Power use at Municipal Wastewater Treatment Plants: Recommendations for Greater Efficiency.

Case Study of South Tipperary County Council Facilities.

by

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ABSTRACT

Until very recently power management has not been much of a concern to those people managing wastewater treatment facilities. Latterly, however, much has been written in the media and elsewhere about “the end of cheap energy”. This has focused minds on the fact that a lot of energy is wasted and could be more efficiently utilised. Efforts are increasing in all industries to improve energy efficiency in tandem with process optimisation and the same is true of the wastewater treatment industry.

Electricity consumption was analysed at eight wastewater treatment plants in South Tipperary and was found to be in the range 1.76 - 8.09 kWh per KG BOD treated, or 36 – 175 kWh per population equivalent and year. Such a broad range of treatment efficiencies may suggest that there is a large amount of scope to improve the performance of some plants with respect to electrical energy efficiency.

Cashel wastewater treatment plant (WWTP) was used as a model to see if it was possible to improve the energy efficiency of a plant with no capital investment. The initial treatment efficiency was found to be 2.83 kWh per KG BOD treated or 61.95 kWh per population equivalent and year during the month of November 2005. After implementation of a range of efficiency improvements, these treatment parameters were measured again in March as 2.33 kWh per KG BOD treated or 51.08 kWh per population equivalent and year. Final effluent quality was maintained throughout the study.

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DEFINITIONS AND ABBREVIATIONS

BOD/ BOD_5:	5-day Biochemical Oxygen Demand.
COD:	Chemical Oxygen Demand.
CHP:	Combined Heat and Power. So-called CHP units utilise digester biogas to harness the power of methane gas.
DO:	Dissolved Oxygen. A measure of the quantity of oxygen which is present in a body of liquid. Can be expressed as mg/l or % saturation.
EPA:	Environmental Protection Agency.
FDS:	Function Design Specification. Also known as a Control Philosophy, this document is a detailed description of the sequence in which various items of equipment operate when in automatic control.
kVA:	Kilovolt Amperes, also known as apparent power.
kVArh:	Kilovolt Amperes reactive hours; wattless units.
kWh:	Kilowatt hours. Active electrical power units consumed by an electrical unit or premises as measured by the ESB meter.
MIC:	Maximum Import Capacity. The level of electrical capacity contracted between a business owner and ESB networks.
PE:	Population Equivalent. The BOD load to a wastewater treatment plant expressed as an equivalent number of people, assuming 60g BOD per person.
PLC:	Programmable Logic Controller. A digital controller used for applications such as on/off control, timing and sequencing.
Power Factor:	A ratio of actual power to apparent power in a circuit.

SCADA:	Supervisory Control and Data Acquisition. Consists of a computer interface that allows the user to alter set-points which dictate the actions of the PLC.
VSD:	Variable Speed Drive. An electronic device that controls the rotational speed of a piece of motor-driven equipment.
WWTP:	Wastewater Treatment Plant.

CONTENTS

INTRODUCTION

Wastewater treatment is an essential component of sustainable development. Economic expansion leads to a rise in waste production (be the rise commensurate with growth or not). One component of waste produced is, of course, wastewater. In order that increased wastewater volumes do not lead to increased pollution of our watercourses, we must reduce the pollution capacity of this waste to low levels. However, as technology improves in the area of wastewater treatment, and as plants expand to accommodate larger volumes, the wastewater treatment plants themselves can become a large drain on resources. While these resources can include manpower, chemicals, building materials and capital requirements, this project is more concerned with electricity consumption.

The optimisation of electrical energy efficiency at wastewater treatment plants should be a much greater priority than is currently the case. It has very often been overlooked, heretofore, in favour of process optimisation alone. Some studies have shown that 25% of the running costs of a plant are energy costs (Balmer, 2000). If we could minimise these energy costs, the economic benefits to the plant operator are obvious; lower electricity bills and less unnecessary use of machinery leading to longer working life. Any savings "go straight to the bottom line", in financial parlance. The project will focus on possible savings that do not involve a capital outlay, as any commitment to replace inefficient machinery would involve a more thorough examination and management approval.

There is also a bigger picture. Much discussion is ongoing regarding so-called "carbon taxes" as a means of combating global warming. Should such a tax be eventually introduced in the form of, say, a levy, large energy consumers such as wastewater treatment plants are unlikely to escape unscathed. By becoming *au fait* with energy efficiency principles and establishing relevant benchmarks now, the shock of any introduction of a “carbon tax” will be lessened by reducing to a minimum the tax payable by the operating company or Local Authority. Further benefits to the environment accrue from any reduction in electricity usage by lessening the amount of power that the utilities must produce, thereby requiring the burning of less fossil fuels (SEI, 2004). The emission of less CO_2 gas to the atmosphere is the obvious benefit from this situation.

AIMS AND OBJECTIVES

In order to understand where we stand on energy consumption and efficiency at present, some baseline information must be gathered, i.e., benchmarks have to be set down. This will also allow us to make meaningful comparisons between power use now and power use after any efficiency measures are put in place. As Ingildsen, et al (2002) put it, benchmarking is about finding out "how good is my wastewater treatment plant doing compared to other wastewater treatment plants?" In order to include as many plants as are available to the writer as possible, eight different plants in South Tipperary are featured in the project. According to Balmer & Mattsson (1994), "the only possibility to evaluate efficiency is to compare costs with similar plants". The efficiency of the plants will be compared by attempting to establish comparable efficiency parameters; in order to compare like with like, relevant variables will be taken into account.

It would seem reasonable to assume that economies of scale would apply to wastewater treatment; however, a survey of wastewater utilities in Iowa, USA (Sauer & Kimber, 2002) found that there was no significant decrease in kWh consumption with increasing utility size. It may be possible to test this assertion from the data by comparing smaller plants (1,000-2,000 PE) with medium-sized plants (5,000-11,000 PE) and the largest plant within the scope of this project, Clonmel (80,000PE).

Cashel Wastewater Treatment Plant will be used as a model to see if a reduction in electricity use can be achieved by making specific operational changes, while maintaining final effluent quality. Cashel WWTP was chosen because the author operates that plant and, therefore, is in a position to put any operational changes into place and easily gather detailed information pertaining to it. It is a relatively small plant, catering for a population equivalent (PE) of 9,000. Total electricity consumed over two separate one month periods will be compared. It is hoped that a noticeable drop in electricity consumption will be seen during the second period. An improvement in the efficiency parameters mentioned above should then follow, provided incoming plant loadings are not the sole reason for any drop in electricity charges. The problem with these plans is that “optimality is not uniformly defined” (Ingildsen, 2002), so there are no hard and fast rules as to what changes can lead to efficiency improvements.

The proportion of power used by various pieces of equipment as a fraction of the overall power used at Cashel WWTP will be illustrated. This can help to highlight the most energy hungry equipment in order to focus on what the priorities are when it comes to any energy reduction programme.

Finally, generally applicable guidelines will be produced for a wastewater treatment plant operator who may wish to embark on some cost-cutting measures at his or her own plant. These measures will cover as many areas of plant operation as possible and some may be more relevant to other personnel such as mechanical and design staff. Some suggestions will involve capital replacement or other investment so that a broad spectrum of efficiency measures is covered. All the information gathered and illustrated should be very useful for any one wishing to benchmark their facility against others to see how they compare to the “norm”. This project will provide a useful base for future comparison to see if standards are maintained.

Section 1. Literature Review

1.1 Introduction to Wastewater Treatment

While each individual Wastewater Treatment Plant has its own particular design, size, process methods and unique wastewater stream, the basic principles of treatment remain largely unchanged from plant to plant. This section will give, in general terms, a description of the intended purpose of individual processes and plant items used in South Tipperary. Variations will exist in the size and specific type of plant used for each process. A separate paragraph under each section deals with Cashel WWTP in detail since this plant is the primary focus of the study.

1.1.1 Preliminary Treatment

Incoming raw sewage must first be have debris removed to make it suitable for pumping and handling, so as not to cause undue wear and tear on equipment or cause blockages. Several processes are generally employed: coarse debris removal, fine debris removal, grit removal and grease removal. Most inlet works in the South Tipperary scheme consist of a single tank, which is divided into sections that perform the various debris-removing tasks.

1.1.1.1 Coarse debris removal

Coarse debris removal is not always employed, except in larger schemes. In South Tipperary, coarse debris removal is only in place at Clonmel STW, by far the largest plant in the region. Rotating Bar Interceptor Screens are placed in the inlet channel at depth, with the bars 100mm apart. The bars rotate first one direction, then the other, and in doing so, admit only material which will not damage the fine screening equipment. Bulky items such as tree branches and other large objects are removed at this stage.

1.1.1.2 FINE DEBRIS REMOVAL

Fine debris removal usually consists of a fine screen with 5-6mm apertures. A common type in South Tipperary is the “low-flow” screen, which is immersed in the incoming flow. Wash-water (re-used final effluent) is employed to clean the screenings before they are dried in the compactor and deposited in the screenings bin.

At Cashel WWTP raw sewage enters the inlet work by gravity. Screenings are entrained in 6mm apertures and removed by two inlet screens in duty/ standby mode (however, at high flows both screens operate), which have the following components: screen drive, brush, compactor and impeller. The drive turns the screen and the brush (with the aid of wash-water) cleans the screen as it rotates. The impeller is immersed in the incoming sewage and acts to draw sewage through the screen and macerate larger screenings (Jones & Attwood, 2002).

1.1.1.3 GRIT REMOVAL

After fine screening, the incoming flow area widens considerably in the inlet tank, thereby slowing the flow enough for heavier material (both grit and organic) to settle. The liquid portion continues on to full treatment. When a grit sequence is activated the grit blower lifts the settled material up from the bottom of the tank. The lighter organic material will be re-suspended so that it becomes entrained in the inlet flow once more and is treated as normal. The heavier grit and stone particles are merely agitated so that they are washed. A grit pump then pumps the grit particles and stones across to the grit classifier where they are dried and deposited into the grit waste bin (Jones & Attwood, 2003a).

Cashel WWTP has a duty/ standby grit blower arrangement with a grit pump to convey the grit-laden water to the grit classifier. The plant operator can change any part of the grit removal sequence (using SCADA) as well as the number of sequences that occur throughout the day (Earthtech, 2005).

1.1.1.4 GREASE REMOVAL

Fat and grease are not easily treated in conventional secondary treatment plants and usually end up causing problems such as blockages and unsightly scum on clarifier and aeration basin surfaces. Grease removal is also performed at the inlet works immediately after grit removal. The grit blower blows air through a different pipe with several smaller bore pipes at its end. This forms small bubbles which rise through the incoming raw sewage, causing fat and grease to float to the surface and from a scum layer. A grease conveyor then scrapes the scum off the liquid surface into the grease bin (Jones & Attwood, 2003).

The grit blowers at Cashel WWTP also double as grease blowers during a grease removal sequence. When operating, however, they blow air through a different pipe, which is connected to four ¼ inch plastic pipes that float any grease to the inlet tank surface. A conveyor then removes the grease to a waste bin. The blowing and scraping sequences alternate a predetermined number of times. Similarly to grit removal, the number of sequences per day and the grease removal sequence can be changed (Earthtech, 2005).

1.1.2 PRIMARY TREATMENT

Primary treatment is used to remove heavier settleable solids and thereby remove up to 30% of the BOD load and 60-70% of the suspended solids load onto the plant (CIWEM, 1995). Primary treatment tanks are designed very similarly to final settlement tanks (shown in figure 1-2). This treatment stage is only in use at present at Clonmel WWTP in South Tipperary, although Cashel WWTP has an existing primary tank which will be used if an extra treatment stream is required in the future.

1.1.3 SECONDARY TREATMENT

Secondary treatment is the term given for the use of activated sludge in the stabilisation and break-down of raw sewage. Activated sludge is formed by providing oxygen to a diverse array of huge numbers of bacteria which, when mixed with raw sewage, carry out the treatment process. The sludge is then settled, leaving a clear final effluent. Settled sludge is returned to treat more incoming raw sewage and any excess is removed for further treatment before disposal (CIWEM, 1997). Figure 1-1 shows the general arrangement of a typical secondary treatment plant. (Note that both surface and diffused air systems are generally not used concurrently).

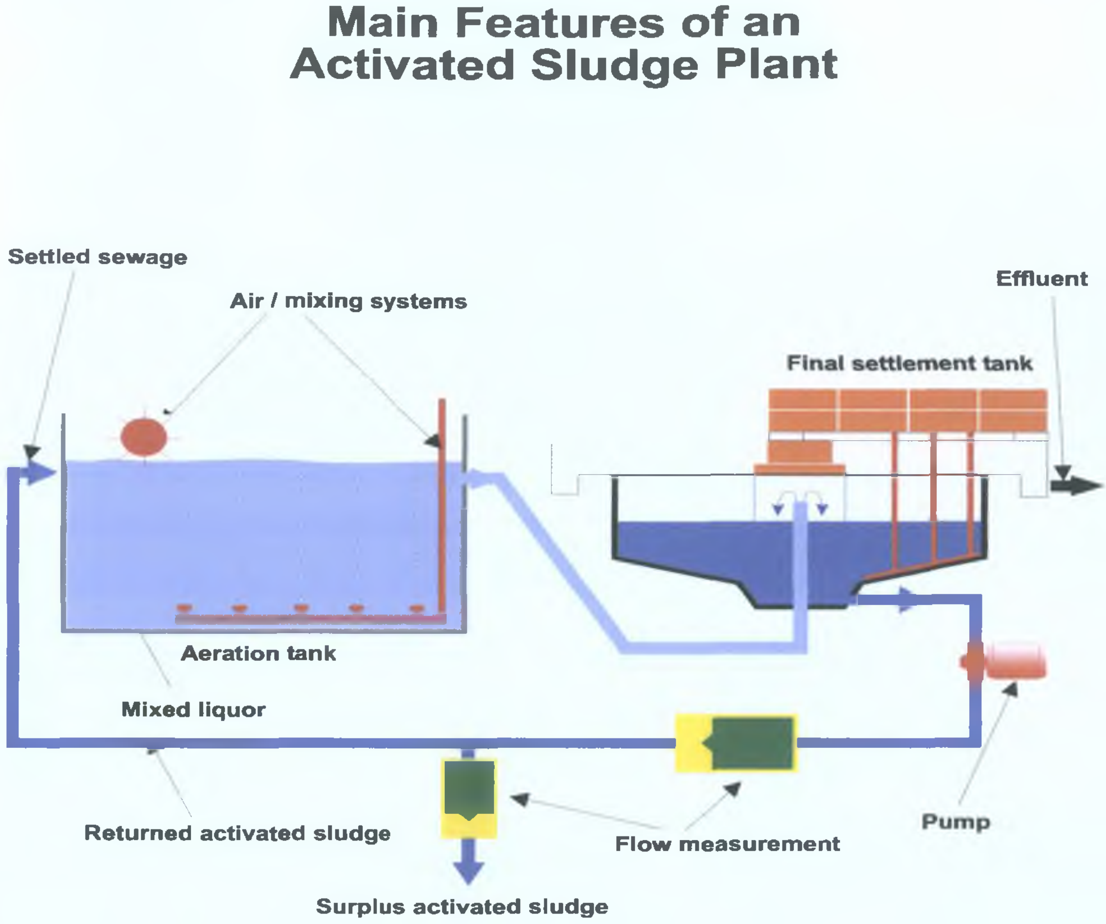


Figure 1-1: General layout of a secondary treatment plant (FÁS, 1999).

