctant to use these materials because of the regulatory obligations they will incur. It is easier to take in a virgin raw material, usually at no financial cost for the product. Processed paper mill residues, made to a specification (i.e. not just all the mills waste) requires to be classified as a product, not a waste.
- The economics of the drying system have to be re-examined by the manufacturer. Energy costs are a barrier to drying sludge so that it can be separated and turned into useful products. During the trials the energy costs were far higher than projected by the manufacturer. Achieving the specified cost of approx £3.5 per tonne would be sustainable and this has to be achieved to make the process viable.

14.3 Market Development Summary

From the initial review of the possible applications, thirteen market sectors were selected where there could be a use for any of the four products offered (fibre, filler, dried mixed fibre and filler, briquettes).

This led to a listing of fifty-six companies operating in these sectors, which were contacted and an initial view taken of whether detailed discussion might lead to an application and to one of the five trials that were the objective.

Nineteen companies were selected for detailed discussions. Of these a number were ruled out at the first stage.

Ten organisations (so a higher proportion than targeted) saw value in the products and were prepared to carry out work amounting to a test or trial. These applications were:

- For fibre: Softboard
- Millboard
- Loose Insulation

- For filler: Plasterboard
- Brick
- Cement
- Insulation Sheet

The best fibre manufactured contained about 50% filler but the trials of softboard, millboard, and insulation were unsuccessful due to the low fibre content. Product was made, but it was of inferior quality. However, if the fibre stream is improved, the way is open to rerun the trials.

The filler suffered from the same problem as the fibre but to a lesser extent. The filler still contained nearly 30% fibre, and this is a barrier to use in (for instance) plasterboard. However, some trials in brick were successful first on a laboratory scale, then on a small-scale production. Trials continue to use the material in full-scale production.

As these trials progress it is likely that separation of filler and fibre may not always be required for brick manufacture, though consistent moisture is important.

Brick appears to be the major opportunity, with value for both the brickworks and the papermaker.

The economics are driven by the low cost of most virgin materials in the applications. However, the avoidance of disposal costs for waste is a benefit. It is possible that in the range £0 to £10 per tonne is a delivered price, which is sensible for producer and user.

15.0 Project Summary

This project took a novel technology and applied it to a longstanding and increasing problem – to convert a major waste stream into useable products.

This report has detailed the strengths and weaknesses of the pilot plant that was built, its ability to create the predetermined specifications of output products and the reception given by the market to the products that were actually made.

The key findings from the project can be summarised thus:-

- This method of drying to improve the separation of fibre and filler fractions is technically sound.
- Progress was made towards the end of the project demonstrating that the plant could be developed and deliver the target fraction qualities.
- Whilst there was a failure to achieve the splitting efficiency required, it was demonstrated that good markets do exist for the split fractions.
- The application of wet sludge in the making of brick is a direct result of this project, with a meaningful potential rate of use.
- Pelletising of sludge and sludge fractions was proved to be possible and allows a number of different quality pellet products to be made. Selected products have commercial potential.
- Production of a pellet from the output of the Micronex, without attempting to obtain fibre or filler fractions, could prove economic as a biomass fuel, to be added along with wood pellets, and reduce or eliminate the high costs of other disposal methods.

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