ULTRASOUND & TOTEX:
THE PERFECT MATCH BETWEEN TECHNOLOGY AND ECONOMY

Vergara, L.
Ultrawaves Reactors Ltd.
+44 151 424 4621 / luis@ultrawaves.co.uk

Abstract

Future societal and environmental challenges such as population growth, climate change and growing demand for water/energy, are some of the issues which a company customer needs to drive when looking for the best value for money. A new approach considering expenditure in a more holistic way is inevitable. Such change is manifesting itself through the introduction of increased competition and retail/wholesale separation, and a move to outcomes and TOTEX-based regulation. At this stage, there are a good number of processes in water/renewable industries where ultrasound is a well-proven solution. However, if TOTEX is the driver to assess companies against long term measured, then, ultrasound turn into one of the most efficient solutions. On the existing CAPEX or OPEX approaches, ultrasound offered good results for anaerobic digestion, biological nutrient removal and controlling bulking and foaming problems respectively. Under a TOTEX perspective, such figures make the argument for ultrasound even more compelling.

Keywords

Holistic, TOTEX, CAPEX, OPEX, ultrasound, driver, efficient, anaerobic digestion, biological nutrient removal, bulking and foaming.

Introduction

For the next five year Asset Management Programme (AMP6) the UK water companies will come under increased pressure to improve their relative efficiency whilst achieving improved wastewater effluent quality. This need is being driven by factors such as regulators, customers' expectations and an increasingly tough competition within the water industry.

That means that so very companies are currently focused on developing their business plans with many not yet considering how they should optimise performance when the impacts of TOTEX and outcome-based regulation begin to be felt in little more than a year. Recent analysis indicate that a fully integrated approach to TOTEX could yield efficiency gains of over 20 percent, meaning companies who adopt such practices will become the new frontier performers leaving others in their wake. This will not be achieved by merely fine tuning existing approaches. In order to maximise performance in a TOTEX environment, many companies will need to fundamentally change their culture and ways of working.

Moreover, the water sector is not the only one implementing a TOTEX approach, since the Ofgem's review of energy network regulation concluded in 2010 that a similar approach, focusing on reducing costs over the long term, would provide lasting benefits for energy customers. The RIIO model (setting Revenue using Incentives to deliver Innovation and Outputs) aims to incentivise electricity network providers to deliver outcomes aligned to a large extent with Ofwat's intentions in the water sector which states that a total expenditure, or TOTEX, approach considers expenditure in a more holistic way rather than separate OPEX and CAPEX allowances.

According to the above, Ofwat and Ofgem perspectives promote the two alternatives (wastewater and renewables) in which both market niches might found interesting solutions through the Ultrawaves Ultrasound (US) Technology over the forthcoming years. This particular technology meets all the characteristics and features to produce the best numbers within this (TOTEX) approach. Indeed, as the TOTEX modelling procedure adopted by Ofwat/Ofgem for this price review (PR14) is a new process to the water/renewable industry, the opportunity to submit representations on the TOTEX models is welcomed to remove the perceived OPEX or CAPEX bias. This is exactly the purpose of this paper.

The TOTEX challenge

The move to assessing companies against long term outcome measures, proposed by the individual companies and determined through customer consultation, will support a TOTEX based approach. Since privatisation, OPEX (both Operational Expenditure and the Infrastructure Renewals Charge) has been funded through company revenue ("fast money"). On the other hand, CAPEX has been debt funded through the Regulatory Capital Value (RCV) mechanism ("slow money"), with companies earning a rate of return against the RCV. The Capital Incentive Scheme provides financial benefits for companies to outperform the agreed baseline capital costs.

The new model will see baselines established on a TOTEX basis, rather than CAPEX and OPEX separately. Companies will propose a proportional split within the TOTEX of these two components in order to determine the split between fast and slow money. The RCV mechanism will still be used to allow a rate of return on capital employed, with adjustments to RCV for capital asset enhancements. The Retail Price Index (RPI) and RCV mechanisms, together with the Interim Determination measure, are seen as mitigating shareholder and funding risks.