1.1.3.1 TYPES OF SECONDARY TREATMENT

There are two major methods of aerating activated sludge; diffused air and mechanical (surface) aeration. Both of these methods have a double function; they both aerate and mix the sludge (CIWEM, 1997). Surface aeration can be carried out by both vertical- and horizontal-shaft aerators. A vertical-shaft surface aerator is shown in figure 2. Horizontal-shaft aerators usually operate in “racecourse” type tanks, so-called due to their particular shape. These “racecourse”-shaped tanks are more correctly known as oxidation ditches. In South Tipperary, most plants employ fine-bubble diffused air, although there are some examples of surface aeration. Two plants utilise oxidation ditches: Tipperary Town and Killenaule WWTPs. Fethard

WWTP and Clonmel WWTP employ surface aerators, while the remaining plants under this contract utilise diffused air for aeration and mixing purposes. Figure 1-3 illustrates a typical fine bubble aeration tank showing distribution equipment and the disc-diffusers which create the fine-bubbles required for this type of system.

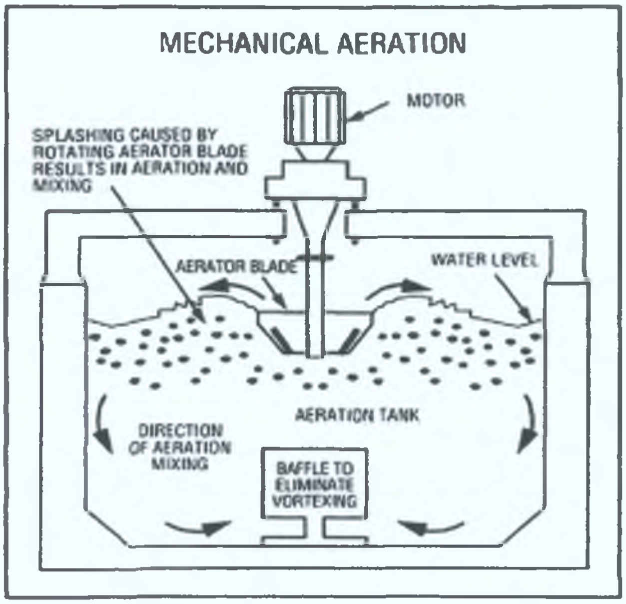


Figure 1-2. Vertical-Shaft Surface Aeration, cross section (Pakenas, 1995).

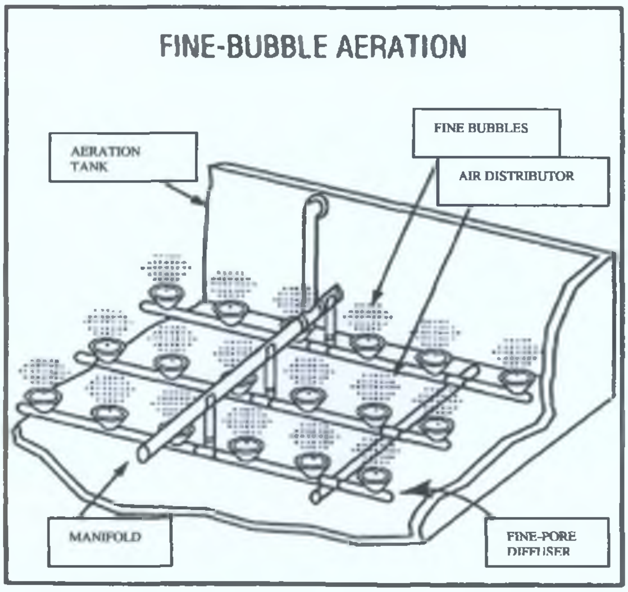


Figure 1-3. Fine-Bubble Aeration Tank, cross section (Pakenas, 1995).

As the aeration system consumes approximately 50- 65% of the net power demand for a typical activated sludge wastewater treatment plant (USEPA, 1999), this is an area of particular interest with respect to reducing power use. In the case of oxidation ditches, the USEPA (2000) suggests that they offer significantly lower operation and maintenance costs than other secondary treatment processes. That assertion is contradicted, however, by Pakenas (1995), who states that, based on oxygen transfer efficiency, there are energy cost savings of 40-50% with fine-bubble air diffusion systems compared to mechanical aerators. It may be possible to offer a tentative opinion as to which view is more accurate from the findings of this study.

One further secondary treatment type is biological trickling filtration. Biological filtration is used in Clonmel WWTP by means of biotowers, which are enclosed. Cashel WWTP has a biological filter located downstream of the primary tank, so that it is not currently in use, but is available when future increases in plant load require it. Figure 1-4 shows the basic arrangement of a biological filter.

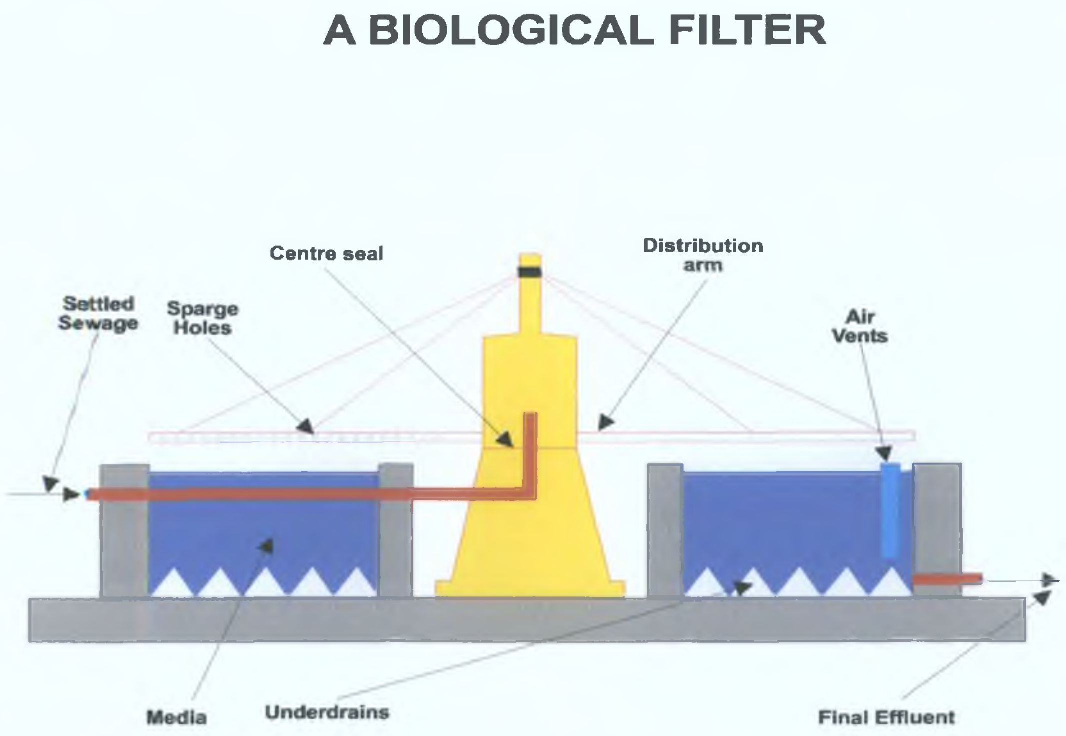


Figure 1-4: Typical Biological Trickling Filter Structure (FÁS, 1999).

In a biological filter, treatment takes place on the media surface (media can be stones of uniform size or even plastic, provided the surface area is large) where a biological film comprising the bacterial population resides.

1.1.3.2 OTHER FEATURES OF SECONDARY TREATMENT

Some plants have separate return sludge and waste sludge pumps, while others simply use one set of pumps that pump the sludge back to the aeration tank or to the picket fence thickener based on the PLC commands.

The final settlement tank is where sludge is settled and final effluent is decanted off. Figure 5 shows the general layout of a final settlement tank in greater detail in both plan and elevation views. Note that the desludging bellmouth is a feature of Fethard WWTP, but no other plant in South Tipperary. Usually sludge movement from the bottom of the final settlement tank is pump controlled.

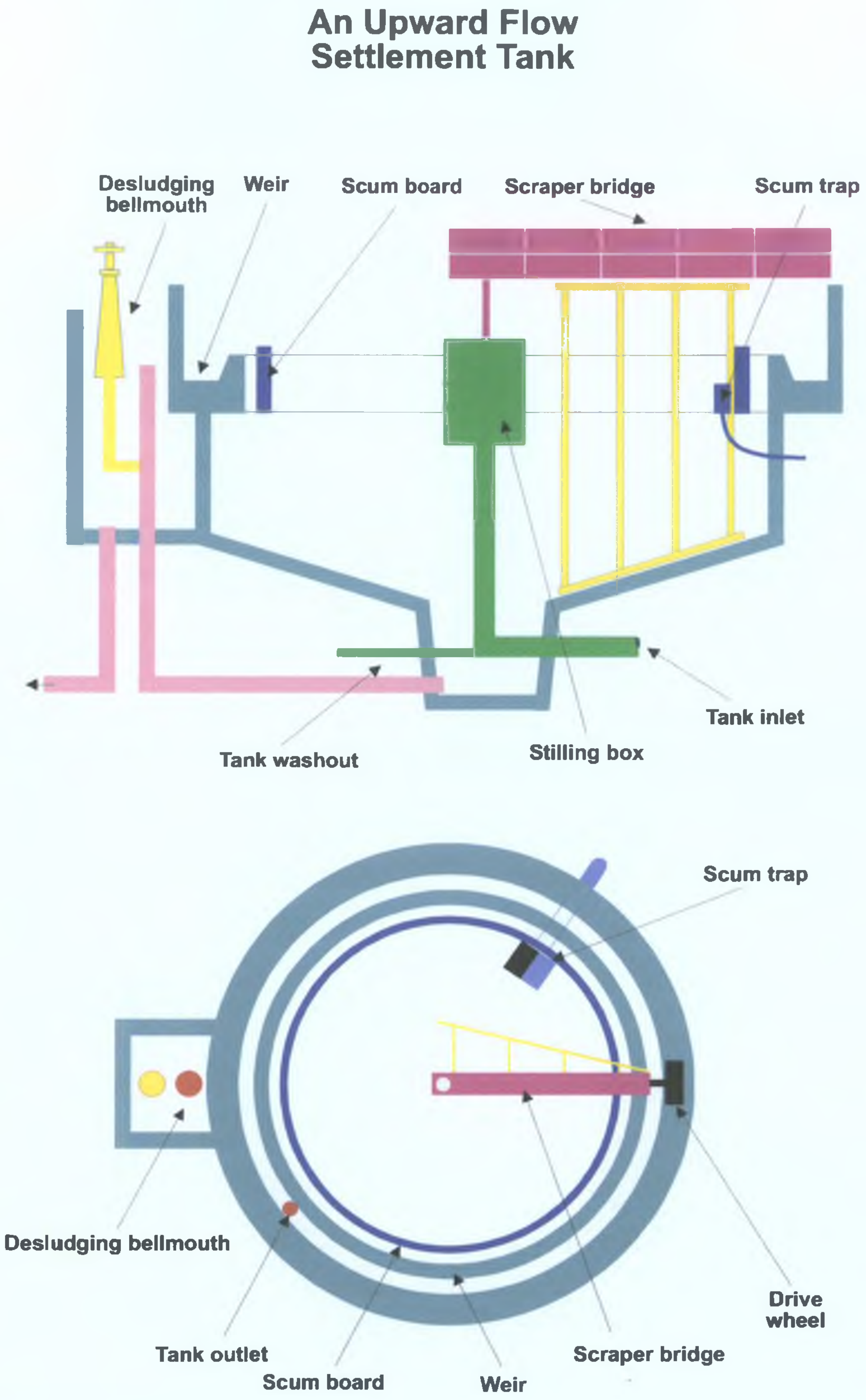


Figure 1-5: Typical Final Settlement Tank Layout (FAS, 1999). The top diagram is a section view, while the bottom shows the layout in plan view.

Cashel WWTP utilises diffused air provided by a duty/ standby air blower arrangement. Two aeration cells flow into one final settlement tank and sludge is returned to the aeration tanks by a duty/ standby sludge return pump arrangement. Sludge wasting is carried out using the same pumps by means of a valve which diverts the sludge into the sludge blending tank rather than back to aeration. This valve is controlled by an operator-defined timer located on SCADA.

1.1.4 TERTIARY TREATMENT

Further treatment of the final effluent is often required. This can involve disinfection, filtration and/or phosphorous removal to further improve quality. Disinfection is relatively uncommon (used at one plant in South Tipperary; Ballyclerihan), while several of the newer plants in South Tipperary have sand filters to reduce BOD and suspended solids in the final effluent. Phosphorous removal is achieved at the plants featured in this project by chemical dosing in the form of Ferric Sulphate. Ferric Sulphate precipitates phosphorous so that it is incorporated into the sludge mass (FAS, 1999).

1.1.5 SLUDGE TREATMENT

Waste sludge must be dealt with so as to prepare it for eventual disposal. Waste sludge of about 1% dry solids content is thickened to about 3% dry solids in the picket fence thickener. Once thickened, the sludge must be further dried in order to reduce sludge volumes and, therefore, reduce transportation costs. This process is known as dewatering and is carried out by either a filter belt-press or centrifuge in South Tipperary. The sludge produced must be at least 18% dry solids, but is typically

20-22% dry solids. Only Clonmel WWTP employs the use of a belt-press. Ultimately, the final sludge cake is removed by sub-contractors and used as a composting material. The ancillary costs of transportation and disposal are not considered as part of this project, but the dewatering process itself is still an energy-intensive process.

At Cashel WWTP waste sludge is stored in the blending tank. The function of this tank is to mix waste activated sludge with any imported sludge before pumping forward to the picket fence thickener for thickening. It is from here that the duty centrifuge feed pump sends the thickened sludge to the centrifuge.

1.2 MUNICIPAL WASTEWATER TREATMENT IN SOUTH TIPPERARY

In September 2003, Earthtech Ireland Ltd. was awarded the contract for the South Tipperary Grouped Operational Scheme. Takeover of the various plants happened on a phased basis and began a period of very substantial expansion of treatment capacity in the South Tipperary region. The contract is basically thus: Earthtech Ireland has been charged with upgrading of certain plants, building some plants from scratch and operation of all plants for a period of twenty years, once the construction (interim) period has elapsed. There are twelve plants in all included under the contract. The final three plants, namely Ballyporeen WWTP, Clogheen WWTP and Ardfinnan WWTP, have not yet been commissioned (as of 2005) and so are not referred to below. Also, Kilsheelan WWTP is not included as it was not under the control of Earthtech Ireland Ltd. for the entirety of 2005.

The 8 plants outlined below are being operated by Earthtech Ireland and have been under their control for at least one year in each case. By outlining the processes employed at each plant in some detail, we may be able to explain any differences in plant efficiency performance. It is necessary to know the types of plant involved in this project to allow for a meaningful comparison with any future study. It is also necessary to be aware of the final effluent standards required in each case, as a less stringent standard would confer an "advantage" on that plant in terms of energy efficiency.

1.2.1 CLONMEL WWTP

Clonmel is by far the largest plant included under the contract, having been designed to cater for a population equivalent of 80,000 people. Final effluent discharge limits are:

Parameter	**Concentration (mg/L)**
BOD_5	25
Total Suspended Solids	35
COD	125
Total Phosphorous	1.0

Table 1-1. Final effluent limits for Clonmel WWTP (Nicholas O'Dwyer, 2002).

Where: BOD_5 is the 5-day Biochemical Oxygen Demand, and

COD is the Chemical Oxygen Demand

The following treatment processes are employed:

- Inlet Works; coarse screening and sewage pumping
- Preliminary Treatment; fine screening, grit and grease removal

- Balancing Tanks; sewage strength equalisation
- Primary Settlement Tanks
- Primary Effluent Pumping
- Biotowers
- Intermediate Settlement Tanks
- Aeration Tanks; with surface aeration
- Final Settlement Tanks
- Diffuser Outfall

Sludge treatment equipment consists of:

- Primary Sludge Thickening
- Secondary Sludge Thickening
- Sludge Blending; primary and secondary sludge
- Anaerobic Digesters and Associated Equipment
- Biogas Storage and Treatment
- Energy Recovery; CHP unit
- Sludge Holding Tank
- Sludge Dewatering
- Lime Stabilisation of the cake sludge

Supernatant return pumps send clarifier scum, belt press centrate and picket fence thickener supernatant back to the inlet works. A filter belt-press is used to obtain the final sludge cake, which is lime stabilised before removal from site. Ferric Sulphate is dosed for removal of phosphate from the wastewater stream (Nicholas O'Dwyer, 2002; Earthtech, 2003d).

1.2.2 CAHIR WWTP

Cahir WWTP is designed to cater for a population equivalent of 5,000. Final effluent discharge limits are:

Parameter	**Concentration (mg/L)**
BOD_5	20
Total Suspended Solids	30
COD	125
Total Phosphorous	1.0

Table 1-2. Final effluent limits for Cahir WWTP (Nicholas O'Dwyer, 2002).

Treatment consists of a mechanically raked inlet screen and grit removal, followed by one aeration basin containing a fine bubble diffused air system and a secondary settlement tank, with a half-bridge scraper. Centrate return pumps send centrifuge centrate and picket fence thickener supernatant back to the inlet works. Final effluent is pumped to various points around the plant for washing purposes. Sludge treatment consists of a picket fence thickener and centrifuge for dewatering. Stormwater handling facilities are also employed. Ferric sulphate is dosed for removal of phosphate from the wastewater stream (Nicholas O'Dwyer, 2002; Earthtech 2003a).

1.2.3 CASHEL WWTP

Cashel WWTP is designed to cater for a population equivalent of 9,000. Final effluent discharge limits are:

Parameter	**Concentration (mg/L)**
BOD_5	20
Total Suspended Solids	30
COD	125
Total Phosphorous	1.0

Table 1-3. Final effluent limits for Cashel WWTP (Nicholas O'Dwyer, 2002).

Treatment consists of inlet screening and grit removal, followed by two aeration basins containing fine bubble diffused air systems and a secondary settlement tank, with a half-bridge scraper. Supernatant return pumps send clarifier scum, centrifuge centrate and picket fence thickener supernatant back to the inlet works. Final effluent is pumped to various points around the plant for washing purposes. There is an imported sludge intake screen for receipt of sludge from satellite plants. Sludge treatment consists of a blending tank, picket fence thickener and centrifuge for dewatering. Stormwater handling facilities are also employed. The existing plant (one primary tank, trickling filter and humus tank) is not in use, but may be used in future as load demands. Ferric sulphate is dosed for removal of phosphate from the wastewater stream (Nicholas O'Dwyer, 2002; Earthtech, 2003c).

1.2.4 FETHARD WWTP

Fethard WWTP is designed to cater for a population equivalent of 2,000. Final effluent discharge limits are:

Parameter	**Concentration (mg/L)**
BOD_5	5
Total Suspended Solids	5
COD	125
Total Phosphorous	1.0
Ammonia	10
Total Nitrogen	20

Table 1-4. Final effluent limits for Fethard WWTP (Nicholas O'Dwyer, 2002).

Treatment consists of inlet screening and grit removal. followed by one aeration basin using a surface aerator and a secondary settlement tank, with a half-bridge scraper. Supernatant return pumps send clarifier scum, centrifuge centrate and picket fence thickener supernatant back to the inlet works. Final effluent is polished in a continuous backwash sand filter. Final effluent is pumped to various points around the plant for washing purposes. There is an imported sludge intake screen for receipt of sludge from satellite plants. Sludge treatment consists of a picket fence thickener and centrifuge for dewatering. Stormwater handling facilities are also employed. Ferric sulphate is dosed for removal of phosphate from the wastewater stream (Nicholas O'Dwyer, 2002; Earthtech, 2003e).

1.2.5 KILLENAULE WWTP

Killenaule WWTP is designed to cater for a population equivalent of 1,200. Final effluent discharge limits are:

Parameter	**Concentration (mg/L)**
BOD_5	5
Total Suspended Solids	5
COD	125
Total Phosphorous	1.0
Ammonia	10
Total Nitrogen	20

Table 1-5. Final effluent limits for Killenaule WWTP (Nicholas O'Dwyer, 2002).

Treatment consists of inlet screening and grit removal, followed by one oxidation ditch with one horizontal oxidation rotor and a secondary settlement tank with a half-bridge scraper. Supernatant return pumps send clarifier scum and picket fence thickener supernatant back to the inlet works. Final effluent is polished in a continuous backwash sand filter. Sludge treatment consists of a picket fence thickener and liquid sludge holding tank. Stormwater handling facilities are also employed.

There is no sludge dewatering at Killenaule WWTP as it is considered to be more economical to remove the thickened sludge to Fethard WWTP for dewatering. Ferric Sulphate is dosed for the removal of phosphate from the waste stream (Nicholas O'Dwyer, 2002; Earthtech Ireland, 2003f).

1.2.6 TIPPERARY TOWN WWTP

Tipperary Town WWTP is designed to cater for a population equivalent of 9,800. Final effluent discharge limits are:

Parameter	**Concentration (mg/L)**
BOD_5	5
Total Suspended Solids	5
COD	100
Total Phosphorous	1.0

Table 1-6. Final effluent limits for Tipperary WWTP (Nicholas O'Dwyer, 2002).

Treatment consists of inlet screening and grit removal, followed by two oxidation ditches with two horizontal oxidation rotors per ditch and a secondary settlement tank with a half-bridge scraper. Final effluent is polished in a single sand filter. Sludge treatment consists of a picket fence thickener and centrifuge for dewatering. Stormwater handling facilities are also employed. There is an imported sludge intake screen for receipt of sludge from satellite plants. Ferric sulphate is dosed for removal of phosphate from the wastewater stream (Nicholas O'Dwyer, 2002; Earthtech, 2003g).

1.2.7 CARRICK-ON-SUIR WWTP

Carrick-on-Suir WWTP is designed to cater for a population equivalent of 11,000. Final effluent discharge limits are:

Parameter	**Concentration (mg/L)**
BOD_5	20
Total Suspended Solids	30
COD	125
Total Phosphorous	1.0
Ammonia	5
Total Nitrogen	15

Table 1-7. Final effluent limits for Carrick-on-Suir WWTP (Nicholas O'Dwyer, 2002).

Treatment consists of inlet screening and grit removal, followed by two aeration basins containing fine bubble diffused air systems and two secondary settlement tanks, with half-bridge scrapers. Supernatant return pumps send clarifier scum, centrifuge centrate and picket fence thickener supernatant back to the inlet works. Final effluent is pumped to various points around the plant for washing purposes. There is an imported sludge intake screen for receipt of sludge from satellite plants.

Sludge treatment consists of a picket fence thickener and centrifuge for dewatering. Stormwater handling facilities are also employed. Ferric sulphate is dosed for removal of phosphate from the wastewater stream (Nicholas O'Dwyer, 2002; Earthtech, 2003b).

1.1.8 BALLYCLERIHAN WWTP

Ballyclerihan WWTP is designed to cater for a population equivalent of 2,000. Final effluent discharge limits are:

Parameter	**Concentration (mg/L)**
BOD_5	5
Total Suspended Solids	5
COD	125
Total Phosphorous	1.0
Ammonia	5
Total Nitrogen	15

Table 1-8. Final effluent limits for Ballyclerihan WWTP (Nicholas O'Dwyer, 2002).

Treatment consists of inlet screening and grit removal, followed by two aeration basins containing fine bubble diffused air systems and two secondary settlement tanks, with valved bellmouths for scum removal. Supernatant return pumps send clarifier scum and picket fence thickener supernatant back to the inlet works. Final effluent is pumped to various points around the plant for washing purposes. Sludge treatment consists of a picket fence thickener and liquid sludge storage tank. Final effluent is polished in a continuous backwash sand filter. Sodium hypochlorite is added to the final effluent before discharge for disinfection purposes. Stormwater handling facilities are also employed.

There is no sludge dewatering at Ballyclerihan WWTP as it is considered to be more economical to remove the thickened sludge to Cashel WWTP for dewatering. Ferric sulphate is dosed for removal of phosphate from the wastewater stream (Nicholas O'Dwyer, 2002; Earthtech, 2003).

1.3. ELECTRICITY USE AT MUNICIPAL WASTEWATER TREATMENT PLANTS.

The Electricity Supply Board (ESB) is still the major power supplier in this country and duly supplies all the plants in South Tipperary with electrical power. There are differing power needs for each plant, depending on both the size of the plant and its effect on the local supply. For this reason the ESB has different tariffs, which are applied to each plant as the situation demands. The tariffs outlined below are not necessarily all the available tariffs from the ESB, but are the ones applicable to this study.

1.3.1 LOW-VOLTAGE MAXIMUM DEMAND TARIFF

The ESB has 1.7 million customers. These customers' aggregate demands at any one time must be met. Usually, daytime demand exceeds that at night, weekday use is greater than weekend use and power used in winter is much higher than during the summer. Since electricity cannot be stored, sufficient generation, transmission and distribution capacity must exist to meet the highest demand likely (ESB website).

In order to maintain some degree of control over the peak demands, larger users are given tariffs designed to encourage them to control electricity demand at daytime peaks. Maximum demand tariffs are structured to reflect not only the amount and rate of electricity use, but also the time of day (ESB website). The demand charge is based on the highest power consumption made over a 15 minute period during the billing period (Spitzer, 1987).

The low-voltage maximum demand tariff is suited to customers who are supplied at 400/230V and whose Maximum Import Capacity (MIC) is 50kVA or more. There are seven elements to this type of bill.

1.3.1.1 Standing charge

This is levied each month regardless of the level of electricity use.

1.3.1.2 Public Service Obligation levy

This levy relates to the fact that, to preserve security of supply, the ESB must purchase the output of certain peat generated electricity. It also must purchase, to protect the environment, the output of certain generating stations which use renewable, sustainable or alternative forms of energy. The charge is a set amount, or, in the case of those customers with a kVA greater than or equal to 30kVA, there is a charge per kVA per month.

1.3.1.3 Demand Charge

This is a charge per kW of Chargeable Maximum Demand (subject to a minimum chargeable demand of 30kW), i.e. this is based on the highest instantaneous rate of electricity usage in the billing period.

1.3.1.4 Service Capacity Charge

This is a charge per kVA of Maximum Import Capacity. The rate doubles (excess capacity charge) when the MIC allowable is exceeded.

1.3.1.5 Day Unit Charges

The Chargeable Maximum Demand (outlined in 3.1.3 above) for the customer multiplied by 350 kWh will yield the first block of day units which is charged at a particular rate. Units used in excess of this are charged at a reduced rate.

1.3.1.6 Night Unit Charges

This refers to units used between 6pm and 8am are charged at approximately half the Day Unit Charges.

1.3.1.7 Wattless Charges

A surcharge is levied when the wattless units (kVARh) exceed one third of the kWh used in any billing period. Wattless units arise when the power factor falls below 0.95 (ESB website).

Note that for the Demand Charge, Maximum Import Capacity and Day Unit Charges there is a higher winter charge than in summer (ESB website).

1.3.2 RESIDENTIAL BUSINESS PREMISES CHARGES

This type of bill is somewhat simpler in structure than the Maximum Demand tariff. There is a standard charge for every two month billing period. A charge per kWh is applied to the first 1500kWh used. Units in excess of this figure are charged at a higher rate. A Public Service Obligation levy is charged depending on the Maximum Import Capacity (ESB website).

1.3.3 SELECTING THE CORRECT TARIFF

It may be possible to achieve cost savings by careful analysis of electrical use throughout the day. The type of tariff applied to a plant is decided before power is supplied, so it is only a best guess of the electrical demand and use. This tariff may be incorrect, or may change over time, depending on the plant's needs. By switching to a different rate schedule, savings may be possible, such as: a plant doing most of its sludge handling at night could benefit from an on-peak/ off-peak rate classification (Malcolm Pirnie, 1995).