Success in a TOTEX world requires a seamless asset management approach, integrating asset policy and strategy, investment planning, intervention delivery and operations and maintenance functions across the asset life cycle on a "plan-do-review" basis to evaluate the investment in the technology as an asset. Understanding the interrelationship between CAPEX and OPEX will determine the level of success achieved by implementing TOTEX. Ultimately, success will result from making the right decisions across the asset life cycle, whether it is asset strategy or component optioneering. For these reasons Ultrawaves will use an econometric model based on the Net Present Value (NPV) and the Internal Rate of Return (IRR) as metric tools.

Robust asset data

TOTEX decision making requires robust asset data covering performance, risk, asset condition, capital cost and operating cost that is dynamic and updated regularly. With over 12 years in the market, Ultrawaves has achieved a high degree of maturity in capital cost data worldwide, as well as others in terms of Operation and Maintenance (O&M) and basic asset inventory information. The long term performing at Bamberg Wastewater Treatment Plant (WWTP) in Germany (Houy *et al*., 2010) is just an example of the approximately 200 units already installed worldwide which constantly feedback the Ultrawaves data background.

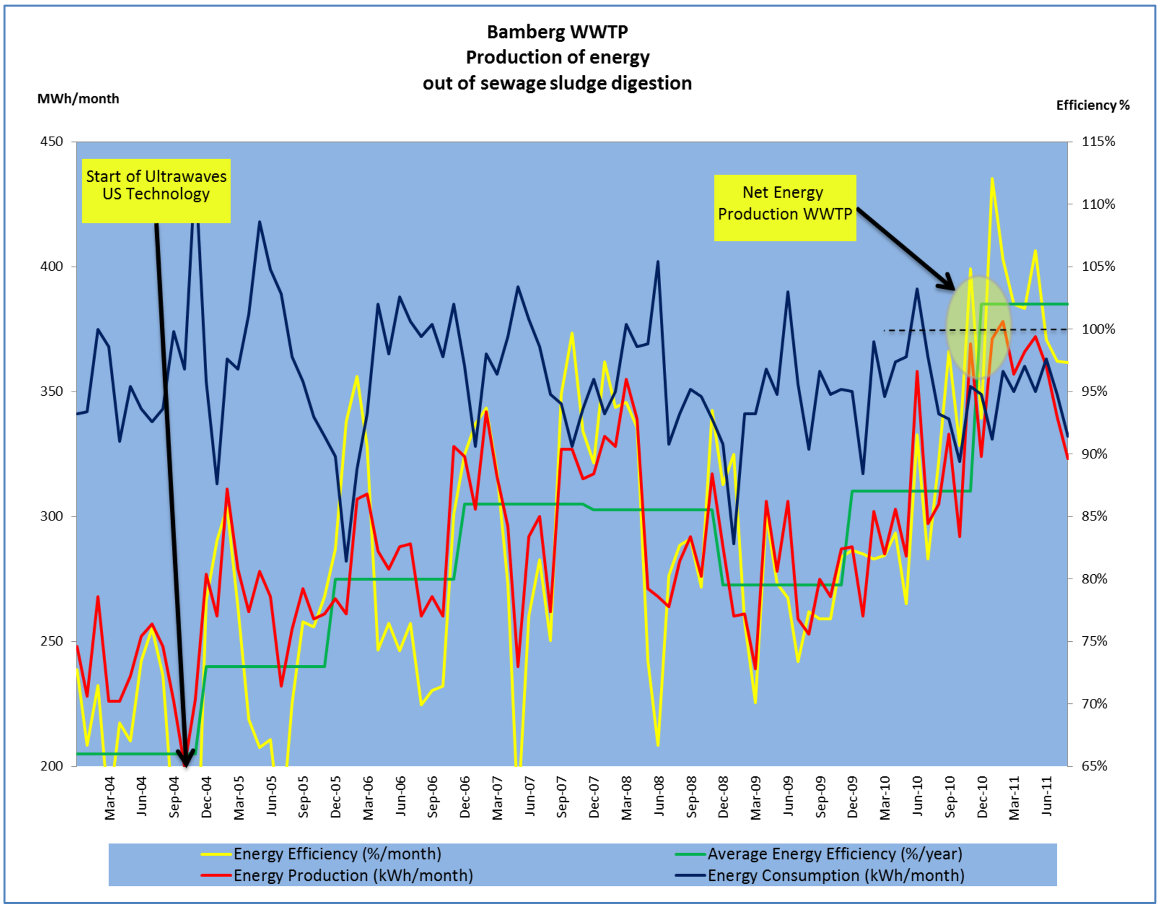

***Figure 1**: Ultrawaves performance at Bamberg WWTP since 2004.*

A proposed mathematical model to integrate the business

The following model proposes a TOTEX benchmarking to turn the results of historical performance into (AMP6) projections, which involves making projections of the exogenous and explanatory variables in the model, and considering issues around time trends, real price effects and productivity changes. Below, some guidelines:

- The Ultrawaves technology is considered as an asset.
- An asset is undergone to depreciation over a time period.
- Along the considered lifetime of the asset, the net cash flows have to be updated.

- The rate of interest (or discount rate) to be applied goes in trend with parallel markets.
- A sensitive analysis is introduced to cover all the interest rates.

These patterns will describe a reality in which it is possible to undertake a NPV and IRR modelling. However, the key to such approach is the discount factor and the lifetime period in which the calculation is carried out over. So, if the discount rate is understood as the rate of return that could be earned on an investment in the financial markets with similar risk, that is, the opportunity cost of capital, then it is possible to make rational decisions based upon a metric around the financial approach of this figure (NPV & IRR) and the asset (the technology) to invest.