1.4. POTENTIAL AREAS FOR ENERGY EFFICIENCY GAIN

1.4.1 INTRODUCTION

The first point to be made about implementing cost-reducing measures is that energy can be saved with no additional investments (Al-Ghanim, 2003). It is not unreasonable for a company starting out in energy management to achieve a 20% reduction in their energy bills by good housekeeping measures alone (SEI, 2004). On this basis, Cashel WWTP was used as a model to investigate whether such savings could be achieved in practice by merely changing the way certain activities were carried out. As Turner (2001) states, the first step in reducing power costs is to achieve the minimum cost possible with the present equipment and processes. This involves reviewing current set-points, identifying possible action points and implementing those changes.

Furthermore, in order to evaluate the effectiveness of any changes made, one needs to review afterwards whether improvements in electricity usage were brought about. It is therefore necessary to gather as much data as possible on current electricity use, especially the major power consuming items. As Bolles (2001) says, learning all there is to know about a facility is one of the first steps needed to develop projects focused on reducing operating costs. He goes on to state that if we are to verify project performance, sufficient data must be collected during the initial stages of the project to produce a baseline that shows current energy use and process parameters. To this end, electricity consumed by individual items is illustrated to highlight the individual costs, which will helps to focus on high-consuming equipment.

Another important point to note is that energy conservation does not mean that utilities must be cut back to save energy; it simply means that the same degree of utility is achieved with less energy, through a series of prudent actions and choices (SEI, 2004). There would be no point in making operational changes if excessive cutting back on power use were to lead to a breach in final effluent quality standards.

The phenomenon of 'power factor' is something that requires due consideration. As the ESB charges for wattless energy at power factors below 0.95 (ESB website), this could be an obvious area for economic savings. Cashel WWTP, for instance, exhibits a rather low power factor (0.75-0.85) much of the time and is rarely above 0.95. The net result of this fact is that there are almost an equal number of wattless units consumed as there are day plus night units; at some plants no wattless units are consumed much of the time.

1.4.2 ENERGY-SAVING STRATEGIES

Proper management of electric motors at wastewater treatment plants can yield substantial savings, with some plants saving as much as 40% on energy costs (Jones, 2003). Depending on the information source, it would seem that over the life-span of electric motors they can consume 100 times their purchase price (SEI, 2004). On this basis, an illustration of typical running costs associated with various pieces of equipment should help to inform management of the real costs of the equipment being fitted in wastewater treatment plants. In simple terms, this can be summarised as: Total Cost = Capital Cost + Running Costs.

By showing the possible savings, it is hoped that, at the very least, the question will be asked, "should we replace motor A with a high efficiency motor if a fault arises with it?" The illustration of stark figures on a page with respect to ongoing costs should also cause a change in the mindset of both design personnel and those responsible for purchasing. Rather than opt for the lower up front cost to save money, a life cycle analysis should be carried out for the motor lifetime, which can easily be ten (and even up to twenty) years. Remember, an electric motor can consume electricity to the equivalent of its capital cost within the first 500 hours of operation, only 3 weeks of continuous use (CDA, 1997). ETSU (1998) states that there are estimates of 20% savings on pumping costs being possible in UK industry and suggests several reasons why. Two of the reasons most pertinent to this discussion are that there is a lack of awareness of pumping costs, and life-cycle costs (initial costs and maintenance costs) are rarely considered at design stage. For instance, over the 20 year lifetime of a pump, the costs are:

- 2.5% on initial capital cost of pump and motor
- 2.5% on maintenance, and
- 95% on running energy costs (ETSU, 1998)

Certain basic information can be obtained from motors on site to determine the level of power use at present. Quite detailed information can be obtained from the SCADA computer present on all sites, such as hours run, times of operation (day or night) and, in the case of Variable Speed Driven (VSD) equipment, speed of the motor throughout the day. Much of the remaining information that is required can be calculated from motor plate details where direct measurement does not take place, as shown below.

The power output of a motor in kW is:

$$kW = \frac{V \text{ x } A \text{ x } PF \text{ x } 1.732}{1000}$$

(Spitzer, 1987)

where V is the operating voltage,

A is the current in amperes, and

PF refers to the Power Factor.

The power output of any motor multiplied by both the annual number of running hours and the average cost of electricity will reveal the yearly electricity cost associated with that motor (Warne, 1998). Due to the variable cost of electrical power over time, however, it will be more useful to exclude electricity unit prices and simply use kWh. As Balmer & Mattsson (1994) point out, monetary units have a very short lifetime, hence the use of non-monetary data.

Obviously, the bigger the motor (and hence power output), the greater the scope for savings when efficiencies are introduced. As well as introducing changes to running regime and other operational changes, the possibility of changing the motor entirely should be investigated. Replacement of a motor with a high efficiency alternative can yield savings with respect to running costs. CDA (1997) points out that the economics of the installation of high-efficiency motors are best when new plant is being built. This is because the incremental cost of fitting the improved motor can be paid back in a very short space of time, whereas the replacement of a perfectly well operating motor with one of higher efficiency will require a much longer payback period.

In the case of existing motors on site, it may be possible to influence efficiency by prudent operational means. One motor phenomenon that can be beneficially exploited by a plant operator is that the efficiency of a motor improves with speed (Hughes, 1990). At a constant torque, power output rises proportionally with speed, while electrical losses are more or less the same. Therefore, efficiency improves (Hughes, 1990). It would seem apparent, then, that motors with variable speed capability should be run at their top speed, where possible.

The number of pump starts from static should also be minimised. The reason for this is that while pump characteristics are often approximately represented by assuming that the torque required is proportional to the cube of the speed, most pumps have a significant breakaway torque to be overcome when starting (Hughes, 1990).

The same is true of induction motors at start-up; the "direct-on-line" starting current for an induction motor can be six or seven times the normal full load current (Warne, 1998), adding further weight to the argument to reduce the number of motor starts. It is also the case that frequent starts increase wear on belt drives and bearings, while the extra heating due to high starting current can shorten the life of the motor insulation system (Warne, 1998).

1.4.3 HOW TO ACHIEVE COST SAVINGS

A large part of the cost-saving effort will be achieved by brain storming and analysing potential projects that will help reduce operating costs (Bolles, 2001). It is often the case that an operator will run a plant a certain way for ease of operation and maintenance of effluent quality. However, by considering energy efficiency as a normal part of plant operation, the same operator should be able to introduce at least a few efficient ways of running the plant without external expertise or recourse to literature.

It is probably a good idea to introduce a Motor Management Policy to site. The European Copper Institute, ECI, justifies the adoption of a Motor Management Policy thus: “the opportunities for making decisions that will save energy can appear complex and often have to be taken in a hurry. By committing to a Motor Management Policy specific to the needs of one’s own organisation, one can make the best decision on whether to repair or replace a motor” (ECI website). A Motor Management Policy will basically consist of documents incorporating:

- a systematic maintenance programme,
- a clear purchasing policy to buy higher efficiency motors where feasible,
- replacement or rewinding of failed motors based on lifetime costs (Warne, 1998).

To develop this further, some sort of efficiency programme would allow for continuous improvement in efficiency performance (Turner, 2001). One way of doing this would be to incorporate energy management into the company ISO 14001 system (SEI, 2004).

Many of the principles behind energy management are similar to this environmental management system, i.e.:

1. Get senior management commitment.
2. Assess current situation.
3. Set goals and targets.
4. Establish an action plan.
5. Allocate resources.

6. Implement plan.
7. Review and evaluate. (SEI, 2004)

This is the ideal scenario for a company attempting to introduce an energy management system, but can be onerous for some smaller organisations.

The National Standards Authority of Ireland has produced a new standard for Energy Management Systems, I.S 393:2005. As suggested above, this new standard is structured so that it can be seamlessly incorporated into existing ISO systems, such as 9001 and 14001, both of which Earthtech Ireland is accredited to (National Standards Authority of Ireland, 2005).

The U.S. Dept. of Energy (Motor Challenge Fact Sheet) states that consideration should be given to buying an energy-efficient motor in the following circumstances:

- For all new installations.
- When purchasing equipment packages such as pumps.
- When major modifications are made to facilities or processes.
- Instead of rewinding older, standard efficiency units.
- To replace oversized and under-loaded motors.
- As part of a preventative maintenance or energy conservation programme.

The introduction of a high efficiency motor can help to obtain a 3% improvement in motor efficiency (illustrative figure, applies to smaller motors generally) (US Dept. of Energy). However, in the case of the opportunity cost of rewinding a faulty motor, the improvement in efficiency can be greater. This is because even if proper care is taken during repair, the efficiency of the repaired motor will fall by at least 0.5%. The net difference between a new high efficiency motor and a repaired motor could now be at least 3.5% (Warne, 1998).

While this may seem like a small percentage, it can lead to some gains in terms of electricity savings, as illustrated in table 1 below (adapted from Warne, 1998):

Rated	**% of Full Load**	**'Standard' Efficiency**	**'Higher' Efficiency**	**Annual Saving (Euro)***
3 kW	100	82	84.5	86
	75	82	85.5	90
	50	79	85	108
7.5 kW	100	87	89	154
	75	87	89.5	144
	50	86	89	118
15 kW	100	90	92	290
	75	90	92.5	270
	50	90	91.5	110

(*Annual saving using a higher efficiency motor compared to a standard efficiency motor, assuming the motor runs for 8,000hrs/ year at a cost of 10 cent/ kWh.)

Table 1-9. Savings with High Efficiency motors.

There are other benefits to the fitting of high efficiency motors (U.S. Dept. of Energy):

- Better power factors
- Longer insulation and bearing lives
- Lower waste heat output
- Less vibration.
- Longer life-spans
- Reduced maintenance requirements

- Modern high efficiency motors are likely to suffer much lower losses in efficiency after being rewound (Warne, 1998).
- They are more tolerant of overload conditions and phase imbalance (Jones, 2003).

All these factors add up to increased reliability (US Dept. of Energy).

1.4.4 HOW TO SHOW COST SAVINGS

The energy savings to be gained from any motor replacement need to be calculated to justify any potential change. Warne (1998) gives a means of calculating this saving (as used in table 1-9 above):

Annual saving = $h \times kW \times \%FL \times p/kWh \times [(1/\acute{\eta}_{std}) - (1/\acute{\eta}_{hem})]$

Where: h = annual running time in hours

kW = output power in kW

%FL = fraction of full load at which motor runs

p/kWh = price of electricity per kWh

$\acute{\eta}_{std}$ = efficiency of standard motor at the load point

$\acute{\eta}_{hem}$ = efficiency of high efficiency motor at the load point

1.4.5 SCOPE OF EFFICIENCY STRATEGIES

This dissertation is not concerned with reducing lighting or heating costs as part of the overall efficiency drive. Heating is considered to be a negligible fraction of the power consumption in the plants under consideration, so any efforts to improve heating efficiency would have too little effect to justify much allocation of time to that end.

Lighting is estimated as being only responsible for 3% of the electricity used in sewage treatment (Pakenas, 1995). Many of the lights in the plants are already of the fluorescent variety and there is not likely to be too much scope to reduce the amount of time that lights are in use.

1.4.6 COMPARISON OF PLANT EFFICIENCY PERFORMANCE

For fair comparison of treatment plant efficiency with respect to electricity consumption, it is necessary to decide on what performance parameters to use. Obviously plants treating a different amount of waste will use a different amount of electricity even if their efficiency is similar. As Gillot, et al (1999) assert: "operating costs may be related to global plant parameters (e.g. average flow rate, population equivalent),…however, such relationships apply to the average performance of plants and often suffer from a high uncertainty, unless very similar plant configurations are considered". Balmer (1998) says that simply using the amount of wastewater treated has serious drawbacks. He says that flow can vary considerably from year to year, but that "this flow variation has only marginal impact on operation costs but will have full impact on cost per m^3 treated." He goes on to suggest that the best way to avoid this shortcoming is to relate consumption "to the number of people connected or to the applied load." On this basis, results below are shown as kWh consumed per Kg BOD removed (also Kg BOD treated per kWh consumed) and kWh consumed per PE per year.

It was decided, for convenience, not to include the load exerted by nitrification requirements and by nitrogen and phosphorous treatment. It has previously been shown by Nowak (2000) that “the additional requirements for nitrification, nitrogen and phosphorous removal have only a little influence on the expenses for the operation.”

SECTION 2. METHODOLOGY

In comparing treatment plant energy efficiency performance (be it between plants, or a single plant over time), a common set of parameters must be used to allow for a meaningful comparison. There were some energy studies at wastewater treatment plants in the literature which suggested various means of expressing energy use (kWh per PE per year was the most common means), which take into account the variability of the incoming load. The most appropriate parameter for the purposes of this study was considered to be influent BOD load, as this takes into account the flow into a plant and the "strength" of that flow from a treatment point of view. The cost of nitrogen and phosphorous removal was not taken into account as it has been stated by Nowak (2000) that this extra cost is negligible. Use of BOD removed means that the final effluent load leaving the plant is taken into account, so that only BOD which has actually required an energy input is factored in. Energy use is, therefore, presented in kWh per Kg BOD removed (and vice versa). kWh consumed per PE per year is also shown because this also presents energy use as a function of BOD load, but may be a more useful figure in comparing plants and comparing these results to those found in the literature.

1. Case Study of Cashel WWTP

Cashel WWTP was chosen as the test case for this study as the author operates this facility and was easily able to access all site information required and implement any operational changes deemed appropriate to the study. Other plants could not be chosen due to the fact that they are operated by other colleagues and are not as easily accessed by the author. One plant is sufficient as a case study, as the same general template can be applied to any other plant to be investigated in detail under the same criteria. Having chosen appropriate energy efficiency parameters, two one-month periods were compared for efficiency performance. It would have been more informative to compare longer periods of time, but this was not possible due to time constraints.

2. Power Use of Different Equipment

The presentation of power use by individual units of equipment is a useful means of illustrating where the greatest power consumption arises. Any subsequent study or operator review of these results could then focus on those areas consuming most electrical power, as the largest savings are likely to accrue from the areas consuming most of the power.