In finance, NPV of a time series of cash flows, both incoming and outgoing, is defined as the sum of the Present Values (PVs) of the individual cash flows. Each cash inflow/outflow is discounted back to its PV and then they are summed. Therefore, NPV is the sum of all terms minus the initial investment:

$$PV = \sum_{j=1}^{n} \frac{R_j}{(1+r)^j}$$

$$NPV = PV - K$$

Where:

- n = lifetime of the investment.
- j = number of time periods.
- R = net cash flow during the period. R = C (collection) - P (payment).
- r = discount rate.
- K = initial investment.

Moreover, there is a certain discount rate often used in capital budgeting that makes NPV of all cash flows from a particular project equal to zero. This discount rate is known as IRR.

$$NPV = f(r) \rightarrow IRR = r \mid f(r) = 0$$

Generally speaking, the higher a project's IRR, the more desirable it is to undertake the project. As such, IRR can be used to rank several prospective projects a firm is considering. Assuming all other factors are equal among the various projects, the project with the highest IRR would probably be considered the best and undertaken first.

Ultrawaves technology as an asset

It is pertinent to note that the cost of the Ultrawaves technology as an asset is its purchase price, including import duties and other deductible trade discounts and rebates. In addition, costs attributable to bringing and installing the asset in its needed location have been included as part of this cost. The use of assets in the generation of revenue takes a certain period of time which is usually more than a year. It is therefore obligatory that in order to accurately determine the net income or profit for a period, depreciation is charged on the total value of asset that contributed to the revenue for the period in consideration and charge against the same revenue of the same period of time. However, due to the high Return Of Investment (ROI) that the technology provides, the selected model just considers that the residual value as an asset is negligible and the O&M costs associated with the technology work cover the estimated lifetime of the asset to provide with the forecasted performance. Below, some pictures of the reactor (figure 2) and also some pictures in regard to an actual installation of the technology in a facility (figures 3 and 4).

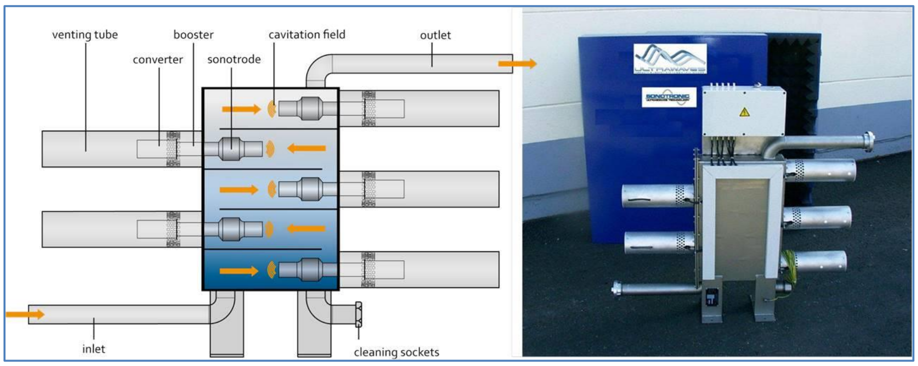

Figure 2*. Ultrawaves ultrasound reactor. Standard unit of 5 kW.*

Figure 2 provides with a clear idea about the simplicity of the technology. The standard unit (5 kW) is sized with 1.5 x 0.3 x 1.1 m (LxWxH) and 101 kg, which is a big advantage when integrating into existing plants as compared with other technologies. Nevertheless, to cover all the inherent costs of the technology as an asset, the single reactor (as shown in figure 2) should be assessed when installed. On that way the costs of the peripherals and ancillaries, installation and others may be included into the mathematical model. Figure 3 and 4 display an actual installation where all these subjects have been considered. Moreover, once the technology is installed, O&M costs are also included in the calculus.

Figure 3*. Ultrawaves unit installed at Kirkby in Ashfield STW, UK.*

Figure 4*. Ultrawaves unit at Kirkby. Connections (left) and components (right).*

Figure 4 exhibits two important details to take into consideration. In the photograph on the left it is shown the very simple integration with an existing process (in this case a RAS pipe). In the picture on the right, the easy body of ancillaries (pump, flowmeter, pressure transmitter and piping) to make the technology work is shown. Both details will have a big impact on the CAPEX associated with ultrasound.

Like all technologies, Ultrawaves has to face an OPEX to keep the performance and efficiency up. Just energy consumption and sonotrode replacement must be taken into account. The sonotrode is a piece of metal (titanium) that is exposed to ultrasonic vibration, and then gives this vibratory energy (acoustic energy) in the element to apply (sludge or biomass). The standard reactor (5 kW) is equipped with 5 oscillating units which each one has a sonotrode (see figure 2). Figure 5 shows two sonotrodes (new and after 1.5 to 2 years of operation).

Figure 5*: New sonotrode and after 1.5 to 2 years running.*

To undertake the easiest analysis, a standard ultrasound reactor (5 kW) will be assessed as an asset. This is a good approach because the technology is easily scalable and adapted to smaller or bigger facilities (for instance, at Kirkby in Ashfield STW just 4 kW were required while at Bamberg WWTP was necessary to install 10 kW). All the costs are scalable to the standard unit. For that reason, the following case studies to be shown will be realistically adapted to the sizes that just require a 5 kW unit.

Case study No. 1: Anaerobic digestion in WwTW

It is not the target of this paper the description of the ways whereby the technology provides the benefits. An extensive literature is available throughout the Ultrawaves website. In simple terms, the technology provides with the following improvements when performing in AD (Neis *et al*., 2000):

- More volatile solids (VS) degradation.
- More biogas production.
- Less digested sludge.
- Better dewaterability.
- Less viscosity.

These improvements of the AD process could be economically framed within three different sides. Energy, disposal and consumables. Thus, as stated earlier, a WwTW specially sized for one ultrasound reactor of 5 kW is considered and table 1 below displays some relevant figures of such facility.