3. Plant Operation Guidelines

Efficient plant operation guidelines have been compiled (section 3) that attempt to provide any plant operator with tips on efficient plant operation. Some of the guidelines will also apply to maintenance and design staff. Not all of these guidelines will be applicable to all plants (due to differing processes or machine/pump types), but some may be workable with a little tweaking. A certain amount of competence on the part of the operator using the guidelines is assumed; the guidelines are not meant to be a plant operation manual, but a handy extra tool. An alternative to efficient plant operation guidelines that was considered was the compilation of a sample motor management policy. This idea was not pursued due to the fact that a motor management policy is probably the responsibility of maintenance and purchasing departments. The study is aimed more towards plant operators, so guidelines tailored to the needs of this target audience are more appropriate.

SECTION 3. GUIDELINES FOR EFFICIENT PLANT OPERATION

3.1 GUIDELINES FOR PLANT OPERATORS

Recommendations for energy-saving under the control of the plant operator:

- Clogging of the diffused air system can be a big problem due to the fine pores involved. This can impair oxygen transfer efficiency and generate high head loss (USEPA, 1999). Mixed liquor solids may settle on the diffusers when the system is turned off, or a biological slime layer can develop on the pores resulting in blockage. These materials must be removed, which might require draining of the aeration basin(s).
- Dust and dirt can be taken in by the air blowers and block the diffuser media. It is vital that the air filters are cleaned or replaced frequently. No unfiltered air must enter the system (Pakenas, 1995). Keeping fan filters clean will minimise pressure drops (Warne, 1998).
- The micro-organisms in mixed liquor exist at various life-cycle stages. Those in the endogenous phase still consume oxygen, but contribute little or nothing in terms of waste degradation. Energy is also expended in keeping these bacteria in suspension. By keeping the sludge age at the minimum to maintain final effluent quality, the non-viable fraction of bacteria can be minimised (Pakenas, 1995).

  It would certainly be possible to apply this strategy to, for example, Cashel WWTP. Final effluent discharge limits do not apply to nitrogen at Cashel WWTP, so it is probably unlikely that a sludge age of 20 days is necessary (it *is an extended-aeration plant). It should be possible to reduce the sludge age to 15 days or so, but trials could optimise this figure. Even plants requiring nitrification/ denitrification may not need a sludge age of fully 20 days, depending on biological load to the plant.*

- Set-points used for automatic control of a WWTP should be well thought out and not simply inputted for convenience of operation. Many set-points used during plant commissioning may be set by personnel other than the plant operator. Therefore, most set-points will allow for some level of plant operation to proceed, but may lead to process inefficiencies.

  To illustrate this point, take an example of an activated sludge aeration basin. Initial set-up of the automatic controls is performed by the controls engineer. Without prior knowledge of proper control, the DO (Dissolved Oxygen) control set-point could be set to any figure between and 1 and 10mg/l. A control setting of 2mg/l DO is recommended for a nitrifying activated sludge system (CIWEM, 1997). If a setting of 5mg/l were used instead during commissioning, twice as much energy would be required to transfer a kilogram of oxygen to mixed liquor than at a setting of 2mg/l (EPA, 1997).

- Ensure that all pumps are completely free of blockages. Partial blockages that don't result in a trip condition put an extra stress on the pump motor. By having to use more current to achieve the same flow rate, the efficiency of the pump is reduced.

  An example of this is with the inlet pumps at Tipperary WWTP. The normal running current (for one duty pump) without blockages is 10.8 amps, but this can rise to 14.8 amps before tripping out on current overload. The *difference in power required when running at 10.8 amps and, say 14 amps (a common occurrence with a partial blockage) is 0.66kW, for one of these pumps. If such a blockage were left unattended for a period of one month, this would add up to an extra 240kWh consumed.*

- When dewatering, ensure that the centrifuge or belt-press does not run without product. Even when running without product, a centrifuge can still consume substantial amounts of electricity.

  At Cashel WWTP, the centrifuge is designed to dewater a maximum feed flow of $6m^3$*/ hour at 2.6% solids. This size of centrifuge will consume approximately 4.3kW when running at full speed with no product.*

- With reference to those plants that have sludge blending tanks, it is recommended that the level be maintained at a low level as much as possible. While this may not be desirable in some cases (proper mixing of different types of sludges may be essential to ensure proper centrifuge operation at some facilities), it may not adversely affect the dewatering process at some plants. By maintaining a low level (below the start level) the blending tank mixer will not operate, thereby saving power.

  At Cashel WWTP, for instance, the blending tank contains mostly waste activated sludge, and whether mixed properly with imported sludge or not, the dewatering process is not affected. By maintaining a low level and not running the blending tank mixer, large savings in terms of kWh consumed can be made (refer to table 4-5).

3.2 GUIDELINES FOR OTHER PERSONNEL

Further suggestions are outlined below as to how to improve treatment plant performance. Most of these tips are aimed at maintenance and design personnel, but some may concern a general plant operative with a broader range of responsibilities (such as at smaller facilities).

3.2.1 PUMPING

Recommendations specific to pumps (Warne, 1998):

- Select an efficient pump and operate it close to its rated design flow and head.
- If consistently under-loaded, install a smaller impeller or trim the existing one.
- Minimise the number of sharp bends in pipework.
- Consider improving pump efficiency by using low friction coatings.
- Always use lower friction piping in new installations and consider refurbishing older pipework.
- Check pump inlet pressures are satisfactory (sump liquid level is adequate).
- Maintain the pump. Without maintenance, pump efficiency could fall by 10% of its value when new.

The installation of a smaller high efficiency pump alongside a larger existing pump, in a system with low flow periods, can yield electrical savings. In most systems, pumps are designed to meet peak demands. In times of low flow a large pump will have to operate at a lower speed, which will be less efficient, or switch on and off frequently, which is also undesirable with respect to efficient operation. A smaller pump running at high speed (i.e. at or near to maximum efficiency) could potentially give substantial savings (Malcolm Pirnie, 1995). Alternatively, if the low-flow period is extended, installation of a smaller impeller can be energy efficient. Flow is reduced and power consumption is also reduced (Malcolm Pirnie, 1995).

3.2.2 BELT DRIVES

In the case of air blowers and centrifuge drives, these recommendations are specific to belt drives (Warne, 1998):

- Modern flat or wedge belts can be more efficient than traditional 'V' belts. Also, 'V' and wedge belts deteriorate with age by about 4% of efficiency, plus a further 5- 10% if the belts are poorly maintained.
- Over-sizing or under-sizing 'V' belts can produce additional losses.
- Ensure belts are properly tensioned.
- If one belt on a multiple belt drive fails, replace them all.
- Check pulley alignment.
- When the pulleys need replacing, it is particularly cost-effective to consider changing the drive type.

3.2.3 EFFICIENT DEWATERING

The use of the centrifuge as the dewatering method of choice rather than the belt press is justified by the USEPA (2000). It suggests that the likely lower operation and maintenance costs associated with centrifuges may outweigh the higher capital costs over a belt filter press.

Regardless of the dewatering method, a substantial amount of time should be spent optimising the flow through the machine. This involves using the correct polyelectrolyte and then maximising the sludge feed while minimising the polyelectrolyte dose. (Polyelectrolyte is used to separate sludge from water to make the sludge amenable to dewatering).

3.2.4 DEMAND-SIDE MANAGEMENT

Demand-Side Management is “a programme of cost-effective measures undertaken by an electricity utility to reduce growth in, and change the pattern of, electricity demand while meeting customer needs” (Reynolds, 1996). We can adapt this definition to a wastewater treatment site by saying that the plant can be run on the same basis, with the customer needs instead being the final effluent quality. The benefits of the programme accrue to the stakeholders in the plant. The following list of energy-saving suggestions take advantage of Demand-Side Management techniques. Capital investment of some description is required in some cases.

- Install a turbine-generator at the final effluent outfall to capture the energy of the flowing liquid. This technique is dependant on flow and outfall characteristics (Pakenas, 1995).
- In the case of WWTPs that operate under on-peak/off-peak electricity rates, substantial savings could be made by treating normal flows during off-peak hours when power costs are lower. Where capacity allows, an operator should minimise the degree of sewage treatment and sludge management during more expensive on-peak hours. These aims could be achieved by storing wastewater on site or in the sewerage system where possible. Sludge may be stored for batch processing at off-peak times. Energy savings can accrue from all pumping systems and activated sludge treatment by smoothing out the diurnal peaks that are associated with the most expensive electrical costs and by taking advantage of the possibility of treatment at off-peak times. Where off-

peak billing is available, and with sufficient storage, savings of 5-10% of pumping costs can be achieved (Malcolm Pirnie, 1995). Other benefits of this method include:

  - reduced operational problems caused by flowrate variations (including high and low wastewater concentration, inappropriate sludge return flowrate)
  - improved performance of downstream treatment facilities
  - reduced size and cost of downstream treatment facilities
  - reduced potential of overflows and resultant pollution or health problems (Malcolm Pirnie, 1995).

- Installation of an electric demand controller could assist in reducing peak demand at a facility. In conjunction with a PLC, the electric demand controller shuts off certain plant operations when the instantaneous electric demand reaches a certain level. Energy savings depend on the site, but it is suggested that savings of 5-10% can be made (Malcolm Pirnie, 1995). It is probable that this type of control would only be cost-effective in a large facility with many ongoing processes.

SECTION 4. RESULTS

4.1 PLANT EFFICIENCY COMPARISON

Table 4-1 below shows the number of kWh consumed for the whole of 2005 for each of the eight plants in South Tipperary featured in this study. BOD treated is the total BOD removed for the year, which is calculated by taking the outgoing BOD in the final effluent from the incoming BOD load.

Plant	**Total kWh consumed, 2005**	**Incoming BOD load (kg)**	**Outgoing BOD load (kg)**	**BOD treated (kg)**	**Average Population Equivalent****
Ballyclerihan	118,560	9,653	159	9,494	440
Cahir	305,580	84,606	897	83,709	3,863
Cashel	614, 082*	112,418	6,147	106,271	4,852
Carrick-on-Suir	544,464	179,432	11,084	168,348	8,193
Clonmel	1,090,082	529,054	21,940	507,114	24,157
Fethard	496,440	133,659	2,764	130,895	6,103
Killenaule	128,315	19,478	389	19,089	889
Tipperary	822,240	139,721	6,267	133,454	6,379

(*Refer to Appendix A for method of calculation.

**While each plant is obviously designed based on a particular population equivalent, the figure quoted here is the PE based on the actual BOD load to the plant shown below (i.e. assuming 60g BOD/ person/ day)).

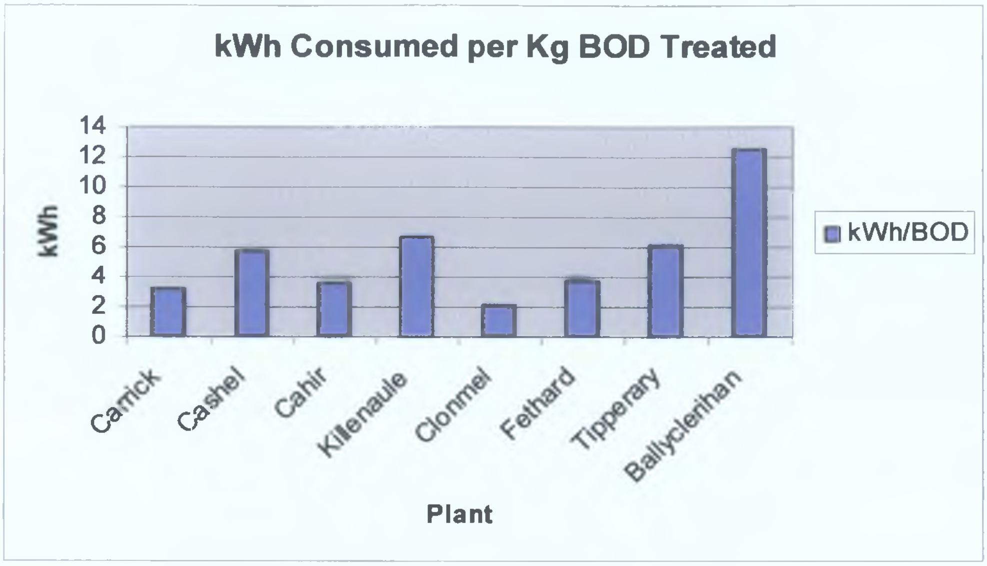
Table 4-1. Energy consumption comparison for WWTPs in South Tipperary (inclusive of wattless units).

In order to make a meaningful comparison between the performance of the plants with respect to energy efficiency, table 4-2 shows the amount of power consumed as a function of the amount of BOD treated and vice versa. Also included for comparison is the number of kWh used per PE per year (PE as calculated from load figures, as shown in table 4-1). The final column shows the actual PE (in terms of biological load) of each plant from load data, expressed as a percentage of the design PE. The information in table 4-2 is graphically represented in graphs 4-1 to 4-3.

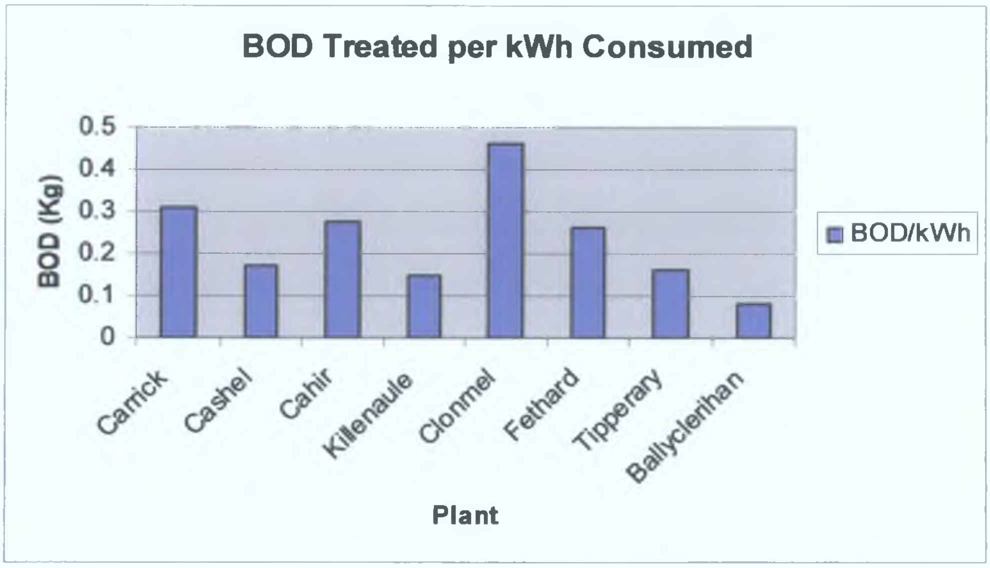
Plant	kWh/Kg BOD treated	Kg BOD treated/kWh consumed	kWh consumed per PE per Year	Actual PE as percentage of design PE*
Ballyclerihan	12.48	0.08	269.45	22%
Cahir	3.65	0.274	79.95	77.3%
Cashel	5.78	0.173	126.56	53.9%
Carrick-on-Suir	3.23	0.31	66.45	74.5%
Clonmel	2.15	0.46	45	30.2%
Fethard	3.79	0.26	81.34	305.2%
Killenaule	6.72	0.149	147.15	74.1%
Tipperary	6.16	0.16	128.9	65.1%

(*The design PE for each plant can be found in section 1.2.)