Parameter	Quantity	Unit
Sludge load to be digested (total solids)	8.00	t TS/d
Concentration	4.00	%
Digestion volume	4.000	m^3
Digestion efficiency (VS-degradation)	45.00	%
Biogas production	2.160	Nm^3/d
Sludge cake	20.00	%
Cost of purchased energy	0.10	£/kWh
Price of produced energy	0.12	£/kWh
Cost of sludge for disposal (wet solids)	20.00	£/t WS
Cost of polymer for dewatering	2.00	£/kg

Table 1: *WwTW-AD sizing considered for the case study No. 1.*

Data collected in table 1 just concern the AD process (WwTW-AD) and include technical figures as well as typical costs for energy, consumables and disposal. The 5 kW system (including all the peripherals and ancillaries around the ultrasound reactor) would provide with the benefit and cost values as shown in table 2.

Parameter	Quantity	Unit
Electrical energy production (income)	45.84	£k/y
Sludge for disposal (saving)	33.71	£k/y
Polymer addition for dewatering (saving)	1.77	£k/y
Energy consumption in dewatering (saving)	4.02	£k/y
Energy consumption to run the ultrasound system (cost)	6.80	£k/y
Sonotrode replacement (cost)	3.75	£k/y

Table 2: *Cost & benefit analysis of the required 5 kW unit on WwTW-AD.*

From table 2 it is possible to calculate the cash flow (R_j) per period (a year will be considered as time period) which the technology can provide. The following stages are the settings for NPV and IRR. According to the model, that implies a decision to be taken regarding "K", "r" and "n". The following assumptions are contemplated:

- "K" embraces all the expenses associated with the investment. That includes the technology, ancillaries, peripherals, installation, commissioning and monitoring during the adaptation period of the technology (approx. 3 digestion cycles). This figure may vary from one to other installation and for this model a value of £175k has been chosen.
- "n" will be considered as 10 years. This value is quite common in WwTW technologies/equipment and perfectly matches with the Ultrawaves track records.
- "r" will be considered, in the beginning, as an average of the indexes of other markets (i.e. stock or retail). A value of 4% is the first choice but a wide range of this parameter will be lately covered.

Table 3 shows NPV and IRR for the selected K, R, n and r.

n	K	C_j	P_j	R_j	r	$(1+r)^j$	$R^j/[(1+r)^j]$
y	£k	£k	£k	£k	%	-	£k
0	175.00	0.00	0.00	-175.00	0.00	0.00	0.00
1	0.00	85.34	10.55	74.79	0.04	1.04	71.92
2	0.00	85.34	10.55	74.79	0.04	1.08	69.15
3	0.00	85.34	10.55	74.79	0.04	1.12	66.49
4	0.00	85.34	10.55	74.79	0.04	1.17	63.93
5	0.00	85.34	10.55	74.79	0.04	1.22	61.48
6	0.00	85.34	10.55	74.79	0.04	1.27	59.11
7	0.00	85.34	10.55	74.79	0.04	1.32	56.84
8	0.00	85.34	10.55	74.79	0.04	1.37	54.65
9	0.00	85.34	10.55	74.79	0.04	1.42	52.55
10	0.00	85.34	10.55	74.79	0.04	1.48	50.53
						PV (£k)	606.65
						NPV (£k)	431.65
						IRR (%)	41.40

***Table 3**: NPV & IRR figures for a 5 kW system performing in WwTW-AD.*

NPV and IRR reached by ultrasound are extremely attractive for potential investors and decision makers. There are few markets in which an investment has to overcome this opportunity cost. At this point it should be positive to keep in mind some figures regarding other markets as well as its benchmarking with ultrasound. For instance, over the last 30 years the Stock Market has arisen (in average) almost 6.12% per year. Moreover, the Retail Price Index has also arisen approximately 3.75% per year on average for the same time period.

Figure 6 plots a wide range of NPV for each r where r covers from zero up to the IRR given by ultrasound (IRR = 41.4% for a 5 kW unit performing in WwTW-AD application as shown in table 3). As observed, the range of manoeuvres is quite encouraging for a considerable body of values for r. This analysis plays a key role for the TOTEX approach as described in sections above.

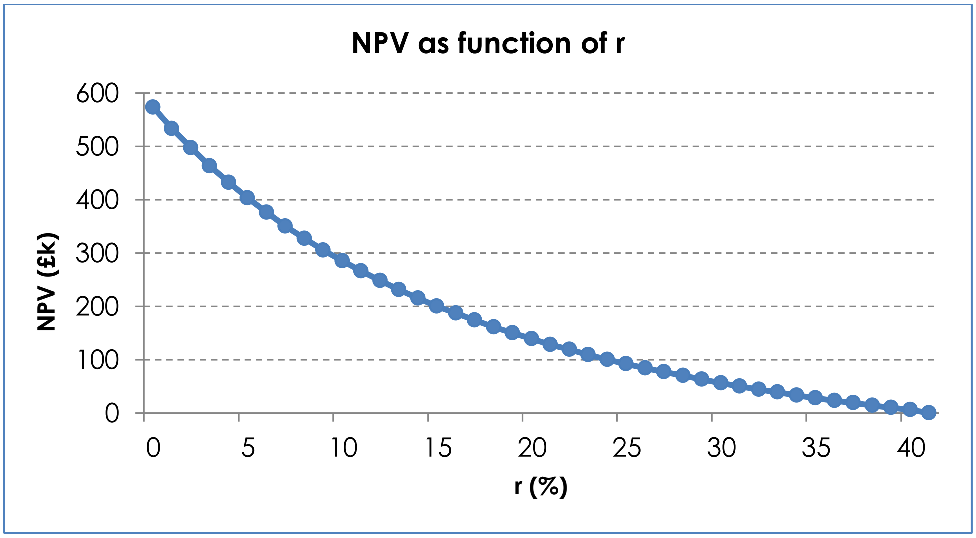

Figure 6: *NPV as function of r for the 5 kW unit performing in WwTW-AD.*

Case study No. 2: Bulking and foaming in WwTW

Once again, just the improvements associated with ultrasound when performing in this operation (combating bulking) are described below (Neis *et al.*, 2002). More documentation about this this application is already available (Vale *et al.*, 2014):

- Filamentous bacteria break down.
- BOD_5 and O_2 diffusion facilitation.
- Less sludge volumetric index (SVI).
- Less turbidity (NTU).
- Less Filament Index (FI).
- A significant impact on the optical impression of the tank surfaces.

These improvements in the Activated Sludge Process (ASP) could be economically assessed within three different ways. Consumable (chemical), disposal and energy. Thus, as stated in the previous case, a WwTW specially sized for one ultrasound reactor of 5 kW is also considered for this case study and table 4 below displays some relevant figures of such facility.

Parameter	Quantity	Unit
Inlet flow	8,000	m³/d
RAS flow	12,000	m³/d
Sludge age	10.00	d
SVI	200	mL/g
Bulking season	180	d/y
Filamentous bacteria (dominant specie)	*M. Parvicella*	
Chemical solution (PAX dose / RAS flow)	150	ppm
Chemical cost	0.15	£/kg
Cost of purchased energy	0.10	£/kWh
Cost of sludge for disposal (dry solids)	400	£/t TS

Table 4: *WwTW-ASP sizing considered for the case study No. 2.*

Proceeding as earlier, table 4 summarises the data for the theoretical WwTW-ASP where the 5k kW of ultrasound are required. Technical figures as well as typical costs for energy, consumables and disposal have been added. The 5 kW system (including all the peripherals and ancillaries around the ultrasound reactor) would provide with the benefit and cost values as shown in table 5.