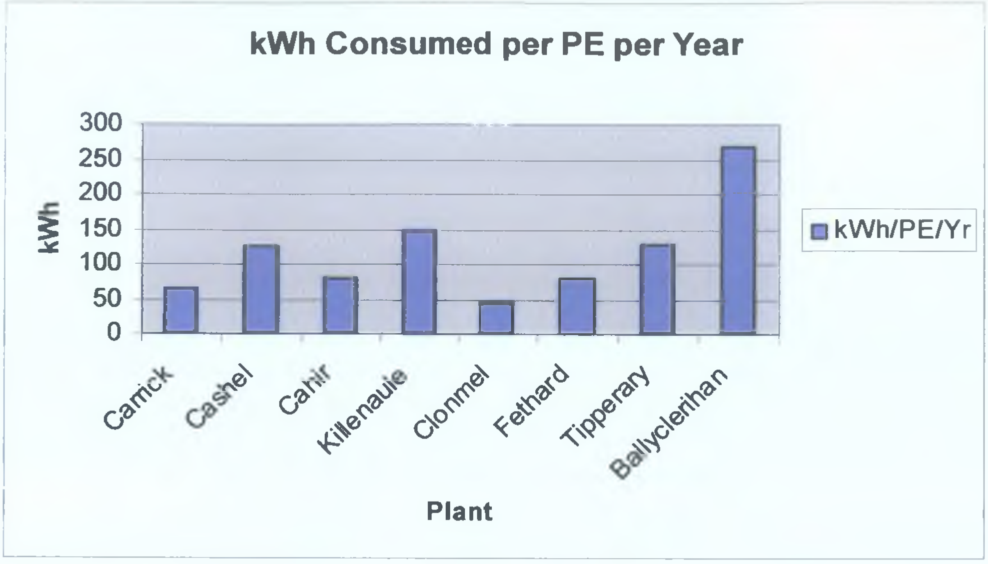
Table 4-2. Energy efficiency performance for WWTPs in South Tipperary.



Graph 4-1. kWh consumed per KG BOD treated



Graph 4-2. BOD treated per kWh consumed.



Graph 4-3. kWh consumed per PE per year.

All the information presented above is inclusive of wattless units (kVArh). This allows us to see how power factor correction becomes an important facet of good plant management when compared with the same parameters below without wattless units. If we present the same information as above, but with only day and night units used, we will get a truer picture of kWh actually consumed by the relevant plant. Another reason to exclude wattless units from the tables and graphs is that there is a different billing structure associated with them; wattless units are only charged on those in excess of one third of the day plus night units (and at a lower rate). The main reason for excluding wattless units, however, is that they do not represent true power consumption. A charge is levied on wattless units merely as a penalty for inefficient use of electrical supply.

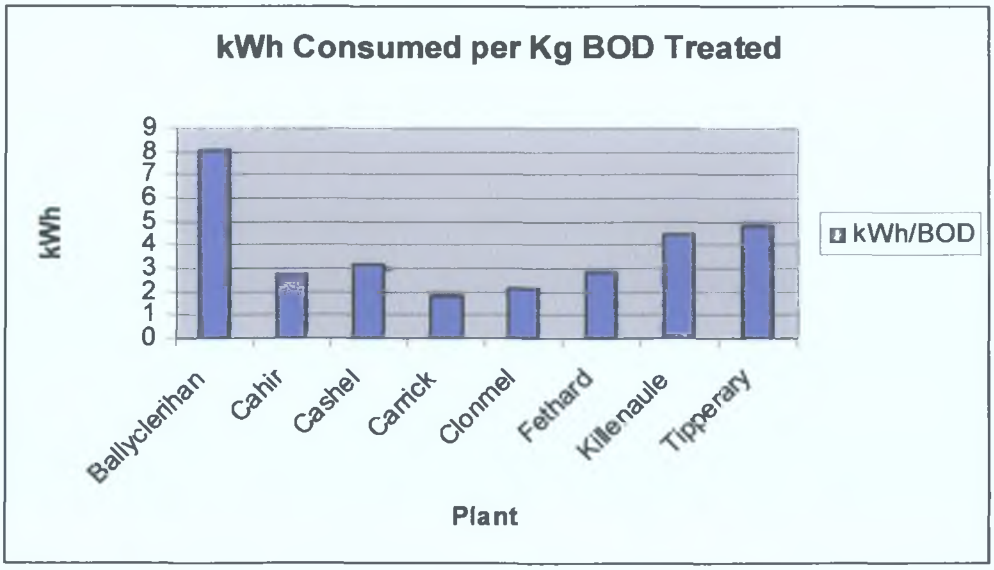
Plant	Day + Night kWh consumed, 2005	Incoming BOD load (kg)	Outgoing BOD load (kg)	BOD treated (kg)	Average Population Equivalent
Ballyclerihan	76,860	9,653	159	9,494	440
Cahir	226,740	84,606	897	83,709	3,863
Cashel	335,564*	112,418	6,147	106,271	4,852
Carrick-on-Suir	296,280	179,432	11,084	168,348	8,193
Clonmel	1,090,082	529,054	21,940	507,114	24,157
Fethard	367,600	133,659	2,764	130,895	6,103
Killenaule	85,257	19,478	389	19,089	889
Tipperary	646,680	139,721	6,267	133,454	6,379

(*Refer to Appendix A for method of calculation.)

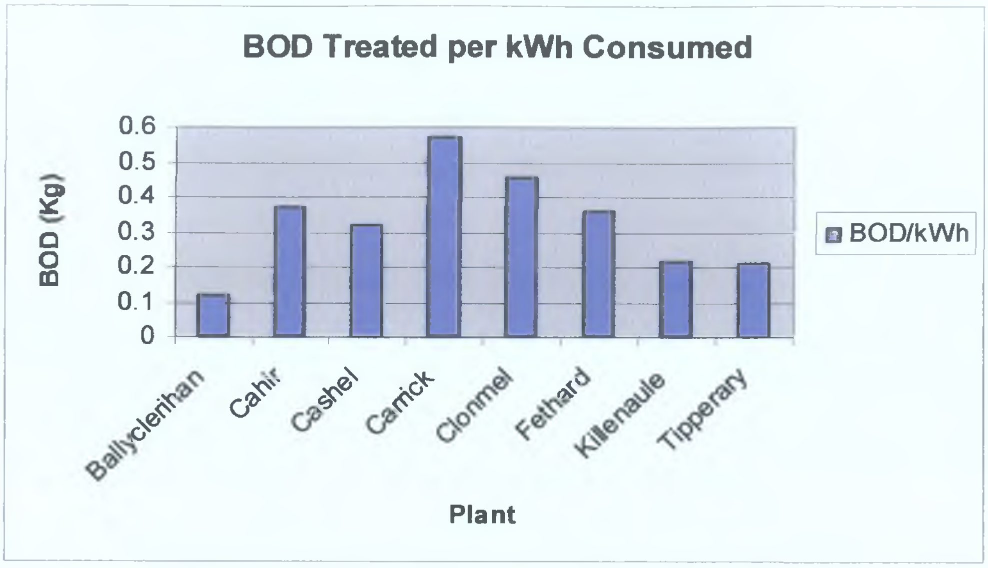
Table 4-3. Energy consumption comparison for WWTPs in South Tipperary (exclusive of wattless units).

Plant	Day + Night kWh/Kg BOD treated	Kg BOD treated/D + N kWh consumed	D + N kWh consumed per PE per Year
Ballyclerihan	8.09	0.12	174.68
Cahir	2.71	0.37	58.69
Cashel	3.16	0.32	69.16
Carrick-on-Suir	1.76	0.57	36.16
Clonmel	2.15	0.46	45
Fethard	2.81	0.36	60.23
Killenaule	4.47	0.22	95.9
Tipperary	4.84	0.21	101.37

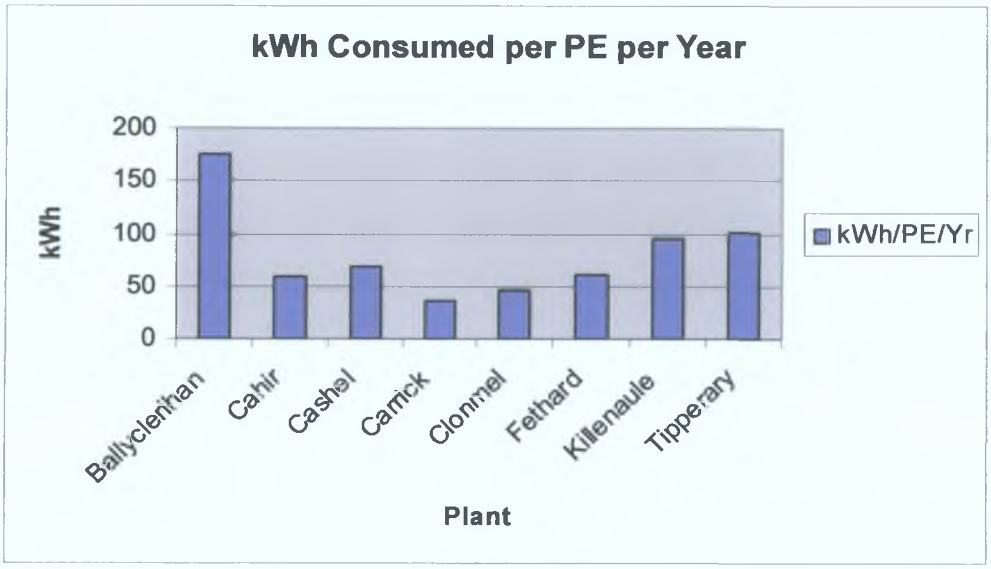
Table 4-4. Energy efficiency performance for WWTPs in South Tipperary (exclusive of wattless units).



Graph 4-4. kWh consumed per KG BOD treated (excluding wattless units).



Graph 4-5. BOD treated per kWh consumed (excluding wattless units).



Graph 4-6. kWh consumed per PE and year (excluding wattless units).

4.2 POWER CONSUMPTION AT CASHEL WWTP

Table 4-5 below shows the amount of electricity attributable to each item of equipment on site. The power output is based on average running speeds and this is multiplied by the number of hours of operation to get the units of electrical power consumed for the year. Electricity consumed by related equipment is also added together to show the power consumed by various processes (e.g. inlet screening consumed 6,351kWh in total) and this is then expressed as a percentage of the total amount of electricity consumed.

Equipment	**Motor Size (kW)**	**Hours Run per Year***	**kWh per Year**	**kWh per Year per Location**	**% of Total**
Fine Screen no.1 Drive	0.37	1277	406	6351	2.87
Fine Screen no.1 Brush	0.37	1277	364		
Fine Screen no.1 Compactor	0.55	2099	912		
Fine Screen no.1 Impeller	3.0	472	1062		
Fine Screen no.2 Drive	0.37	1400	445		
Fine Screen no.2 Brush	0.37	1400	399		
Fine Screen no.2 Compactor	0.55	2294	997		
Fine Screen no.2 Impeller	3.0	785	1766		
Grease Conveyor Drive	0.18	479	82	5042	2.28
Grit/Grease Blower no.1	7.5	358	2014		
Grit/Grease Blower no.2	7.5	376	2115		
Grit Pump	4.0	225	639		
Grit Classifier	0.75	356	192		

Air Blower no.1	15	2025	26284	115280	52.07
Air Blower no.2	15	6735	87420		
Air Blower no.1 Hood Fan	0.18	2025	364		
Air Blower no.2 Hood Fan	0.18	6735	1212		
Sludge Import Screen Drive	0.75	497	190	866	0.39
Sludge Import Screen Brush	0.75	496	268		
Sludge Import Screen Compactor	0.75	540	365		
Sludge Import Screen Pump	2.88	20	43		
Return/Waste Sludge Pump no.1	2.5	4112	9149	18821	8.50
Return/Waste Sludge Pump no.2	2.5	4347	9672		
Final Settlement Tank Motor	0.25	8749	1794	1794	0.81
Storm Return Pump no.1	2.9	124	270	504	0.28
Storm Return Pump no.2	2.9	96	209		
Storm Tank Washer	3.0	11	25		
Blending Tank Mixer	7.83	5373	31552	31552	14.25
Picket Fence Thickener Feed Pump no.1	1.5	1402	1577	4620	2.09
Picket Fence Thickener Feed Pump no.2	1.5	2705	3043		
Ferric Dosing Pump No.1	0.37	0	0	1626	0.73
Ferric Dosing Pump No.2	0.37	639	177		
Ferric Dosing Pump No.3	0.37	5225	1449		
Picket Fence Thickener Drive	0.25	4763	893	893	0.40
Inlet Odour Removal Unit	0.11	264	26	26	0.01

Picket Fence Thickener Odour Removal Unit	0.11	0	0	0	0
Blending Tank Odour Removal Unit	0.11	521	54	54	0.02
Sludge Building Odour Removal Unit	0.11	1826	179	179	0.08
Sludge Import Screen Odour Removal Unit	0.11	138	3	3	0
Supernatant Return Pump no.1	1.81	485	658	1399	0.63
Supernatant Return Pump no.1	1.81	546	741		
Final Effluent/Washwater pump no.1	3.95	703	2082	3877	1.75
Final Effluent/Washwater pump no.2	3.95	606	1795		
Centrifuge Feed Pump no.1	1.5	515	588	15683	7.08
Centrifuge Feed Pump no.2	1.5	418	478		
Centrifuge Main Motor Drive	15	1020	7711		
Centrifuge Scroll Drive	2.85	1020	1326		
Centrifuge Cake Pump	5.5	1160	3758		
Centrifuge Bridge Breaker	1.96	1185	924		
Poly Pump no.1	0.57	879	159		
Poly Pump no.2	0.57	317	99		
Poly Tank Mixer no.1	0.75	484	323		
Poly Tank Mixer no.2	0.75	476	317		

Water Booster Pump no.1	3	**1900	4275	12825	5.79
Water Booster Pump no.2	3	**1900	4275		
Water Booster Pump no.3	3	**1900	4275		

(* Hours run for the year are extrapolated from data for 8 months.