Parameter	Quantity	Unit
Chemical solution (saving)	48.60	£k/y
Sludge for disposal (saving)	23.09	£k/y
Energy consumed in RAS pumping (saving)	9.82	£k/y
Energy consumption to run the ultrasound system (cost)	6.80	£k/y
Sonotrode replacement (cost)	3.75	£k/y

***Table 5**: Cost & benefit analysis of the required 5 kW unit on WwTW-ASP.*

The cash flow (R_j) per period (again one year) can be recalculated from the numbers shown in table 5. NPV and IRR displayed in table 6 keep the same figures regarding "K", "r" and "n" as considered in the former case.

n	K	C_j	P_j	R_j	r	$(1+r)^j$	$R^j/[(1+r)^j]$
y	£k	£k	£k	£k	%	-	£k
0	175.00	0.00	0.00	-175.00	0.00	0.00	0.00
1	0.00	81.51	10.55	70.96	0.04	1.04	68.23
2	0.00	81.51	10.55	70.96	0.04	1.08	65.61
3	0.00	81.51	10.55	70.96	0.04	1.12	63.09
4	0.00	81.51	10.55	70.96	0.04	1.17	60.66
5	0.00	81.51	10.55	70.96	0.04	1.22	58.33
6	0.00	81.51	10.55	70.96	0.04	1.27	56.08
7	0.00	81.51	10.55	70.96	0.04	1.32	53.93
8	0.00	81.51	10.55	70.96	0.04	1.37	51.85
9	0.00	81.51	10.55	70.96	0.04	1.42	49.86
10	0.00	81.51	10.55	70.96	0.04	1.48	47.94
						PV (£k)	575.57
						NPV (£k)	400.57
						IRR (%)	39.05

***Table 6**: NPV & IRR figures for a 5 kW system performing in WwTW-ASP.*

A similar curve as plotted in figure 6 could be also graphed for this case (it will not be performed to avoid a saturation of data). The curve and the interpretation of NPV and IRR for this case study should follow a similar reasoning as exhibited in the former case study. The figures (£401k and 39.1% in NPV and IRR respectively) are also quite encouraging for a TOTEX approach.

Case study No. 3: Anaerobic Digestion Facility (ADF)

ADFs cover the second big market niche for Ultrawaves which is renewable energy (anaerobic digestion). Albeit the core of the application is the same as WwTW-AD, that is, an increase in the VS-degradation, the operation by itself is not exactly the same. In other words, the ultrasonic effect may be managed in order to enhance the biogas production or also over the feedstock saving (Brusini, 2014) which obviously is out of the scope in the wastewater application. Thereby, the improvements provided by the technology when it is implemented in ADFs may be highlighted as follows:

- More VS-degradation.
- More biogas production and/or feedstock saving.
- More methane content.
- Less viscosity.

Following with the logic of previous cases, an ADF sized for 5 kW of ultrasound power is described in table 7 below.

Parameter	Quantity	Unit
Feedstock daily load (maize)	25.00	t WS/d
Dry solids concentration	33.00	%
Volatile solids concentration	95.80	%
HRT	60.00	d
Biogas production	4,500	Nm^3/d
Methane content	52.00	%
Plant size	475	kW
Cost of purchased energy	10.00	p/kWh
Price of produced energy	11.52	p/kWh
Cost of the feedstock	0.05	£/kg

***Table 7**: ADF sizing considered for the case study No. 3.*

Due to the possible dual use that the VS-degradation improvement generated by ultrasound may offer when performing on ADFs, this particular application, that is, this case study, will be split into two subcases. Such different subcases are energy production and feedstock saving.

Subcase study 3.1.
This scenario pursues the energy (biogas and electricity) production. Table 8 exhibits the averaged benefits and cost figures for this application.

Parameter	Quantity	Unit
Electrical energy production (income)	78.69	£k
Mixing (saving)	5.26	£k
Energy consumption to run the ultrasound system (cost)	7.36	£k
Sonotrode replacement (cost)	3.75	£k

***Table 8**: Cost & benefit analysis of the required 5 kW unit on ADF in subcase 3.1.*

Note that the power (energy) consumption of the ultrasound system in ADFs is a little higher than in the case of wastewater. The reason lies in the fact that the peripherals and auxiliary equipment are different in both cases.