**Water booster pump hours run are a best estimate from hours run associated with processes requiring wash-water: inlet screening, centrifuge flushing, storm tank washing and sludge import screen.)

Table 4-5. Sources of power consumption at Cashel WWTP.

Yearly kWh consumed = h x kW x %FL

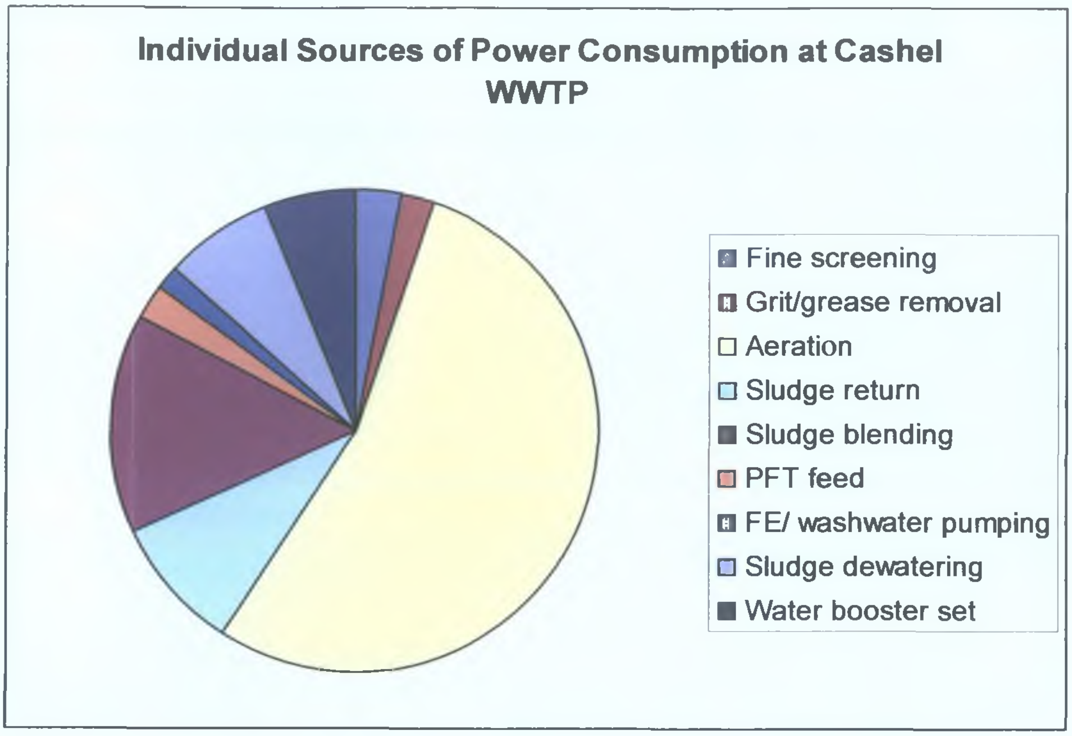
Where: h = annual running time in hours

kW = output power in kW

%FL = fraction of full load at which motor runs

Further information on source data from the above table can be found in appendix A.

Pie chart 4-1 below illustrates the information in table 4-5 above. For simplification purposes, those areas consuming less than 1% of the total power requirement at Cashel WWTP have not been included. Fine screening is represented at 12:00 on the pie chart, with the remaining areas in descending order appearing clockwise.



Pie Chart 4-1. Individual sources of power consumption at Cashel WWTP

4.3 COMPARISON OF POWER USE AT CASHEL WWTP BEFORE AND AFTER EFFICIENCY IMPROVEMENTS

Due to time constraints involved in compiling data for this dissertation, we can only take a snapshot of what power consumption was like before and after making efficiency improvements. Approximately one month's worth (32 days) of data from beforehand is compared with a similar period afterwards. A period from the 1st of November to the 2nd of December 2005 inclusive was taken to illustrate power consumption at Cashel WWTP as it was before the study.

No. of Day units used	No. of Night units used	No. of Wattless units used
394.8	184.5	529.7

Table 4-6: November metered units consumed

The units quoted above were taken directly from the ESB meter at Cashel WWTP and must be multiplied by a factor of 50 to get the actual number of kilowatt hours consumed (F. Ryan, personal communication).

No. of Day kWh used	No. of Night kWh used	No. of Wattless kVArh used
19,725	9,225	26,485

Table 4-7: November kWh consumed

The number of day plus night units consumed was 28,950kWh for the November period. The total number of units consumed including wattless units was 55,435kWh.

The BOD load on the plant during this period was 10,495KG and the outgoing BOD was 260KG, so BOD treated was 10,235KG. This equates to a population equivalent of 5,330 (using 60g BOD per person). In terms of treatment performance (day plus night units) this works out at:

2.83kWh per Kg BOD treated
0.35KG BOD per kWh consumed
61.95kWh consumed per PE per year.

Table 4-8: November performance parameters (day + night units)

(kWh consumed per PE per year is calculated by: [(28,950/32) x 365] / 5,330)

The performance of the plant, adding wattless units, was:

5.42kWh per Kg BOD treated
0.18KG BOD per kWh consumed
118.63kWh consumed per PE per year.

Table 4-9: November performance parameters (inclusive of wattless units)

(kWh consumed per PE and year is calculated by: [(55,435/32) x 365] / 5,330)

Several changes were made to the operational set-points at Cashel WWTP to reduce the amount of power consumed, while maintaining final effluent quality. These set-points were changed on SCADA.

The following changes were implemented at Cashel WWTP:

- Inlet screen start and stop levels were extended; the stop level was lowered from 0.55m to 0.54m, while the start level was raised from 0.57m to 0.58m. The assist start level (i.e. the level at which the standby screen operates) was raised from 0.57m to 0.59m. The effect of this change was to reduce the number of starts during the day. This also had the added benefit of allowing only one screen to operate the majority of the time, once it was felt that one screen could handle the incoming hydraulic load.
- Inlet screen impellers were turned off. This had no discernible effect on the operation of the screens as there was sufficient flow into the plant (the impellers act to “draw-in” the incoming liquid stream).
- Forward feed of waste sludge from the blending tank to the picket fence thickener was changed so that the forward feed pumps only operated at the

top speed of 50Hz. This meant that the quantity of sludge being pumped forward was greater and it was also observed that the running current of the feed pumps at 50Hz was 3.59amps. At the previous typical forward feed speed of 30Hz the running current was 3.83amps, and the quantity pumped was obviously smaller. By pumping forward at a lower speed it was hoped that the sludge would settle better and minimise the possibility of solids decanting from the picket fence thickener with the supernatant. However, at 50Hz, no particular adverse effects have been noticed.

- Centrifuge shut-off when there is no feed sludge was changed from 30 minutes to 15 minutes. In the event of a centrifuge feed or poly pump trip, the centrifuge now shuts itself down in 15 minutes, thereby saving on power. 15 minutes is still sufficient to allow for a proper flushing sequence.
- The difference between the start and stop levels of the supernatant sump pumps, blending tank mixer and import sludge pump were extended to reduce the number of pump starts.
- Dissolved Oxygen set-point in the aeration basins was reduced from 2.0mg/L to 1.5mg/L. It was hoped that the duty air blower would consume less power by having to provide less air to maintain the new set-point. As we have already seen in section 4.2, the air blowers consume 52% of the power at Cashel WWTP, so any saving here would have a marked effect on kWh consumed for the plant as a whole.
- Polyelectrolyte make-up tank mixers run times were reduced by eliminating intermittent operation during centrifuge run-time, as it was found to be unnecessary.

- Odour removal units around the plant were all turned off, with the exception of the dewatering building unit. The units concerned were located at the inlet works, blending tank and picket fence thickener. No objectionable odour has arisen in any of these areas on foot of the change.
- Daily grit removal cycles were reduced from six to four, with no change to the cycle duration. There would still appear to be adequate grit removal with the reduced routine.
- Another beneficial action which was not a set-point change was a repair of a small leak from the centrifuge flushing line. The net effect of this action was that the water booster pumps no longer ran for most of the day, but only intermittently as demand arose from water points around the plant (inlet screens, storm tank and sludge import screen).

The process operational set points outlined above were changed at the end of February. Therefore, the period between the 9th of March and the 9th of April 2006 inclusive (32 days) is used to investigate if the operational changes made had any effect in terms of power efficiency improvement.

No. of Day units used	**No. of Night units used**	**No. of Wattless units used**
397.3	165.8	428.5

Table 4-10: March metered units consumed

No. of Day kWh used	No. of Night kWh used	No. of Wattless kVArh used
19,865	8,290	21,425

Table 4-11: March kWh consumed

The number of day plus night units consumed was 28,155kWh for the March period. The total number of units consumed including wattless units was 49,580kWh.

The BOD load on the plant during this period was 10,088KG and the outgoing BOD was 176KG, so BOD treated was 10,712KG. This equates to a population equivalent of 5,579. In terms of treatment performance (day plus night units):

2.63kWh per Kg BOD treated
0.38KG BOD per kWh consumed
57.56kWh consumed per PE per year.

Table 4-12: March performance parameters (day + night units)

(kWh consumed per PE and year is calculated by: [(28,155/32) x 365] / 5,579)

The performance of the plant adding wattless units was:

4.63kWh per Kg BOD treated
0.22KG BOD per kWh consumed
106.1kWh consumed per PE per year.

Table 4-13: March performance parameters (inclusive of wattless units)

kWh consumed per PE and year is calculated by: [(49,580/32) x 365] / 5,330

Apart from aeration costs, which are mostly consumed by BOD treatment, the blending tank mixer and sludge dewatering are the areas that consume most power that is variable (sludge return is static from month to month). As BOD is dealt with above as a function of power consumption, the power consumed by the blending tank mixer and sludge dewatering should be analysed.

- In the November period the centrifuge operated for 137 hours, compared to 117 hours for the March period. The extra kWh consumed in November by operating for 20 hours more adds up to 290kWh.
- The blending tank mixer ran for only 31 hours in the November period, which is 182kWh. In March the blending tank mixer ran for 620 hours, which is 3,641kWh. The difference in kWh consumed is 3,459.

This adds up to an extra 3,169kWh used in the March period that can be controlled by the plant operator directly. In other words, due to the size of the blending tank (900m^3), the operator can allow the sludge to build up to a large degree depending on circumstances. The number of hours that the centrifuge is run, then, can vary from month to month because of operator discretion rather than process reasons. Similarly, the blending tank mixer will only run when the sludge is above a particular level in the blending tank. In November, the blending tank mixer ran very little due to a low level being maintained in the blending tank, while in March the level was above the start set-point most of the time.

If we remove these variable factors from the figures above, the March treatment efficiency performance would be further improved as compared with November. (The figures below are for day plus night kWh only as we do not know how many wattless units were attributable to centrifugation and sludge blending).

The number of day plus night units consumed was 28,155kWh for the March period. Take away the excess kWh attributable to extra dewatering and sludge blending during March compared to November (3,169kWh, from above) and we get 24,985kWh.

The BOD load treated was 10,712KG. This equates to a population equivalent of 5,579. In terms of treatment performance (day plus night units):

2.33kWh per Kg BOD treated
0.0.43Kg BOD per kWh consumed
51.08kWh consumed per PE per year.

Table 4-14: March performance parameters after correction.

(kWh consumed per PE and year is calculated by: [(24,985/32) x 365] / 5,579)

*Please note that this last set of figures (table 4-14) is merely used to show that when comparing like with like between November and March, the improvement in treatment efficiency is shown to be even more pronounced. These figures, therefore, should not be compared with the plant performance parameters for the various plants illustrated earlier.

SECTION 5. DISCUSSION

5.1 PLANT EFFICIENCY COMPARISON

Before embarking on this study, little was known about the likely efficiency performance of the wastewater treatment plants in South Tipperary. No previous information was available for either the plants in the study, nor was a similar study undertaken at any other Earthtech-commissioned or operated plant that the author was aware of. A review of wastewater-related literature uncovered a small number of somewhat similar studies. Discussion below centres on day and night unit consumption alone, i.e. actual electrical consumption.

Balmer (2000), in a study of operation costs at wastewater treatment plants, has found that energy consumption is in the range 31-47kWh per PE per year. (Studies carried out by Nowak (2000) suggest an average consumption of 35kWh per PE and year; however the exact scope of the energy sources of power consumption is not detailed). This would seem to be considerably better than the 36-175kWh per PE per year found in South Tipperary (table 4-4). Balmer's study, however, did not include most pumping costs (which are volume related). Further investigation of the above study by Balmer shows a table of total electricity consumed: it is in the range 41-99kWh per PE and year. If the figure for Ballyclerihan WWTP is removed from this study the highest figure obtained is 101kWh per PE per year (for Tipperary WWTP). The two ranges are now very much comparable.

The reason for removing Ballyclerihan WWTP from the comparison is not just to improve the results from South Tipperary. It is an unusual case in that it is extremely under-loaded, as evidenced by the fact that the yearly load is only 22% of the design. Chronic under-loading causes a poor efficiency performance by virtue of the fact that a minimum amount of power must be used to keep the plant operational regardless of load. For instance, the air blowers must run at a minimum speed to maintain adequate mixing. At low-loading, the minimum speed may be excessive for the purposes of oxygenation, i.e. the DO concentration in the aeration basin(s) will often remain above the desired set-point of 2mg/l. It is probable that the plant load could increase considerably without extra power requirements.

Ballyclerihan WWTP (PE of 2,000) is among the 3 smallest plants in the study, along with Fethard WWTP (PE of 2,000) and Killenaule WWTP (PE of 1,200). The low load on Ballyclerihan WWTP is further illustrated by comparison with Killenaule WWTP in table 4-3. Ballyclerihan WWTP consumes almost as much power as Killenaule WWTP despite catering for a population equivalent to roughly half that of Killenaule. Fethard performs better than both (in terms of energy efficiency) despite having the added burden of sludge dewatering and consuming 4-5 times the amount of electricity of the other two plants. Excessive plant loadings (well in excess of design load) explain why. As mentioned earlier, a certain minimum amount of energy is needed to run a plant; above this, the marginal cost of treating more BOD must reduce dramatically. Hence the plant with the heaviest load is the most efficient.