Table 9 below presents the same cash flow, PV, NPV and IRR analysis as carried out in former cases studies. Likewise, the relevant parameters for the mathematical model (K, n, and r) remain with the same values.

n	K	C_j	P_j	R_j	r	$(1+r)^j$	$R^j/[(1+r)^j]$
y	£k	£k	£k	£k	%	-	£k
0	175.00	0.00	0.00	-175.00	0.00	0.00	0.00
1	0.00	83.95	11.11	72.84	0.04	1.04	70.03
2	0.00	83.95	11.11	72.84	0.04	1.08	67.34
3	0.00	83.95	11.11	72.84	0.04	1.12	64.75
4	0.00	83.95	11.11	72.84	0.04	1.17	62.26
5	0.00	83.95	11.11	72.84	0.04	1.22	59.87
6	0.00	83.95	11.11	72.84	0.04	1.27	57.56
7	0.00	83.95	11.11	72.84	0.04	1.32	55.35
8	0.00	83.95	11.11	72.84	0.04	1.37	53.22
9	0.00	83.95	11.11	72.84	0.04	1.42	51.17
10	0.00	83.95	11.11	72.84	0.04	1.48	49.21
						PV (£k)	590.76
						NPV (£k)	415.76
						IRR (%)	40.20

***Table 9**: NPV & IRR figures for a 5 kW system performing in ADF in subcase 3.1.*

Figures (£416k and 40.2% in NPV and IRR respectively) are again very positive for the scheme and methodology concerning TOTEX that comes developing along the different case studies.

Subcase study 3.2.

The target here is the feedstock saving while the conventional biogas production does not change (conventional means without the ultrasound performance). Table 10 exhibits the averaged benefits and cost numbers for this particular application.

Parameter	Quantity	Unit
Feedstock saving (income)	58.01	£k
Mixing (saving)	5.26	£k
Energy consumption to run the ultrasound system (cost)	7.36	£k
Sonotrode replacement (cost)	3.75	£k

***Table 10**: Cost & benefit analysis of the required 5 kW unit on ADF in subcase 3.2.*

It is interesting to remark that the only difference between subcases 3.1 and 3.2 resides in the different prices for energy or feedstock. Table 7 shows the prices in regard to the energy produced (11.52 p/kWh according to FITs) as well as the cost of the feedstock purchased (0.05 £/kg). These figures allow the calculation of the income in each scenario as displayed in tables 8 and 10 respectively. This circumstance in turn brings a new platform to discuss, since it could be developed an approach between both prices and analyse their correlation (Swain *et al*., 2013). A new curve would be plotted where NPV and IRR are function of a range of energy and feedstock prices. There will be a pricing structure in which NPV and IRR are the same for each case (energy and feedstock) and this particular scenario will generate very awesome information concerning the two inherent parallel markets.

Coming back to the cash flow analysis, table 11 below presents the same study that carried out in the previous subcase.

n	K	C_j	P_j	R_j	r	$(1+r)^j$	$R^j/[(1+r)^j]$
y	£k	£k	£k	£k	%	-	£k
0	175.00	0.00	0.00	-175.00	0.00	0.00	0.00
1	0.00	63.27	11.11	52.16	0.04	1.04	50.15
2	0.00	63.27	11.11	52.16	0.04	1.08	48.22
3	0.00	63.27	11.11	52.16	0.04	1.12	46.37
4	0.00	63.27	11.11	52.16	0.04	1.17	44.59
5	0.00	63.27	11.11	52.16	0.04	1.22	42.87
6	0.00	63.27	11.11	52.16	0.04	1.27	41.22
7	0.00	63.27	11.11	52.16	0.04	1.32	39.64
8	0.00	63.27	11.11	52.16	0.04	1.37	38.11
9	0.00	63.27	11.11	52.16	0.04	1.42	36.65
10	0.00	63.27	11.11	52.16	0.04	1.48	35.24
						PV (£k)	423.05
						NPV (£k)	248.05
						IRR (%)	27.09

Table 11*: NPV & IRR figures for a 5 kW system performing in ADF in subcase 3.2.*

Again the numbers speak by themselves.

Ultrawaves Reactors Ltd.
www.ultrawaves.co.uk

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