Cahir WWTP, Cashel WWTP, Carrick-on-Suir WWTP and Tipperary WWTP are designed for population equivalents ranging from 5,000 to 11,000. It may be expected that, if economies of scale do exist at wastewater treatment plants, better results would be obtained for these plants than the three previous examples due to their larger size. There is not a compelling case for saying that they do perform better, however. Carrick-on-Suir WWTP is the most impressive, consuming only 36kWh per PE per year. The fact that this plant was built on a green-field site only three years ago may be a factor here. Cahir WWTP is nearly 10 years old, as is Tipperary WWTP. Cashel, Killenaule and Fethard WWTPs were all upgrades from existing plants. Ballyclerihan WWTP was built from scratch, but its performance has been explained.

It should be noted that the results presented for Cashel WWTP are estimated yearly consumption figures from two month's worth of data. This fact lessens the accuracy of data shown for Cashel WWTP due to the natural variation in electrical consumption from month to month (refer to appendix B).

It is noteworthy that Tipperary WWTP (101kWh per PE per year) and Killenaule WWTP (96kWh per PE per year) show a similar number of kWh used per PE per year. These two plants utilise oxidation ditches as their mode of secondary treatment. The high results in these cases as compared to other means of treatment would seem to contradict the USEPA (2000) assertion (mentioned in section 1.0.3.1) that oxidation ditches offer lower operation and maintenance costs than other forms of treatment. A more detailed study of this area would be required to make more definite statements. Tipperary's slightly higher figure (than Killenaule) could be explained by the fact that there is sludge dewatering at that plant.

There may be some mitigating circumstances in Tipperary WWTP's relatively poor performance. Looking at incoming flows, Tipperary WWTP had an average daily flow for 2005 of 4,649m^3, compared to Fethard WWTP, with a very similar biological load, (refer to table 4-1), which had an average daily flow for 2005 of 1,270m^3. It is entirely possible that a biological load to Tipperary WWTP commensurate with its incoming flow might improve its efficiency performance as there is no facility to vary aeration power at Tipperary WWTP. However, an inability to increase the aeration capacity of the plant may hinder efforts to completely treat the increased load and achieve the stringent final effluent licence limits.

There are further reasons for the high cost of treatment at Tipperary WWTP. The power consumed by inlet pumping is increased by the frequent start/stop operation of the inlet pumps. Due to the absence of VSDs (Variable Speed Drives) on the inlet pumps and the large hydraulic flows received, these pumps run very frequently. It was stated in section 1.4.2 that the number of pump starts should be minimised. As mentioned in section 3.1, pump blockages should be cleared to minimise the power consumed by pumps. However, frequent inlet pump and sludge return pump blockages were a feature of plant operation in Tipperary WWTP for much of 2005, due to insufficient screening at the inlet works.

Clonmel WWTP is the largest plant in this study and is second only to Carrick-on-Suir in terms of efficiency performance. As there is anaerobic digestion at this plant, power is returned to the system by generating electricity from biogas. This power has not been included in the above figures, so that they appear to be slightly better than is actually the case. Plant loading as a fraction of the design load has been mentioned as a factor at Ballyclerihan WWTP and may be a factor in the case of Clonmel WWTP also. 30% of the design load would appear to be quite a light load. The other plants that performed well in efficiency, namely Cahir, Cashel and Carrick-on-Suir (leaving Fethard aside as it operated at 305% of its design PE in 2005) were loaded at 77%, 54% and 74.5% of their design load respectively. Perhaps as the load increases over time into the same range at Clonmel WWTP, it will see a further improvement in treatment efficiency.

Clonmel WWTP has a much higher industrial loading on it than the other wastewater treatment plants. While it is outside the scope of this discussion to dwell on this fact, perhaps any future study should include an analysis of the proportion of industrial waste in the incoming flow, as it may be a factor in comparing treatment performance.

A final point about Clonmel WWTP (although outside the scope of this particular study) is that the digestion process removes about 35% of the solids produced (J. Maher, personal communication). Sludge transportation costs are therefore lessened substantially.

Power costs are typically 85-95% of the total operation and maintenance costs of in-plant pumping stations (USEPA, 2000). The savings between plants employing inlet pumping stations and those that rely on gravity are immediately obvious. With this in mind, Cashel WWTP, Cahir WWTP and Carrick-on-Suir WWTP should enjoy a “competitive advantage” over the other plants in the study. These 3 plants either have gravity flow into the inlet works or have satellite pumping stations, the running costs of which are not within the scope of the project. It would seem that, perhaps, the results in table 4-4 bear this out.

Final effluent discharge limits are not uniform across all 8 plants. The extra requirement to improve the final effluent to 5mg/l BOD and 5mg/l suspended solids requires further energy input in the form of tertiary filter operation. The less onerous limits on final effluent at Cashel, Carrick-on-Suir and Clonmel removes tertiary treatment requirements entirely at these plants, thus allowing the consumption of less electricity at these plants than elsewhere.

5.2 EFFICIENCY IMPROVEMENTS AT CASHEL WWTP

The important figures in this section, once again, are the performance parameters excluding wattless units. In the November period, efficiency performance was (table 4-8):

2.83kWh per Kg BOD treated
0.35KG BOD per kWh consumed
61.95kWh consumed per PE per year.

These figures are slightly more impressive than the figures for 2005 as a whole, so it is difficult to make any accusation that a period of poor efficiency was chosen, thereby making it easier to show an improvement in the March period.

Any operational changes made during February as outlined in section 4.2 were decided upon by the author by applying the lessons learned from reviewing the relevant literature and carefully looking at each individual item of equipment. While a total of 10 changes were made to various set-points (and also the maintenance item leading to more efficient use of the water booster pumps), there was no guarantee that a noticeable reduction in kWh consumed could be achieved. Taking account of the small size of most of the motors concerned, it was entirely possible that reducing their frequency of operation would lead to a negligible decrease in electricity consumed.

From reading several sources (most notably USEPA, 1999) it was apparent that an effort should be made to improve aeration efficiency if any tangible benefit was to be realised. A VSD operates the air blowers and is speed-controlled by reference to a particular DO set-point. Therefore, the only change seen to be possible on the part of the operator was to change the DO set-point of 2mg/l. This set-point was used to ensure that nitrification occurred (CIWEM, 1997) and had never been tampered with. It was felt that it was worthwhile reducing the DO set-point, as any worsening in process conditions (such as poor sludge settlement or incomplete BOD removal) could be quickly reversed by reverting to the original set-point of 2mg/l. It was also very relevant that there are no final effluents limits on nitrogen discharges, therefore nitrification did not absolutely have to occur (although desirable from an environmental point of view). As it turned out, final effluent results continued to be very good for all parameters, including low ammonia results.

March efficiency performance was (table 4-12):

2.63kWh per Kg BOD treated
0.38KG BOD per kWh consumed
57.56kWh consumed per PE per year.

The figures above show a 7% improvement in efficiency performance in March over the November period. This is quite a significant improvement for an initial effort, especially considering that no financial outlay of any kind was required to achieve it. A review of the operation of the dewatering equipment and the blending tank mixer found that they added 3,169kWh more to the March total than they did to the November total. As explained in section 4.2, it was felt that by removing these extra kWh a fairer comparison would be made.

The new results for March were (table 4-14):

2.33kWh per Kg BOD treated
0.0.43Kg BOD per kWh consumed
51.08kWh consumed per PE per year.

This equates to a 17.5% improvement in electricity efficiency over November. Not only did the changes save almost 4,000kWh (28,950kWh in November versus 24,985kWh for March when corrected), but a very impressive efficiency gain was achieved.

Wattless units consumed were very high for both the November and March periods. A reduction in wattless units consumed should be a priority in any effort to make the plant more energy efficient. However, this would be a matter of ensuring proper power factor correction, which is achieved by electrical means and is not controllable by operational manipulation.

SECTION 6. CONCLUSIONS

Results obtained in the study of Cashel WWTP showed that there is little doubt that efficiency improvements suggested by the literature are not “pie in the sky”, but are actually achievable with a minimum of investment. It seems likely that, as this study was a first attempt to improve power consumption efficiency, it should be possible to further improve on the results obtained here. Some method of encouraging continuous improvement, such as adoption of IS393:2005, would be the ideal way to achieve this. This would apply to all plants, rather than just Cashel WWTP.

Having benchmarked the performance of these eight plants, there is now a good reference point for compiling a study of other plants, as well as further investigation of the plants featured here. Any future study should involve much less work as the template outlined here can be used again. For instance, if the recommendations in section 7 are followed, it will not be necessary to extrapolate a small amount of data in order to get results for a full year. This will obviously make for a much more accurate representation of actual performance of a particular plant.

Economies of scale were not found to be a significant factor in plant performance. However, this hypothesis deserves further investigation should a statistically significant number of plants be included in a study. In a plant comparison, plants with similar biological loadings should be compared, as this study found that the degree of loading as a fraction of the design load may be a factor in explaining efficiency performance.

It was felt that the parameters used for illustrating power consumption efficiency at the different plants allowed for a fair comparison. Parameters used were similar to other studies (e.g. Balmer, 1998), although the sources of power consumption included may have been different.

Illustration of the sources of power consumption proved to be a useful exercise, as evidenced by the fact that the second-highest power-consuming item of equipment at Cashel WWTP was the blending tank mixer. This was certainly unforeseen, and although it was a recommendation in the guidelines to reduce the amount of time that the mixer runs for (section 3.1), the extent of the savings possible was surprising. It was also shown that, at 52%, aeration costs were of a similar proportion to those seen elsewhere. In the area of aeration, it was shown that slavishly following literature recommendations without some experimentation could lead to a waste of energy; a lowering of the DO set-point did not adversely impact on the aeration process whatsoever.

This point was supported by S. Kelly in a personal communication. He conducted a study a number of years previously into how he could reduce aeration costs. By systematically reducing the DO set-point of each of four aeration cells, while monitoring the effects on final effluent quality, considerable costs savings were made. From an initial point where two aeration cells were controlled to 2mg/l DO and two cells controlled to 1mg/l DO, the final configuration was for a DO set-point of 0.75mg/l in all four cells, with no deterioration in final effluent quality. The calculated savings on power consumption were 20.4% (10,560kWh per month) for the aeration process, or 10.5% of the overall site power consumption.

Methods of improving energy efficiency performance at a wastewater treatment facility are many and varied, and can be employed at several stages from design to operation. Recommendations included in this report apply to plant designers and maintenance personnel, as well as the plant operator. While there is a section dedicated to efficiency guidelines (section 3), there are many other efficiency techniques outlined throughout this dissertation, most notably in section 1.4. Most of these can be applied to almost any plant and should yield cost savings of some description.

SECTION 7. RECOMMENDATIONS FOR FUTURE STUDIES

Due to time constraints involved in compiling data for this dissertation, there is an incomplete picture of power use for the duration of the study. Ideally, one year's worth of data before and after making efficiency improvements would be required to make more definitive assertions regarding the success or otherwise of any measures taken. By taking a full year into account, seasonal factors should at least be similar to the following year. The problem with comparing one month with another is that natural variation in temperature, etc. from month to month may "move the goal posts". One is no longer certain to be comparing like with like.

With adequate resources and time, a detailed study of each plant should be undertaken, similar to that done at Cashel WWTP here. More direct comparison between different types of process might then be possible and could be very informative for future plant design. Any differences between plant performance in this study cannot be explained with any degree of certainty due to a lack of specific information. Only general suggestions as to possible reasons can be made.

Results from this study have suggested that the degree of loading on a wastewater treatment plant may have a significant influence on its energy efficiency. With this in mind, it may be prudent for planners, consultants and designers to review the long term design policy of new and upgraded plants. At present, most new plants are designed with a 20 year time frame in mind. Civil structures are usually oversized to absorb future load increases and standby structures are often very large, in that they may double the treatment capacity of the plant. Pumps and other items of electrical equipment are also sized with peak or maximum design flows in mind.

A suggested alternative method would be to adopt a modular design approach (H. McMonagle, personal communication). This method would entail the construction of a number of smaller treatment cells or tanks, rather than one or two large tanks. The same would apply to pumps and other mechanical equipment; several pumps of various sizes (to deal with a multitude of flow scenarios), capable of operating alone or in parallel, should be installed (or a pipework arrangement put in place which allows for easy installation of pumps of varying size as conditions demand). As the plant loading increased over time, one of these smaller cells/ tanks and the duty pump that best matched the prevailing conditions could be put into operation to cope with the additional load. The theory behind this method is that the plant would operate closer to its optimum (and therefore most efficient) load; this study has presented some evidence that a plant will operate most efficiently at a relatively high load. Several texts (such as Hughes, 1990) have also stated that electrical equipment such as pumps operate most efficiently at, or near, maximum output. Installation of this modular design would also afford a plant operator added flexibility in terms of process control.

SECTION 8. REFERENCES

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APPENDIX A

Calculation of kWh consumed at Cashel WWTP for 2005

This was calculated by using the reliable kWh data from the two detailed periods of study of Cashel WWTP in November and March (1140 units in 62 days) and extrapolating from that to get a figure for yearly power consumption ([1140/ 62] x 365). This figure was then multiplied by a factor of 50 to get the number of kWh consumed.

The same period was used to get a figure for wattless units used. During the 62 days, the fraction of wattless units compared to day plus night units was 0.83. Yearly kWh consumed calculated above as 335,564 was multiplied by 0.83 to get the likely wattless units consumed from this power use. The wattless units were added to the original figure to get the resulting number of 614,082 kWh.

Source data for Cashel WWTP power use

As the air blowers operate on VSDs, the average speed was estimated to be 50Hz by detailed review (using SCADA historical information) of running speed throughout the year. (Full speed for these blowers is 60Hz, low speed is 18Hz). A speed of 50Hz equates to 21.3Amps, which was used in the calculation for power output.

Maximum current drawn by the centrifuge main motor is 26A, but 12A is the observed average speed at normal feed rates, giving a normal power usage (instantaneous) of 7.56kW.

The scroll drive kWh figure is only a guesstimate due to a lack of information on actual running current. It was calculated by looking at the main drive normal power usage of 7.56kW as a fraction of full load power input of 16.4kW. Using the same fraction (7.56/16.4 = 0.46), normal power usage for the scroll motor (with a full load power rating of 2.85kW) was calculated as 2.85kW x 0.46 = 1.3kW.

Typical running currents were taken from associated dewatering equipment as follows:

- Cake pump, 6A
- Bridge breaker, 2.4A
- Feed pumps, 2.2A
- Poly pumps, 0.6A

Water booster pump running current is unknown, so a figure of 75% of full load current is assumed.

APPENDIX B

The graph below shows the seasonal variation in electrical consumption. (Pakenas 1995)